DeustoTech Mobility

TRAZAMED

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Sistema basado en tecnología de identificación RFid para la trazabilidad de productos farmacéuticos durante la fase de distribución

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Prólogo

El trabajo de investigación presentado se entronca dentro de una de las líneas de investigación aplicada que el equipo DeustoTech Mobility ha venido impulsando en el último trienio (2010-2012). Ésta se focaliza en el desarrollo de soluciones telemáticas para la trazabilidad en el transporte de mercancías, como respuesta a las necesidades identificadas en distintos operadores logísticos que operan en diferentes sectores de actividad (alimentación, sanidad, paquetería, etc.).

Dentro de esta línea de investigación nos centraremos en exclusiva en los trabajos ejecutados para su aplicación en el ámbito de la sanidad. En concreto para la trazabilidad de productos farmacéuticos durante la fase de distribución (en el transporte desde el distribuidor farmacéutico hasta el punto de venta en las farmacias). Así, lo que presentamos en esta solicitud es el conjunto de actividades y resultados cosechados dentro de esta línea de trabajo, aglutinando:

(1) *Desarrollo tecnológico*. Fruto de varios proyectos de investigación financiados por administraciones públicas y por inversión privada de empresas. En concreto, son cuatro proyectos financiados, a nivel regional, autonómico, estatal y con aportación privada de empresa, los que han soportado el citado desarrollo, con una financiación de 751.625 euros en un recorrido de 3 años de ejecución.
El resultado es un piloto funcional que posibilita un análisis del proceso de distribución y una gestión en tiempo real de incidencias, apoyada en una serie de servicios de soporte al transportista que son provistos de forma no intrusiva en su modelo operacional. La solución tecnológica combina: (a) una solución embarcada implementada a través de un sistema embebido con capacidad de identificación de cubetas farmacéuticas por RFid y comunicación multipropósito (bluetooth, Wifi y 3G); (b) una solución software móvil que corre sobre un Smartphone operado por el transportista y que le sirve de apoyo en el proceso de entrega de cubetas; y (c) una solución software de centro de control capaz de monitorizar en tiempo real el proceso de distribución e incidencias, así como el análisis en diferido de rutas, desviaciones, etc.

(2) *Transferencia tecnológica*. A fecha de redacción de este informe realizada a las cuatro empresas de base tecnológica que colaboran en los citados proyectos (Cenker Robotics, S.L., Bilbomatica, S.A., Creativ IT, S.L. y Wellness Telecom, S.L.), incluyendo como parte de ésta la implantación del sistema en un distribuidor farmacéutico, Centro Farmacéutico del Norte, S.A. (Cenfarte).

(3) *Difusión en revistas indexadas internacionales y ponencias invitadas*. Habiendo sido posible combinar a la perfección la vertiente aplicada de este trabajo con la vertiente científica. La calidad de la primera queda patente a tenor de la alta financiación privada obtenida y de la segunda a través de tres publicaciones en revistas internacionales indexadas JCR (una focalizada en el análisis del entorno

radioeléctrico de la furgoneta de reparto y otras dos que combinan este análisis con el diseño y validación de la solución global de trazabilidad). Por otra parte, se cuenta con otras seis publicaciones en congresos internacionales. También a nivel divulgativo se cuenta con una ponencia invitada en la II Jornada Logística de Euskadi.

(4) *Lazos de colaboración con grupos de investigación de alto rendimiento*. Es el caso de la colaboración iniciada a raíz de este trabajo con los grupos de Jesús Villadangos y Francisco Falcone de la Universidad Pública de Navarra, con gran experiencia y producción científica en el campo de la simulación de entornos radioeléctricos. Esta línea de trabajo ha posibilitado una colaboración de carácter multidisciplinar con ellos, que sigue prolongándose en la actualidad a través de nuevos proyectos, dado que nuestro equipo se centra exclusivamente en el diseño de soluciones a nivel de sistema, complementándonos a la perfección con los análisis que ellos realizan a nivel de capa física, posibilitando un diseño integral de la solución.

Consideramos que el trabajo presentado posee como principal valor el haber sido capaz de combinar a la perfección el *impacto e interés industrial y social,* traducido en una altísima capacidad de financiación de las actividades, con el *impacto científico*, traducido en varias publicaciones en revistas indexadas.

Alcance del proyecto e interés social de la investigación

El trabajo de investigación presentado cumple un doble objetivo de satisfacción de necesidades (1) sociales y (2) empresariales, que tienen como timón las directrices en materia de trazabilidad de medicamentos establecidas por el Real Decreto 29/2006.

(1) *Necesidades sociales*. En la actualidad, los sistemas implantados por las distribuidoras farmacéuticas, cumpliendo con el anterior real decreto RD 725/2003, incluyen el seguimiento del medicamento hasta el instante en que cada lote es recibido por un almacén intermedio a través del código de lote y la fecha de caducidad impresos en el propio envase. Sin embargo, el aumento en la circulación de medicamentos falsificados así como una mayor internacionalización del sector farmacéutico conlleva la necesidad de realizar una mayor vigilancia que permita a las autoridades minimizar el tiempo de reacción ante la detección de un problema de seguridad para la salud. Así, la nueva regulación del sistema nacional de salud sobre garantía de autenticidad y trazabilidad de medicamentos de uso humano recogidos en el RD 29/2006 (con anexos y ampliaciones en 2007, 2009 y 2011), de eminente trascendencia sanitaria, tiene como objetivo establecer un mecanismo a través del cual los laboratorios farmacéuticos, los almacenes de distribución farmacéutica y las oficinas de farmacia suministren a las Comunidades Autónomas y al Ministerio de Sanidad, Servicios Sociales e Igualdad la información necesaria para realizar un seguimiento de cada unidad de medicamento puesta en el mercado. Es decir, lograr una trazabilidad integral que funcione, no a nivel de lote, sino a nivel

de unidad de presentación, cubriendo todas las etapas de distribución, desde que es producido en el almacén farmacéutico hasta que es dispensado a un paciente desde una oficina de farmacia con el fin de garantizar en todo momento la accesibilidad y el abastecimiento de los fármacos y la seguridad de los mismos.

(2) *Necesidades del tejido empresarial*. Este nuevo RD, de obligado cumplimiento en los próximos años, exige una alteración en el modelo actual de distribución farmacéutica, causando un total desasosiego a las partes implicadas. En especial a los distribuidores farmacéuticos, los cuales exigirán a sus empresas proveedoras de tecnología de soluciones que permitan el cumplimiento de las nuevas directrices.

El alcance de la investigación es justamente desarrollar una solución tecnológica, no existente hasta la fecha, que permita la trazabilidad de medicamentos demandada por el antiguo Ministerio de Sanidad y Consumo en su proyecto de RD 29/2006 y recomendada por la UE en la directiva 2003/94/CE.

Objetivos del proyecto

El boceto del Real Decreto 29/2006 presentado por el anterior Ministerio de Sanidad y Consumo, el cual exige una trazabilidad integral de medicamentos a nivel de unidad de presentación, desde que es producido en el almacén farmacéutico hasta que es dispensado en una oficina de farmacia, define dos alternativas tecnológicas para lograr este fin: (a) códigos de barras en dos dimensiones (DataMatrix) o (b) identificación por radiofrecuencia (RFid).

Los laboratorios farmacéuticos recomiendan el uso de la tecnología DataMatrix al considerar inviable económicamente el empleo de la tecnología RFid debido al coste actual de las etiquetas identificativas que en ocasiones podría superar el coste del propio medicamento. Por otro lado, el empleo de esta tecnología por las empresas distribuidoras supone un cambio radical en su modelo de negocio. Al tratarse de códigos de barras bidimensionales es necesario el contacto visual entre el sistema lector y el código de barras impreso, lo cual dificulta las tareas de transporte involucradas en el proceso de trazabilidad, ralentizando los procesos de carga y descarga e imposibilitando el abastecimiento de las farmacias en los términos en los que se lleva a cabo actualmente.

Por su parte, la identificación por radiofrecuencia (RFid) es una tecnología emergente que permite la identificación de los componentes etiquetados a través de ondas de radio sin necesidad de visión directa entre emisor y receptor (etiqueta y lector). El empleo de etiquetas de frecuencia ultra alta (UHF) permite la detección de etiquetas a larga distancia (hasta los 50m) mediante el empleo de antenas de alta ganancia en el lector. La implantación de esta tecnología permitiría a los transportistas desempeñar sus funciones sin alterar el modo de operación actual, siendo por tanto la recomendada por éstos.

Esta falta de acuerdo entre los diferentes agentes que forman el sector farmacéutico ha causado una alarma en el sector y un posicionamiento del mismo radicalmente en contra del boceto del RD 29/2006 presentado por el Ministerio de Sanidad y Consumo.

La investigación aquí planteada persigue la convivencia de ambas tecnologías, permitiendo unir posturas entre los diferentes agentes y minimizar el coste de implantación de un sistema que permita la trazabilidad integral de los medicamentos exigida por este Real Decreto.

a) *Aproximación técnica*

Este trabajo plantea primeramente adaptar los sistemas automatizados de dispensación y recepción de medicamentos en distribuidores mayoristas y oficinas de farmacia, incorporando lectores de códigos de barras bidimensionales DataMatrix a éstos. Y por otra parte plantea la colocación de etiquetas RFid en las cubetas de almacenaje en las que se transportan los medicamentos que son adquiridos por las oficinas de farmacia. La instalación de sistemas lectores RFid de alta ganancia en los vehículos de transporte permitirá detectar todas las etiquetas que se encuentran en el interior del mismo, siendo posible localizar en todo momento cada envase unitario a partir de la ubicación de la cubeta en la que se encuentra.

Cada vehículo contará con un módulo embebido de control y comunicaciones que permite la conectividad en tiempo real con el centro de gestión del distribuidor farmacéutico. Además, ayudado por un sistema de posicionamiento por satélite, podrá monitorizar el estado de la carga, registrar el punto geográfico en el que ésta sufre alguna modificación (carga o descarga) y detectar incidencias en forma de desviaciones respecto al plan de distribución establecido.

El sistema incluye también el desarrollo de una aplicación móvil que corre sobre un Smartphone portado por los transportistas y que les permite disponer de información sobre la hoja de ruta, las acciones de transporte a llevar a cabo en cada parada y las posibles incidencias acontecidas. Finalmente existe una solución software de centro de control capaz de monitorizar en tiempo real el proceso de distribución y las incidencias acontecidas.

b) *Retos científico-tecnológicos*

Las contribuciones científico-tecnológicas que este trabajo implica son las siguientes:

(1) Diseñar un sistema de trazabilidad extremo a extremo aplicado a la distribución de productos farmacéuticos. La innovación radica en la aproximación integral al diseño del sistema, desde la capa física hasta la arquitectura a nivel de aplicación, empleando un enfoque «bottom-up» que permita un análisis de necesidades individualizado en cada una de las capas y aporte de valor científico-tecnológico e innovación en cada una de ellas. Así, en el diseño se incide en aspectos tales como la eficiencia en términos de cobertura/capacidad, consumo energético y de gestión de la fusión global de datos, o en aspectos como la estandarización e interoperabilidad que ofrezcan al sistema una alta capacidad para ser generalizado, extendido y adaptado a múltiples necesidades y escenarios.. Siendo éste un aspecto no funcional diferenciador con respecto a otras soluciones que siguen un enfoque «top-down» y han sido diseñadas específicamente para un escenario objetivo de uso y tienen escasas posibilidades de evolución hacia otros.

(2) Analizar la capa física y las particularidades a los que se enfrenta el canal radioeléctrico de los sistemas de aplicación potencial en entornos cerrados vehiculares, así como en su interacción con elementos en la red exterior. Esta caracterización de un entorno radioeléctrico heterogéneo servirá de base para el diseño de la infraestructura de comunicaciones en capas superiores y permitirá innovar en el diseño de algoritmos para la gestión de la información obtenida mediante la fusión de diferentes sistemas radioeléctricos, garantizando la integridad de la información así como su escalabilidad en términos de usuarios y nuevos servicios.
(3) Diseñar transceptores RFID de corto alcance (empleo de etiquetas pasivas) para su uso en entornos intra-vehiculares, conjugando en su diseño tanto las características de robustez, adaptabilidad y bajo consumo, con un coste contenido, mediante el aprovechamiento de desarrollos establecidos en el mercado. La innovación reside en la aplicación de nuevas técnicas de diseño de antenas no invasivas (una primera aproximación es su impresión con pintura conductora en el cuerpo metálico de los vehículos), así como la miniaturización de las mismas y la reducción de su coste de fabricación.
(4) Definir una arquitectura hardware y software que soporte la integración de los distintos componentes del sistema telemático y que ofrezca un conjunto de servicios de trazabilidad de alto nivel, con funcionalidades de gran valor añadido como la provisión de información fiable y en tiempo real, sin requerir cambios en el modelo operacional de las personas involucradas. La relevancia reside por una parte en resolver problemas críticos de escalabilidad e interoperabilidad entre sistemas y tecnologías emergentes en un ámbito cuya heterogeneidad supone barreras, y por otra en dotar de inteligencia, a través de conectividad ubicua, capacidad de procesamiento autónomo y autonomía energética, al entorno vehicular.
(5) Evaluar el sistema a nivel de piloto en escenarios reales de distribución de productos farmacéuticos.

c) *Impacto económico*

Más allá de las alteraciones en términos de trazabilidad incluidas en el boceto del Real Decreto de Trazabilidad del Ministerio de Sanidad y Consumo comentados anteriormente, la situación de crisis en la que nos encontramos a nivel estatal exige reducir ostensiblemente el gasto farmacéutico. La reducción de los márgenes, ya de por sí apretados, en un sector tan sumamente competitivo y sobre todo la dispensación de medicamentos en dosis unitarias, exige modificaciones en todas las etapas de distribución de los medicamentos. Los procesos de envasado en el laboratorio, almacenamiento de las nuevas dosis, distribución hacia las oficinas de farmacia y dispensación desde éstas hacia el paciente final van a llevarse a cabo desde una nueva perspectiva que exigirá la adaptación y en ocasiones la modificación total de los sistemas instalados actualmente. Esta situación, que ha hecho temblar los cimientos de un sector tan consolidado como el farmacéutico genera una oportunidad de negocio que será aprovechada por aquellas empresas que antes sean capaces de adecuarse a los cambios exigidos.

Paralelamente, la alta competitividad del sector de distribución de medicamentos, determinada por tener el margen fijado y no existir prácticamente diferencias en el precio de los productos suministrados, provoca que la calidad del servicio sea el elemento diferenciador que determina la contratación de una u otra empresa distribuidora. Para las empresas distribuidoras de medicamentos la implantación de una solución como la que aquí se describe aporta una serie de prestaciones adiciones que mejoran el servicio a las farmacias y abaratan el proceso de distribución. Por ejemplo este sistema permitirá conocer la ubicación de cada cubeta de medicamentos minimizando la perdida de unidades. Un estudio realizado por la empresa distribuidora Centro Farmacéutico del Norte, S.A., sobre la que se ha llevado a cabo el piloto de pruebas, cifra en 1.000 unidades las cubetas de medicamentos perdidas anualmente exigiendo realizar una inversión periódica importante para reemplazar las unidades distribuidas. Además, el sistema de trazabilidad permitirá indicar en tiempo real a las oficinas de farmacia el instante en el que se producirá la entrega de un pedido, mejorando el servicio de distribución. Además disponer de información de los tiempos necesarios entre los diferentes puntos de cada ruta permite mejorar la planificación y eliminar los tiempos de espera.

Componentes del equipo de trabajo

Investigador	Categoría profesional
Ldo. Ignacio Angulo Martínez (Jefe de Proyecto)	Profesor Encargado (Ingeniería), Investigador (DeustoTech)
Dr. Asier Perallos Ruiz	Profesor Encargado Doctor (Ingeniería), Investigador Principal (DeustoTech)
Dr. Ignacio Julio García Zuazola	Investigador Senior (DeustoTech)
Ing. Asier Moreno Emborujo	Investigador Junior (DeustoTech)
Ing. Aitor Chertudi Ozamiz	Investigador Junior (DeustoTech)
Ing. Hugo Landaluce Simón	Becario de Doctorado (DeustoTech)
Ing. Pilar Elejoste Larrucea	Investigador (DeustoTech)
Ing. Asier San Nicolás Guimón	Investigador Junior (DeustoTech)
Ing. Roberto Carballedo Morillo	Profesor Encargado (Ingeniería), Investigador (DeustoTech)
Dr. Unai Hernández Jayo	Profesor Encargado Doctor (Ingeniería), Investigador (DeustoTech)
Dr. Nekane Sainz Bedoya	Profesor Encargado Doctor (Ingeniería), Investigador (DeustoTech)
Ing. Itziar Salaberria Larrauri	Investigador Junior (DeustoTech)
Ing. Pablo Fernández Muga	Investigador Junior (DeustoTech)
Ing. Gorka Urquiola Arévalo	Investigador Junior (DeustoTech)

Metodología de trabajo utilizada

La metodología seguida es la que nuestro equipo viene empleando con éxito para el arranque y dinamización de líneas de trabajo, a través de la búsqueda y consecución de un conjunto de proyectos de investigación que den respuesta a necesidades de la industria en ese ámbito y generen contribuciones científicas. A saber:

(1) *Identificación de necesidades en un sector.* La trazabilidad de mercancías ya había sido identificada con anterioridad como un elemento clave para la competitividad de las empresas. Sin embargo, era necesario identificar un sector concreto de aplicación en el que las capacidades de nuestro equipo pudiesen ponerse en valor. La llave nos la dio una de las empresas con las que el equipo colabora frecuentemente, Cenker Robotics, S.L., quien tiene como cliente a Centro Farmacéutico del Norte, S.A. (Cenfarte). Nos indicaron sus problemas en la distribución de medicamentos y las nuevas exigencias a cumplir por Real Decreto.
(2) *Búsqueda de financiación*. Se analizaron distintos programas de financiación pública de I+D+i existentes a nivel regional, autonómico y nacional con el fin de complementar la inversión que Cenfarte estaba dispuesta a realizar por la solución que le planteamos. La concurrencia a estos programas y el desarrollo tecnológico a abordar requería la búsqueda de nuevos socios en forma de empresas que complementaran nuestras capacidades tecnológicas y aportaran conocimiento del sector, con posibles usuarios y escenarios de uso. Se presentaron varias solicitudes de proyecto a estos programas, obteniendo financiación en todos ellos.
(3) *Identificación de retos científicos*. Cubierta la vertiente tecnológica y de financiación del proyecto, nuestro equipo identificó aquellos elementos del mismo con un carácter más científico. Son estos elementos los que posibilitan la generación de nuevo conocimiento y producción científica de alto impacto. En este caso fue el diseño de antenas RFid en miniatura y optimizadas para entornos metálicos cerrados. Además, se buscaron aliados en otros grupos de investigación que nos complementaran en esta parte más científica.
(4) *Ejecución del trabajo tecnológico-científico*. Se siguió nuestro esquema habitual: (a) para el desarrollo tecnológico se formó un equipo dirigido por un jefe de proyecto; (b) para la parte científica se confeccionaron equipos formados por director y doctorando que arrancaran proyectos de tesis a desarrollar a medio plazo.
(5) *Acciones post-proyecto*. Que aglutinan: (a) transferencia tecnológica a empresas, realizada a través de prototipos funcionales resultado de los proyectos; y (b) difusión de resultados, donde se combina la publicación en congresos de los desarrollos tecnológicos funcionales y en revistas especializadas para las contribuciones científicas. Finalmente, el post-proyecto termina con (c) la búsqueda de nuevos escenarios de aplicación a los que adaptar la nueva tecnología y diversificación de los agentes a los que transferirla.

Descripción de los resultados obtenidos

El principal resultado es un desarrollo tecnológico materializado en un piloto funcional que implementa un sistema de trazabilidad de productos farmacéuticos durante la fase de transporte desde el distribuidor hasta los puntos de venta en las farmacias. Este piloto funcional combina (a) una solución telemática capaz de conectar en tiempo real las flotas de vehículos encargados de la distribución con el centro de gestión del distribuido farmacéutico; y (b) un sistema de identificación de cubetas no intrusivo basado en una antena RFid.

Este piloto se encuentra descompuesto en cuatro módulos: (a) una solución embarcada implementada a través de un sistema embebido con capacidad de identificación de cubetas farmacéuticas por RFid y comunicación multipropósito (bluetooth, Wifi y 3G); (b) la propia antena RFid diseñada para ser pintada en la carrocería del vehículo y conectada al sistema embebido; (c) una solución software móvil que corre sobre un Smartphone operado por el transportista; y (d) una solución software de centro de control capaz de monitorizar en tiempo real el proceso de distribución e incidencias, así como el análisis en diferido de rutas, desviaciones, etc.

Antena RFid

Sistema Embarcado

Panel de Centro de Control

La principal *innovación* de este trabajo reside en:

(1) Proporcionar una solución tecnológica viable en coste y operativa para resolver una exigencia introducida a las distribuidoras farmacéuticas en el RD 29/2006. La tecnología RFid hace técnicamente posible esta solución y el uso de cubetas reutilizables para el transporte de medicamentos, hace viable económicamente la inversión. Por otro lado, el haber diseñado un vagón inteligente antenizado permite una identificación de cubetas no intrusiva. A esto hay que añadir la capacidad para gestionar incidencias en el transporte en tiempo real. No existiendo hoy en el mercado soluciones con todas estas prestaciones.

(2) Diseñar una antena RFid optimizada en coste, tamaño y prestaciones. La novedad de ésta es su diseño en miniatura, oculto y pintado dentro de la propia carrocería de las furgonetas de reparto, lo cual hace viable en un futuro su fabricación dentro de la propia cadena de montaje de los vehículos.

A destacar es la validación del piloto a través de su implantación en un distribuidor farmacéutico (Cenfarte), estando ya en fase de pruebas pre-industrialización por parte de las empresas colaboradoras. Y al margen del desarrollo tecnológico, están las publicaciones científicas (ver sección de difusión) y las nuevas líneas de investigación arrancadas, con dos proyectos de tesis doctoral en curso: (a) diseño de antenas y (b) diseño de algoritmos de lectura RFid. También a reseñar son las nuevas oportunidades de actividad identificadas en otros sectores tales como trazabilidad de productos perecederos, mercancías de alto valor, etc.

Canales de difusión utilizados para dar a conocer los resultados de la investigación

Tres han sido los canales de difusión empleados para dar a conocer los resultados de esta investigación:

(1) *Publicaciones en revistas internacionales indexadas*. En concreto, distintas facetas de los resultados de este trabajo han sido publicados en tres revistas internacionales indexadas JCR, una de ellas, Sensors, ubicada en el primer cuartil (Q1) dentro de su categoría.

a. Moreno, A.; Angulo, I.; Perallos, A.; Landaluce, H.; Zuazola, I.J.G.; Azpilicueta, L.; Astrain, J.J.; Falcone, F.; Villadangos, J. «IVAN: Intelligent Van for the Distribution of Pharmaceutical Drugs». *Sensors 2012*, 12, 6587-6609. [JCR Impact Factor (2010): 1.771]
b. Azpilicueta, L; Falcone, F; Astráin, J.J.; Villadangos, J.; García Zuazola, I.J.; Landaluce, H.; Angulo, I.; Perallos; A. «Measurement and Modeling of an UHF-RFID system in a metallic closed vehicle». *Microwave and Optical Technology Letters*, Volume 54, Issue 9, 2126–2130, 2012. [JCR Impact Factor (2010): 0.656]
c. García Zuazola, I.J.; Moreno, A.; Landaluce, H.; Angulo, I.; Perallos, A.; Hernández-Jayo, U.; Sainz, N.; Ziai, M.A.; Batchelor, J.C.; Elmirghani, J.M.H. «A telematics system for the intelligent transport distribution of medicines». *IET Intelligent Transport Systems*, 2012 (in press) [JCR Impact Factor (2010): 0.473]

(2) *Comunicaciones en congresos internacionales*. Concretamente, fruto de esta investigación se acumulan cinco comunicaciones en congresos internacionales.

a. Landaluce, H., Perallos, A., Angulo, I. «Towards an improved RFID anticollision algorithm», *IADIS International Conference (e-Society),* Berlin, Germany, March 2012.
b. Azpilicueta, L. Astráin, J.J., Landaluce, H., Angulo, I., Perallos, A., Villadangos, J., Falcone, F. «Analysis of an UHF-RFID System in a Metallic Closed Vehicle», *6th European Conference on Antennas and Propagation (EuCAP),* ISBN: 978-1-4577-0918-0, pp. 2009-2012, Prague (Austria), March 2012.

c. Moreno, A., Landaluce, H., Angulo, I., Perallos, A., García Zuazola, I.J., Azpilicueta L, Astráin, J.J., Falcone, F., Villadangos, J. «Intelligent Van Based on Wireless Technologies for Pharmaceutical Drugs Traceability and Incidences Reporting», *5th International Symposium on Ubiquitous Computing and Ambient Intelligence (UCAmI),* Riviera Maya (Mexico), December 2011.
d. Azpilicueta, L. Astráin, J.J., Landaluce, H., Angulo, I., Perallos, A., Villadangos, J., Falcone, F. «Análisis de Funcionamiento de un Sistema RFID en un entorno vehicular cerrado». *XXVI Simposium Nacional de la Unión Científica Internacional de Radio (URSI),* Leganes (Madrid), 2011.
e. Moreno, A., Angulo, I., Landaluce, H., Perallos, A. «Easy to deploy solution for pharmaceutical drugs traceability in distribution warehouses». *IEEE International Conference on Intelligent Transportation Systems (ITSC),* Washington DC (USA), 2011.
f. Moreno, A., Angulo, I., Landaluce, H., Perallos, A. «Easily deployable solution based on wireless technologies for traceability of pharmaceutical drugs». *IEEE International Conference on RFID-Technologies and Applications (RFID-TA 2011),* Sitges (España), ISBN: 978-1-4577-0028-6, pp. 252-258, Sept. 2011.

Asimismo, se cuenta con una ponencia invitada en la II Jornada Logística de Euskadi.

(3) *Notas de prensa*. Finalmente los distintos proyectos que nutren esta investigación han sido publicitados a través de notas de prensa emitidas por algunas de las entidades colaboradoras. En este caso, quienes han usado estos medios de difusión han sido Bilbomatica, S.A., Wellness Telecom, S.L. y Universidad Pública de Navarra.

— Bilbomatica S.A.
http://bilbomaticainnovacion.blogspot.com.es/2011/03/trazamed-plataforma-integral-basada-en.html
— Wellness Telecom
http://www.wtelecom.es/iplusdplusi/proyectos/trazamed/mobileversion.aspx
— Universidad Pública de Navarra
http://www.unavarra.es/actualidad/noticias?contentId=152505
— DeustoTech
http://www.deustotech.deusto.es/cs/Satellite/ingenieria/es/1328107467635/id-empresas/casos-de-exito-0/trazamed/generico

Entidad que subvencionó el proyecto

Este trabajo de investigación ha sido soportado económicamente a través de cuatro proyectos financiados. Tres de ellos con financiación procedente de programas de I+D+i de administraciones públicas (regionales, autónomas y estatales) y el restante a través de inversión privada de empresas.

(1) Ministerio de Ciencia e Innovación (Programa INNPACTO 2010). Financiación: 400.843 €
Proyecto TRAZAMED: Plataforma integral basada en tecnologías de identificación RFID y Datamatrix para la trazabilidad de medicamentos [IPT-090000-2010-007]

— Duración: 26 meses.
— Entidades participantes: Bilbomatica, S.A. (líder), Creativ IT, S.L., Wellness Telecom, S.L., Universidad Carlos III, Universidad de Deusto.

(2) Gobierno Vasco - Departamento de Educación (Programa Euskadi+09). Financiación: 45.000 €
Proyecto TRAZEK: Plataforma integral de gestión de la trazabilidad de medicamentos [UE09+/64]

— Duración: 14 meses.
— Entidades participantes: Universidad de Deusto, Microticker, S.L.

(3) Diputación Foral de Bizkaia (Plan de Promoción de la Innovación y la Cooperación 2010. Área 3: Centros de Excelencia). Financiación: 200.782 €
Proyecto TRACETIC: Tecnologías y arquitecturas innovadoras para la trazabilidad de mercancías y la provisión de servicios de geolocalización [6/12/TK/2010/14]

— Duración: 20 meses.
— Entidades participantes: Universidad de Deusto (líder), Robotiker – Tecnalia, Clúster de Movilidad y Logística, Avangroup Business Solutions, S.L., Microticker, S.L.

(4) Bilbomatica, S.A., Cenker Robotics, S.L., Cenfarte, S.A. (Inversión Privada). Financiación: 105.000 €
Proyecto: Implantación y prueba del piloto de trazabilidad en instalaciones de Centro Farmacéutico del Norte, S.A.

— Duración: 12 meses.

Además, este trabajo de investigación plantea interesantes líneas futuras. Éste es el caso de la adaptación de los sistemas automatizados de dispensación y recepción de medicamentos en distribuidores mayoristas y oficinas de farmacia, para la incorporación de lectores de códigos de barras bidimensionales, garantizando de este modo su trazabilidad a nivel de unidad de presentación. Esta nueva línea de trabajo está siendo impulsada desde el equipo, habiendo obtenido ya financiación para un proyecto de dos años de duración.

(5) Gobierno Vasco - Departamento de Industria (Programa GAITEK 2011). Financiación: 39.000 €
Proyecto IDAMED: Robot de identificación automatizada de medicamentos

— Duración: 19 meses.
— Entidades participantes: Cenker Robotics, S.L., Avangroup Business Solutions, S.L., Tecnológico Fundación Deusto.

Presupuesto solicitado y concedido

Dado que los proyectos solicitados a las distintas fuentes de financiación, aun siendo en escenarios diferentes, poseen actividades comunes y dado que además que existe un porcentaje importante de financiación privada, a pesar de los recortes que las fuentes de financiación pública aplican en las subvenciones, la complementariedad de las fuentes de financiación ha permitido cubrir íntegramente el coste de la investigación. La financiación obtenida ha sido de 751.625 euros para una actividad de 3 años de duración.

Resultados de investigación

TRAZAMED.
Plataforma integral basada en tecnologías de identificación RFid y DataMatrix para la trazabilidad de medicamentos

Especificación de requisitos

Índice de contenidos

1. INTRODUCCIÓN

1.1. **Propósito del documento**

Mediante el presente documento de especificación de requisitos se pretende definir de forma clara y suficientemente detallada el objetivo, alcance, estructura global y requerimientos específicos tanto funcionales como no funcionales de cada uno de los elementos y sistemas tanto hardware como software a desarrollar y que componen el proyecto TRAZAMED: PLATAFORMA INTEGRAL BASADA EN TECNOLOGÍAS DE IDENTIFICACIÓN RFID Y DATAMATRIX PARA LA TRAZABILIDAD DE MEDICAMENTOS, en el que participan Bilbomática, Creativ-IT, Wellness Telecom, la Universidad de Deusto y la Universidad Carlos III de Madrid.

1.2. **Ámbito del sistema**

El transporte de medicamentos, desde que son producidos en un laboratorio hasta que llegan a la farmacia desde la que son suministrados al usuario final, incluye una serie de etapas de distribución cuyo control es necesario tanto desde la perspectiva económica como de la sanitaria.

Actualmente los sistemas implantados en las empresas distribuidoras, cumpliendo con el anterior Real Decreto 725/2003, incluyen el seguimiento del medicamento hasta el instante en el que cada lote es recibido por un almacén intermedio a través del código de lote y la fecha de caducidad impresos en el propio envase. Sin embargo, el aumento detectado en la circulación de medicamentos falsificados así como una mayor internacionalización del sector farmacéutico conllevan la necesidad de realizar una mayor vigilancia que permita a las autoridades minimizar el tiempo de reacción ante la detección de un problema de seguridad. El nuevo proyecto de Real Decreto de Trazabilidad del Ministerio de Sanidad y Consumo incorpora el seguimiento de los medicamentos hasta el momento de su dispensación al paciente para garantizar en todo momento la accesibilidad y el abastecimiento de los fármacos y la seguridad de los mismos.

La obligación de implantar un sistema de trazabilidad que funcione, no a nivel de lote, sino a nivel de unidad de presentación y que cubra todas las etapas de distribución desde que es producido en el almacén farmacéutico hasta que es dispensado a un paciente desde una oficina de farmacia exige una alteración en el modelo actual de distribución farmacéutica, causando un total desasosiego a las partes implicadas.

2. DESCRIPCIÓN GENERAL

2.1. **Objetivos del proyecto**

El objetivo principal del presente proyecto consiste en el desarrollo de una solución industrial (hardware + software) que permita la trazabilidad de medicamentos demandada por el Ministerio de Sanidad y Consumo en el nuevo proyecto de Real Decreto de trazabilidad y recomendada por la Unión Europea mediante la directiva 2003/94/CE. La solución aquí presentada pretende minimizar, a través de la correcta aplicación de las tecnologías de información y comunicación, no sólo el coste de implantación de las diferentes partes implicadas (laboratorios, distribuidores y farmacias) sino también la alteración sobre el modelo de negocio actual que conlleve la integración de este sistema.

El boceto del real decreto presentado por el Ministerio de Sanidad y Consumo define dos alternativas tecnológicas para el sistema de trazabilidad: códigos de barras en dos dimensiones (DataMatrix) o identificación por radiofrecuencia (RFID). Este proyecto presenta una solución que combina ambas tecnologías para generar una solución que se adapte a las necesidades de los diferentes agentes que intervienen en el proceso de distribución de medicamentos.

La identificación por radiofrecuencia RFID es una tecnología emergente que permite la identificación de los componentes etiquetados a través de ondas de radio sin necesidad de visión directa entre emisor y receptor (etiqueta y lector). El empleo de etiquetas de frecuencia ultra alta (UHF) permite la detección de etiquetas a larga distancia mediante el empleo de antenas de alta ganancia en el lector. Estas distancias pueden llegar a rozar los 50 m.

Aunque la tecnología RFID está integrada en múltiples soluciones de trazabilidad, el presente proyecto propone un empleo de la misma que aporta un nivel de garantía en la trazabilidad superior al de cualquier solución existente, permitiendo poder comprobar en cualquier momento el contenido de una unidad de transporte.

En lugar de los sistemas actuales que detectan las etiquetas al pasar por un determinado punto (puerta) de la cadena de transporte, o bien al ser cargados mediante una herramienta determinada (dotada de un lector RFID), el sistema propuesto incluye la instalación de un lector de alta ganancia en cada vehículo capaz de detectar todas las etiquetas que se encuentran en el interior del mismo. El sistema deberá ser auto-configurable controlando la potencia de emisión para determinar si una etiqueta se encuentra dentro del vehículo (en el vagón de carga) o bien en el exterior. Esta funcionalidad se consigue mediante el diseño de antenas direccionales que se ajusten a la morfología y condiciones que se pueden encontrar en la caja de carga de un vehículo de transporte.

Cada unidad de transporte contará con un módulo de control y comunicaciones que permita ser preguntado por el contenido de la carga, así como almacenar el punto geográfico, al incluir un sistema de posicionamiento por satélite, en el que la carga sufre alguna modificación. Esta información podrá ser transferida en el instante en el que se produce mediante comunicación GPRS, o al finalizar el servicio de transporte al disponer de conectividad WiFi.

Además el proyecto incluye el desarrollo de una aplicación móvil que permita al conductor disponer de información sobre la hoja de ruta, las acciones de transporte a llevar a cabo en cada parada y las posibles incidencias que se produzcan desde un Smartphone que se conecta al sistema de control y comunicaciones de manera inalámbrica pudiendo cotejar la correcta ejecución de cada acción.

2.2. **Alcance del proyecto**

El alcance del proyecto contempla el diseño, desarrollo y prueba piloto de una Plataforma Integral basada en Tecnologías de Identificación RFID y DataMatrix para la Trazabilidad de Medicamentos. Dicha prueba piloto será desplegada en el almacén de la empresa mayorista de productos farmacéuticos Cenfarte – Centro Farmacéutico del Norte S.A. situado en la localidad de Baracaldo. La prueba piloto se desplegará sobre tres vehículos de transporte propiedad de la compañía mencionada.

La solución propuesta cuenta con tres partes bien diferenciadas:

- El dispositivo embarcado en las unidades de transporte encargado de detectar el contenido de la carga mediante tecnología RFID y de las comunicaciones con el servidor central y la unidad móvil del transportista.
- La aplicación móvil instalada en el Smartphone del transportista que permitirá al sistema, mediante un interfaz gráfico, indicar el plan de trabajo en cada servicio de transporte
- La solución software de control desde el que monitorizar la trazabilidad de los medicamentos, planificar las rutas optimizadas y posicionar las diferentes unidades de la flota de transporte.

2.2.1. *Dispositivo embarcado*

Los sistemas de dispensación de medicamentos automatizados instalados en la mayoría de almacenes de distribución se encargan de coordinar todos los pedidos realizados por cada oficina de farmacia a través del sistema ERP (planificación de recursos empresariales) implantado por el distribuidor farmacéutico. Estos sistemas organizan por medio de cubetas de medicamentos cada unidad de distribución solicitada por las distintas oficinas de farmacia planificando las rutas que serán llevadas a cabo por las diferentes unidades de transporte. En caso de faltar alguna unidad solicitada por la oficina de farmacia la cubeta incompleta se deposita en la sección de errores de aprovisionamiento para ser supervisada manualmente. Todas las cubetas completadas correctamente son transportadas por el sistema hasta el muelle de carga de la unidad de transporte (vehículo) encargada de cada ruta.

Cuando la unidad de transporte llegue al almacén y se coloque en el muelle de carga asignado, el dispositivo embarcado, que se instalará en cada unidad de transporte, se conectará vía WiFi con el módulo de control del sistema de almacenamiento automático descargando toda la información necesaria para cada servicio de transporte: identificador de cada cubeta asignada a la ruta, paradas establecidas en la ruta, cubetas a descargar en cada parada, etc. El dispositivo embarcado dispondrá de un lector RFID capaz de detectar las etiquetas de todas las cubetas de medicamentos ya introducidas en el vagón de carga. Mediante dos indicadores luminosos incluidos en el propio dispositivo (Led Rojo y Led Verde) el transportista podrá observar si ya ha introducido todas las cubetas asociadas a su servicio de transporte, momento en el cual comenzará su ruta. En caso de que falte alguna cubeta, el dispositivo embarcado enviará, mediante conexión Bluetooth, el identificador de las cubetas extraviadas al Smartphone del conductor para que este pueda reclamarlas a la administración del almacén. De esta forma se evitan discrepancias entre pedidos y suministros evitando el desabastecimiento de las oficinas de farmacia.

Una vez la unidad de transporte comienza su ruta el dispositivo embarcado, gracias a un sistema receptor para Sistemas de navegación por Satélite (GNSS), se encarga de almacenar la ruta realizada, enviando al panel de control el posicionamiento en tiempo real para posibilitar la gestión de la flota. En cada parada el sistema validará las cubetas descargadas y registrará las cubetas devueltas por la farmacia, enviando cualquier incidencia o discrepancia con la planificación tanto al dispositivo móvil del transportista como al sistema de control.

El dispositivo embarcado deberá ser un equipo hardware fácilmente configurable para los diferentes modelos de vehículos de transporte que deberá incluir los siguientes elementos.

— Módulo controlador capaz de registrar y validar la ruta realizada, las variaciones de la carga a lo largo del servicio de transporte y de las comunicaciones.
— Conectividad WiFi para recibir la información de cada servicio de transporte desde el sistema de control en el momento de la carga y enviar en sentido contrario el registro de la ruta al retornar al almacén.
— Receptor GNSS. Debido a que las rutas se desarrollan fundamentalmente en zonas urbanas con cobertura limitada el geo-posicionamiento de cada vehículo de transporte se llevará a cabo mediante un receptor multifrecuencia que acceda no solo a los satélites GPS sino que esté preparado para la recepción de los satélites del sistema Galileo cuando este se implante.
— Conectividad Bluetooth. Cada transportista dispone de un Smartphone que le permite comunicarse con el sistema de control y validar el desarrollo de cada servicio de transporte. Para la comunicación entre el dispositivo embarcado y el dispositivo móvil se empleará tecnología Bluetooth.
— Sistema Lector RFID. Compuesto por un módulo lector RFID de banda ultra alta y ganancia variable y dos antenas monolíticas de alta ganancia capaces de detectar las etiquetas RFID que se encuentren en el interior del vagón de carga del vehículo.
— Dispositivo de aviso luminoso compuesto por dos diodos Led de alta luminosidad que informarán al transportista sobre la correcta actuación en cada punto de la ruta para validar las acciones a realizar en cada momento.

2.2.2. *Solución móvil*

Para mantener el contacto con cada transportista, cada vehículo tendrá asociado un dispositivo móvil tipo Smartphone que llevará instalada una aplicación que permita, a través de un interfaz gráfico, informar al transportista de todo lo necesario en cada servicio de transporte. La enorme oferta de terminales y los diferentes sistemas operativos existentes exigen el desarrollo de una aplicación multiplataforma que garantice su funcionamiento en la mayoría de móviles existentes en el mercado. Los operadores de servicios móviles ofrecen a los clientes corporativos ciertos terminales inteligentes con las necesidades tecnológicas exigidas por esta aplicación (Wifi, GPS, GPRS/HSPA) con unas condiciones económicas muy favorables.

La aplicación residente en el dispositivo móvil dispondrá de las siguientes funcionalidades:

— Ayuda a la navegación: mostrará la hoja de ruta indicando, de forma amigable, el orden en el que debe realizar cada parada en la ruta planificada. En caso de que sea necesario permitirá asistir al conductor en la navegación hasta cada punto de la ruta sin necesidad de configurar el software de navegación. Además cada parada incluida en la ruta asignada a un vehículo dispondrá de información relacionada como dirección, comentarios realizados por el mismo u otros conductores o desviaciones en las estimaciones temporales planificadas.
— Soporte para las actividades de transporte: indicará cada acción a llevar a cabo en cada punto de la ruta validando la correcta ejecución de la misma mediante la conectividad con el dispositivo embarcado. En caso de que las cubetas que hayan sido descargadas no coincidan con las marcadas en la hoja de ruta, el transportista recibirá un aviso en su terminal móvil indicando la desviación respecto a la planificación y permitiendo corregir dicha acción previamente al envío de una incidencia al servidor central.
— Gestión de incidencias: la aplicación dispondrá de un sistema que permitirá el envío de incidencias de cualquier tipo (accidentes, averías, extravíos, etc.) hacia el servidor central. En función de la naturaleza y urgencia de la incidencia el servidor central redirigirá su gestión al centro de control encargado de la misma.

2.2.3. *Solución software de Control*

El alcance del proyecto propuesto incluye el desarrollo de un panel de control desde el que gestionar el sistema. Este panel de control incluye dos funcionalidades principales

2.2.3.1. Trazabilidad de medicamentos

El sistema dispondrá de un robusto sistema de base de datos en el que se almacenará la oficina de farmacia en la que se ha distribuido cada unidad de envase de un medicamento, indicando el lote al que pertenecía y la fecha de caducidad. Este sistema permitirá llevar a cabo una búsqueda mostrando la ubicación en la que se encuentra cada unidad de envase de un determinado lote independientemente de que se haya dispensado en una oficina de farmacia, se encuentre en un determinado almacén o incluso en el interior de un vehículo durante un servicio de transporte.

Paralelamente el sistema controlará la ubicación de las cubetas empleadas en el transporte de medicamentos permitiendo localizar donde se han extraviado las cubetas que no se han devuelto al almacén para su posterior reclamación.

2.2.3.2. Gestión de Flotas

El sistema permitirá geo-posicionar sobre un mapa los diferentes vehículos empleados en la distribución de los medicamentos, almacenando las rutas llevadas a cabo y registrando el tiempo empleado en cada parada. El sistema aportará a la empresa distribuidora las siguientes funcionalidades:

— Cálculo aproximado del tiempo restante para la entrega de un pedido en una farmacia.
— Optimización contextual de las rutas en función de la hora de entrega, el tráfico y la urgencia del abastecimiento.
— Control de retrasos en los envíos permitiendo monitorizar el desarrollo de la ruta y las paradas llevadas a cabo durante un servicio de transporte penalizado.

2.2.3.2.1. Planificación Optimizada de Flotas

Basándose en la información almacenada en el sistema de gestión de base de datos que registra el desarrollo de las rutas y empleando técnicas de inteligencia artificial esta aplicación permitirá, a partir de la información generada por el sistema de planificación de recursos empresariales ERP implementado por el distribuidor de productos farmacéuticos que se encarga de recoger los pedidos ejecutados por las diferentes oficinas de farmacia, generar las rutas a llevar a cabo por cada vehículo de transporte optimizando su desarrollo de acuerdo a factores como la posición de cada oficina de farmacia, el tráfico, la franja horaria o la urgencia de cada producto solicitado.

3. REQUISITOS ESPECÍFICOS

3.1. **Requisitos funcionales del sistema**

3.1.1. *Dispositivo embarcado*

3.1.1.1. Detección de cubetas

La principal tarea del dispositivo embarcado es tener un control exhaustivo en todo momento de las cubetas que se hallan en una unidad de transporte. Desde el momento en que se cargan todas las cubetas al inicio de una ruta hasta el final de la misma, se lleva un seguimiento de todas ellas para saber donde y cuando se han cargado o descargado y si dichas acciones se han realizado según lo previsto.

Para la realización de esta tarea, se dispone de un lector RFID, que controlado por el dispositivo embarcado, es capaz de leer las etiquetas de todas las cubetas.

3.1.1.2. Conexión inalámbrica

La comunicación entre los distintos dispositivos o módulos que forman parte de la solución global, se realiza de forma inalámbrica. En el caso del dispositivo embarcado, es necesario que establezca comunicación tanto con el dispositivo móvil como con el módulo de control. Para ello, aprovecha las distintas tecnologías de las que dispone.

3.1.1.2.1. Conectividad con el dispositivo móvil

La conexión con el dispositivo móvil es realizada utilizando tecnología Bluetooth. Es necesaria la comunicación con el dispositivo móvil para diversas tareas, como por ejemplo: la identificación de un conductor, el inicio de una ruta, o la transmisión de incidencias graves al módulo de control.

El diseño del dispositivo embarcado se ha realizado de forma que estas tareas sean transparentes al conductor que porta el dispositivo móvil.

3.1.1.2.2. Conectividad con el módulo de Control

La conectividad con el módulo de control se realiza mediante tecnología WiFi. Solo se dispondrá de dicha conectividad cuando la unidad de transporte en la que se encuentra el dispositivo embarcado se halle en el almacén, es decir, al inicio y final de una ruta.

En el inicio de una ruta, se establecerá conexión con el módulo de control para descargar la Hoja de Ruta, que contiene toda la información acerca de la ruta que el transportista debe realizar.

Al finalizar una ruta, se vuelve a establecer conexión con el módulo de control para transmitirle el informe generado por el dispositivo embarcado a lo largo de la ruta realizada.

3.1.1.3. Recepción de posicionamiento

Es también requisito indispensable para el dispositivo embarcado el tener en todo momento conocimiento sobre su posición. Para ello dispone de un receptor GNSS capaz de acceder tanto a satélites GPS como a los satélites del sistema Galileo (aún sin implantar).

El posicionamiento es necesario para almacenar con detalle el camino seguido por la unidad de transporte a lo largo de la ruta así como para detectar donde se han realizado cada una de las paradas y así identificar las cubetas que se deben descargar en cada una de ellas.

3.1.1.4. Generación de informes e incidencias en ruta

El dispositivo embarcado es capaz de generar informes e incidencias durante el transcurso de una ruta. El Informe de Ruta contiene todas las acciones realizadas (cargas y descargas), información del posicionamiento seguido a lo largo de la ruta e incidencias ocurridas. Estas incidencias, están clasificadas en distintas prioridades según su gravedad.

Cono ya se ha señalado con anterioridad, las incidencias de carácter grave, además de ir incluidas en el informe de ruta, son enviadas en el momento en que se dan al dispositivo móvil mediante Bluetooth para que este último las retransmita al modulo de control.

3.1.1.5. Indicadores luminosos de respaldo

Cada unidad de transporte dispone de dos dispositivos luminosos de tipo LED instalados en el vagón de carga, uno de color rojo y otro de color verde. Estos indicadores, controlados por el dispositivo embarcado, señalan al transportista encargado de cargar y descargar las cubetas si la acción realizada en cada parada la ha realizado correctamente de acuerdo a la ruta establecida.

En el momento que la puerta del vagón de carga se abra en una parada, el indicador rojo se encenderá y permanecerá así hasta que no se hayan descargado todas las cubetas correspondientes en dicha parada. Cuando se haya terminado de descargar las cubetas necesarias, se apagará el indicador rojo y se encenderá el verde, señalando así que la descarga se ha realizado correctamente.

3.1.2. *Solución móvil*

3.1.2.1. Interfaz gráfica

Un requisito importante de la solución móvil debe ser una interfaz gráfica amigable, que no suponga un esfuerzo al usuario comprender y manejar la aplicación en cuestión. Dicha interfaz debe estar diseñada para que sea el sistema sea lo menos intrusivo posible, de forma que el empleado pueda realizar su trabajo normal sin perder el tiempo de forma innecesaria e interactuando el menor tiempo posible.

3.1.2.2. Multiplataforma

Debido a la enorme oferta de teléfonos móviles de última generación existentes en el mercado, así como los diferentes sistemas operativos que hay hoy en día, se considera necesario que la aplicación sea multiplataforma, para que pueda ser soportada por la mayoría de terminales existentes. Cumpliendo este requisito, se pretende que se tenga elección del móvil a utilizar, abriendo la oferta a terminales más adaptables, más baratos o más sofisticados.

3.1.2.3. Conectividad inalámbrica

La aplicación, tanto para obtener datos del panel de control como para comunicarse con el sistema embebido, debe de poseer sistemas de conectividad inalámbricos, tales como Wifi, 3G o Bluetooth. Esto permite tanto reducir el cableado con el sistema embebido, como poder conectarse de forma sencilla con el panel de control cuando sea necesario por la tecnología deseada.

3.1.2.4. Hoja de ruta y navegación

Mediante la interfaz amigable antes comentada, el sistema debe poder mostrar la hoja de ruta enseñando cada una de las paradas que el camión debe hacer, de forma ordenada, con todos los detalles necesarios en cada una de las paradas como la planificación de la parada, dirección del lugar, comentarios sobre el lugar, etc.

Además de mostrar cada parada, el sistema debe ayudar a asistir al conductor a la hora de llegar a una parada concreta asistiendo al mismo en la navegación.

3.1.2.5. Acciones de transporte

Como se ha indicado, es necesario que se muestre la hoja de ruta que debe realizar el vehículo. Pero además, en cada parada se debe indicar que acciones debe realizar el propio conductor (descargar materiales, carga de los mismos,…) no sólo para la comprobación, sino para que el sistema avise en caso de error (por ejemplo que se cargue algo que no debería cargarse o que olvide algo por cargar) siempre que sea necesario. Para ello, se cree imprescindible que se conecte la aplicación móvil con el sistema embebido, como se ha mencionado, para registrar los materiales que están siendo cargados o descargados.

3.1.2.6. Aviso de desviaciones

El sistema debe ser capaz de avisar al panel de control de forma inmediata cualquier desviación que ocurra durante la ruta. Siempre que se lleve a cabo una acción con alguna irregularidad (por ejemplo: una cubeta no ha sido descargada en la parada donde debe Haberse descargado), la solución móvil debe informar en el momento de la situación.

Debe poder registrarse incidencias de todo tipo, como por ejemplo averías, extravíos, accidentes, etc. Y se deben priorizar las incidencias que sean urgentes.

3.1.3. *Solución software de Control*

3.1.3.1. Almacenamiento de la información

El sistema contará con un SGBD (sistema de gestión de base de datos) en el servidor que servirá como almacén de la información. El sistema propuesto cuenta con una gran cantidad de información relevante que deberá ser registrada en la BBDD (base de datos) para poder ser consultada y consumida con posterioridad.

Las entidades relevantes que deberán ser recogidas por el sistema son:

— Conductores: datos personales básicos.
— Rutas: identificadas unívocamente, con fecha y estado* actualizados.
— Recogidas y Entregas de cubetas: fecha y hora, farmacias y cubetas implicadas.
— Farmacias: identificadas unívocamente, con la dirección y posición GPS.
— Cubetas: identificadas unívocamente, con estado** actualizado.

* No iniciada, Iniciada, Pausada, Finalizada.
** En el almacén, Cargada/Descargada, Extraviada.

3.1.3.2. Sistema de comunicaciones

La información almacenada en el servidor deberá ser consultada en el desarrollo de las rutas por la aplicación móvil cuyos requisitos han sido definidos en el punto 3.1.2 del presente documento.

Toda la información registrada en la BBDD del aplicativo deberá estar disponible para su consulta desde el dispositivo móvil. Para ello se diseñará un servicio web, desplegado en el servidor y accesible vía GPRS/3G por el móvil en ruta, encargado de exponer la información mediante interfaces descriptivos y desarrollados con datos primitivos y objetos de dominio serializables con el fin de conseguir una total interoperabilidad entre sistemas.

3.1.3.3. Aplicación gráfica de geoposicionamiento

El panel de control dispondrá de una utilidad con capacidad de visualización (basada en geoposicionamiento sobre mapa) que mostrará las rutas, paradas e incidencias producidas y señalará mediante colores/iconos identificativos el estado de cada una de ellos, en ese momento.

La aplicación será un medio de acceder al sistema de información de una forma visual, mostrará los emplazamientos situados en el mapa y la información relativa a cada una de las rutas (duración, distancia, conductor, etc.) así como de las cubetas descargadas en cada una de las paradas.

3.1.3.4. Gestión de Incidencias

Una de las características fundamentales del sistema a desarrollar es la gestión de las posibles incidencias. El sistema contempla 2 tipos de incidencias según su nivel de urgencia y tratamiento asociados:

- Incidencias Urgentes: el dispositivo móvil se comunicará en el acto con el servicio web en el servidor y la incidencia quedará registrada en el instante para su tratamiento.
- Incidencias No Urgentes: el dispositivo embebido se encargará de su registro en ruta de modo que sean enviadas con posterioridad al servidor.

En el servidor un proceso dedicado se encargará de recibir el fichero XML generado con el estado de la ruta y las posibles incidencias. Se definen en el sistema 2 tipos fundamentales de incidencias:

- Incidencias en la actividad del transporte: paradas no planificadas o desviaciones en tiempo de la ruta establecida.
- Incidencias en la actividad de proceso de cubetas: cubetas extraviadas, no descargadas o descargadas incorrectamente.

La aplicación tratará la incidencia almacenando su información para posteriores revisiones y/o estadísticas de funcionamiento del transporte además de informar mediante el Panel de Control en el momento en que esta es recibida.

3.1.3.5. Búsqueda y filtrado de la información

La información almacenada en el servidor deberá poder ser consultada en todo momento mediante el Panel de Control. Para hacer más accesible y entendible dicha información, deberán ofrecerse mecanismos de búsqueda y filtrado de datos. Se han definido los siguientes campos para la realización de las búsquedas:

— Fecha de la ruta.
— Vehículo.
— Identificador de la Ruta.
— Conductor.
— Identificador de Cubeta.

El resultado será el conjunto de rutas que cumplan con las condiciones de filtrado y será mostrado en la interfaz gráfica así como en formato de tabla para facilitar la consulta de los datos.

3.1.3.6. Gestión del sistema / Administración web

Se habilitará una sección en la aplicación web mediante la cual el administrador debidamente logueado y autenticado en el sistema pueda realizar tareas comunes de administración de la información. El usuario administrador tendrá la posibilidad de realizar altas, bajas, modificaciones o consultas sobre los contenidos de la base de datos del sistema de modo que pueda gestionar la plantilla de conductores, el registro de vehículos o la cantidad de cubetas.

Dicho panel de administración ofrecerá una interfaz sencilla al administrador del sistema de modo que este no tenga que realizar modificaciones directas sobre el sistema gestor de base de datos (SGBD) subyacente al mismo.

3.1.3.7. Planificación y optimización de rutas

El servidor contará con un proceso en ejecución encargado de recoger la información de las rutas finalizadas y comparar su desarrollo con el registro de rutas previo ya existente. Esta comparación de los datos obtenidos y el posterior almacenamiento de la información relevante constituirá la base de conocimiento del sistema de optimización de rutas.

El procesamiento de los datos obtenidos basados en el conocimiento adquirido permitirá a la aplicación generar rutas óptimas de acuerdo a los siguientes factores definidos:

— La posición de cada oficina de farmacia en la ruta.
— El tráfico en dicha franja horaria.
— La urgencia de cada producto solicitado.

3.2. **Requisitos no funcionales**

Debido a la rápida evolución de las tecnologías y nuevas formas de comunicación es fundamental basar el desarrollo del proyecto en una arquitectura que tenga la suficiente agilidad para soportar cambios, actualizaciones, nuevas funciones y futuras especificaciones que pueden surgir en el proceso de mantenimiento del sistema. Es por esto que para el desarrollo de este proyecto se tiene en cuenta desde cero todas estas circunstancias de tal manera que cumpla una serie de requisitos no funcionales fundamentales.

Estos requisitos específicos justifican que el desarrollo de una solución a medida es necesaria si se quieren conseguir unos resultados de excelencia del sistema, ya que en el mercado no existen herramientas comerciales que satisfagan la funcionalidad y los requisitos no funcionales que se detallan a continuación.

Debido a la importancia que tiene que la presente plataforma sea capaz de soportar cambios y futuros servicios implementados sobre ella, su desarrollo se realiza con el mayor número de estándares del mercado con el motivo de facilitar estas actualizaciones y nuevos servicios, y garantizar que su implantación tenga el menor impacto posible sobre el entorno de producción.

3.2.1. *Arquitectura abierta*

Desde el primer momento el diseño de la arquitectura se realiza teniendo en cuenta que este sistema es una primera versión cuya funcionalidad va a sufrir una evolución y va a necesitar integrar futuros servicios. Por esto se ha diseñado una arquitectura de N capas independientes entre sí, de manera que se establece un desacoplamiento que permita flexibilidad de uso de cada una de las capas por separado. Esta separación de responsabilidades entre las capas proporciona además un incremento sobresaliente en la mantenibilidad del software, aspecto crítico y principal desembolso económico de un proyecto sino se tiene en cuenta desde un principio.

3.2.2. *Escalabilidad*

La plataforma debe estar preparada para un aumento en el número de usuarios y/o peticiones a lo largo del tiempo, es necesario que el sistema garantice su correcto funcionamiento independientemente de este hecho. La escalabilidad es pues una característica muy importante que permite que el sistema crezca junto a sus necesidades, ofreciendo siempre el mejor servicio. Este requisito se ve cumplido gracias a un servidor de aplicaciones que posee las siguientes características:

— Trabajo en modo granja de servidores o modo clúster: esta característica permite que una misma aplicación se ejecute en varios servidores de manera simultánea y compartiendo sus recursos.

Figura 1

Granja de Servidores

— Balanceo de carga: las peticiones recibidas en los servidores son redirigidas siempre al servidor que se encuentre con una menor carga de tráfico de red, garantizando el uso óptimo de la misma.
— Replicación de la información: la replicación de la información es necesaria en el caso de necesitar escalabilidad ya que agiliza el proceso de instalación de un nuevo servidor en la plataforma.

3.2.3. *Modularidad y reusabilidad*

El diseño de la plataforma se ha realizado dividiendo las responsabilidades más significativas entre distintas capas. De esta manera se pueden distinguir capas de lógica de negocio, capas de persistencia de datos, capas de modelo de datos, capas de servicios, capas de comunicaciones. Todas estas capas son independientes y reutilizables de forma autónoma, de este modo la implementación de un nuevo servicio o incluso de una nueva capa lógica en el sistema de información no tendrá ningún impacto negativo sobre el funcionamiento de la plataforma.

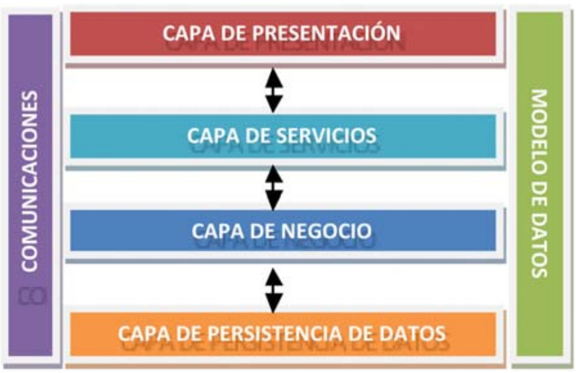


Figura 2

Capas lógicas de la Plataforma

Gracias a este diseño basado en módulos y capas se hace un uso extensivo de la reusabilidad que decrementa drásticamente el tiempo y el esfuerzo invertido en la construcción de la plataforma. Así encontramos diferentes módulos reutilizables como:

— Módulo RFID: Realizando toda la gestión de la tecnología RFID en un módulo independiente se consigue que el desarrollo de la funcionalidad de detección de cubetas pueda realizarse de manera autónoma sin tener que preocuparse por saber cómo funcionan los dispositivos RFID, ya que esta lógica esta encapsulada en su modulo correspondiente. Además este modulo es aprovechable para futuros servicios que precisen el uso de tecnologías RFID.
— Módulo de Notificaciones: A lo largo de toda la funcionalidad de la plataforma nos encontramos con la necesidad de enviar notificaciones a distintos dispositivos, ya sean terminales móviles u otros dispositivos de proveedores de servicios que necesitan una manera de recibir y enviar notificaciones de distinta índole. Este módulo independiente expone toda esta funcionalidad que facilita en gran medida la manera de trabajar.
— Módulo de Comunicaciones: Tal vez el módulo más importante de la plataforma. Es el encargado de exponer un protocolo y una manera de comunicarse desde cualquier dispositivo de la plataforma. Estandarizando las comunicaciones internas se consigue eliminar cualquier ambigüedad o fallo de comunicación que pudiese existir al contar con una manera preestablecida y definida de comunicarse.

3.2.4. *Interoperabilidad*

En una plataforma como esta es importante contar con una interoperabilidad total entre los diferentes elementos que la componen. Utilizando métodos de comunicación ágiles y simples se consigue una colaboración fluida entre los actores del sistema y entre los agentes externos que utilicen cualquier tipo de tecnología.

Gracias al uso de Servicios Web fácilmente inteligibles y descriptivos y que estén desarrollados con datos primitivos y objetos de dominio serializables se consigue una total interoperabilidad entre sistemas que usen incluso diferentes tecnologías. Así por ejemplo, los servicios web desarrollados alojados en un servidor de aplicaciones IIS (Internet Information Services) de .NET serán totalmente accesibles en el futuro por cualquier otro tipo de aplicación desarrollada en cualquier lenguaje de programación como por ejemplo JAVA usando JBOSS.

Utilizando los servicios web como una de las formas de comunicación, utilizando nomenclaturas extendidas y normalizadas en todos los apartados del sistema, y asegurando el desarrollo de una documentación paralela al progreso de la construcción de la plataforma garantizan todos los ámbitos de interoperabilidad: organizativa, técnica, semántica y perdurable en el tiempo.

3.2.5. *Alta disponibilidad y fiabilidad*

La arquitectura de la plataforma cuenta con los recursos suficientes para recuperarse en caso de producirse un fallo o avería en cualquier punto del sistema. Todos los servicios críticos del sistema como son el servidor central o las comunicaciones internas cuentan con servidores de respaldo que entran en funcionamiento en cuanto se les necesita.

Gracias al servidor de aplicaciones IIS la configuración de servidores de respaldo es sencilla e intuitiva. Además, utilizando la replicación de las bases de datos y de la información de los servidores, el mantenimiento de los mismos se realiza de manera automática.

En caso de producirse una avería tanto del servidor central como de los servidores de respaldo, existen mecanismos de almacenamiento local de información que aseguran que todas aquellas operaciones puedan ser recuperadas en un futuro y restablecer su funcionamiento de una manera eficiente.

3.2.6. *Rendimiento*

Gracias a la tecnología del servidor de aplicaciones IIS, el máximo rendimiento del sistema está asegurado, ya que cuenta con un mecanismo propio integrado de balanceo de carga. El balanceo de carga funciona de tal manera que cuando se recibe una petición nueva en la granja o clúster de servidores, se enruta hacia el servidor que se encuentra más libre de carga. Esto asegura que se mantiene optimizado el tráfico interno entre servidores y se garantiza un tiempo de respuesta bajo.

El crecimiento de la plataforma tanto en número de servidores como en número de clientes y usuarios está totalmente soportada gracias a las características ya mencionadas en el apartado de escalabilidad del sistema.

3.2.7. *Seguridad*

La seguridad de toda la información sensible de la plataforma está totalmente garantizada gracias al uso de protocolos seguros de red y del cifrado de la información. Todos los datos de los clientes y la información sobre la autenticación se transmite por la red utilizando mecanismos de encriptación Triple DES MD5 basados en doble encriptación; primero se escoge una palabra clave y se extrae su MD5, y con ese MD5 se realiza la encriptación de la información. Así incluso si se realizará una intrusión en el sistema o se capturara el tráfico de red, toda la información estaría protegida ante tales ataques y sería ininteligible para el atacante.

Además las comunicaciones se realizan sobre protocolos seguros HTTPS, que no solo ofrecen estándares de seguridad que facilitan su integración con futuros servicios y ampliaciones de la plataforma sino que representan una forma segura de comunicación.

Diseño de las comunicaciones

Índice de contenidos

1. INTRODUCCIÓN

Mediante el siguiente documento se procederá a explicar en detalle el diseño de las distintas comunicaciones que se realizan dentro del sistema completo del proyecto TRAZAMED: PLATAFORMA INTEGRAL BASADA EN TECNOLOGÍAS DE IDENTIFICACIÓN RFID Y DATAMATRIX PARA LA TRAZABILIDAD DE MEDICAMENTOS, en el que participan Bilbomática, Creativ-IT, Wellness Telecom, la Universidad de Deusto y la Universidad Carlos III de Madrid.

El objetivo principal del presente proyecto consiste en el desarrollo de una solución industrial (hardware + software) que permita la trazabilidad de medicamentos demandada por el Ministerio de Sanidad y Consumo en el nuevo proyecto de Real Decreto de trazabilidad y recomendada por la Unión Europea mediante la directiva 2003/94/CE.

La solución propuesta cuenta con tres elementos o sistemas bien diferenciados que ya han sido descritos en anteriores documentos:

— El dispositivo embarcado en las unidades de transporte encargado de detectar el contenido de la carga mediante tecnología RFID y de las comunicaciones con el servidor central y la unidad móvil del transportista.
— La aplicación móvil instalada en el Smartphone del transportista que permitirá al sistema, mediante un interfaz gráfico, indicar el plan de trabajo en cada servicio de transporte
— La solución software de control desde el que monitorizar la trazabilidad de los medicamentos, planificar las rutas optimizadas y posicionar las diferentes unidades de la flota de transporte.

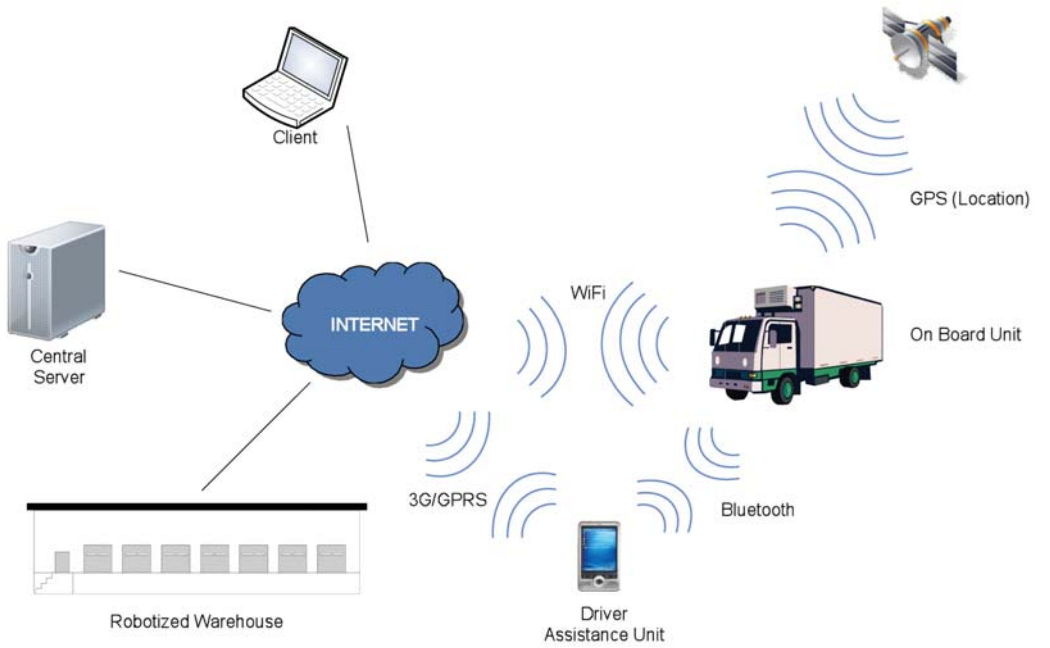
Para el presente documento, en el que se describen todas las comunicaciones que se efectúan entre los distintos elementos del sistema global, además de los tres elementos principales citados se incluyen otros dos elementos, que son externos al sistema implementado.

— El almacén robotizado: Se trata del almacén automatizado mediante robots para el llenado de las cubetas con medicamentos.
— Los clientes o personal de la empresa de medicamentos: Son los que consumirán como clientes los servicios que proporcione el servidor central.

2. DESCRIPCIÓN DEL SISTEMA DE COMUNICACIONES

El esquema que se presenta a continuación pretende ilustrar todas las comunicaciones que se dan dentro del sistema y los elementos que las efectúan.

En los siguientes puntos se explicaran en detalle cada una de esas comunicaciones.



2.1. **Comunicación de localización GPS**

Para la localización en todo momento de las unidades de transporte, los dispositivos embebidos que controlan cada una de ellas incluyen un receptor de tipo GPS. Este receptor, gracias a una antena conectada que irá situada en la parte superior del vehículo (por fuera) es capaz de comunicarse con los satélites y obtener datos de geolocalización de una precisión menor que unos pocos metros.

Se utiliza el protocolo NMEA para el envío de tramas entre el receptor GPS y el dispositivo embebido, aunque el receptor también soporte protocolo SiRF. Esta comunicación entre los dos dispositivos se realiza mediante comunicación serie (RS 232).

El receptor GPS envía sus tramas cada segundo y todas son leídas por el embebido, pero la frecuencia con la que estas son almacenadas para el registro de una ruta es configurable. Actualmente se estima que con guardar las tramas de posicionamiento cada 5 segundos es suficiente. Tampoco son necesarias todos los tipos de tramas NMEA que el receptor envía, con tan solo dos tipos de trama es suficientes para obtener la información requerida. Las tramas utilizadas son las siguientes:

— GGA: Global Positioning System Fix Data.
— RMC: Recommended Minimum Navigation Information.

La información que se obtiene de estas dos tramas se enumera a continuación.

— Hora (UTC) y fecha.

— Latitud y Longitud.
— Velocidad.
— Altitud.
— Indicador de calidad de la señal GPS.
— Número de satélites a la vista.

2.2. Comunicación Bluetooth

Bluetooth es la tecnología seleccionada para realizar la comunicación entre el dispositivo embebido de las unidades de transporte y el dispositivo móvil (Driver Assistance Unit).

El dispositivo móvil es el medio a utilizar por los conductores de los vehículos para saber en cada momento las acciones a realiza, es decir, las cubetas que son necesarias cargar y descargar. Aunque los vagones de carga también disponen de señales luminosas (verde y roja) que indican si la carga o la descarga de cubetas se ha realizado correctamente, para saber con exactitud cuántas cubetas faltan o sobran siempre se podrá realizar la consulta en el dispositivo móvil.

Además de asistir al conductor el dispositivo móvil es el encargado de identificar que conductor va a realizar una ruta concreta. Al comienzo de una ruta es necesario que el conductor introduzca su DNI en la aplicación y seleccione una ruta entre las disponibles que será la que vaya a realizar. Estas dos acciones son las únicas obligatorias de realizar con el dispositivo móvil para el correcto funcionamiento del sistema, todas las demás consultas que realice el conductor en la aplicación móvil son opcionales.

En la comunicación Bluetooth entre los dos dispositivos, el dispositivo embebido hace las veces de Servidor mientras que el dispositivo móvil será el cliente. La conexión se establece al inicio de una ruta cuando el conductor inicia la aplicación en su móvil y se identifica. Después, durante el transcurso de la ruta, es posible (o muy probable) que haya desconexiones en la comunicación Bluetooth cada vez que el conductor entra y salga del vehículo para transportar las cubetas a las farmacias, debido a que la distancia excede de las limitaciones de cobertura que tienen los dispositivos Bluetooth. En cualquier caso, el sistema está diseñado para que la conexión se restablezca siempre y de forma automática una vez el conductor este de nuevo a una distancia suficientemente cercana.

El intercambio de información entre los dispositivos se realiza mediante dos tipos de tramas:

— Comandos cortos: Se ha creado un pequeño protocolo de comandos simples que sirven para acciones como iniciar la ruta o identificar al conductor entre otras.
— Incidencias: Las incidencias son creadas por el dispositivo embebido y enviadas al dispositivo móvil. Proporcionan principalmente información de posicionamiento y acerca de las cubetas que son necesarias cargar y descargar en cada momento. Están construidas en un formato de etiquetas XML para que sea más fácil extraer la información en el dispositivo móvil.

Existen 10 tipos de incidencias diferentes, descritas con detalle cada una de ellas en el documento E15 (Código fuente del firmware del módulo de control del dispositivo embarcado). Se muestra a continuación a modo de ejemplo la estructura de una incidencia real.


```
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</fechaIncidencia>
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</incidenciaDTO>
```


2.3. **Comunicación 3G/GPRS**

El dispositivo móvil, además de cómo asistencia al conductor, también hace las veces de puente para que las incidencias creadas por el dispositivo embebido lleguen también al Sistema Central. Utiliza para ello la red 3G (o GPRS en caso de no disponer de cobertura 3G) para reenviar las incidencias recibidas por Bluetooth a través de Internet al Servidor Central.

Las incidencias marcadas como «Urgentes» (campo <urgente> del XML igual a 1) deben ser reenviadas instantáneamente por 3G. En cambio, las marcadas como «No Urgentes» (campo <urgente> del XML igual a 0) no son enviadas, en su lugar se van almacenando en el dispositivo embebido y al finalizar una ruta son enviadas vía WiFi por este último.

Tanto unas como otras, son enviadas a un servicio Web del Servidor central que las tratara para que se muestren los correspondientes datos en el panel central y las almacenará para que formen parte de un registro de históricos.

2.4. **Comunicación WiFi**

El dispositivo embebido instalado en las unidades de transporte utiliza su conectividad WiFi para conectarse a la red del almacén robotizado. Esta comunicación se establece para permitir la comunicación del dispositivo embebido y del servidor central.

En el transcurso de una ruta, son dos las veces que el embebido se conectará a la red del almacén: una al inicio de la ruta, cuando se debe realizar la carga de las cubetas en el vehículo y otra tras finalizar la ruta, cuando el vehículo vuelve al almacén. Se describe a continuación la información intercambiada en estas dos conexiones:

— Inicio de la ruta: Tas la identificación, en el momento que el conductor selecciona mediante el dispositivo móvil la ruta a realizar, el embebido realiza una petición a un servicio Web del servidor central para descargarse la hoja de ruta correspondiente. Esta hoja de ruta contiene toda la información necesaria para saber todas las cubetas que se tienen que cargar en el vehículo y posteriormente en que farmacias es necesario que sean descargadas.
— Final de la ruta: El dispositivo embebido, a lo largo de la ruta, va almacenando una serie de archivos con la información de todo lo acontecido en su transcurso. En concreto estos tres archivos son el Informe de Ruta, el Informe de Incidencias y el Trazado de la Ruta (descritos con detalle en el documento E15). Mediante la conexión WiFi, el embebido carga estos archivos en el servidor central.

2.5. **Comunicación del Almacén Robotizado**

El almacén robotizado es el encargado, mediante una serie robots, de el llenado de las cubetas con medicamentos. En base a los pedidos que llegan al almacén de cada una de las farmacias, que son introducidos mediante una aplicación de gestión de pedidos en una base de datos, el robot se pone en marcha dos veces al día (una a la mañana y otra al mediodía) para cargar todas las cubetas necesarias ordenándolas por rutas de departo en unos carriles de cilindros instalados en el almacén.

Cuando el proceso del robot termine, las cubetas situadas en el final de cada uno de los carriles serán las que deban ser cargadas en los vehículos de transporte, cada una de ellas en una ruta diferente.

Para que el sistema central tenga la información necesaria acerca de las cubetas y las farmacias en las que deben ser entregadas, es necesario que establezca una comunicación con el almacén robotizado, más concretamente con su base de datos. Por ello, se ha creado una aplicación que instalada en una maquina que controla el almacén robotizado, a la vez que se pone en marcha el proceso de llenado de las cubetas, obtiene toda la información necesaria relativa a la ruta y la transmite mediante la conexión de Internet del almacén al servidor central.

2.6. **Comunicación de los Clientes**

Como clientes, se conoce a los empleados de la empresa farmacéutica o del almacén que actuaran como usuarios de los servicios proporcionados por el sistema central.

Los clientes, mediante un PC u ordenador portátil cualquiera con una conexión a Internet podrán realizar multitud de acciones de las que se destacan las siguientes:

— Consultas de las rutas en tiempo real y a posteriori: Podrán visualizar el estado actual de cada una de las rutas, conociendo así la ubicación de cada una de los vehículos de transporte, farmacias atendidas y no atendidas, tiempos estimados y reales de cada entrega etc.
— Planificar y optimizar rutas: Previamente al inicio de las rutas, se podrán simular y mediante algoritmos obtener las rutas más optimizadas en tiempo de duración.
— Gestionar incidencias en línea: El envío de incidencias en tiempo real permite conocer si las entregas en cada farmacia se han hecho correctamente y así poder gestionar posibles errores cometidos durante la ruta.

2.7. **Comunicación del Servidor Central**

El servidor central es el elemento del sistema que se comunica con el resto de elementos, siempre a través de la red. Ya se ha detallado en anteriores puntos el modo en el que se comunica con cada uno de ellos así como la información que se intercambian (explicada con más detalle en el documento E15). A modo de resumen se enumeran los elementos con los que se comunicará el servidor central:

— Clientes.
— Almacén Robotizado.
— Dispositivo embebido (vía WiFi).
— Dispositivo móvil vía (3G/GPRS).

El servidor central podrá estar instalado en el propio almacén robotizado de la empresa farmacéutica o bien en la sede central de la misma, siempre que tenga acceso a las redes necesarias.

Diseño del dispositivo embarcado

Índice de contenidos

1. INTRODUCCIÓN

Mediante el siguiente documento se procederá a explicar en detalle el diseño del dispositivo embarcado que formará parte del sistema completo dentro del proyecto TRAZAMED: PLATAFORMA INTEGRAL BASADA EN TECNOLOGÍAS DE IDENTIFICACIÓN RFID Y DATAMATRIX PARA LA TRAZABILIDAD DE MEDICAMENTOS, en el que participan Bilbomática, Creativ-IT, Wellness Telecom, la Universidad de Deusto y la Universidad Carlos III de Madrid.

Se pretenden definir en el todos los diferentes elementos que forman parte de la solución del dispositivo embarcado y de cada uno de ellos, detallar sus especificaciones y propósito.

2. ESQUEMA GENERAL DE DISPOSITIVOS

El dispositivo embarcado está formado por una serie de dispositivos diferentes interconectados entre sí para permitir así sus múltiples funcionalidades. Mediante el siguiente esquema se pretende mostrar una visión global de todos los elementos que conforman el sistema.

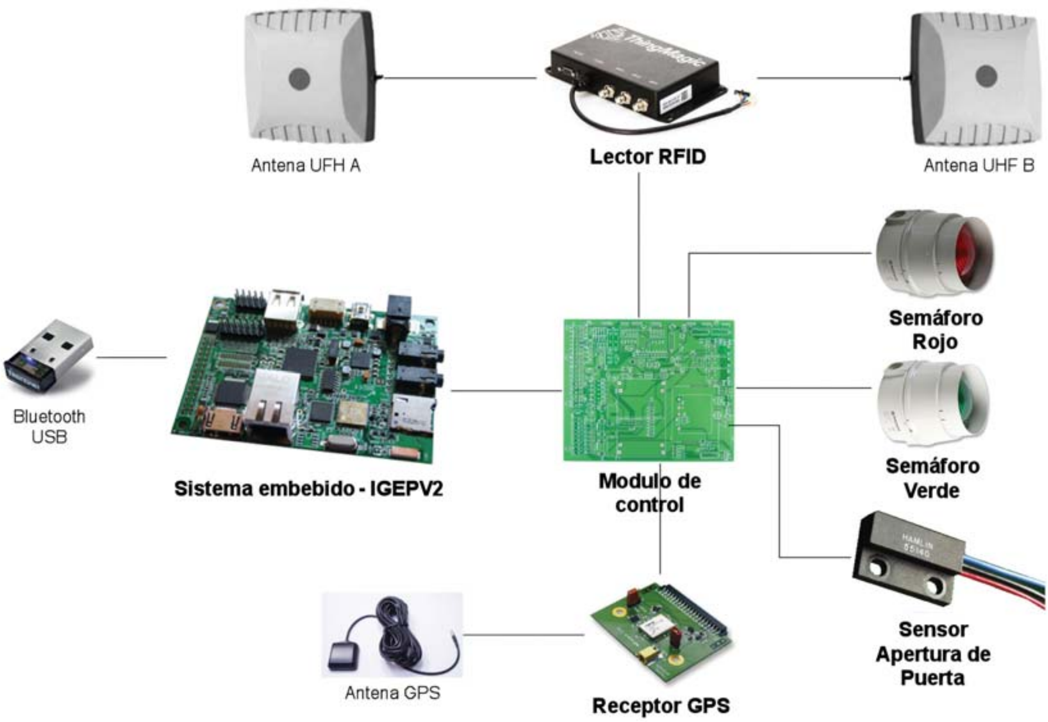


Figura 1

Esquema general de los dispositivos

Como se puede observar en la figura de la página anterior, existen 6 dispositivos o elementos principales que son diferenciados que forman parte del dispositivo embarcado. Estos elementos son el Sistema embebido, el Modulo de control, el Lector RFID, el Receptor GPS, los Semáforos rojo y verde y el Sensor de Apertura de Puerta. Algunos de estos elementos tienen otra serie de dispositivos conectados a ellos, como por ejemplo, antenas.

El esquema también muestra que elementos están conectados entre sí. Las líneas que unen los distintos elementos representan a conexiones mediante líneas o cableado físico, de las que se dará más detalle posteriormente.

A continuación se explicaran en detalle cada uno de los distintos elementos.

3. ELEMENTOS DEL DISPOSITIVO EMBARCADO

3.1. **Sistema Embebido**

El sistema en su conjunto, funciona de tal manera que toda su inteligencia reside en el Sistema embebido. Es este el que dispone de los recursos necesarios para controlar todos los demás dispositivos que forman parte del Dispositivo Embarcado.

El sistema embebido en cuestión se trata de un dispositivo IGEPv2 Board de ISEE, que está basado en un procesador ARM Cortex-A8 e incluye entre sus módulos con WIFI IEEE 802.11b/g, Bluetooth 2.0, USB 2.0 OTG etc. Es un dispositivo de bajo coste y alto rendimiento.

3.1.1. *Comunicaciones del Sistema Embebido*

Su función principal, como se ha citado, es controlar el sistema en su conjunto y a todos los demás dispositivos. Para ello deberá establecer comunicaciones tanto con elementos que forman parte del Dispositivo Embarcado, pero también con los demás sistemas que forman parte de la solución global, es decir, la solución móvil y la solución del software de control.

Se enumeran y especifican a continuación los elementos con los que se comunica el Sistema Embebido.

3.1.1.1. Bluetooth y solución móvil

Para comunicarse con la solución móvil, el sistema embebido utiliza un protocolo Bluetooth. El propio embebido dispone de un módulo Bluetooth interno que es perfectamente capaz de establecer conexión con la solución móvil. Aún así, para este cometido se ha tenido que utilizar un dispositivo Bluetooth externo conectado por USB en ved de utilizar el interno.

El problema de utilizar el Bluetooth interno, reside en que el IGEPv2 utiliza la misma antena física tanto para las comunicaciones WIFI y Bluetooth. Esto imposibilita el utilizar en el mismo instante los dos módulos de comunicación, y para evitar el choque no deseado de las tramas y sufrir problemas a bajo nivel dentro del embebido se ha optado por añadir un dispositivo Bluetooth externo.

El dispositivo Bluetooth externo se trata de un adaptador USB Micro Bluetooth de la marca TRENDNet, que irá directamente conectado al puerto USP del IGEPv2.

3.1.1.2. WIFI y Solución del software de Control

El sistema embebido también es el encargado de establecer comunicaciones con el software de control que se hallara instalado en el almacén, base de las unidades de transporte. Para la comunicación con este software se establecerá una comunicación directa mediante WIFI entre el sistema embebido y la red WIFI que dispone el almacén.

En este caso se utilizará el módulo WIFI que el propio embebido tiene integrado para establecer este tipo de comunicaciones, ya que el uso del dispositivo Bluetooth externo, posibilita su correcto funcionamiento.

3.1.1.3. Comunicaciones mediante el Modulo de Control

Las comunicaciones con el resto de elementos dentro del dispositivo embarcado (lector RFID, receptor GPS y Semáforos), se realizan mediante cableado. Se utilizan para ello el puerto Serie y las líneas de Entrada/Salida que dispone el IGEPv2.

Pero tal y como se puede observar en la figura que muestra el esquema general de dispositivos, el sistema embebido está directamente conectado al Modulo de Control que a su vez se conecta con los demás dispositivos.

Los diferentes motivos por el que las conexiones tienen que pasar por este modulo de control son los siguientes:

— Es necesario multiplexar el puerto Serie del IGEPv2 para que se pueda conectar tanto con el Lector RFID como con el Receptor de GPS.
— Las líneas de Entrada/Salida del IGEP funcionan con una tensión de 1.8 V y tanto los Semáforos como el sensor de apertura de puerta funcionan a tensiones diferentes.
— Es necesario transformar las tramas que el Receptor GPS envía y recibe en TTL a RS232 para que sean entendibles por el IGEPv2.

Los distintos elementos que forman parte del Modulo de Control son explicados más adelante en el apartado destinado a ello.

3.1.2. *Funciones del Sistema Embebido*

Con el fin de dar a entender mejor el propósito del sistema embebido y la necesidad de los diferentes dispositivos que se hallan conectados a él, se van a enumerar las tareas y funciones más importantes del mismo.

- — Configurar el Lector RFID para la lectura de Tags (etiquetas de RFID que van adheridas a cada una de las cubetas para los medicamentos).
- — Configuración del dispositivo Bluetooth para establecer comunicación con la Solución Móvil. El sistema embebido hará las veces de servidor en la comunicación, y la solución móvil será el cliente.
- — Configuración del Puerto Serie y del Receptor GPS para recibir tramas NMEA.
- — Conexión con la red WIFI del almacén para descargar los datos de una ruta antes de iniciarla y para subir informes al terminarla.
- — Configuración de los GPIOs (general purpose input/output pins) que controlan los semáforos y el sensor de apertura de la puerta.
- — Generación de informes e incidencias en el transcurso de una ruta.
- — Envío de incidencias mediante Bluetooth en el transcurso de una ruta.
- — Detección inteligente de paradas en farmacias así como de estacionamientos indebidos.
- — Control exhaustivo de cubetas cargadas y descargadas en cada una de las paradas y generación de incidencias en caso de cargas o descargas inadecuadas.
- — Detección de fallos de comunicación GPS, Bluetooth y WIFI.

3.1.3. *Conexiones del Sistema Embebido*

A continuación se presenta una imagen que muestra las conexiones necesarias a realizar para la correcta comunicación del sistema embebido IGEPv2 con los demás elementos del sistema.

Las conexiones se encuentran numeradas en la imagen y se explican en las siguientes líneas:

1. Alimentación: El embebido deberá ser alimentado con una tensión de 5 Voltios en el conector J200 del IGEPv2 (el número 1) como se muestra en la imagen.
2. Bluetooth: El Adaptador Bluetooth se conectará al puerto USB del IGEPv2.
3. Puerto Serie: El puerto Serie que se utiliza para comunicar el embebido con el receptor GPS y el lector RFID irá conectado mediante un cable plano de 2 × 5 vías (espaciado entre pines de 2.54 mm) entre el conector J960 de la placa y el módulo de control para que en este último sea multiplexado.
4. GPIO: Los pines de Entrada/Salida serán conectados mediante un cable plano 2 × 14 vías (espaciado entre pines de 2.54 mm) entre el conector J990 del IGEPv2 y el módulo de control.

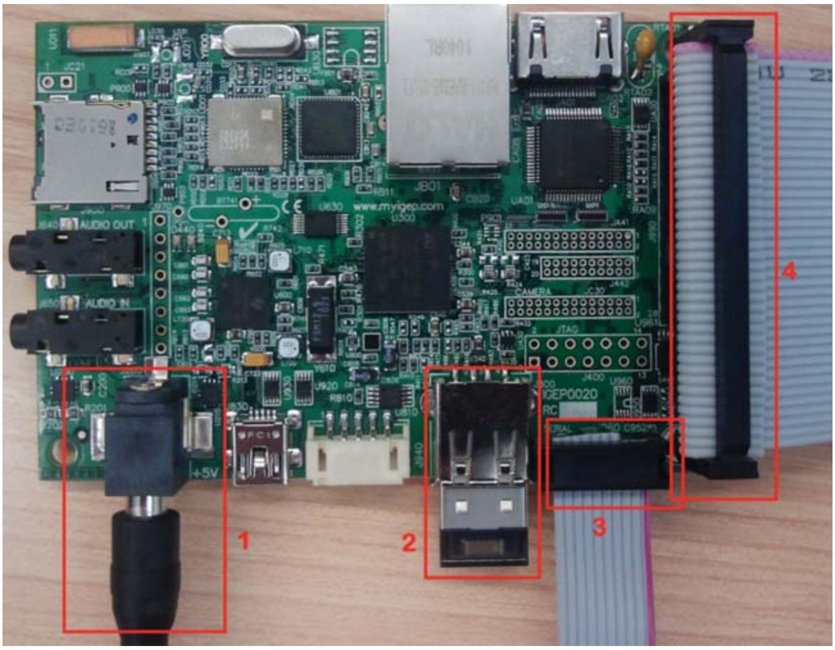


Figura 2

Conexiones del Sistema Embebido

3.2. **Módulo de Control**

Como ya ha sido mencionado el cometido del módulo de control es interconectar los distintos elementos del dispositivo embarcado con el sistema embebido.

Este módulo de control consiste en una placa PCB de diseño propio que contiene los componentes necesarios para la interconexión de cada uno de los elementos además de las diferentes alimentaciones necesarias.

A continuación se mostrará en detalle los esquemas de construcción de la placa PCB y se especificaran cada uno de sus elementos.

3.2.1. *Diseño de la placa PCB*

Para realizar el diseño de la placa PCB se ha utilizado la herramienta de diseño EAGLE (Easily Aplicable Graphical Layout Editor) de CadSoft.

3.2.1.1. Esquema eléctrico

Los siguientes esquemas muestran el esquema eléctrico con los componentes que componen el módulo de control.

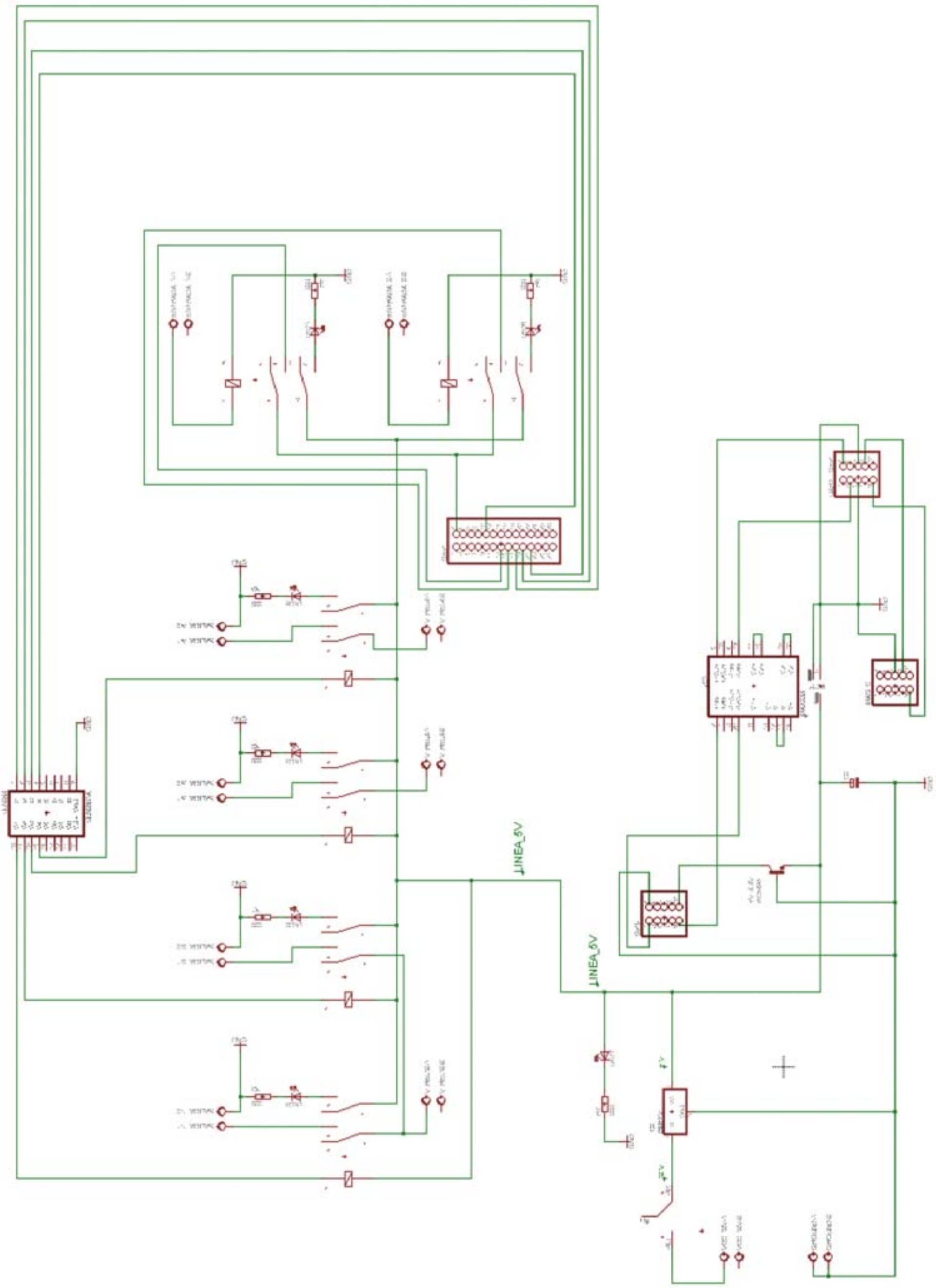


Figura 3
Esquema eléctrico de la placa PCB

3.2.1.2. Layout

El esquema del Layout muestra la traducción del esquema eléctrico de las figuras anteriores a una placa impresa PCB, con las vías, pads, etc. necesarios para su construcción.

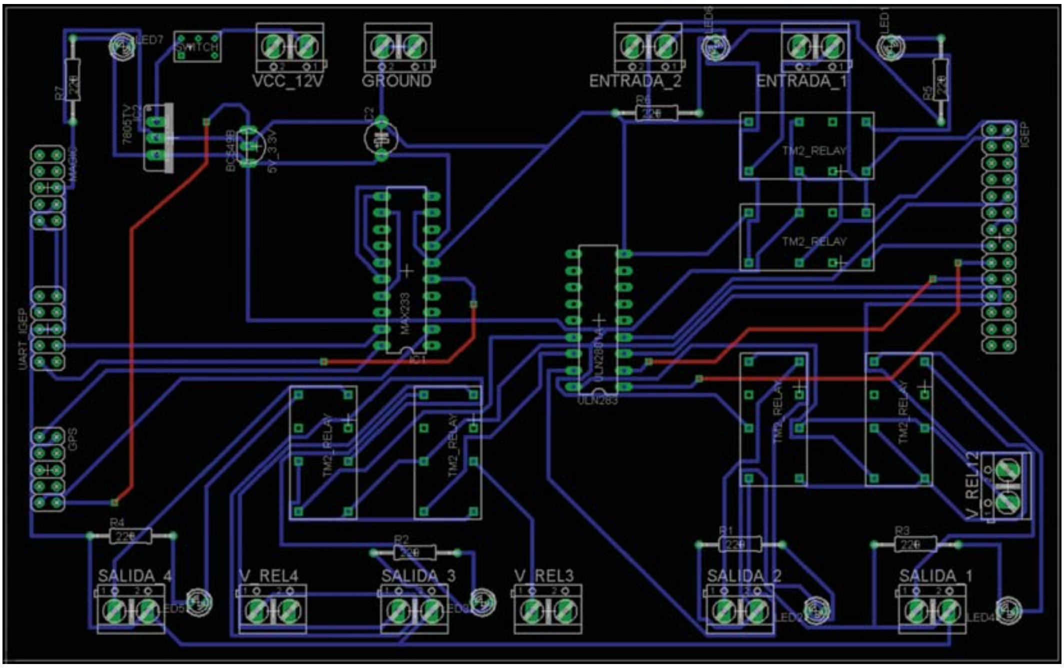


Figura 4

Esquema del Layout de la placa PCB

3.2.2. *Elementos de la placa PCB*

A continuación se enumeraran y detallaran las entradas y salidas de las que dispone el módulo de control, así como algunos de los elementos más importantes que la componen. Los nombres que identifican a cada una de las Entradas/Salidas y elementos se pueden observar con letra blanca en la figura de arriba.

Entradas y Salidas:

- — VCC_12V: Entrada para la alimentación del módulo de control a 12 V. El propio módulo de control incluye conversores de tensión a 5 y 3.3 V para alimentar algunos de sus elementos.
- — GROUND: Entrada de tierra del módulo de control.
- — GPS: Conector de cable plano 2 × 5 (distancia entre pines 2.54 mm) para conectar el módulo de control con el receptor GPS.

— MAGIC: Conector de cable plano 2 × 5 (distancia entre pines 2.54 mm) para conectar el módulo de control con el lector RFID.
— V_REL12: Conector para la entrada de tensión de alimentación de los elementos que se conecten a las salidas 1 y 2.
— SALIDA_1: Conector de salida a tensión V_REL12 controlado por el IGEPv2. En principio su uso está reservado para el semáforo Rojo.
— SALIDA_2: Conector de salida a tensión V_REL12 controlado por el IGEPv2. En principio su uso está reservado para el semáforo verde.
— V_REL3: Conector para la entrada de tensión de alimentación de los elementos que se conecten a la salida 3.
— SALIDA_3: Conector de salida a tensión V_REL3 controlado por el IGEPv2. Su uso no se encuentra definido.
— V_REL4: Conector para la entrada de tensión de alimentación de los elementos que se conecten a la salida 4.
— SALIDA_4: Conector de salida a tensión V_REL4 controlado por el IGEPv2. Su uso no se encuentra definido.
— IGEP: Conector de cable plano 2 × 14 (distancia entre pines 2.54 mm) para conectar el módulo de control con el conector GPIO del IGEPv2.
— ENTRADA_1: Conector de entrada para el elemento de control externo de una de las entradas del IGEPv2. En principio reservado para el sensor de apertura de puerta.
— ENTRADA_2: Conector de entrada para el elemento de control externo de una de las entradas del IGEPv2. Reservado para un posible segundo sensor de apertura de puerta.

Otros elementos:

— Circuitos integrados: MAX233 y ULN283.
— Relés: AGQ200S12.
— Switch.
— Resistencias.
— LEDs.
— Condensador.
— Conversores de tensión.

3.3. **Receptor GPS**

El receptor GPS conectado mediante el módulo de control al sistema embebido permite obtener un seguimiento constante de la posición en la que se encuentra la unidad de transporte en la que se haya instalado el dispositivo embarcado.

El dispositivo de recepción GPS utilizado en concreto se trata de un IT310 GPS Receiver de Fastrax. Este dispositivo utiliza un protocolo NMEA para el envío de tramas de posicionamiento al IGEPv2 y también acepta un protocolo SiRF.

Para lograr una mejor conectividad con los satélites que proporcionan la señal GPS al receptor, se le conectará una antena externa al dispositivo, que idealmente irá colocada en la parte superior del vehículo.

3.3.1. *Intercambio de tramas*

El receptor GPS, como todos los demás elementos del dispositivo embarcado está controlado por el sistema embebido. Por lo tanto, el inicio de la comunicación e intercambio de tramas entre ambos comienza a petición del embebido.

En el inicio de la comunicación el envió de tramas de posicionamiento del GPS esta desactivado. Cuando una nueva ruta comienza, el embebido envía unas tramas al receptor para que este comience a enviarle tramas con los datos de posicionamiento. El tipo de tramas que quiere que el receptor le envíe y la frecuencia con las que las debe enviar es configurable. Al finalizar una ruta, el embebido vuelve a desactivar la recepción de tramas para que así el puerto serie del embebido no reciba tramas innecesarias y así liberar recursos y velocidad de procesamiento.

Las tramas NMEA que el embebido recibirá por defecto cada segundo una vez iniciada la ruta, y que son las mínimas necesarias para el correcto funcionamiento del sistema, son las siguientes:

— GGA: Global Positioning System Fix Data.
— RMC: Recommended Minimum Navigation Information.

Para la activación y desactivación de la recepción de estas tramas en el GPS se utilizaran mensajes de entrada SiRF NMEA (SiRF NMEA Input Messages).

Las estructuras tanto de las tramas NMEA como de los mensajes de entrada SiRF NMEA están detalladas en dos de los documentos anexos al presente documento.

3.3.2. *Conexiones del receptor GPS*

El la página siguiente se presenta una imagen que muestra las conexiones necesarias a realizar para la correcta comunicación del receptor GPS con los demás elementos del sistema.

Las conexiones se encuentran numeradas en la imagen y se explican en las siguientes líneas:

1. Antena: La antena GPS que proporciona una mayor cobertura de los satélites GPS irá conectada al conector J1 del módulo IT310 tal y como muestra la figura.
2. Conector de cable plano 2 × 5: El conector une las líneas del IT310 necesarias para la transmisión y recepción serie de su puerto A además de la alimentación y toma a tierra. Como se puede observar en la figura, las líneas del cable plano se conectan a los pines del conector J2 necesarios.

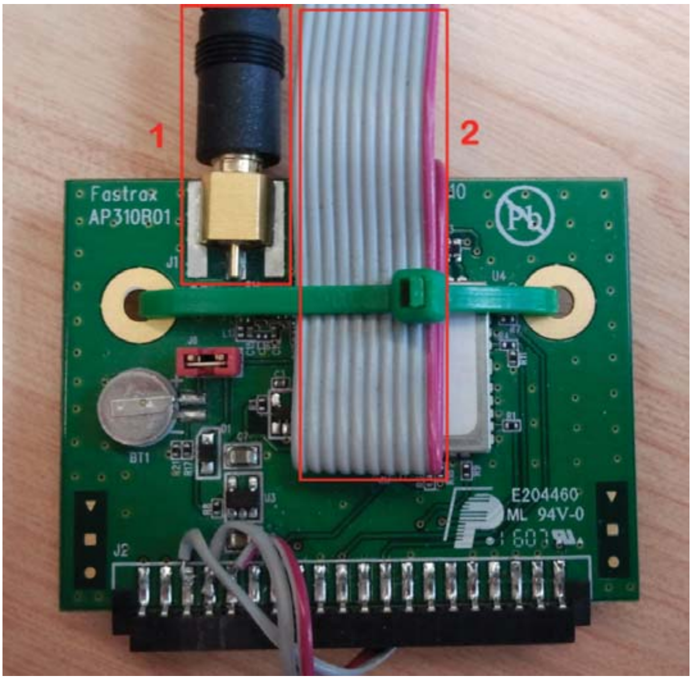


Figura 5

Conexiones del Receptor GPS

3.4. **Lector RFID**

El cometido del lector RFID, siempre controlado por el sistema embebido, es el de leer los tags que corresponden a cada una de las cubetas y tener así un control de ellas en todo momento.

El receptor tendrá conectadas dos antenas UHF de diferentes polarizaciones para ser capaz así de detectar todas las cubetas que se encuentren en cada momento en el interior del vehículo de transporte.

El dispositivo lector se trata de un Vega Reader de ThingMagic. Este Lector tiene entradas para conectar hasta tres antenas diferentes y se comunica mediante un protocolo de envió de tramas por puerto serie propio de ThingMagic. Está pensado para su utilización en vehículos.

3.4.1. *Conexiones del lector RFID*

A continuación se presenta una imagen que muestra las conexiones necesarias a realizar para la correcta comunicación del receptor GPS con los demás elementos del sistema.

Fig. 6

Conexiones del Lector RFID

Las conexiones se encuentran numeradas en la imagen y se explican en las siguientes líneas:

1. Puerto Serie: Mediante el puerto serie se conectará el Vega Reader con el módulo de control.
2. Alimentación: Cable de conexión para la alimentación a 12 V. Preparado para ser conectado directamente a una batería de coche.
3. Antena A: Conector para una de las antenas UHF.
4. Antena B: Conector para una de las antenas UHF.

3.5. **Semáforos**

Los semáforos son indicadores luminosos que irán en el interior del vagón de carga del vehículo de transporte, en un lugar visible. Su cometido es el de indicar si en cada una de las paradas, o a la hora de realizar la carga de las cubetas en el almacén, se está haciendo correctamente según la hoja de ruta establecida.

El sistema embebido es quien conoce la hoja de ruta, que previamente ha descargado mediante la red WIFI del almacén, y por tanto es quien controla la iluminación de los semáforos.

Se dispondrá de dos semáforos, uno de color rojo y el otro de color verde, y ambos permanecerán apagados siempre que la puerta del vagón de carga esté cerrada. Cuando la puerta se abra en una parda, el semáforo rojo sirve para indicar que todavía no se han descargado todas las cubetas correspondientes o que se ha descargado alguna que no se debía. Permanecerá encendido hasta que la descarga se haya realizado correctamente, y solo en ese caso se apagará para encenderse el semáforo verde. Durante la carga de cubetas en el almacén, el semáforo rojo permanecerá encendido hasta que se hayan cargado todas las cubetas necesarias para la ruta.

Las cubetas vacías que se recojan en las farmacias y que sean cargadas en la unidad de transporte no influirán en el cambio de luces de los semáforos.

Los semáforos que van a ser empleados en la construcción del prototipo del sistema embarcado van a ser los modelos 89020000 de WERMA, uno de color rojo, y otro de color verde.

Figura 7

Semáforos

3.6. **Sensor de apertura de puerta**

Este sensor es el encargado de detectar la apertura y cierre de las puertas del vagón de carga de la unidad de transporte en la que se encuentra instalado el dispositivo embarcado.

Para el funcionamiento del sistema en su conjunto es importante la detección de las aperturas y cierres de las puertas para detectar el inicio y final de las paradas y las cargas y descargas en el almacén.

El sensor que se instalará en las puertas del vehículo será un sencillo sensor de proximidad magnético (o dos, dependiendo del modelo del vehículo) que adherido a la parte interior de las bisagras de la puerta será capaz de detectar cuando esta se encuentra abierta o cerrada.

El sensor estará conectado a través del módulo de control a una de las entradas del sistema embebido para que este realice las tareas correspondientes a los inicios y finales de paradas, cargas y descargas.

El modelo concreto del sensor a utilizar todavía no se encuentra definido, como por ejemplo un 55140 de HAMLIN.

Figura 8

Sensor magnético

Diseño de la solución móvil

Índice de contenidos

1. INTRODUCCIÓN

1.1. **Propósito del documento**

Mediante el presente documento de diseño de la solución móvil se pretende definir de forma clara y suficientemente detallada el alcance, la estructura global y las decisiones de diseño tomadas para el desarrollo software de la solución móvil que forma parte del proyecto TRAZAMED: PLATAFORMA INTEGRAL BASADA EN TECNOLOGÍAS DE IDENTIFICACIÓN RFID Y DATAMATRIX PARA LA TRAZABILIDAD DE MEDICAMENTOS, en el que participan Bilbomática, Creativ-IT, Wellness Telecom, la Universidad de Deusto y la Universidad Carlos III de Madrid.

1.2. **Ámbito del sistema**

El transporte de medicamentos, desde que son producidos en un laboratorio hasta que llegan a la farmacia desde la que son suministrados al usuario final, incluye una serie de etapas de distribución cuyo control es necesario tanto desde la perspectiva económica como de la sanitaria.

Actualmente los sistemas implantados en las empresas distribuidoras, cumpliendo con el anterior Real Decreto 725/2003, incluyen el seguimiento del medicamento hasta el instante en el que cada lote es recibido por un almacén intermedio a través del código de lote y la fecha de caducidad impresos en el propio envase. Sin embargo, el aumento detectado en la circulación de medicamentos falsificados así como una mayor internacionalización del sector farmacéutico conllevan la necesidad de realizar una mayor vigilancia que permita a las autoridades minimizar el tiempo de reacción ante la detección de un problema de seguridad. El nuevo proyecto de Real Decreto de Trazabilidad del Ministerio de Sanidad y Consumo incorpora el seguimiento de los medicamentos hasta el momento de su dispensación al paciente para garantizar en todo momento la accesibilidad y el abastecimiento de los fármacos y la seguridad de los mismos.

La obligación de implantar un sistema de trazabilidad que funcione, no a nivel de lote, sino a nivel de unidad de presentación y que cubra todas las etapas de distribución desde que es producido en el almacén farmacéutico hasta que es dispensado a un paciente desde una oficina de farmacia exige una alteración en el modelo actual de distribución farmacéutica, causando un total desasosiego a las partes implicadas.

2. DESCRIPCIÓN GENERAL DE LA SOLUCIÓN MÓVIL

2.1. **Alcance de la solución móvil**

Para mantener el contacto con cada transportista, cada vehículo tendrá asociado un dispositivo móvil tipo Smartphone que llevará instalada una aplicación que permita, a través de un interfaz gráfico, informar al transportista de todo lo necesario en cada servicio de transporte. La enorme oferta de terminales y los diferentes sistemas operativos existentes exigen el desarrollo de una aplicación multiplataforma que garantice su funcionamiento en la mayoría de móviles existentes en el mercado. Los operadores de servicios móviles ofrecen a los clientes corporativos ciertos terminales inteligentes con las necesidades tecnológicas exigidas por esta aplicación (Wifi, GPS, GPRS/HSPA) con unas condiciones económicas muy favorables.

La aplicación residente en el dispositivo móvil dispondrá de las siguientes funcionalidades:

— Ayuda a la navegación: mostrará la hoja de ruta indicando, de forma amigable, el orden en el que debe realizar cada parada en la ruta planificada. En caso de que sea necesario permitirá asistir al conductor en la navegación hasta cada punto de la ruta sin necesidad de configurar el software de navegación. Además cada parada incluida en la ruta asignada a un vehículo dispondrá de información relacionada como dirección, comentarios realizados por el mismo u otros conductores o desviaciones en las estimaciones temporales planificadas.
— Soporte para las actividades de transporte: indicará cada acción a llevar a cabo en cada punto de la ruta validando la correcta ejecución de la misma mediante la conectividad con el dispositivo embarcado. En caso de que las cubetas que hayan sido descargadas no coincidan con las marcadas en la hoja de ruta, el transportista recibirá un aviso en su terminal móvil indicando la desviación respecto a la planificación y permitiendo corregir dicha acción previamente al envío de una incidencia al servidor central.
— Gestión de incidencias: la aplicación dispondrá de un sistema que permitirá el envío de incidencias de cualquier tipo (accidentes, averías, extravíos, etc.) hacia el servidor central. En función de la naturaleza y urgencia de la incidencia el servidor central redirigirá su gestión al centro de control encargado de la misma.

3. DISEÑO DE LA SOLUCIÓN MÓVIL

3.1. **Diseño Arquitectónico**

El diseño arquitectónico de la solución móvil se ha constituido sobre una infraestructura de servicios y comunicaciones. El desarrollo por tanto se enfocará hacia una arquitectura SOA (Service Oriented Architecture) en la que la lógica que soporta las funcionalidades ofrecidas por el dispositivo móvil se encuentra distribuida en el servidor, liberando de carga de procesamiento a dichos dispositivos, que accederán a la lógica mediante mensajes SOAP hacia el servicio web a desarrollar como funcionalidad del centro de control y que centralizara las peticiones de los dispositivos móviles.

La figura 1 muestra las principales características ofrecidas por la arquitectura SOA además de realizar una comparativa con el modelo arquitectónico por capas, de uso más extendido.

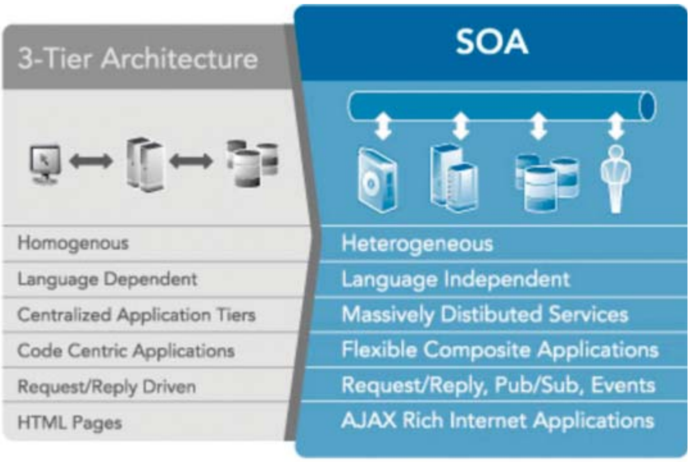


Figura 1

Características SOA

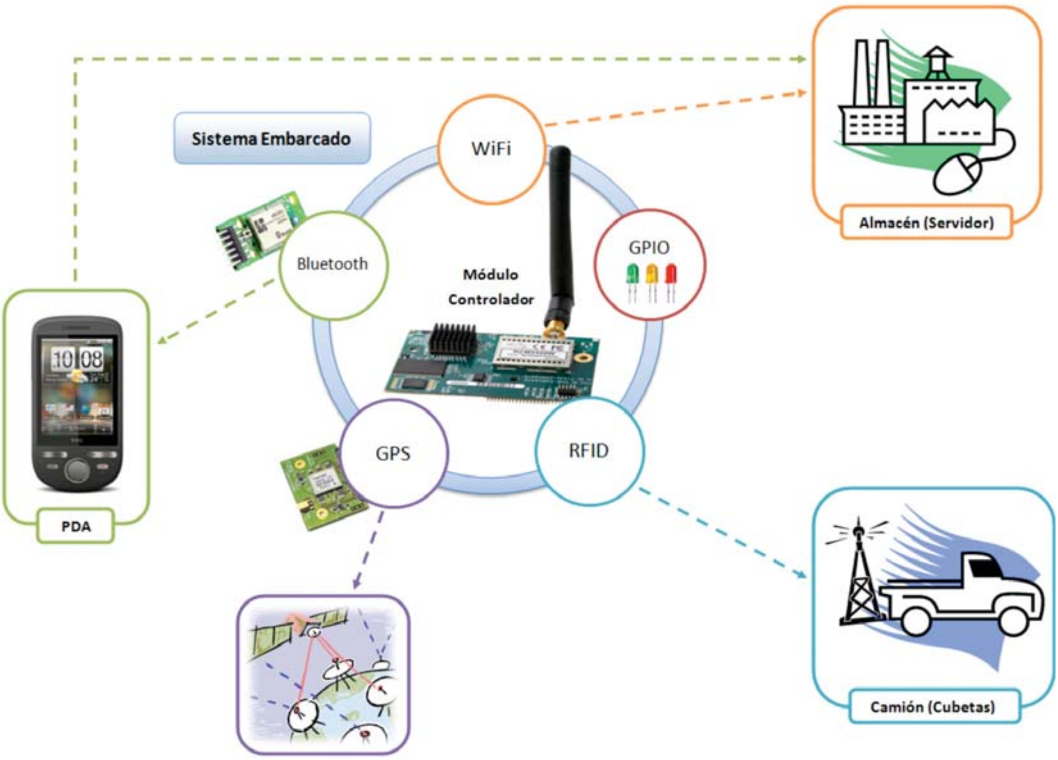


Figura 2

Arquitectura de comunicaciones

3.2. Diseño de la infraestructura de comunicaciones

En cuanto al diseño de comunicaciones entre el móvil y el dispositivo embebido se ha considerado, de acuerdo a los requisitos específicos, la utilización del protocolo RFCOMM Bluetooth para el envío de mensajes entre ambos dispositivos. La figura 2 muestra la arquitectura de comunicaciones seguida en el diseño del sistema y, entre otros, muestra las interfaces de comunicación de las que es participe el dispositivo móvil:

— Mensajes SOAP XML al Servicio Web mediante GPRS/3G.
— Mensajes Bluetooth al dispositivo embebido mediante el protocolo RFCOMM.

A continuación se muestra parte del código utilizado para la realización de la conexión Bluetooth entre el dispositivo móvil y el módulo controlador embebido.

```
 /**
 * Start the ConnectThread to initiate a connection to a remote device.
 * @param device The BluetoothDevice to connect
 */
public synchronized void connect(BluetoothDevice device) {
   if (D) Log.d(TAG, "connect to: " + device);
   // Cancel any thread attempting to make a connection
   if (mState == STATE_CONNECTING) {
      if (mConnectThread != null) {mConnectThread.cancel(); mConnectThread = null;}
   }
   // Cancel any thread currently running a connection
   if (mConnectedThread != null) {mConnectedThread.cancel(); mConnectedThread = null;}
   // Start the thread to connect with the given device
   mConnectThread = new ConnectThread(device);
   mConnectThread.start();
   setState(STATE_CONNECTING);
}
```

Figura 3

Código para la conexión Bluetooth

3.3. Diseño de casos de uso

Han sido analizadas las actividades que debe desempeñar la aplicación móvil y se han especificado los casos de uso que deben ser soportados por la solución. Se presenta la secuencia preliminar de acciones a realizar por la solución móvil durante el proceso completo de trazabilidad en ruta:

— Accede al Servicio Web para obtener las rutas planificadas.

- — Carga la información relevante de la ruta seleccionada (paradas, cubetas a descargar, tiempo estimado de ruta, etc.).
- — En cada parada muestra la información obtenida e interactúa con el dispositivo embarcado a la espera de lecturas RFID.
- — En caso de producirse alguna incidencia grave informa al servidor central.
- — Actualiza la Interfaz de acuerdo a las lecturas realizadas e informa e interactúa con el transportista.

3.4. Diseño de Interfaces

El dispositivo móvil que acompaña al transportista es el dispositivo a través del cual se indican todas las características de cada servicio de transporte. Se han diseñado todos los interfaces gráficos que serán necesarios en cada caso de uso especificado en la tarea anterior.

En las siguientes capturas se muestran los prototipos de interfaz diseñados para el dispositivo móvil, en este caso basándose en la plataforma Android como referencia de UI.

Se muestra la pantalla de identificación inicial del conductor e inicio de ruta, la pantalla con los detalles de una ruta en progreso (tanto en modo texto, como en modo mapa), la pantalla de carga/descarga de cubetas, la pantalla de información en ruta y el listado de farmacias en ruta.

Pantalla de identificación

Ruta en progreso - Detalles

Ruta en progreso - Mapa

Cubetas cargadas - RFID

Resumen de ruta

Listado de farmacias en ruta

Design and implementation of antennas adapted to the production process

Ignacio J. García Zuazola, Ignacio Angulo, Asier Perallos

Table of Contents

1. INTRODUCTION

Antenna requirements for the RFID interrogator antennas are given and an intro to the system implementation is presented. A suitable RFID interrogator antenna design is introduced as will that of a prospect tag antennas for cans.

The presented work has given rise to academic publications; an IET proceedings in ITS, and IET letters and an IET proceedings in antennas, three of them are international journals.

1.1. **Scope and objectives**

A growing demand for well-defined telematics systems in the intelligent transport distribution of pharmaceutical drugs is envisaged driven by legislative demands to enable the safe handling of medicines in automotive distributions. The provision is accomplished by providing virtual intelligence to vehicles designated for this form of smart freight transportation. The system provides anytime/anywhere assets tracking while on the move, from departure to destination, supporting reliable courier operation at low labour. The tracking and tracing system provides the vehicle with sufficient intelligence to: be located remotely, track and trace assets, and provide incidence reports. Our architecture is intended to automatically broadcast adaptive logistic-distribution-plans between a central office and a vehicle. The proposed system represents an inexpensive and non-intrusive solution that exploits advanced technologies such as smart environment sensing, RFID, WiFi, and GPS, to support modern industrial needs. The main objective of the presented work was to develop antennas for the Interrogator and the Tag.

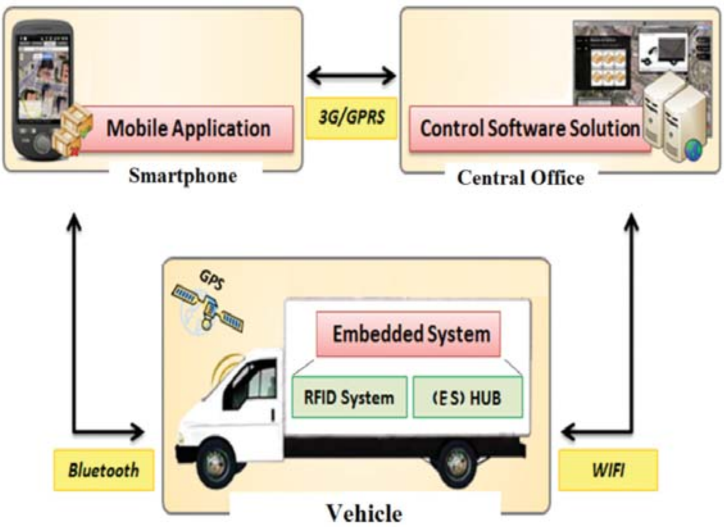


Fig. 1.1

The intelligent system architecture

1.2. **Antennas for the RFID transceivers**

The RFID system encompasses two basic communicators, a reader or interrogator and a tag or transponder. Specifically designed low-cost antennas for the application (reader and tag) are presented in the next sections; inexpensive antennas play a key role for maintaining a low-cost intelligent system.

To meet the EU Governments strive for ensuring reasonable finances and fiscal sustainability in health care [1], the use of consistent and reusable (for economy and permanent tagging) containers for the transportation of goods is essential. This creates a perfect scenario for the attachment of RFID tags needed for the intelligent delivery of medicines to end customers.

1.2.1. *The RFID interrogator design*

UHF is the preferred broadcasting approach to provide an effective interrogation zone as it is less restricted by line of sight compared to other higher bands. It supports ranges longer than those supported at other available low frequencies. To provide optimal interrogation zones within vehicles, interrogator antennas were designed and the strategic location inside the vehicle identified.

1.2.2. *The RFID transponder design*

Certain materials pose challenges to passive RFID tagging, for instance metallic objects cancel electric fields and passive tag antennas may not receive sufficient power to excite the RFID chip.

For use in this application, the UHF-RFID transducer should be thin, insensitive to detuning when attached to medicine containers, cheap, flexible, reliable and small in size. A candidate tag at the WLAN band is presented in Section 3.

1.3. **Antenna requirements**

The antenna requirements for the corresponding antennas above are introduced in the following Sections. The radio standards are first reviewed and then the requirements in terms of electromagnetic propagation field effects are presented.

2. RFID INTERROGATOR ANTENNA

Among the different assets tracking solutions Radio Frequency Identification RFID is a promising technology for in-car communications due to its relatively low cost deployment and real time monitoring and processes. In this paper, a conductive paint is sprayed over a car body to realise a hidden antenna made of a miniature narrow band antenna of dimensions 0.18λ×0.20λ×0.005λ and easy manufacturing is presented. The design relies on a resonator, a negative image of the radiator for improved efficiency when in close proximity to ground planes and is suited for use in radio frequency identification networks using the unlicensed RFID band (865.6-867.6 MHz) is described. The term miniature comes from the fact that the antenna is physically small given the low proximity and insensitivity to the ground plane which facilitates a possible coating layer over the antenna for hidden applications.

2.1. **Introduction**

Radio Frequency IDentification RFID technology has gained huge interest globally due to the diversification of the range of emerging applications and low power, low cost design. The deployment of the widely employed UHF RFID (UHFID) wireless technology will provide real-time identification, management, and assets tracking in vehicles using web based networks for anytime/anywhere article surveillance (i.e.: location and checkout). The low power low cost is achieved using passive (uses no battery) RFID transponders (TPDRs).

Among applications, pharmaceutical item tracking inside vehicles is required to support the needs of Pharmaceutical corporations to pilot their supply chains activities [2].

The two most common implementations of RFID systems are based on the interrogator motion ability. Fixed RFID is utilised since the interrogator inside a vehicle is immobile. Although the vehicle might be moving, antennas placed inside vehicles do not in principle suffer from Doppler Shift [3]. RFID backscattered modulated signals technology is used for the interrogation of transponders [4].

To meet the demands outlined above, a miniature low-cost antenna for use in hidden applications will be introduced in this paper. The antenna radiator will be directly sprayed over the inside car body with acceptable performance for a hidden application. The design is suited for use in radio frequency identification networks using the unlicensed RFID subband b2 (865.6-867.6 MHz) of the ETSI standard [5]. The integration and interaction of the antenna with the car body will be analysed.

2.2. **The design**

2.2.1. *Geometry of the antenna*

The structure of the printed Planar Inverted-F Antenna (printed-PIFA is shown in Fig. 2.1. To realise the miniature narrow band antenna, a conductive paint, conducts electricity with a resistivity, Res < 0.015 ohms/sq. (measured at density-functional theory, DFT = 50 microns) [6], is sprayed over a painted car body with a manufacturer typically

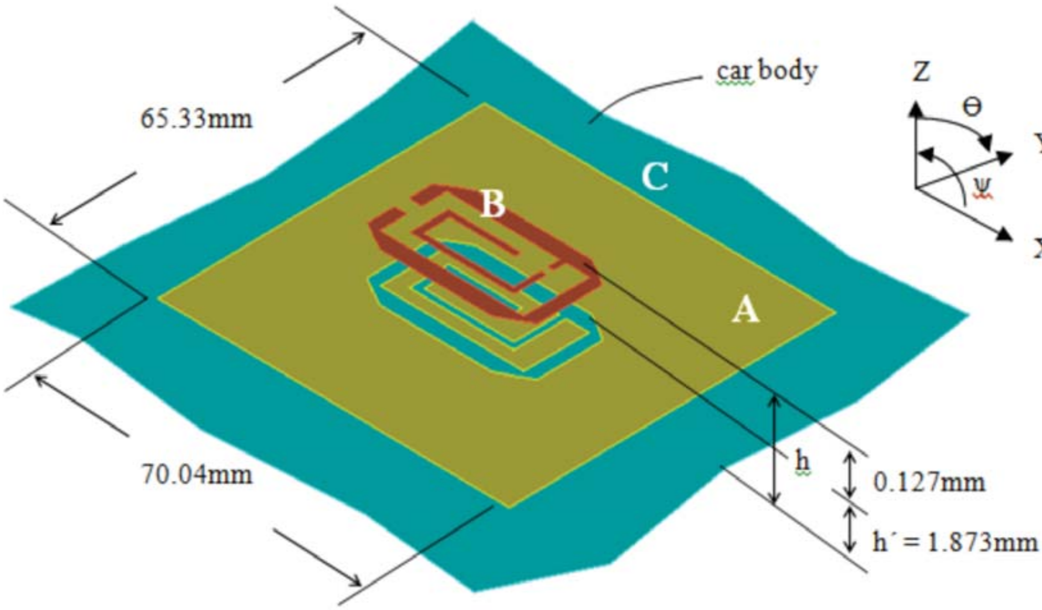


Figure 2.1

The layers of the sprayed printed-PIFA over the car body

employed total paint thickness [7] of 125μm (3.61e-4λ); the final prototype had a total thickness of 2mm (0.005λ), Fig. 2.1. The dielectric constant of a typical coated car (paint) is εr 6.5 [8], and is corroborated by measurements. The principal dimensions are given in Fig. 2.2. The measured permittivity, Fig. 2.3, of the vehicle composite and the paint coating, using a sounding probe method, was 6.31 and 6.53 (back-side of the car chassis panel) respectively; although the antenna was finally sprayed over the composite, this is not of relevant difference for the antenna to be prototyped on the paint coating. A small difference in permittivity was found for the front-side (polished paint) and back-side (unpolished paint) of the car chassis; this is a lower 1.73 and 1.68 respectively for the composite and the coating layers.

The approximate resonant frequency (fr) of a PIFA with a certain size can be determined from [9]. Typically, a microstrip patch antenna performing at the centre band of 866.6 MHz (2 MHz bandwidth) and a 125μm paint substrate would require the size of 0.25λ×0.36λ in contrast to the 0.18λ×0.20λ (including the resonator A, a negative image of the radiator B) using the proposed printed-PIFA.

PIFA designs based on a large ground plane usually lead to bandwidths that are very narrow (less than 8%). The bandwidth is further reduced if the separation between the top radiating and bottom layers is small (about 0.5-0.9% per 0.018 λ, usually for antennas less than 0.168λ in height). Using Zeland IE3D (CAD) software it can be established that an initial design printed-PIFA operating from 864.8-867.7MHz has a total fractional

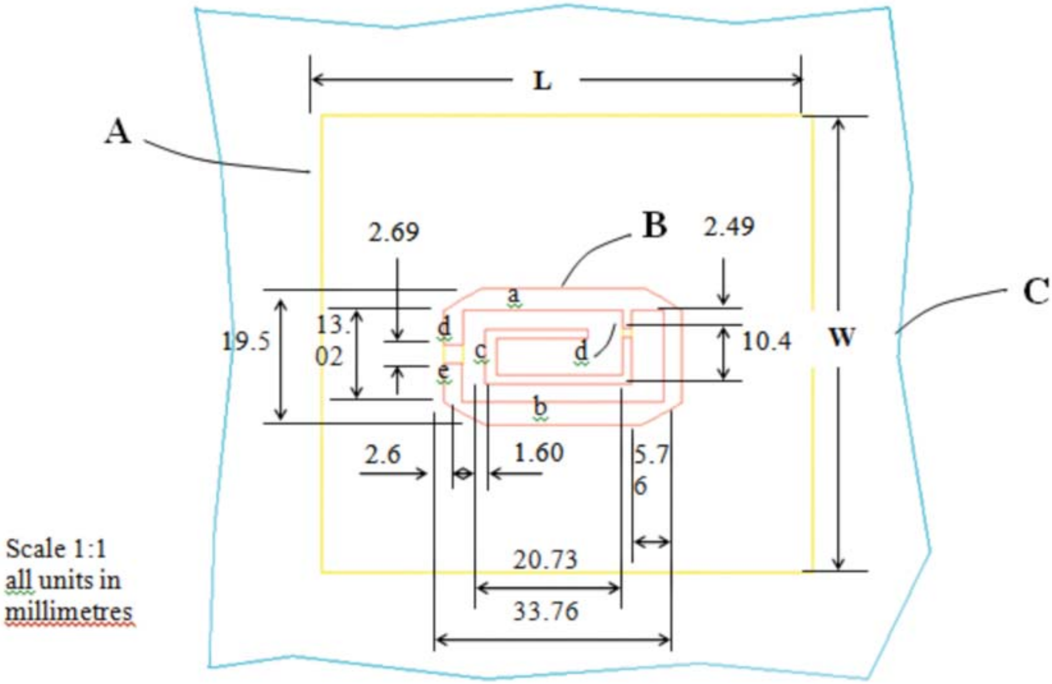


Figure 2.2

The structure dimensions and elements of the printed-PIFA

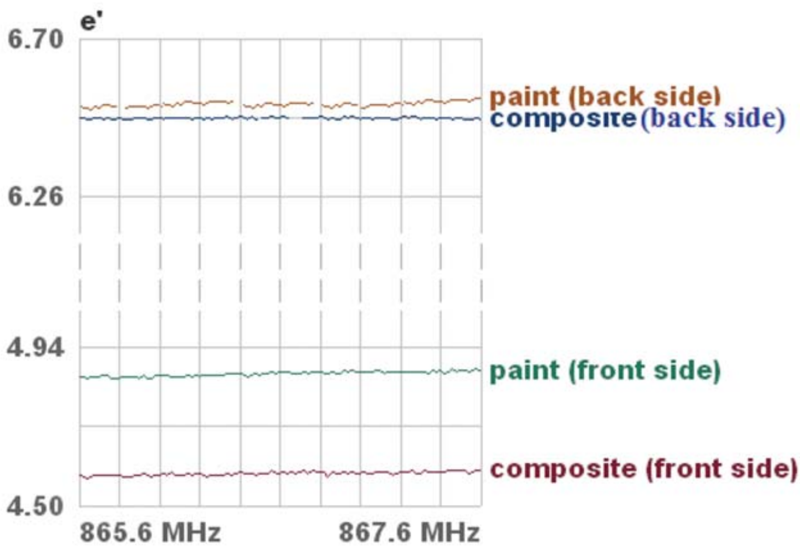


Figure 2.3

Measured permittivity of the composite and paint bandwidth of 0.32% for S11 equal to -10dB. This is a very narrow bandwidth (only a narrow band is required in RFID applications) which is welcome as a contribution to the rejection of the influence of nearby radios.

The printed-PIFA introduced here has a striped top patch to create a meandering current path and reduce the overall length of the structure. The feed is at the central patch of the antenna design to offer a convenient interface to potential transceivers located at the back of the car enclosure. A flexible coaxial cable terminated by an SMA connector was however used to feed the antenna in the measurements. The required elements of the strip pattern in the upper part of the printed-PIFA and the extended image radiator A, which was required to achieve the desired bandwidth using a coat (paint), is shown in Fig. 2. The antenna is implemented first by spraying a conductive ink to realise the resonator A over the coated car body (existing layer), h, Fig. 2.1, second, re-coating A using typical car paint (additional layer), h´, Fig. 2.1, to provide a non-conductive separation layer between A and B, finally, spraying conductive ink to realise the antenna radiator B; the dimensions are given in Figs. 2.1 and 2.2.

2.2.2. *The principal radiating elements*

The initially striped printed-PIFA radiator B of 19.43 × 33.8 × 0.125mm^3 (0.056λ, 0.097λ and 3.61e-4λ) was designed at 825.8MHz offering a fractional bandwidth of 0.22% at -29dB. This however, was seen as a "match load" since -40dBi gain (a near zero radiation efficiency) was observed. Antennas when in very close proximity to a ground plane (PEC) suffer from severe lack in radiation efficiency [10]. This is due to the "mirroring effect" reverse image current cancellations caused in the PEC and counteracting the impedance mismatch (typically a poor return loss) of the antenna. EBGs (an in-phase reflection coefficient) can improve the radiation efficiency; however, current inevitable thickness of constructed EBGs, ~2mm [11] and the additional required separation between the radiator and the EBG in order to perform, an air-gap of ~3mm [11], increases the final width design of prospect antenna structures using this technology.

Observation on predictions showed that when the printed-PIFA radiator B is 2mm (0.005λ) away from the ground plane, a -22.5dBi gain (a 2.25% radiation efficiency) was achieved; this is a 1.7/1 improvement. However, the return loss (RL) of the antenna was constrained by a ratio of 0.012/1. This is attributed to the improved radiating performance of the printed-PIFA and the no longer "match load" behaviour. Adding a resonator A, a negative image of the radiator B with an extended plane of 2.07/1 and 3.35/1 respectively for length, l, and width, w, of the plane, is an effective plane for favouring fringing edges currents of the radiator B by impinging them to a resonator A; it was found that when this plate is 65.33mm 70.04mm 0.18λ0.20λ, best gain and impedance matching is achieved (reducing l, greater operational frequency; increasing w, deeper RL). A 2 dBi gain (a 51% radiation efficiency) is achieved; this is a 24.5/1 improvement as compared to the printed-PIFA without the resonator A. Simulated results for different l and w dimensions are given in Table 2.1. Adjusting equally percentages for l and w, lower and upper shifts of the central resonance frequency is achieved with intervals sufficient to encompass worldwide RFID bands (a required total band of 78MHz and a typically used sub-channel band of 2MHz). Among the worldwide RFID frequency bands are 902-928MHz (FCC; NA, SA), 865.6-867.6MHz (ETSI; EU), 865-867MHz (MCIT; India) to 866-870MHz and 940-943MHz (China) [12].

Table 2.1

Element / and *w*	Centered frequency (MHz)	Total bandwidth (%)	Upper and lower roll-offs (dB/MHz)	Return loss (dB)
+ 12mm	775.52	0.46	0.58	-2
+ 8mm	729.9	0.87	0.37	-2
+ 4mm	823	0.24	0.85	-10
/ and *w*	866.6	0.24	0.85	-10
- 4mm	910.51	0.24	0.85	-10
- 8mm	960.79	0.24	0.85	-10
- 12mm	1010.13	0.24	0.85	-10

The structure was modelled and the current density was observed. A simulated RF current distribution, Fig. 2.4, show the contour field difference for the printed-PIFA radiator B with and without the resonator A. It can be seen that currents originating in the ground plane (immediately underneath the radiator B) in Fig. 2.4a are no longer seen in Fig. 2.4b, and that the resonator A positively contributes to the impinging currents from radiator B. The resonator A has a significant role; compared the printed-PIFA without A, the antenna with A presents an improved 2/1 and 1.7/1 respectively for the gain and efficiency. To achieve the same gain of 2dBi without the resonator A, the printed-PIFA has to be 0.07λ away from the ground plane, C; this for the proposed printed-PIFA antenna can be seen as a 1/14 antenna size reduction.

The antenna radiator B is now described. PIFA antennas printed on a substrate can contribute to simplified designs with improved bandwidth [13]. Introducing strips to form the top patch creates a meandering current path that reduced the overall length of the antenna [13]. Strips were used to design the antenna radiator, Fig. 2.2. Element a, showing a U shape geometry has the length required for the resonance at 866.6MHz. The inclusion of element b facilitates the antenna feeding by providing a right interface between element b and element e. The feed is at near the central patch of the antenna for via through connection. Element c and d forms a capacitive coupling which adjusts for impedance resonance to be centred with a fine range. In addition, the gap provided by the elements reduces the electrical length of the PIFA by creating a meandering path for the radiator. Element e adjusts the impedance resonance of the antenna for an increased/reduced bandwidth of the PIFA by a fine range of 0.17MHz while leaving the operational frequency unchanged. This beneficially rejects nearby frequencies. The radiator B is not connected to the ground plane C which has the effect of increasing the gain by 2dBi.

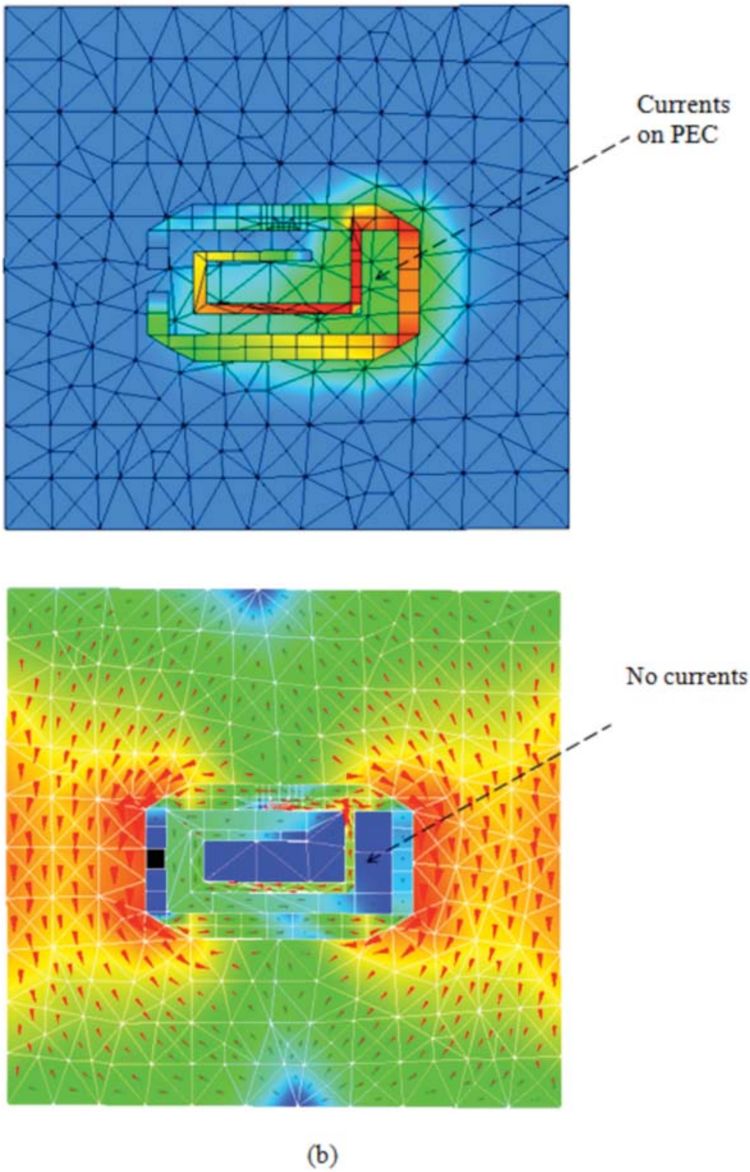


Figure 2.4

RF current distribution of the radiator B, a) without and b) with the resonator A

The final RF current distribution of the optimally tuned antenna with the dimensions given in Fig. 2.2 is depicted in Fig. 2.4b.

The term ‘miniature’ is applied to this printed-PIFA as the gain is 2 dBi for a compact size of 65.33 × 70.04 × 2mm^3 where the electrical dimensions in terms of wavelength are respectively 0.18λ×0.20λ×0.005λ. The antenna is therefore considered as miniature as it provides high efficiency in a compact volume.

The constructed printed-PIFA shown in Fig. 2.1 with the dimensions of Fig. 2.2 was generated by spraying a conductive ink using negative masks with a scale 1/1 fabricated in polyurethane sticker. To account for any possible variations in the manufacturing process, Table 2.2 provides with the expected centre frequencies, total bandwidth, return loss, including the upper and lower roll-offs values, and the gain of the antenna for trivial

Table 2.2

Thickness, h (mm)	Centre Frequency (MHz)	Total Bandwidth (%)	Upper and lower roll-offs (dB/MHz)	RL (dB)	Gain (dBi)
3.8	839.76	0.4	0.09	-2	-3.1
3.2	845.34	0.24	0.28	-5	-1.5
2.6	852.79	0.16	0.66	-10	2.5
2.508	854.65	0.19	0.58	-10	2.5
2.381	856.52	0.2	0.52	-10	2.5
2.254	859.31	0.24	0.45	-10	2.1
2.127	862.10	0.24	0.39	-10	2.8
2	**866.6**	**0.24**	**0.85**	**-10**	**2.5**
1.873	n/a	short circuit	n/a	n/a	n/a
Thickness, h′ (mm)	Centre Frequency (MHz)	Total Bandwidth (%)	Upper and lower roll-offs (dB/MHz)	RL (dB)	Gain (dBi)
4.054	895.62	0.33	0.16	-10	3.5
3.454	890.03	0.33	0.29	-10	4.5
2.854	882.58	0.31	0.36	-10	4.2
2.254	873.27	0.26	0.36	-10	3.2
2.127	870.48	0.26	0.41	-10	3.3
2	868.62	0.25	0.47	-10	3.1
1.873	**866.6**	**0.24**	**0.85**	**-10**	**2.5**
1.746	863.96	0.22	0.36	-10	1
1.619	861.17	0.21	0.41	-10	1.2
1.492	857.45	0.22	0.49	-10	1.5
0.892	839.76	0.33	0.22	-5	-2.7
0.292	n/a	mismatch	n/a	0	-32

thicknesses of h and h´ paint coating layers. Whereas greater gains are observed for larger thicknesses of h till a maximum value of h = 3.2, this is compromised with bandwidth. For the case of h´, maximum gains are observed for h´ = 3.45.

2.3. **Experimental set-up**

For the simulated in-car system set-up, the cargo area of a Ford Transit van modelled as a complete shield room of 1.8 × 2.6 × 1.4 m^3 for the carriage of goods was used; Fig. 2.5 shows a high-level block diagram for the in-car system. The printed-PIFA is located in the middle of the ceiling of the vehicle; as preliminary predictions indicated to be the preferred location to ensure optimal radio propagation illumination inside the vehicle. The printed-PIFA was used as a transceiver (transmit and receive) and had a gain of 2 dBi. Commercially available tags [14] (identify parcels containing medicines) were assumed to receive and backscatter power inside the vehicle; they retrieve the required power to make them active (integrated chip). In general, passive (no battery powered) RFID tags use the received power of an antenna interrogator to power their integrated chip and backscatter (reflection) the power to back transmit to the interrogator. The maximum receive sensitivity of a typical transceiver is -65dBm assuming a full transmit power with a 1.5:1 VSWR antenna [15], and no maximum sensitivity enforcement is probable. Because the employed antenna corresponds to a 1.92:1 VSWR it is reasonable to expect a receiver sensitivity of -64.72dBm. The

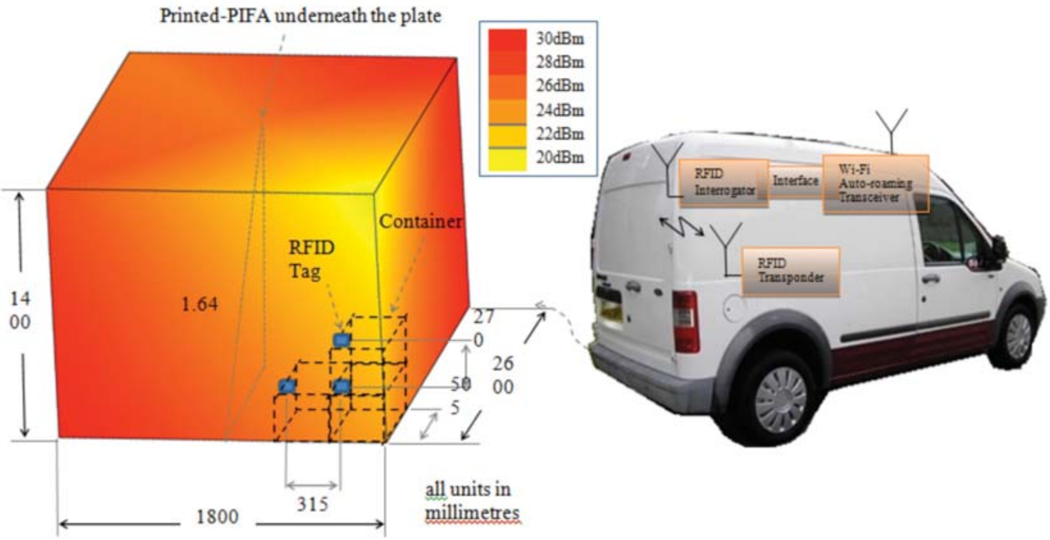


Figure 2.5

The experimental set up in a typical in-car showing maximum expected simulated power strength at the edges of the car body transmission is given by a maximum output power of 30 dBm (1W) for the subband b2 (8.656-8.676 GHz). The employed antenna VSWR response, introduced in Section 2.2.4, corresponds to a mismatch loss of 0.458 dB. Maximum allowed transmit power of RFID is dictated by ETSI to 1W Effective Radiated Power (ERP) [5]; this is, a 1.6W EIRP. Because the transceiver emits an output power up to 30 dBm (1W), simulated results of Fig. 2.5 anticipates that a non-greater than a 2dBi antenna can be utilised in this application to meet the regulation criteria; using higher gain antennas would require a reduced inputpower to the antenna and effectively lead to large designs; a 2dBi antenna design is therefore perceived as a size optimized antenna for the application.

2.4. **Results**

Figure 2.6 shows a comparison of the measured and simulated return loss of the narrowband printed-PIFA antenna. Construction tolerances, mainly given by the voltage currents raised at the junction between the feed and the antenna structure, meant there was some difference between the simulated and measured S11 for the printed-PIFA. The measured results present a return loss of -10dB for the entire bandwidth of 266MHz. Additionally, the narrow band antenna presents a flat response of about -5dB for the upper and lower frequencies. The return loss of the antenna over a larger ground plane, D, of dimensions 510 × 800 × 0.75 mm^3 showed no mismatch or de-tuning of the input

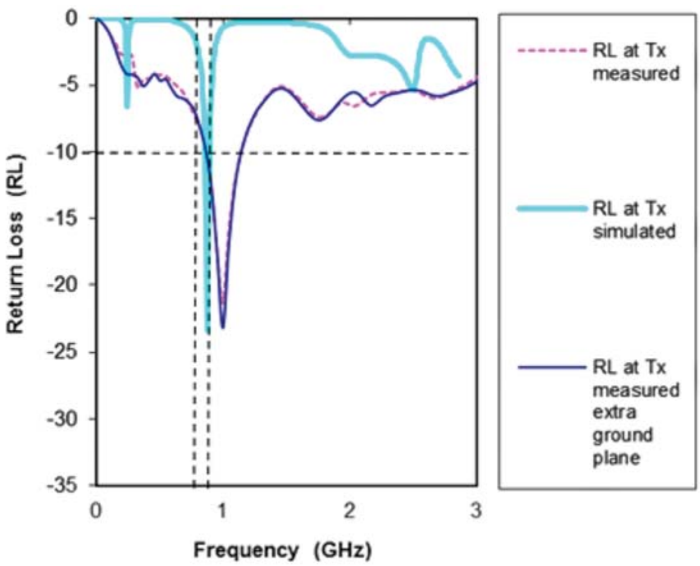


Figure 2.6

Return Loss of the printed-PIFA

impedance response of the antenna. The antenna can then be considered insensitive to larger ground planes and therefore platform tolerant.

The radiation patterns were measured in an anechoic chamber in polar patterns for the frequency band of interest. Figure 2.7 shows the antenna radiation patterns covered 360º for the azimuth H-plane. This 360º antenna characteristic can be useful for in-vehicle applications [6] where the pattern projects in all the orientations inside the vehicle.

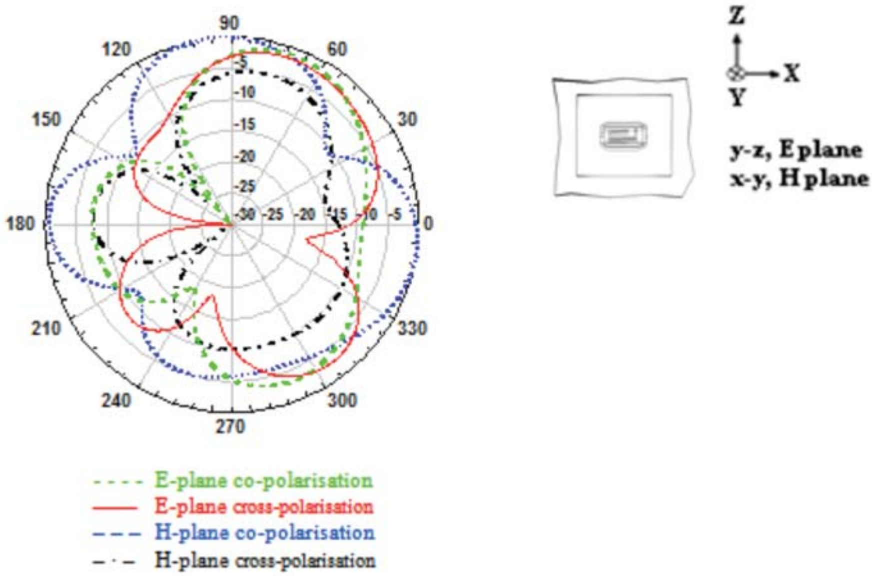


Figure 2.7

Radiation pattern of the printed-PIFA

Figure 2.8 shows a simulated antenna radiating efficiency of 46%, an antenna gain of 2 dBi and associated high directivity (for the extremely low separation, 2mm, between the radiator and the ground plane of the antenna) at a calculated VSWR 1.92:1. The results indicate that this antenna is potentially adequate for in-vehicle hidden applications where the antenna radiator is sprayed over the coating of a vehicle body. In addition, other applications (e.g. embedded in coated metals) such as kitchen appliances are also envisaged. The antenna (using the paint substrate) gain was measured 4 dBi down as compared to the simulated and was given by manufacturing tolerances; the substrate thickness was smaller than that of the initial design. Future developments are encouraged to retune the load of the antenna to match the chip of an RFID tag; this can bring the antenna to applications such as the use in bikes, fire extinguishers, vehicle's plate registration numbers, vehicles and heavy machinery.

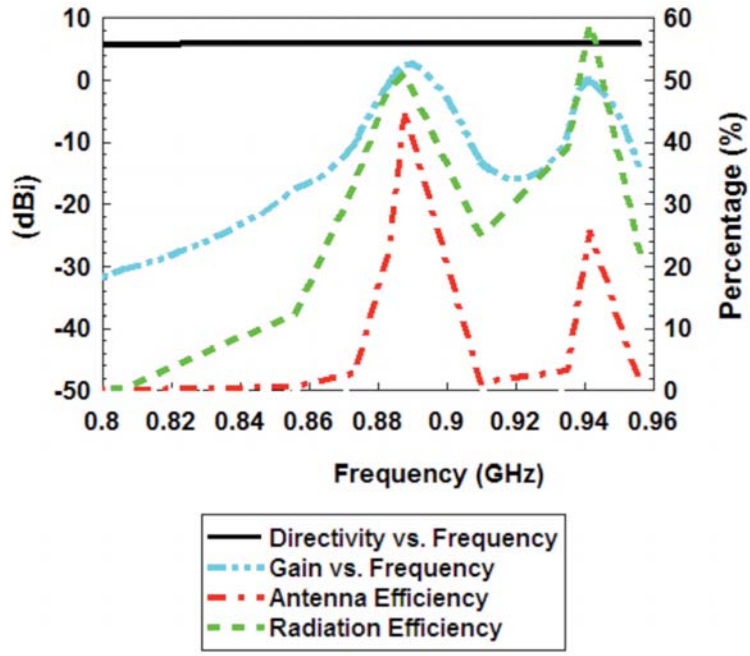


Figure 2.8

Efficiency, directivity and gain of the antenna

This antenna can easily be integrated in vehicles, such as cars, and other articulated vehicles and in applications where large ground planes are encountered. The addition of the additional ground plane, D, does not significantly alter the bandwidth and return loss of the antenna, Fig. 2.6; any possible weak resonance can be expected due to the effect of the enclosure. However, the antenna enclosure (the car body) could act as an antenna resonator (an excited cavity), this is subsequently analyzed.

Figures 2.9 and 2.10 show respectively the corresponding radiation patterns of the printed-PIFA in the far-field with and without the extra ground plane, D, and the pattern seen outside the fuselage of the vehicle (when the printed-PIFA is located inside the vehicle). This can predict surface waves occurring at the enclosure resonance which might have significant effect to the properties (i.e.: change the VSWR performance due to originated reflections) of the antenna. Measured radiation patterns present a printed-PIFA antenna covering 360º for the azimuth H-plane and thus propagating in all the orientations inside the vehicle, Fig. 2.9. The simulated gain seen outside the fuselage of the car body (printed-PIFA antenna inside the vehicle), Fig. 2.10, was about 20dBi lower than that compared to the printed-PIFA antenna (without the body). This gives confidence that radio propagation is encountered outside the vehicle and ensures the possibility of using higher powers inside the vehicle (up to 4W ERP indoors); this is translated to an increase of 3.16dBm in the actual power at the interrogator.

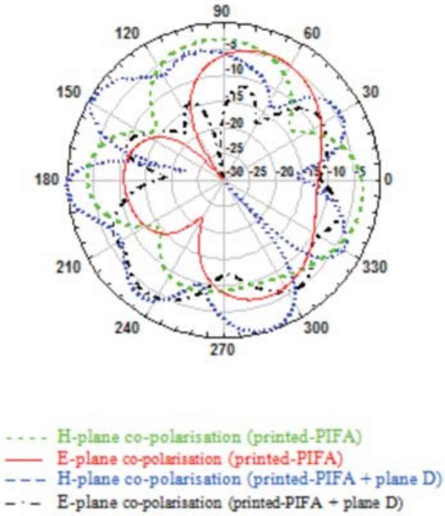
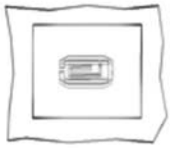


Figure 2.9

Radiation pattern of the printed-PIFA with and without the extra ground plane D



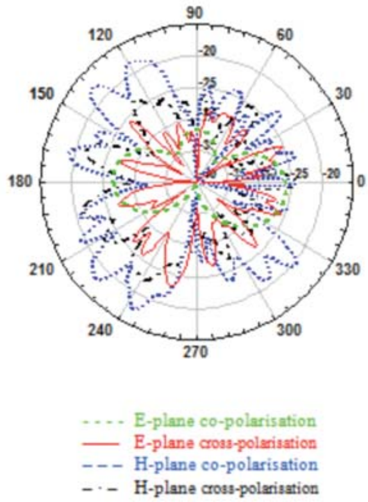


Figure 2.10

Radiation pattern seen outside the fuselage of the vehicle (simulated)

2.4.1. *Signal strength and Propagation coverage*

In principle, radiation propagation inside vehicles is favoured for seizing RF energy with minimal loss, however, because the enclosure is not a perfect shield, surface losses due to the metal imperfection are originated. As antennas do not radiate power uniformly in all directions, the signal strength inside the car body (interrogation zone) is therefore analysed. IE3D software using a full wave Finite Difference Frequency Domain (FDFD) is used for the simulation. Although the ray tracing technique [16] is typically utilised to analyse complex environments, FDFD is more precise for this application since the enclosure (car body) can account for a significant impact upon the antenna performance (i.e.: matching) [17]. In addition, because the pattern (radiator) of the designed antenna is directly sprayed over a car body, the enclosure might actually perform as an extra added ground plane (the plane below the antenna radiator) and as a capacity-coupling resonator (the plane above the antenna radiator); this might lead to radiation propagation in a far-field outside the car body. A series of simulations were taken to establish suitable location for the antenna inside the vehicle; it was found that the best location for the antenna was in the middle of the ceiling of the car. The simulated power strength at the edges of the car body (inside) is depicted in Fig. 2.5 showing ~22dBm in the worst case. In addition, performed simulations established that the amount of energy being radiated out of the enclosure has fall 20dB with respect to the antenna without enclosure; this is an expected value since the enclosure is expected to prevent some of the power being radiated out of the car body. It is also expected in this application multipath contributions (nulls due to the out-of-phase multipath interference and positive strong signals [18]) counting towards the available power strength; the received power strength for likely tag locations inside the vehicle is given in Table 2.3; it can be seen focuses of strong signal power for the tags. The analysis for the power predictions used a deterministic approach in near field; the far field cannot be measured inside the vehicle. Far field measurements were used to analyze powers leaving the fuselage of the car. It can be observed that when the tags are closer to the edges of the vehicle chassis the more the radiating power strength is achieved.

Table 2.3

tag	dBm	**tag**	dBm	**tag**	dBm	**tag**	dBm	**tag**	dBm
a	29	**a^1**	29	**a^2**	20.9	**a^3**	28.4	**a^4**	15.8
b	23	**b^1**	30	**b^2**	21.3	**b^3**	28.8	**b^4**	22.8
c	29	**c^1**	18	**c^2**	29.8	**c^3**	23.4	**c^4**	30
d	30	**d^1**	23.9	**d^2**	19.5	**d^3**	25.7	**d^4**	25.8
e	28	**e^1**	29.3	**e^2**	29.3	**e^3**	30	**e^4**	17.7
f	25	**f^1**	30	**f^2**	30	**f^3**	30	**f^4**	25.7
g	24	**g^1**	26.2	**g^2**	29	**g^3**	26	**g^4**	15.8
h	28.8	**h^1**	24	**h^2**	24	**h^3**	23.6	**h^4**	30
i	25	**i^1**	18.2	**i^2**	16	**i^3**	26	**i^4**	24.9
j	30	**j^1**	28.5	**j^2**	25.3	**j^3**	29.5	**j^4**	28
k	23.7	**k^1**	30	**k^2**	30	**k^3**	28.8	**k^4**	25.9
l	23.5	**l^1**	27.3	**l^2**	28.6	**l^3**	26.2	**l^4**	16.3
m	28	**m^1**	23.3	**m^2**	22.8	**m^3**	23	**m^4**	30
n	25	**n^1**	19.8	**n^2**	15	**n^3**	27	**n^4**	24.9
o	29.5	**o^1**	28.2	**o^2**	26.8	**o^3**	30	**o^4**	28
p	27.2	**p^1**	29.8	**p^2**	22	**p^3**	29.5	**p^4**	17.8
q	22.5	**q^1**	30	**q^2**	19.8	**q^3**	29	**q^4**	34
r	28.5	**r^1**	18	**r^2**	30	**r^3**	21.9	**r^4**	30
s	30	**s^1**	23.5	**s^2**	19.7	**s^3**	25	**s^4**	25.8
t	26.5	**t^1**	30	**t^2**	28.9	**t^3**	30	**t^4**	15.9
u	25.5	**u^1**	27.7	**u^2**	20.5	**u^3**	26	**u^4**	25.8
v	30	**v^1**	21.3	**v^2**	28	**v^3**	24	**v^4**	30
w	28.8	**w^1**	28.9	**w^2**	29.1	**w^3**	29.8	**w^4**	27.6
x	27.7	**x^1**	30	**x^2**	30	**x^3**	30	**x^4**	27.4
y	25.4	**y**	22.9	**y**	29.8	**y**	25.1	**y**	24.7

Assuming that the backscattered power of the tag is equal to that it received and has a symmetric path loss in the downlink and uplink, the calculated received power at the interrogator for the 1.3m range is -60dBm; this is 30dBm – (2 × 45dBm) = -60dBm and is a suitable power to be understood by the receiver sensitivity of -64.72dBm. There is no need to increase the amplification of the integrated LNA since these guarantees for a 4.72dBm increase in the receiver sensitivity if improvement of the interrogation zone was desired.

3. SPRAYED ANTENNA ON CANS FOR WLAN-RFID TAGS

A directly printed antenna onto a can body using copper conductive paint and suited for Radio Frequency Identification Wireless LAN (RFID-WLAN) tag applications is presented. The antenna unit is low-cost and compact, provide reasonable gain, and serve prospect RFID transponders with a range of IC impedances. The antenna is fabricated with dimensions of 0.18λ×0.20λ×3.61e-4λ and is relaxed from manufacturing. A design study has been carried out to assess the tuning of the characteristic impedance of the antenna. Return loss, load impedance and radiation patterns are shown.

3.1. **Introduction**

Radio Frequency IDentification (RFID) is being widely used in real-time identification, management, and assets tracking. It uses RFID backscattered modulated signals technology for the interrogation of transponders (TPDs) [19]. Among the frequency bands that have been allocated to RFID in the microwave region, (i.e.: ~0.9GHz, ~2.4 GHz, and ~5.8 GHz), the latter provides antennas that are less impacted when in close proximity to a reflector and therefore provide more compact and conformal structures. The antenna radiator is directly sprayed onto a can body with adequate performance and can be used in hidden applications. The design is suited for use in RFID networks using the unlicensed band (5725-5875 MHz) of the ETSI standard [20] and demanding for long range and high read data rate [21]. The integration of the antenna with the can body is analysed and a fine tuning of the antenna load for a range of possible IC transponders usage given. Among potential applications are food & beverage cans and metal based containers.

3.2. **The design**

This section presents the design and geometry of the proposed antenna.

3.2.1. *Geometry of the antenna*

The dimensions of the proposed on can conductive paint sprayed RFID-WLAN antenna is shown in Fig. 3.1. The can dimensions are high=115.5mm and radius=32.9mm in form of a cylinder. This antenna presents a simple structure to realize a compact and

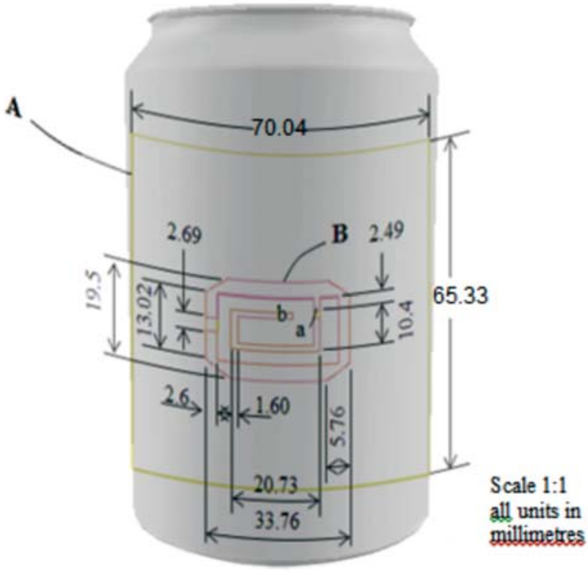


Figure 3.1

Dimensions of the sprayed antenna on a can

conformal manufacturing. It consists of two sprayed planes, A and B (using copper conductive paint – resistivity < 0.015 ohms/sq [22]) each separated by a substrate formed of a sprayed paint (εr = 6.5) of 127µm; the radiating patch, B is on the upper plane, and the resonator A sandwiched between paint layers (substrate). The thickness of the paint layers and antenna conductors are each 127µm. The total volume of the sprayed antenna is 65.33 × 70.04 × 0.127mm^3 and the feed is given by the gap a, between the inner and outer radiate elements; this is to offer a convenient interface to the transponders (TPDs). Trimming the radiator inner strip, b to one extend, provides a fine tuning in the characteristic impedance (load) of the antenna with no significant variation in the resonant frequency.

3.3. **Results**

3.3.1. *The Return Loss*

Figure 3.2 shows a comparison of the measured and simulated return loss (RL) of the sprayed antenna, both over a flat ground plane, C, of dimensions 510 × 800 × 0.75 mm3 and over the can; the antennas had to be independently fabricated, therefore the non-fair comparison. The simulated and measured results (S11) are in good agreement; manufacturing tolerances are attributed to the small difference. A probe connected to a VNA was used for the measurements and calibrated up to the reference plane of the far end pins using the port extensions (open) function (a delay compensation of 29.243ps); the open circuit presented an infinite impedance response to validate the calibration. The measured results present a RL of -10dB for a bandwidth of 785MHz; a greater 187MHz was achieved using the C plane. Although the non-fair comparison, the RL of the antenna over the plane, C, and over the can present significant similarity and validates the antenna for conformal applications. For the antenna to be hidden (adding a coating paint of 127µm above the antenna radiator), the centre frequency of the antenna resonated at 5.294/48GHz with no variation in bandwidth, that is a 400MHz lowered frequency than that without the extra paint layer; this supports that the presence of the extra layer of paint has no significant effect in the RL and corroborates the potential for the antenna to be hidden.

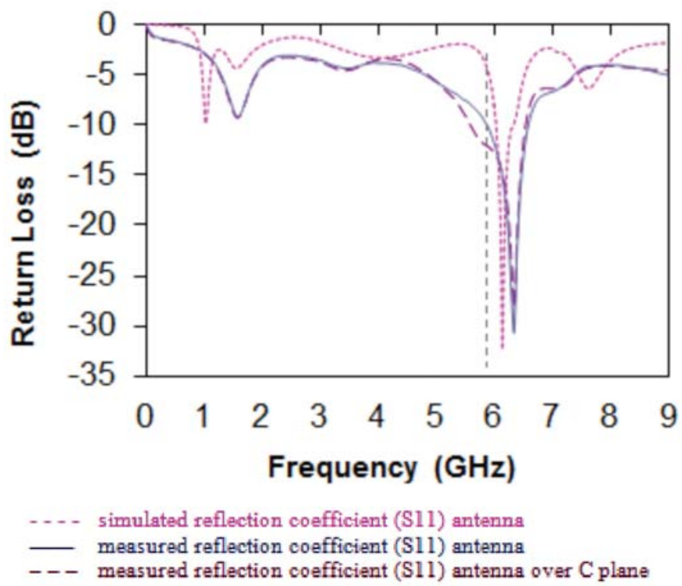


Figure 3.2

Simulated and measured return loss of the antenna

3.3.2. *Characteristic impedance of the antenna*

Figure 3.3 depicts the measured characteristic impedance of the antenna and that using the C plane. Fair agreement is shown between both antenna responses and gives confidence to assume that the impedance response presented in Fig. 3.4 will apply to both antennas; the antenna is yet to be adjusted for full power transfer between the transponder and the antenna.

Figure 3.4 shows the tuning of the antenna load (measured at 5.8GHz) for a range of likely IC RFID transponders. Typically, the impedance of a transponder is highly capacitive

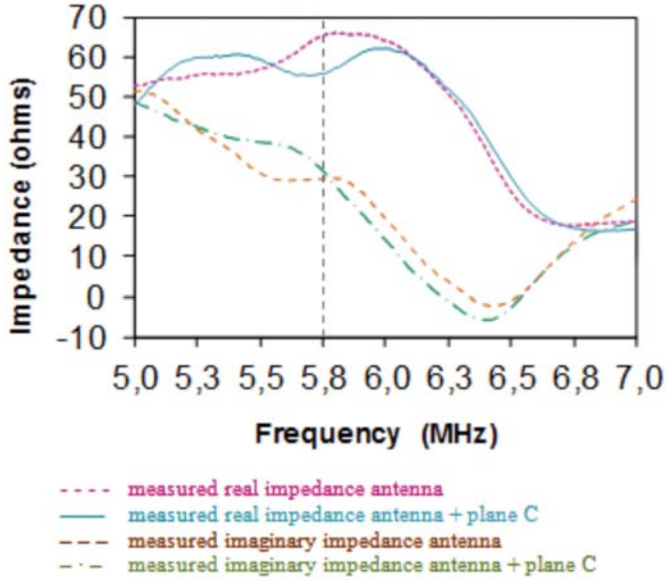


Figure 3.3

Measured characteristic impedance of the antenna

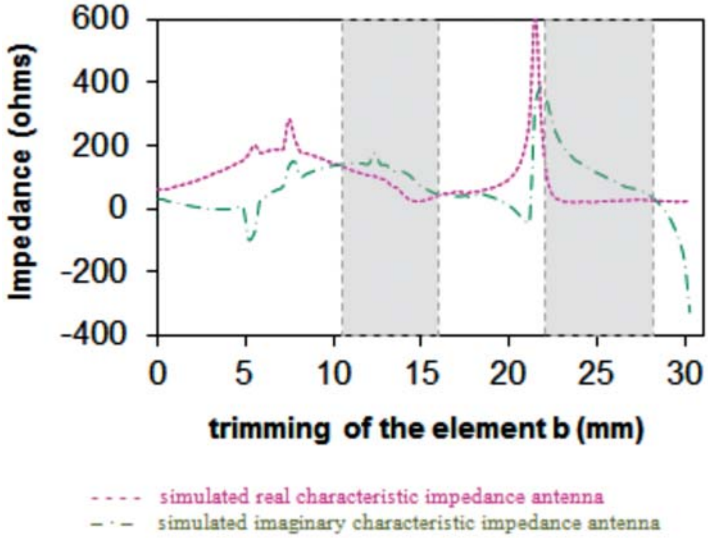


Figure 3.4

Tuning of the characteristic impedance of the antenna, real (resistance) and imaginary(reactance) as a function of the trimming of the length of element, b and to be conjugately matched (Zant = ZIC*) to the antenna for full power transfer, the latter must have a highly reactive response and a relatively low real part of the impedance; the response is achieved by trimming the length of the element b (the initial length is 30mm).

3.3.3. *Radiation patterns and antenna gain*

The radiation patterns were measured in an anechoic chamber in polar patterns and are presented in Fig. 3.5. For the measurements, the antenna was fed using a 50Ω coaxial probe through a via to the edges of the gap a, and is non-electrically connected to the ground (can body). The connector originated to uncompensated radiation front-to-back ratio patterns, and the antenna radiates in all directions, 360º, for both, the azimuth H- and elevation E-planes. Future work should try to minimise the nulls encountered in the radiation patterns. This 360º antenna characteristic can be useful in the application, since the can is able to be seen in all orientations. Future research will have to look at the interaction between cans as they are piled. The measured antenna gain was 3.04dBi. The

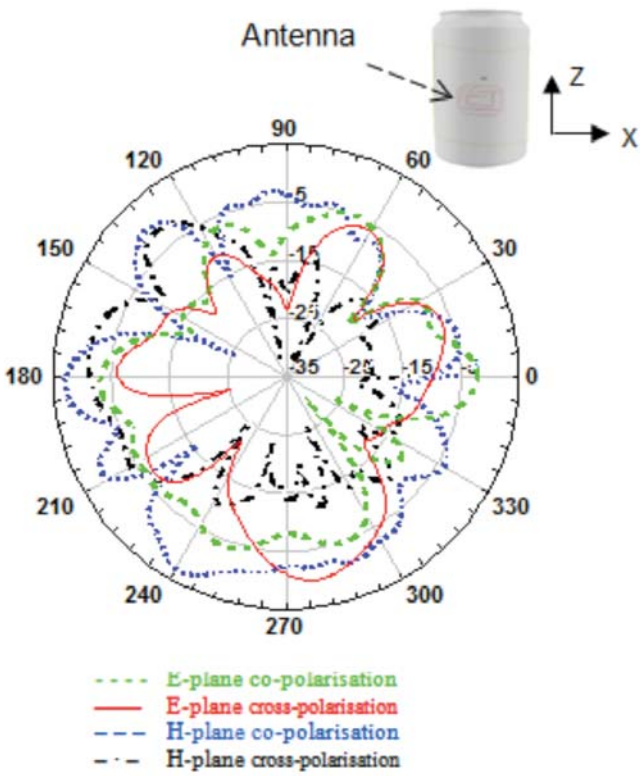


Figure 3.5

Radiation patterns of the can antenna measured at 5.8 GHz antenna is adequate for tagging and is intended for hidden applications where the antenna radiator can be covered using a coated paint.

4. CONCLUSIONS

A low cost miniature narrowband PIFA antenna for straightforward integration inside vehicles and hidden applications has been presented formed by using a conductive paint sprayed over a car body with good return loss, gain and 360º radiation patters in the azimuth H-plane.

Measured and simulated results indicate that this antenna works satisfactorily in the unlicensed UHF RFID (UHFID) band (865.6-867.6 MHz) and can cover worldwide RFID frequency bands, such as the 902-928MHz (FCC; NA, SA), 865.6-867.6MHz (ETSI; EU), 865-867MHz (MCIT; India) to 866-870MHz and 940-943MHz (China) [11], with potentially non-resonances in the nearby lower and upper frequency bands; this provides immunity to adjacent transmitting RF signals in the vicinity. A variant antenna design capable of achieving multiband response using switching technology is to be considered for future research.

The integration and interaction of the antenna inside a car body was analysed, a series of simulations and corroborated measurements characterised the in-car channel and evaluated the performance of a typical RFID interrogation zone in this setting. Results indicate that the design proves to be proficient for in-vehicle applications. The 360º radiation pattern of the proposed interrogator antenna in the azimuth H-plane, guaranties coverage in-car and simulated RF signal powers of 20dBm average. The distributed powers inside the vehicle provided with an efficient communication to likely distributed tags. In addition, a study of measurements of currently unknown models describing the radio channel for a new RFID in real environment applications is needed to overcome the lack of propagation models (statistical-realistic approach) for this application and it is intended that the knowledge gained from this study may be used to characterise such channels, concluding that RFID is a very suitable and promising technology for the interrogation zone able to provide high read rates. LOS transmission can improve the system read rate meaning that potentially directional antennas such as patch arrays and beam steered arrays, could improve the overall system performance. Multiple antenna schemes [23] compared to single antenna settings provide a closer received signal recovery to a transmitted and higher data rates.

The use of EBG structures to shielding the enclosure of vehicles is to be considered in future research. The use of these periodic structures can contribute to higher powers in-car; ideally (this rather occurs in practise) any possible power inside a perfectly design EBG dice will never die [24].

In addition, an antenna suitable for tagging using the unlicensed WLAN-RFID band (5725-5875 MHz) has been presented and formed by using a total conductive paint sprayed on a can body with good return loss, gain and 360º radiation patterns for both, the azimuth H- and elevation E-planes. The tuning of the antenna load allows for a range of likely highly capacitive IC RFID transponders.

5. REFERENCES

[1] Thomson, S., Foubister, T., Mossialos, E.; “Financing Health Care in the European Union, Challenges and Policy Response”, Observatory Studies Series, No. 17, WHO Regional Office for Europe, 2009.

[2] Lauren R. Hartman, *Packaging Digest edition*, 1/1/2006.

[3] I.J. García Zuazola, J.M.H. Elmirghani, and J.C. Batchelor, “High-speed ultra-wide band in-car wireless channel measurements”; *Communications, IET,* Volume 3, Issue 7, July 2009 Page(s): 1115-1123.

[4] Mervi Hirvonen, Kaarle Jaakkola, Pekka Pursula, and Jussi Säily, “Dual-Band Platform Tolerant Antennas for Radio-Frequency Identification”, *IEEE Transactions on Antennas and propagation*, Vol. 54, No. 9, pp. 2632-2637, Sept. 2006.

[5] http://www.etsi.org/website/document/plugtestshistory/2008rfid/tr_10264402v010101p.pdf

[6] 599-B3755 Copper Conductive Coating from Spraylat, available [online] at http://www.spraylat.com

[7] http://www.ehow.com/how_5804374_measure-paint-thickness.html

[8] https://www.clippercontrols.com/pages/dielectric-constant-values#P

[9] Young-hun Lee, Won-hyun Kwon, “Dual-band PIFA design for mobile phones using H-type slits”, *2004 USNC/URSI, National Radio Science Meeting*, 20-25 June 2004, Monterey, California.

[10] http://www.ee.olemiss.edu/atef/documents/publications/2006.04.pdf

[11] Y. Zhao, Y. Hao and C. G. Parini, “Radiation Properties of PIFA on Electromagnetic Bandgap substrates”, *Microwave and Optical Technology Letters, Wiley Periodicals,* Volume 44, No. 1, pp. 21-24, Jan 5, 2005.

[12] Daniel M. Dobkin, “The RF in RFID: Passive UHF RFID in Practice”, *Elsevier Inc*., ISBN: 0750682094, 2007.

[13] Kin-Lu Wong, “Planar Antennas for Wireless Communications”, *Wiley Series in Microwave and Optical Engineering*, Wiley-Interscience, 20 December, 2002.

[14] http://www.confidex.fi/images/stories/pdf/product_datasheets/Carrier_Tough_Datasheet.pdf

[15] http://www.thingmagic.com/fixed-rfid-readers/mercury5/2-fixed-rfid-readers/2-mercury5

[16] R. Wahl, G. Wölfle, “Wave Propagation Inside and Around Vehicles in Dynamic Time Variant Scenarios”, *63rd IEEE Vehicular Technology Conference (VTC-Spring)*, pp. 2883-2886, Melbourne, May 2006

[17] Y. C. Or, K. W. Leung, R. Mittra, K. V. S. Rao, “Platform Tolerant RFID Tag Antenna”, *The 2007 IEEE International Symposium on Antennas and Propagation*, Honolulu, Hawaii, June 10-14, 2007.

[18] http://www.monitoringtimes.com/html/sensitivity.html

[19] Mervi Hirvonen, Kaarle Jaakkola, Pekka Pursula, and Jussi Säily, “Dual-Band Platform Tolerant Antennas for Radio-Frequency Identification”, IEEE Transactions on Antennas and propagation, Vol. 54, No. 9, pp. 2632-2637, Sept. 2006.

[20] ETSI standard available [online] at http://www.etsi.org/deliver/ etsi_en/300400_300499/30044002/01.03.01_60/en_30044002v010301p.pdf

[21] S.Y. Chen and P. Hsu, “CPW-fed folded-slot antenna for 5.8 GHz RFID tags,” Electronics Letter, vol. 40, no. 24, 25th Nov. 2004.

[22] Copper Conductive Coating 599-B3755 from Spraylat, available [online] at http://www.spraylat.com

[23] Biagi, M., Baccarelli, E., "A simple multiple-antenna ultra wide band transceiver scheme for 4th generation WLAN", IEEE 58th Vehicular Technology Conference, Vol. 3, pp. 1903-1907, Orlando, Florida, USA, 2003.

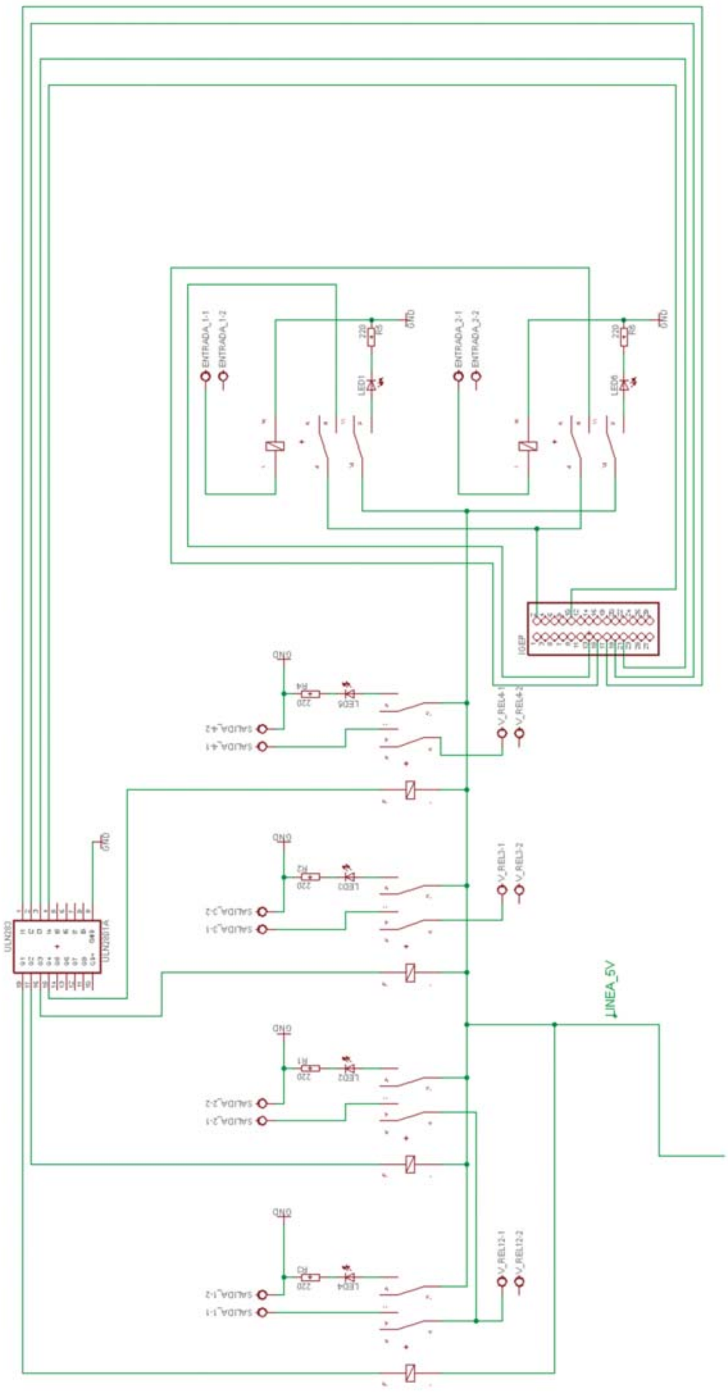
[24] Yablonovitch E., "Photonic Crystals: What's in a name?", *Optics & Photonics News*, vol. 18, no. 3, pp. 12-13, March 2007.

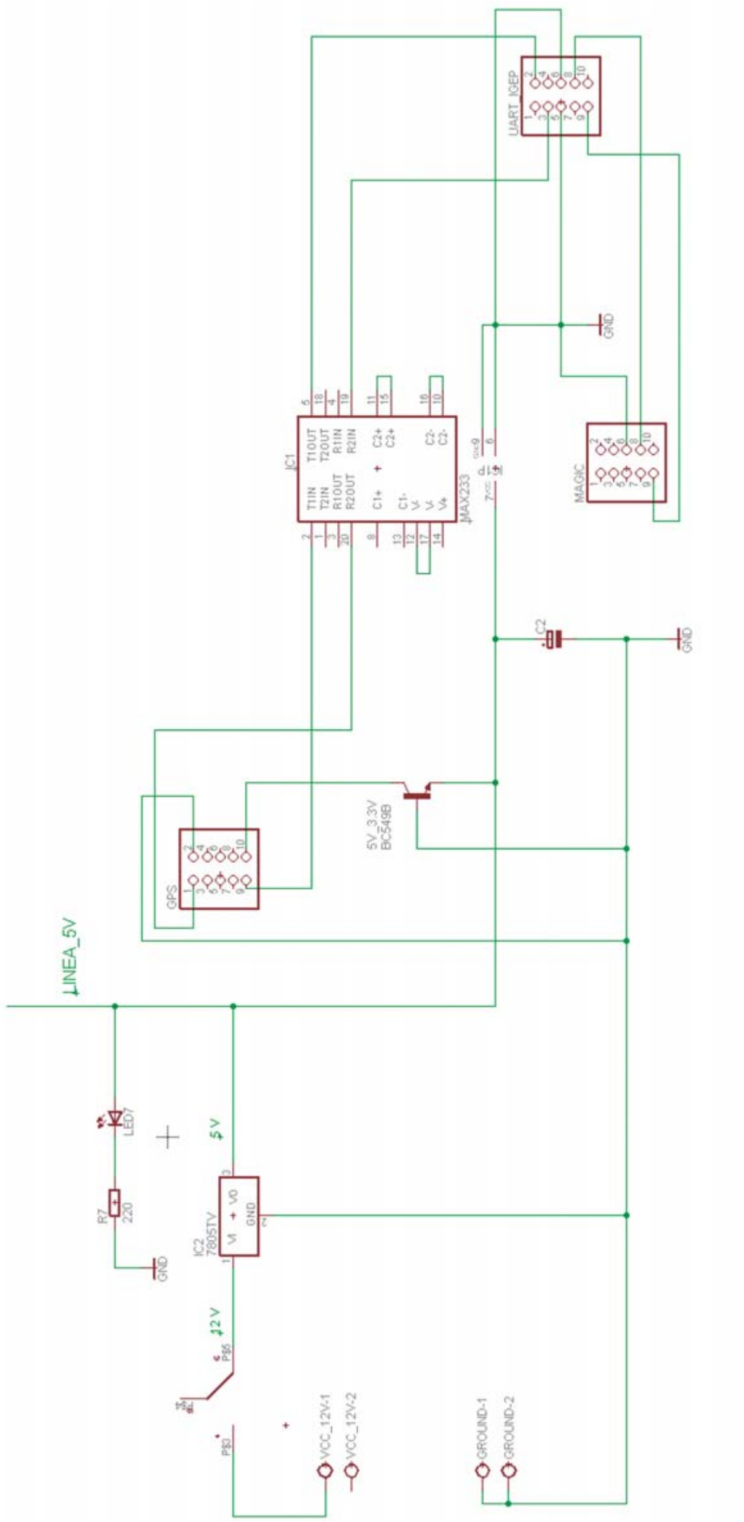
Diseño del esquema eléctrico para la construcción del módulo de control del dispositivo embarcado

Índice de contenidos

1. ESQUEMAS DEL DISEÑO

1.1. Esquema eléctrico

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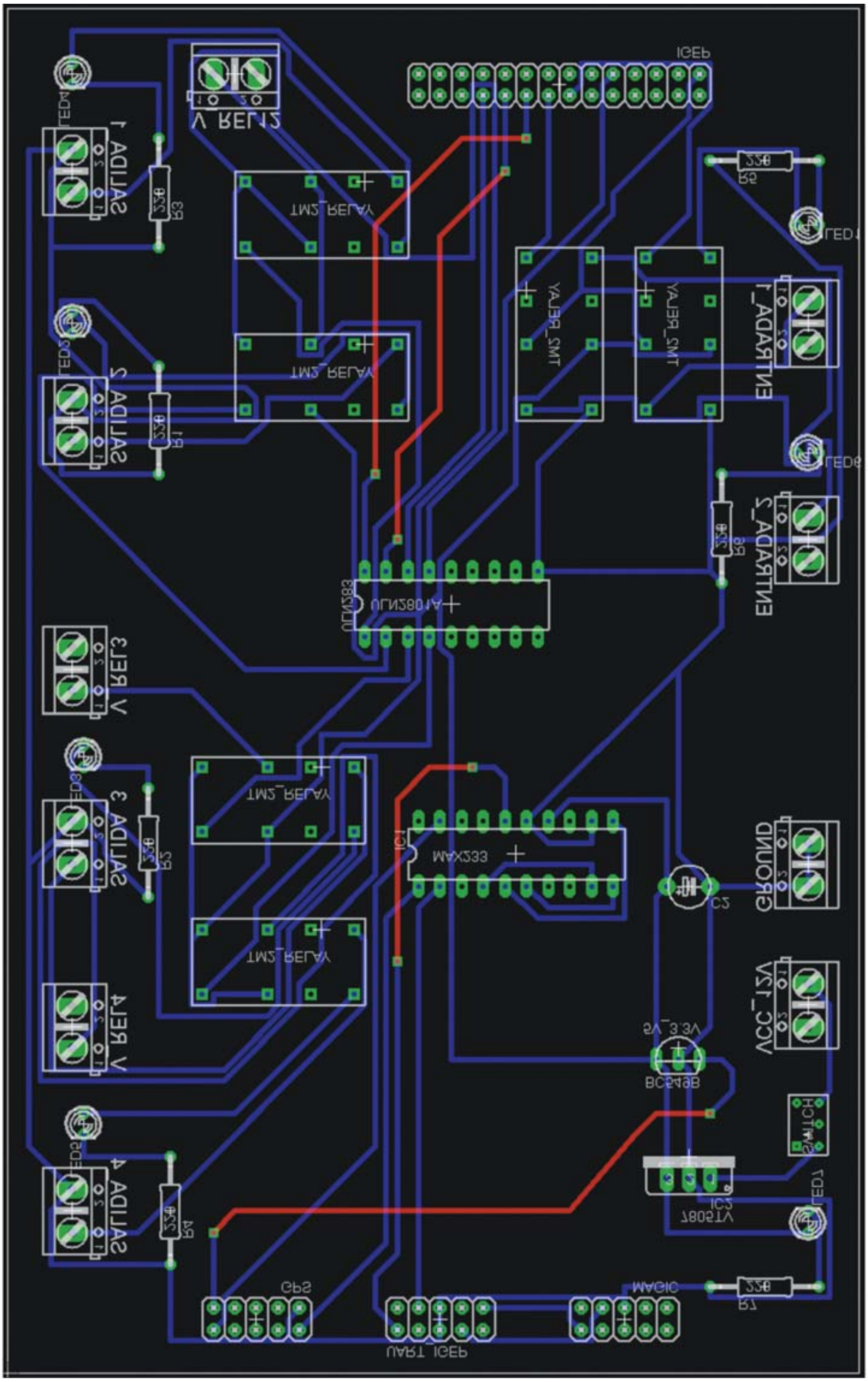
MAX233
GND
MAGIC
C2
GND
5V_3.3V
BC549B
GPS
LINEA_5V
LED7
R7
220
5 V
IC2
7805TV
GND
12 V
VCC_12V-1
VCC_12V-2
GROUND-1
GROUND-2

1.2. Layout



Diseño de la aplicación de seguimiento de flotas

Índice de contenidos

1. INTRODUCCIÓN

1.1. **Descripción de la aplicación de seguimiento de flotas**

La aplicación para el seguimiento de flotas se encarga de procesar la información proveniente de los vehículos de distribución, monitorizando el buen desarrollo de las rutas y emitiendo avisos en caso de que se produzcan desviaciones del comportamiento planificado.

Para esto, se extrae la información relevante del sistema de gestión de la trazabilidad, que a su vez lo obtiene de los dispositivos móviles, incluyendo los datos de los conductores, paradas en las rutas, cubetas a descargar en cada parada, etc. Esta información se procesa para generar incidencias en caso de que sea necesario, como por ejemplo la descarga incorrecta de una cubeta o una parada inesperada en la ruta.

1.2. **Propósito del documento**

Mediante la presente memoria técnica se describe a nivel técnico el funcionamiento de esta aplicación incluyendo sus módulos internos principales, interfaces de extensibilidad y sistema de configuración, en general, todo lo necesario para el uso y mantenimiento de este subsistema.

2. FUNCIONALIDAD COMÚN

2.1. **Acceso a la configuración**

El acceso a al configuración se lleva a cabo a través de la clase `Configuracion` del paquete `es.uc3m.trazamed.comun`. Este asegura que todo acceso pasa a través de los mismos métodos para que un cambio en estos afecte a toda la aplicación.

En todo momento, se mantiene una única instancia de esta clase, a la que se puede acceder con el método estático `getInstance()`. Además de esto, la clase proporciona los métodos `getProperty()` y `getPropertyList()` que dada una clave de configuración devuelve su valor en forma de string o array de strings (separados por punto y coma) respectivamente.

El fichero de configuración se define en la constante `FICHERO_CONFIG`, siendo por defecto un fichero llamado `config` en el directorio de trabajo de la aplicación.

2.2. **Acceso a la base de datos**

Todo el acceso a la base de datos de la aplicación se lleva a cabo a través de la clase ConectorBD del paquete es.uc3m.trazamed.comun, de forma que un simple cambio de configuración se vea reflejado en todos los accesos a la base de datos. Esta clase simplemente proporciona un método estático getConnection() que devuelve la conexión global a la base de datos, a la que se conecta utilizando los parámetros de configuración que se muestran en el listado de código .

```
bd.driver=com.mysql.jdbc.Driver
bd.url=jdbc:mysql://nadir.uc3m.es/trazamed
bd.user=trazamed
bd.password=password
```

Listado de código 1

Configuración de la conexión a la base de datos

3. CARGA DE DATOS

3.1. **Introducción**

En esta sección se describe el funcionamiento de la carga de datos de la aplicación, incluyendo todo el proceso desde el acceso a la base de datos hasta el mapeado de estos datos a la representación interna de la aplicación, así como los parámetros de configuración y la modificación del comportamiento de la obtención de datos.

3.2. **Representación interna de los datos**

Los datos se representan internamente en el conjunto de clases en el paquete `es.uc3m.trazamed.incidencias.datos`, que se muestran en la figura 1.

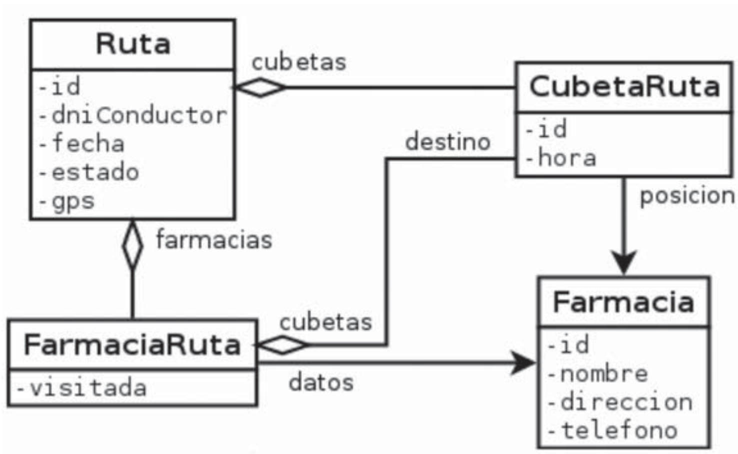


Figura 1

Clases de representación de datos

La clase `Farmacia` contiene la información de cada farmacia del sistema: identificador, nombre, dirección y teléfono; mientras que `FarmaciaRuta` contiene la información específica de una parada de una ruta, que incluye si ya ha sido visitada, la lista de cubetas que tienen esta farmacia como destino y una referencia a un objeto `Farmacia` que representa los datos de la parada.

Por otra parte, cada objeto `Ruta` contiene la información global de la ruta (fecha, conductor, estado y posición GPS si está disponible), además de una lista de paradas (objetos `FarmaciaRuta`) y una lista completa de cubetas asociadas a la ruta, que se corresponde con la unión de cubetas asociadas a cada parada además de otras cubetas que se hayan cargado por error.

Finalmente, la clase `CubetaRuta` representa una cubeta, incluyendo su identificador y la hora en la que se realizó la última acción sobre ella (carga o descarga). Tiene dos referencias distintas a farmacias:

— `destino` representa la farmacia a la que se dirige la cubeta, en un objeto `FarmaciaRuta`
— `posicion` es la farmacia en la que se encuentra actualmente la cubeta o nulo en caso de estar en el vehículo de transporte. Es una referencia a un objeto `Farmacia` ya que no se puede garantizar que la farmacia en la que está pertenezca a la ruta.

3.3. Carga de datos

La carga de datos se realiza mediante clases que implementan la interfaz `CargadorIncidenciasInterface` que se encuentra, junto con la implementación por defecto, dentro del paquete `es.uc3m.trazamed`.incidencias.datos.cargador. Esta interfaz se muestra en el listado de código 2.

```
public interface CargadorIncidenciasInterface {
       public Map<String, Ruta> cargarRutas(Map<String, Farmacia>
       farmacias);
       public Map<String, Farmacia> cargarFarmacias();
}
```

Listado de código 2

Interfaz del cargador de datos

El método `cargarFarmacias()` se llamará al iniciarse la aplicación para recuperar la lista de farmacias en forma de mapa, siendo la clave el identificador de la farmacia para facilitar el acceso. El método `cargarRutas()` se llama periódicamente para refrescar la información sobre las rutas actuales. El método recibe la lista de farmacias, en el caso de que necesitara usarla y debe devolver un mapa de objetos `Ruta`, siendo la clave el identificador de ruta. Estos objetos deben estar completos, incluyendo las referencias a las paradas de la ruta y las cubetas tal y como se indica en el apartado 3.2.

En la aplicación se incluye una implementación por defecto que carga los datos de la base de datos desarrollada por la Universidad de Deusto: `CargadorIncidenciasDeusto`. Esta implementación utiliza las tablas `Ruta` y `Entrega` de esta base de datos, con lo que es capaz de generar los objetos necesarios para el resto de la aplicación.

En todo caso, nunca se debe llamar directamente a la implementación, siendo una clase privada al paquete para intentar evitar esto. En su lugar toda llamada se debe realizar a través de la clase `CargadorIncidencias`, que también implementa la interfaz adecuada, pero además accede al fichero de configuración para determinar la implementación a utilizar.

La implementación asociando el nombre completo (incluyendo la ruta de paquetes) de la clase del cargador a la clave `incidencias.cargador` del fichero de configuración, como se muestra en el listado de código 3.

```
incidencias.cargador=es.uc3m.trazamed.incidencias.datos.cargador.
      CargadorIncidenciasDeusto
```

Listado de código 3

Configuración del cargador de datos

4. PROCESADO DE DATOS

4.1. **Introducción**

En esta sección se describe el procesado de los datos para detectar incidencias. Esto se consigue con distintos gestores, cada uno de los cuáles trata una incidencia concreta, pero que comparten una interfaz, en concreto, toman la representación de datos descrita en el apartado 3.2 y generan una lista de incidencias como salida. Esta interfaz se describe en `GestorIncidenciasInterface` (tal y como se muestra en el listado de código 4) y las incidencias en la clase Incidencia, ambas en el paquete `es.uc3m.trazamed.incidencias.gestor`.

```
public interface GestorIncidenciasInterface {
      public List<Incidencia> ejecutar(Map<String, Ruta> rutas,
      Map<String, Farmacia> farmacias);
}
```

Listado de código 4

Interfaz de los gestores de incidencias

4.2. **Gestor general de incidencias**

El gestor general de incidencias constituye el punto de acceso a los distintos gestores, ocupándose de su ejecución secuencial y la agregación de resultados. En ningún caso debe llamarse directamente a los gestores de incidencias, si no que todo acceso se realizará a través de esta clase que respeta los ficheros de configuración.

Este gestos se implementa en la clase `GestorIncidencias`, e implementa la interfaz anteriormente descrita como método para ejecutar los subgestores. Los gestores a ejecutar vienen determinados por la clave `incidencias.gestores` del fichero de configuración, dónde se listan separados por puntos y comas los nombres de clase de los gestores a utilizar, tal y como se muestra en el listado de código 5. Se utilizan los nombres completos de clases (incluyendo los paquetes) para permitir la carga de clases desarrolladas externamente.

```
incidencias.gestores=es.uc3m.trazamed.incidencias.gestor.
        GestorIncidenciasCubetaSinDescargar;...
```

Listado de código 5

Configuración de los gestores a ejecutar

4.3. **Gestores de incidencias específicas**

En este apartado se describen los gestores de incidencias desarrollados inicialmente para el proyecto Trazamed.

4.3.1. *GestorIncidenciasCubetaSinDescargar*

Gestiona las cubetas sin descargar, cuando ya se ha pasado por una parada. Para ello, intenta detectar que paradas han sido visitadas (aquellas para las cuales al menos una de las cubetas la tienen como posición) y lista las cubetas con destino a esa farmacia que no han sido entregadas. La acción sugerida es comunicar al conductor que vuelva a la parada afectada.

4.3.2. *GestorIncidenciasCubetaIncorrecta*

Detecta cubetas descargadas en farmacias incorrectas, es decir, cuando el destino y posición de una cubeta no coinciden. La acción sugerida es hacer volver al vehículo a la farmacia afectada para recoger la cubeta.

4.3.3. *GestorIncidenciasParadaImprevista*

Se activa cuando el campo de la posición GPS de la base de datos es no-nulo, es decir, cuando se detecta algún problema con la posición. No se sugiere acción, más allá de consultar con el conductor la razón de la parada.

5. SALIDA

La salida del programa también se realiza a través de clases cargadas dinámicamente, en este caso utilizando el parámetro `incidencias.grabador` de la configuración, como se muestra en el listado de código 6.

```
incidencias.grabador=es.uc3m.trazamed.incidencias.grabador.
      GrabadorIncidenciasBD
```

Listado de código 6

Configuración de la salida de datos

En este caso, la clase desarrollada utiliza la conexión a la base de datos ya existente para grabar los datos en la tabla `Incidencia`, que contiene las incidencias detectadas en la última ejecución del grabador de incidencias. La tabla consiste en las siguientes tres columnas:

— **`id`**: Un identificador único de la incidencia, en formato de cadena de caracteres,
— **`causa`**: El problema detectado, y los motivos por los que se produce, en formato de texto.
— **`soluciones`**: Listado de soluciones en texto, separadas por `@@`.

ANEXO A. **Fichero de configuración**

En el listado de código 7 se muestra un ejemplo de un fichero de configuración completo, que utiliza todos los componentes de la aplicación desarrollados.

```
bd.driver=com.mysql.jdbc.Driver
bd.url=jdbc:mysql://nadir.uc3m.es/trazamed
bd.user=trazamed
bd.password=password

incidencias.cargador=es.uc3m.trazamed.incidencias.datos.cargador.
      CargadorIncidenciasDeusto
incidencias.gestores=es.uc3m.trazamed.incidencias.gestor.
      GestorIncidenciasCubetaSinDescargar;
      es.uc3m.trazamed.incidencias.gestor.
      GestorIncidenciasCubetaIncorrecta;
      es.uc3m.trazamed.incidencias.gestor.
      GestorIncidenciasParadaImprevista
incidencias.grabador=es.uc3m.trazamed.incidencias.grabador.
      GrabadorIncidenciasBD
```

Listado de código 7

Ejemplo de fichero de configuración

Diseño de la aplicación para la planificación optimizada de las rutas

Índice de contenidos

1. INTRODUCCIÓN

1.1. **Descripción de la aplicación de planificación de rutas**

La aplicación para la planificación de rutas se encarga de, dado una lista de farmacias a visitar y un número de vehículos disponibles, realizar la asignación de paradas a vehículos de la forma más eficiente posible para optimizar las rutas de reparto, teniendo en cuenta el tiempo estimado de recorrido entre las farmacias.

1.2. **Problema VRP: Generación de rutas para varios vehículos**

El problema a solucionar es conocido en el ámbito de la inteligencia artificial como VRP: Vehicle Routing Problem y ha sido atacado con múltiples familias de algoritmos. Estas soluciones están diseñadas para grandes problemas, con cientos de paradas y docenas de vehículos en cada reparto, lo cuál no es representativo del ámbito de uso de esta aplicación, lo que hace deseable diseñar una solución específica para problemas pequeños.

Al tratar con problemas pequeños se pueden utilizar soluciones más sencillas, que en general tendrán un mejor rendimiento, hallarán mejores resultados al depender menos de heurísticas diseñadas para gran escala, y será más fácil modificarlas para considerar nuevos factores de planificación.

En concreto, una buena aproximación puede ser el uso de algoritmos de búsqueda, que no son generalmente aplicables a problemas de gran tamaño por ser demasiados lentos, pero pueden ser lso adecuados para el tamaño del dominio en cuestión.

1.3. **Propósito del documento**

Mediante la presente memoria técnica se describe a nivel técnico el funcionamiento de esta aplicación incluyendo sus módulos internos principales, interfaces de extensibilidad y sistema de configuración, en general, todo lo necesario para el uso y mantenimiento de este subsistema.

2. FUNCIONALIDAD COMÚN

2.1. **Acceso a la configuración**

El acceso a al configuración se lleva a cabo a través de la clase `Configuracion` del paquete `es.uc3m.trazamed.comun`. Este asegura que todo acceso pasa a través de los mismos métodos para que un cambio en estos afecte a toda la aplicación.

En todo momento, se mantiene una única instancia de esta clase, a la que se puede acceder con el método estático `getInstance()`. Además de esto, la clase proporciona los métodos `getProperty()` y `getPropertyList()` que dada una clave de configuración devuelve su valor en forma de string o array de strings (separados por punto y coma) respectivamente.

El fichero de configuración se define en la constante `FICHERO_CONFIG`, siendo por defecto un fichero llamado `config` en el directorio de trabajo de la aplicación.

2.2. **Acceso a la base de datos**

Todo el acceso a la base de datos de la aplicación se lleva a cabo a través de la clase ConectorBD del paquete es.uc3m.trazamed.comun, de forma que un simple cambio de configuración se vea reflejado en todos los accesos a la base de datos. Esta clase simplemente proporciona un método estático getConnection() que devuelve la conexión global a la base de datos, a la que se conecta utilizando los parámetros de configuración que se muestran en el listado de código.

```
bd.driver=com.mysql.jdbc.Driver
bd.url=jdbc:mysql://nadir.uc3m.es/trazamed
bd.user=trazamed
bd.password=password
```

Listado de código 1

Configuración de la conexión a la base de datos

3. CARGA DE DATOS

3.1. **Introducción**

En esta sección se describe el funcionamiento de la carga de datos de la aplicación, incluyendo todo lo necesario para la planificación de rutas.

3.2. **Carga de datos**

La carga de datos se realiza mediante clases que implementan la interfaz `CargadorRutasInterface` que se encuentra, junto con la implementación por defecto, dentro del paquete `es.uc3m.trazamed.rutas.datos.cargador`. Esta interfaz se muestra en el listado de código 2.

```
public interface CargadorRutasInterface {
       public MatrizDistancias cargarDistancias(Map<String,
       Farmacia> farma);
       public List<String> cargarConductores();
}
```

Listado de código 2

Interfaz del cargador de datos

Para conseguir el mapa de farmacias necesario para `cargarDistancias()`, se puede utilizar el cargador de incidencias del paquete de trabajo 15. Con estos datos se pueden cargar todas las distancias inter-farmacias que se representarán en forma de matriz en la clase `MatrizDistancias`.

Esta clase no es más que una matriz bidimensional que representa todas las distancias entre farmacias (en ambas direcciones, ya que pueden no coincidir) expresadas en tiempo de trayecto en segundos (o cualquier otra magnitud que se desee minimizar con el planificador). También incluye funciones para mapear identificadores de farmacia (texto) a índices en la matriz y viceversa.

El método `cargarConductores()` simplemente devuelve una lista de los identificadores (DNI's) de los conductores disponibles en ese momento para realizar rutas. La longitud de esta lista se corresponde con la cantidad de rutas en la que se dividirá el reparto.

En la aplicación se incluye una implementación por defecto que carga los datos de la base de datos: `CargadorRutasBD`. Esta implementación utiliza las tablas `Distancia` y `Conductor` como fuente de datos, siendo la primera de las dos tablas generada automáticamente tal y como se detalla en el apartado 3.3.

En todo caso, nunca se debe llamar directamente a la implementación, siendo una clase privada al paquete para intentar evitar esto. En su lugar toda llamada se debe realizar a través de la clase `CargadorRutas`, que también implementa la interfaz adecuada, pero además accede al fichero de configuración para determinar la implementación a utilizar.

La implementación asociando el nombre completo (incluyendo la ruta de paquetes) de la clase del cargador a la clave `rutas.cargador` del fichero de configuración, como se muestra en el listado de código 3.

```
rutas.cargador=es.uc3m.trazamed.rutas.datos.cargador.
        CargadorIncidenciasBD
```

Listado de código 3

Configuración del cargador de datos

3.3. **Distancias**

Las distancias se almacenan en la tabla `Distancia` de la base de datos, compuesta de los campos

— **`origen`**: Identificador textual de la farmacia origen.
— **`destino`**: Identificador textual de la farmacia destino.
— **`estimada`**: Distancia estimada (en segundos) entre las farmacias.
— **`empirica`**: Campo adicional para la distancia, que si es no-nulo sobreescribe a estimada.

Esta tabla puede ser rellenada automáticamente, utilizando las APIs de mapas de Google para obtener datos de distancias basados no sólo en la distancia entre dos puntos, si no en el mapa real de calles de la ciudad. Para ello, se hace una petición al API pidiendo un cálculo de ruta entre la farmacia origen y destino y se anota en el campo `estimada` el tiempo devuelto.

Este programa se encuentra implementado en la clase `EstimadorDistanciasApp` del paquete `es.uc3m.trazamed.rutas.utils`, siendo necesario tan sólo ejecutarlo para que complete automáticamente los espacios de la matriz de distancias para los que no se disponga de datos. Por tanto, al insertar una nueva farmacia en la base de datos será necesario ejecutar este programa para rellenar estas distancias y que la planificación pueda tener lugar, ya que lso planificadores no realizan esta tarea automáticamente para evitar alcanzar el límite de peticiones diarias al API de Google Maps.

4. PLANIFICACIÓN

4.1. **Introducción**

En esta sección se describe el procesado de los datos para detectar incidencias. Esto se consigue con distintos gestores, cada uno de los cuáles trata una incidencia concreta, pero que comparten la interfaz `GestorIncidenciasInterface` (tal y como se muestra en el listado de código 4).

```
public interface PlanificadorInterface {
       public ResultadosPlanificador planificar(MatrizDistancias md,
              int nvehiculos, String origen, List<String> farmacias);
}
```

Listado de código 4

Interfaz de los planificadores de rutas

Para planificar es necesario especificar la matriz de distancias entre farmacias, el número de conductores/vehículos disponibles, la farmacia de origen (Almacén) y la lista de farmacias a visitar, siendo imprescindible que todas las farmacias de esta lista y la del almacén se encuentren en la matriz de distancias.

La salida se da por medio de la clase `ResultadosPlanificador` en el mismo paquete que la interfaz, que consiste en una lista de rutas, donde cada ruta es una lista de paradas, y añade métodos para facilitar la gestión.

Además, se implementa un punto de acceso a los planificadores en la clase `PlanificadorRutas`, de forma muy similar al cargador de incidencias descrito en el apartado 3.2. En este caso, se utiliza el parámetro `rutas.planificador` como selector de la clase planificadora a implementar. También es relevante el parámetro `rutas.almacen` que se utiliza para especificar la farmacia que se utilizará como punto de origen y destino de todas las rutas. Ambas se muestra en el listado de código 5.

```
rutas.planificador=es.uc3m.trazamed.rutas.planificador.
       PlanificadorHillClimbing
rutas.almacen=6fe3a596-f167-4fac-8d86-572d3469c0ce
```

Listado de código 5

Configuración del planificador

4.2. **Planificador básico: RoundRobin**

El planificador RoundRobin intenta emular el comportamiento anterior del sistema, con al finalidad principal de facilitar la comparación. Esta implementado en la clase `PlanificadorRoundRobin` y básicamente asigna cada parada a una ruta hasta asignar todas. El resultado es el mismo número de paradas en cada ruta, o una más, pero al ser asignadas sin ningún orden particular, los resultados suelen ser malos.

4.3. **Planificador inteligente: HillClimbing**

Para facilitar la implementación, el problema se ha dividido en dos partes:

— Asignación de paradas a rutas.
— Ordenación de paradas en rutas (problema del viajante, TSP).

El problema completo se soluciona ejecutando la asignación de paradas a rutas, y por cada solución intermedia para este problema, se ejecuta la ordenación de paradas para poder evaluar correctamente las soluciones. Finalmente, la solución es la mejor división de farmacias en rutas, ordenadas para minimizar el coste de forma similar al problema del viajante.

4.3.1. *Problema del viajante*

La solución al problema del viajante se ha implementado en una clase externa al planificador, `TSPResult` del paquete `es.uc3m.trazamed.rutas.planificador.utils`, puesto que puede ser reutilizada por otros planificadores.

Puesto que en el dominio de aplicación, las rutas son cortas, casi nunca superiores a media docena de paradas, se puede intentar resolver el problema por fuerza bruta, que es lo que se implementa en el método `fullTSP()` de dicha clase. Para números de paradas inferiores a 15, se resuelve en cuestión de segundos, y para menos de 10 paradas es casi instantánea. Sin embargo, debido a la alta complejidad computacional de esta solución (O(n!)), a partir de 20 paradas el problema se vuelve impracticable.

Para ello, se incluye otro método, `greedyTSP()` que soluciona el problema utilizando un algoritmo voraz: añade en cada momento la parada con menor coste. Esta solución es muy rápida, pero las soluciones conseguidas no son óptimas, aunque sí aceptables, debido a que sólo considera la distancia de la nueva parada para añadirla. Para esto, recorre toda la lista de paradas, buscando aquella con menor distancia desde el origen o hasta el destino actual (ya que puede haber alguna parada ya añadida a la solución) y la añade.

La solución final, combina ambos métodos, utilizando la solución voraz para más de 8 paradas, y la solución completa para 8 o menos paradas, de forma que en la mayoría de los casos de ejecutará la solución completa, pero en problemas complicados se simplificará el problema aplicando (n-8) veces la solución voraz para solucionar de forma óptima el sub-problema con 8 farmacias.

4.3.2. *Asignación de paradas a rutas*

Este problema consiste en dividir las paradas en tantos grupos como vehículos disponibles, de forma que se minimice el coste máximo de los grupos. La aproximación utilizada es similar al algoritmo HillClimbing, en el sentido que en cada nodo de la búsqueda se elige el siguiente nodo con mejor heurística, es decir, que es mejor a priori.

En este caso, los nodos consisten en la división de rutas en paradas, mientras que el operador consiste en cambiar una parada de una ruta a otra. Para esto, primero se evalúan los costes de cada ruta (utilizando el algoritmo anteriormente descrito), y se toma como heurística la diferencia de coste entre cada par de rutas, siendo mejor valor heurístico cuanto mayor sea la diferencia. Esto hace que siempre se elija quitar una parada de la ruta más larga y añadirla a la más corta.

La parada se elige de forma aleatoria, para evitar el problema de que el algoritmo se atasque oscilando entre dos estados, lo que puede pasar si siempre se elige la parada de la misma forma, y la misma parada es la más adecuada para quitar de ambas rutas.

Dado el carácter estocástico del algoritmo dado por dicha selección aleatoria, es necesario ejecutarlo durante varias iteraciones (100 parece ser suficiente) y ejecutar varias realizaciones (10 parece adecuado) para asegurar suficiente tiempo para que el algoritmo encuentre la solución, y para proporcionarle varias inicializaciones para evitar mínimos locales.

La inicialización se realiza de dos formas distintas:

— RoundRobin: Se asignan las paradas a las rutas de forma que todas las rutas tengan el mismo número de paradas o una más. De esta forma se garantiza que los resultados de este planificador son al menos iguales a los del `PlanificadorRoundRobin`.
— Aleatorio: Se asigna cada parada a una ruta aleatoria, es el caso general.

Finalmente, cada vez que se evalúa una solución, se calcula su coste (longitud de la ruta más larga) y se va guardando en todo momento la mejor solución hasta el momento, que es la que se devuelve al final, de forma que es irrelevante en que momento de la ejecución del algoritmo se encuentre la mejor solución, puesto que siempre se seleccionará la mejor hallada.

4.4. **Evaluación**

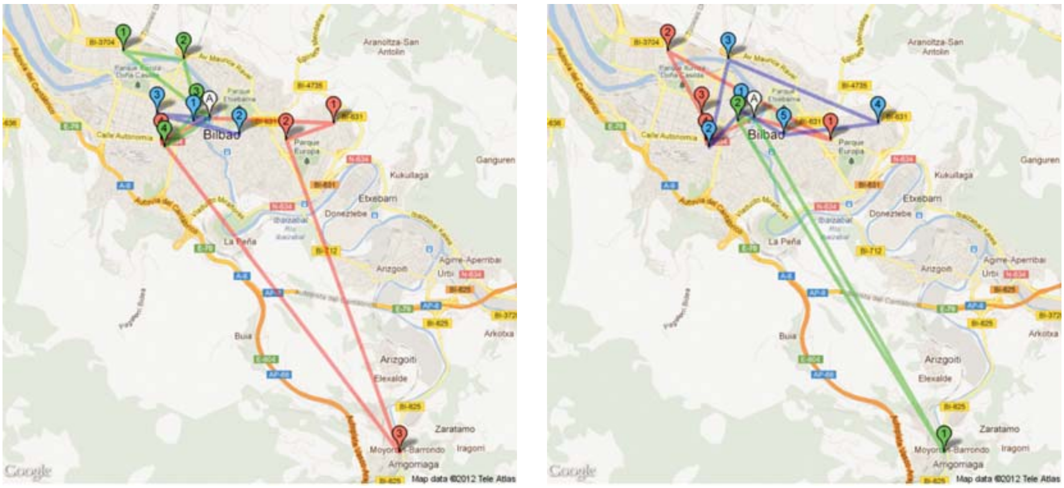
Dada la gran diferencia del problema dependiendo tanto de la posición de las farmacias, la estructura urbana y el número de vehículos disponibles, es imposible realizar una evaluación exhaustiva de todas las combinaciones. En esta sección se presentan algunos datos de funcionamiento típico del sistema, comparando los dos planificadores desarrollados, de forma que los resultados se correponden con la mejora del nuevo sistema respecto al antiguo, ya que el planificador RoundRobin está diseñado para emular el sistema antiguo y facilitar las comparaciones.

Los gráficos aquí mostrados se generan con una utilidad que genera links al API de mapas de Google para mostrar las rutas, en la clase `GeneradorMapas` del paquete `es.uc3m.trazamed.rutas.utils`. Los datos utilizados corresponden a un subconjunto del sistema total utilizados para la evaluación del sistema.

La primera diferencia aparente de los planificadores se muestra de forma gráfica en la figura 1, donde existe una parada lejana. El planificador original no tiene información de las distancias, así que asigna la parada a una ruta cualquiera que pasa a ser la más larga, con un tiempo estimado de 3076 segundos. Sin embargo, el planificador con HillClimbing asigna únicamente esa parada (y otra que está de camino) a una ruta, repartiendo el resto de paradas entre los otros dos vehículos restantes, con un tiempo estimado de 2187 segundos. La diferencia principal es el número de paradas por ruta, siendo de 3, 4 y 4 para el primer caso y 2, 4 y 5 para el segundo.

Otro caso claro es el mostrado en la figura 2, donde aunque todas las paradas están relativamente cerca, el planificador inteligente es capaz de dividirlas en dos partes claramente separadas (este y oeste en este caso) y asignar un conductor en cada zona, en vez de dividirlas en dos mitades sin más información, lo que causa que haya cierto solape en las zonas de reparto, como la zona suroeste en este caso.

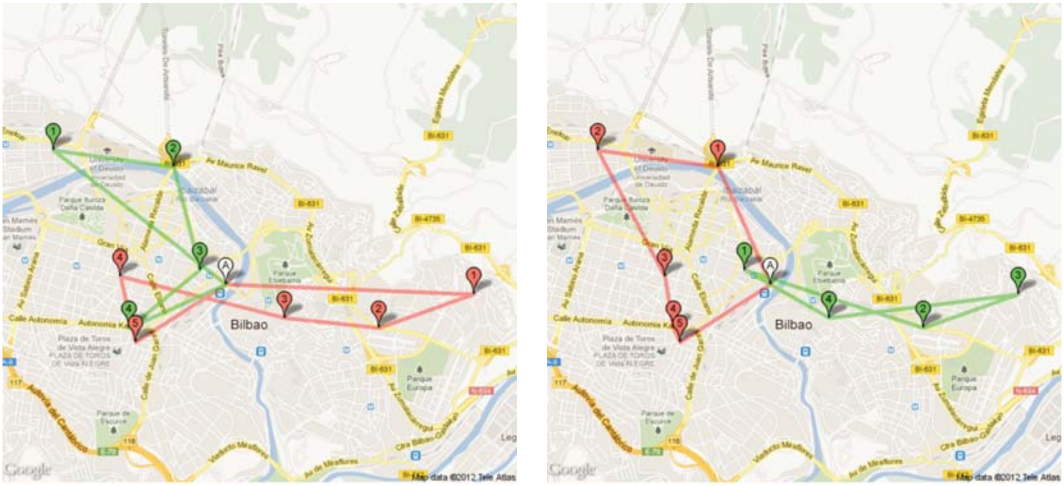
En general, el rendimiento del nuevo planificador es siempre igual o mejor al anterior por construcción, siendo en casi todos los casos la mejor apreciable. Ejecutando



(a) Planificador RoundRobin (3076 segundos) (b) Planificador HillClimbing (2187 segundos)

Figura 1

Comparación c on paradas lejanas



(a) Planificador RoundRobin (2252 segundos) (b) Planificador HillClimbing (1454 segundos)

Figura 2

Comparación con paradas cercanas

20 experimentos aleatorios (selección de paradas aleatoria y número de vehículos aleatorio menor que el número de paradas elegidas), se obtiene una reducción media del 29% de los tiempos estimados para la ruta más larga, lo que supone una mejor significativa en la mejora de los tiempos de distribución.

5. SALIDA

La salida del programa también se realiza a través de clases cargadas dinámicamente, en este caso utilizando el parámetro `rutas.grabador` de la configuración, como se muestra en el listado de código 6.

```
rutas.grabador=es.uc3m.trazamed.rutas.grabador.
       GrabadorRutasBD
```

Listado de código 6

Configuración de grabador de rutas

La clase desarrollada utiliza la conexión a la base de datos ya existente para grabar los datos en la tabla `RutasPlanificadas`, que contiene las rutas planificadas en la última ejecución del programa. La tabla consiste en las siguientes tres columnas:

— **`conductor`**: El identificador del conductor al que se le asigna la parada.
— **`posicion`**: El orden en el que visitar la parada. Empieza en 1 y no incluye el almacén.
— **`parada`**: Identificador de la parada a visitar.

ANEXO A. **Fichero de configuración**

En el listado de código 7 se muestra un ejemplo de un fichero de configuración completo, que utiliza todos los componentes de la aplicación desarrollados.

```
bd.driver=com.mysql.jdbc.Driver
bd.url=jdbc:mysql://nadir.uc3m.es/trazamed
bd.user=trazamed
bd.password=password

rutas.cargador=es.uc3m.trazamed.rutas.datos.cargador.
      CargadorDistanciasBD
rutas.planificador=es.uc3m.trazamed.rutas.planificador.
      PlanificadorRoundRobin
rutas.grabador=es.uc3m.trazamed.rutas.grabador.GrabadorRutasBD
rutas.almacen=6fe3a596-f167-4fac-8d86-572d3469c0ce
```

Listado de código 7

Ejemplo de fichero de configuración

Publicaciones JCR

IVAN: Intelligent Van for the Distribution of Pharmaceutical Drugs

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Abstract

This paper describes a telematic system based on an intelligent van which is capable of tracing pharmaceutical drugs over delivery routes from a warehouse to pharmacies, without altering carriers' daily conventional tasks. The intelligent van understands its environment, taking into account its location, the assets and the predefined delivery route; with the capability of reporting incidences to carriers in case of failure according to the established distribution plan. It is a non-intrusive solution which represents a successful experience of using smart environments and an optimized Radio Frequency Identification (RFID) embedded system in a viable way to resolve a real industrial need in the pharmaceutical industry. The combination of deterministic modeling of the indoor vehicle, the implementation of an *ad-hoc* radiating element and an agile software platform within an overall system architecture leads to a competitive, flexible and scalable solution.

Keywords: intelligent van; pharmaceutical drugs traceability; incidences reporting; non-intrusive; RFID; wireless technologies, deterministic 3D ray launching.

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1. INTRODUCTION

Intelligent transportation systems (ITSs) improve transportation safety and mobility while enhancing productivity through the integration of advanced communications technologies into the transportation infrastructure and in vehicles [1]. In-vehicle intelligent transportation systems are emerging as a major force in mobile communications, where automotive, communications, computer, and software are elements which cooperate among themselves in order to minimize the delivery time to market of the product while maximizing quality in the transportation of sensitive goods.

In particular, the pharmaceutical drug supply chain, from an economic and health perspective, requires controlling all stages of distribution: from the production phases of the drugs in the laboratory until they reach the pharmacies. This requirement is reflected by the Ministry of Health and Consumption of Spain through the new Royal Decree on drugs traceability, redacted in accordance to Directive 2003/94/EC of the Commission of the European Communities [2].

Adapting to the changes required by regulation imposes severe changes in the business model of different actors involved in the pharmaceutical sector. Moreover, associated costs are hardly feasible in a highly competitive industry where profit margins are often set by public administrations.

The features of the existing application scenario in drug delivery from the warehouse to the pharmacy pose particular challenges. The huge competition between pharmaceutical distributors forces them to preserve a high quality of service in terms of delivery time and reliability. Inside a market where all competitors are offering the same products at similar prices, service quality is a key factor because an incomplete or incorrect shipment can result in the loss of a client. These requirements fall on the carrier which is required to complete the route in a minimum time without making any mistakes during delivery. For these reasons it is compulsory to deploy a system that meets the new regulations that does not complicate current tasks of carriers. The installation of a system that requires the carrier to use hardware devices such as handheld RFID readers or Datamatrix adds new tasks in an inherently stressful job. Generally, each distribution route is travelled at least four times a day and a significant delay or wrong delivery often results in the loss of a pharmacy as a client. Therefore, the job of the carriers should be thoroughly reviewed to avoid mistakes and if they commit to defined responsibilities, causing significant disagreements between transport staff and store personnel.

This paper presents a novel system approach designed to adapt the distribution of drugs to the new regulatory environment that does not alter the behavior of workers involved in it. The onboard system in each delivery van will collect all the information required for traceability without any human interaction, with the aid of an embedded RFID system, which has been optimized in order to take into account the complex wireless nature of an enclosed vehicle with a traceable load. An in-house three dimensional deterministic ray launching code has been employed in order to model the indoor vehicle environment, leading to optimal layout of RFID elements, as well as to the later design of a specific antenna element. Furthermore, this system is responsible for validating all actions which vary the deviance with respect to planning. The overall result is an implementation of a Smart Environment, which combines adaption of the wireless scenario and a flexible system architecture to support real time monitoring and interaction. Thus, it represents a successful experience of using Ambient Intelligence (AmI) environments in a viable way to resolve a real logistic need [3]. One of the key elements in the performance of the overall system is the holistic approach, in which precise modeling of physical layer aspects is combined with a novel and flexible software architecture.

This paper is divided into three main parts. Initially the functional characteristics of the system presented are indicated. The Intelligent Van system is described, in which an embedded RFID system is proposed, which increases the reading performance and therefore the traceability capabilities. The data related with the delivery route is controlled and compared by means of the System Architecture, which consists of the necessary middleware as well as with a user friendly application which is resident in a Smartphone device. Finally through the conclusions we will show the results of implementing the system in a real warehouse for distribution of pharmaceuticals located in the north of Spain.

2. INTELLIGENT VAN

The intelligent container concept has been envisaged in logistics and distribution processes. However the specific needs of the scenario corresponding to the distribution chain of medicines requires the development of a customized solution. Furthermore, the high cost of RFID tags imposes restrictions in the implementation of such systems in real applications, especially in scenarios with heterogeneous loads [4]. The use of tags in the 13.56 MHz HF frequency range with reduced reading distance, limits the identification of the packets to the moment in which they are loaded or unloaded. Therefore, the proposed system uses long-distance UHF tags in order to monitor the vehicle cargo at any time. This extension in the reading range is given by the fact that interaction of RFID information is not given by mutual inductance mechanisms, but instead is determined by the modification of the radiofrequency wave, in terms of the radar cross section of the given tag [5].

Two of the main characteristics of this system are the possibility of controlling medical distribution over the complete delivery route and to simplify carriers' workflow. In order to achieve these goals, an intelligent system has been established introducing Radio Frequency Identification technology (RFID) in pharmaceutical drug distribution. This technology is optimal in order to determine the traceability of all drugs delivered and enables the drivers to load and unload the cargo due to the fact that if any error is committed, the system will alert indicating the failure in an autonomous way.

Focusing on the general process, initially automated medical dispensing robots within the main distributor depot have to coordinate orders for each pharmacy. This system organizes all requested medicines in containers and then all of them are sent to the dock ready to be loaded onto distribution vans. There is a passive transponder attached to each container so its Electronic Product Code (EPC code) can be related to what drugs are loaded on each container and the pharmacy destination for each one. Within the regulatory framework of Spanish law, traceability can be established with the use of two technologies, Low Frequency RFID and DataMatrix for the identification of individual packages of medicines. A second phase of this project that will begin in the second quarter of 2012, will implement a robot that can dump the contents of a container and validate, based on identification technologies approved, the packaging of medicines contained within. Thus the system will meet the requirements of traceability required by Spanish law.

Figure 1 shows the process flow indicating the communication established between the three main parts of the system: onboard system (ONB SYS), mobile device (MOB DEV) and central server (CTR SRV). When the delivery van arrives at the warehouse, the onboard system installed on each van is connected to the network of the warehouse via WiFi and is allowed to download from the corporative Enterprise Resource Planning (ERP), all the necessary information about the next route the vehicle must perform. This info includes the number of containers that must be loaded into the cargo area of the Intelligent Van and the Electronic Product Code (EPC) of each transponder attached to containers that have to be distributed along the route.

At this point, carriers start to load vans with their corresponding containers. An RFID reader module is located inside the wagon and each container has attached a passive tag so that it can detect each container that enters or leaves the wagon. It is very important to emphasize that this is a non-intrusive system. The carrier does not have to be concerned about registering loaded or unloaded containers due to the fact that the RFID environment of the proposed system will do it automatically. The RFID module detects transponders EPCs and transmits them to the onboard system. This device stores all the information needed for a correct delivery and monitors what the carrier is doing at any time.

If the carrier makes a mistake loading or unloading a wrong container a red light will switch on in the cargo area of the Intelligent Van and the carrier will know that there is something wrong. Since all van drivers carry a Smartphone with them, a specific application has been designed, so the Smartphone is considered an element of the proposed system. That mobile is connected by Bluetooth to the van's onboard system, having precise knowledge of the list of containers to load into their vans and which containers are being loaded or unloaded. Therefore when the red light switches on, the carrier will get an error message generated by the proposed system on his Smartphone. The driver will try to solve it and in the case that it is not possible to be resolved, the Smartphone will send an incident report to the warehouse manager and that incident will also be registered on the onboard system. The mobile application is resident on the Smartphone and is only accessed by the carrier when the red light indicates an error, so the application shows a description of occurred mistake. In the event that the development of the transport process is executed as planned the carrier does not need to open the application and adds no new tasks to his usual workflow.

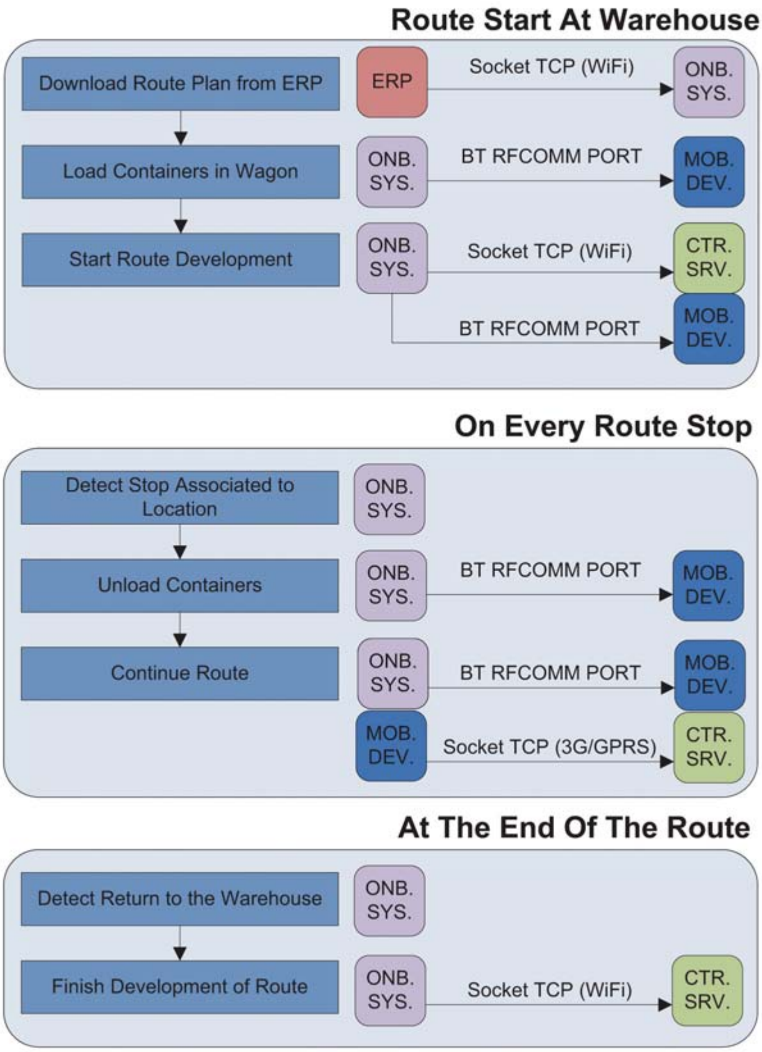

Figure 1

Process flow diagram of the system

Once the cargo is loaded, the van driver starts the delivery. Each driver has a route of pharmacies where some containers must be unloaded at each time. With the aid of a Global Position System (GPS or future Galileo System) transceiver incorporated within the onboard system, the van knows its rough location at any given time. Therefore, the intelligence of the system calculates which containers to unload in the next pharmacy as well as in the remaining stops within the route. When the van stops and the cargo door is opened, the system detects the nearest pharmacy included in the route accessing which containers should be unloaded at this point. When the carrier unloads all containers associated with that stop and no other, the system activates the green light, indicating that unload procedure is correct. If after downloading all containers, the red light remains on, the carrier must check the mobile application to detect the cause of the error. If there is any divergence that cannot be solved, the carrier can continue to the next stop and the system immediately reports an incident to the warehouse manager.

As it is a non-intrusive system, the carrier performs the workflow in the usual fashion, not realizing that behind there is a system controlling every event and being notified only in case of an error. The system in addition includes atmospheric sensors inside the cargo area of the Intelligent Van for temperature, pressure and humidity control of the transported goods, with the capability of introducing new sensors if necessary.

The onboard system stores in a Secure Digital (SD) card, at regular configurable intervals, the location of the van, EPCs of containers loaded and the values of the atmospheric sensors. When the route ends and the van returns to the pharmacy warehouse, the system connects to the network of the warehouse via WIFI and sends an XML file through File Transfer Protocol (FTP) containing all the information stored during the development of the route. This allows the warehouse manager to subsequently review the development of a route through the control panel and search for causes of any errors and delays.

Comparing the key points of our research with other works related to distribution and traceability [6,7] it must be pointed out that the proposed solution in this paper provides innovations that are not accomplished in other proposed traceability systems, such as the ability to perform the cargo tracking and the monitoring of the transport tasks without the aid of the carrier and in a completely non-intrusive way. Most of the existing solutions are only aimed at the traceability of the cargo either manually or automatically [8], but do not have enough intelligence to propose autonomously the tasks to be performed along the way from receipt of order. This potentially leads to a lack of precision in the information provided by these traditional tracking systems as well as in the generated incidents.

3. CARGO IDENTIFICATION SYSTEM

According to the World Health Organization (WHO) drugs must be stored and transported under specific environmental conditions as well as security constraints in the drug delivery process. One of these conditions is the need to use standardized and reusable containers to transport those drugs from warehouses to each pharmacy office. This fact constitutes a suitable scenario for RFID technology and this project in particular, enabling the possibility of controlling which drugs go to each pharmacy if they are contained within a registered recipient. The system is capable of determining the place where containers have been left, supported by a GPS or Location Based receiver. The attachment of a passive tag to each container, not only allows the system to know when containers enter or leave the cargo area of the Intelligent Van, but also makes the investment in tags affordable in a very short time, reducing return of investment cycles, avoiding one of the biggest drawbacks in the adoption of this technology. Carrying drugs into containers that have a transponder attached also allows tracking and traceability of them.

The intelligent system designed is based on several technologies, being RFID the most relevant in the physical layer interaction. This technology uses two basic elements, a tag or transponder and a reader or interrogator. As already mentioned, passive transponders have been attached to containers exploiting its reusability, and an RFID reader has been placed inside each van. To maximize the reader's gain, several tests have been made with different antennas, custom designed and commercial antennas, and with different antenna locations, considering the complexity of the wireless environment of an enclosed vehicle.

3.1. **RFID Tag**

A Confidex's Carrier Tough (Figure 2) tag has been chosen to be attached to a container. It is a passive tag (*i.e.*, no energy sources) covered in hard plastic and resistant to mechanical stress, friction and shock. It also has a paper with a 2-D Data Matrix that is useful for other applications in other parts of this supply management.

Figure 2

Confidex's Carrier Tough passive tag

The tag works using EPC Gen2 Class1 protocol, its frequency range is from 860–960 MHz and its reading range is from 4 to 6 m, enough for a wagon van. The price of tags is decreasing year by year, but it still remains a problem for many companies to adopt this technology. The reusability of these transponders thanks to the fact that they are fixed on the wall of the containers and not on each drug box makes RFID an adequate technology for the project because of its easy investment recovery.

3.2. **RFID Reader**

In order to enable interaction between the system and the containers, an RFID reader is located into each delivery van, which is permanently in contact with the embedded device next to it. The embedded device acts as a control and storage device and tells the reader to read or write tags and send to it received EPCs of the transponders inside the wagon when the system needs it. This reader module has RS-232 communication on one side with the embedded device, and wireless communication with the passive transponders on the other side.

A Thing Magic's Mercury5e-EU RFID Reader [9] has been employed, operating at UHF frequency range to improve interrogation distance and bears EPC Gen2 protocol, more robust against noise and reading interferences. It has 30 dB read gain at the range of 865.6–867.6 MHz according to the European Union regulatory support ETSI (EU) EN 302208. With an antenna of at least 6dBi, it can read tags in 9 m within its nominal sensitivity of −65 dBm.

The operational procedure of this system starts with the embedded device. It interrogates for the information of tags within the cargo area of the van by sending a request through serial port. The RFID reader starts generating a continuous wave to power up those tags and they backscatter their EPC codes (96 bits) modulating the continuous wave generated by the reader [10]. To detect all those backscatter signals generated by transponders [11], a high gain antenna is connected to the reader and is strategically located into the van, in order to minimize the link balance established between the tags and the reader. In this manner the reader improves its reading range limited by the low power response of transponders, increasing wireless coverage inside the vehicle. Once it has completed a read cycle, the reader sends back through serial port all EPCs stored in its internal buffer to the device.

For tests, some useful parameters have been used to improve detection of the tags. When the reader communicates with a tag it stores the received signal strength indicator (RSSI) of the tag read, as well as the time the tag was read, relative to the time the command to read was issued (Timestamp). These parameters have been employed in order to locate the antenna to get the best tag detection results.

3.3. **RFID Antenna**

The coverage range of the indoor RFID system is given by the bi-directional link balance of the wireless channel, in which parameters such as antenna gain, cable and feeder losses and a combination of losses due to interaction of electromagnetic waves with the indoor vehicle environment determine the final result [5]. Initially, from the hardware point of view, to enhance coverage over the wagon an antenna for the reader is needed. As it has been stated, with a 6 dBi antenna, the cargo section of a standard van can be covered. Validation tests and simulations have been made with different commercially available antennas of at least 7 dBi of gain, as well as with an antenna that has been designed specifically for this application within the research group.

Simulations have been made using the van as scenario to analyze commercial antennas' behavior. The wagon has been modeled as a metallic cube full of polypropylene containers and the antenna has been placed at different locations in the ceiling of the van. Simulations are based on the deterministic method of a 3D beam source, with an in-house ray launching code [12] to analyze the complex scenario of a wagon full of containers. It is interesting to stress that the topology and morphology of the indoor cargo section of the vehicle have a significant impact in the response of the system. This is given by the fact that strong multipath is present, as well as diffuse scattering due to the different levels of detail of the surfaces of the vehicle walls, as well as the transporting bins. An additional consideration is the fact that the transporting bins are mainly made of dielectric material (polypropylene), leading to new diffractive components as well as absorption losses. Therefore, an adequate simulation technique has to be applied in order to obtain propagation losses and consequently, link balance results.

Initially, a linearly polarized PATCH-0026 and a circularly polarized PATCH-0025 have been used, which exhibit very similar parameters except for their polarizations. In this way, both antennas have a similar reading range behavior because the wagon is a closed metallic environment so there is multipath propagation. The RFID reader will receive a direct component, if there is direct visibility, or there will be a great number of echoes with different amplitudes, phases and random arriving times. The circularly polarized antenna has been chosen because it has the best coverage over the wagon. Figures 3 and 4 show the power distribution inside the wagon using the latter antenna. The results have been obtained with the aid of an in-house 3D ray launching code implemented within our research group, which takes into account reflection, refraction and diffraction phenomena, as well as the material properties (given by dielectric constant values as well as conductivity values at the operational frequency of the system). This simulation technique is optimal in the terms of precision versus computational time, due to the deterministic nature of the simulation and the geometrical optics approximation. Moreover, the implemented code has been optimized in order to take into account the complex nature of the vehicle. Figures 3 and 4 depict an estimated power received by

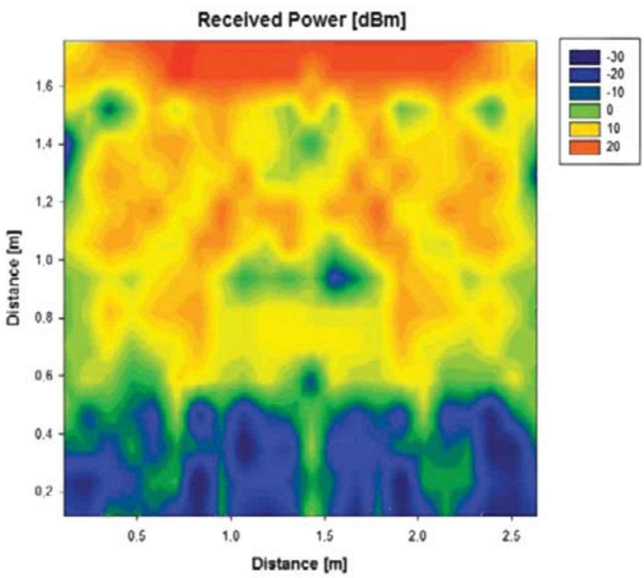

Figure 3

Estimation of received power [dBm] on the second floor of containers, obtained by full 3D ray launching algorithm

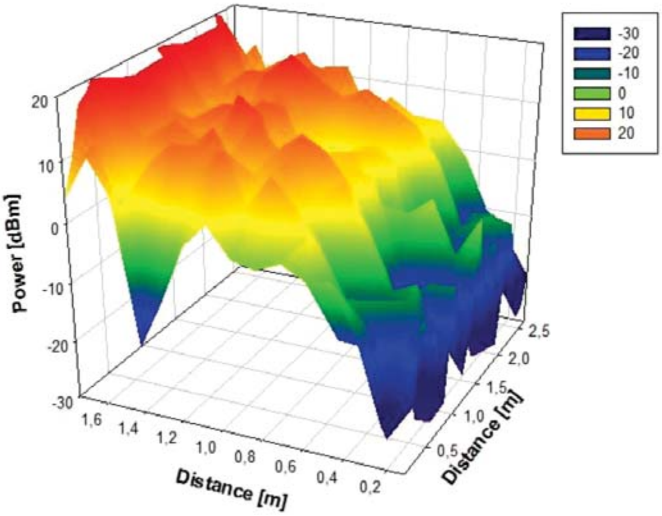

Figure 4

Volumetric view of simulated values of received power [dBm] on the second floor of containers seen from the side

likely tagged containers that are located at the second row of the packing distribution and that in an isotropic view, respectively. It has been placed at the back of the van in the middle of the ceiling offering the optimal results of the simulations performed. Due to its polarization, tags can be read in any orientation. In an environment like the one given by the indoor region of the cargo area of the van, the transmission power decreases with distance with great variability, due to the strong influence of multipath components.

3.4. **Antenna Design**

To maximise space inside vehicles and contribute to a less bulky UHF-RFID interrogator unit, an novel antenna was implemented to satisfy the demands of the proposed system. Spraying adhereable copper particles [13,14] to form conductors leading simple structures and manufacturing of antennas suited for use in radio frequency identification networks using the unlicensed RFID subband b2 (8.656–8.676 GHz) of the ETSI standard [15] are presented. The on-going prototype presents advantages such as consistency against likely antenna instability while on-the-move [16], is inherently hidden to account against fraudulent hacking and exhibits a small footprint, leading to an overall compact device.

On-going studies suggest that the antenna can be also used as a tag at a −5 dB return loss (RL), providing available transponder chips with characteristic impedances in the range of ~12.50 + j17.30; this would bring applications for tagging complete metal shielded objects in a wide range of situations, such as boxes, bottles and cans, typically used for the transport of liquid based medicines with advanced care.

The geometry of the manufactured antenna for both the interrogator and the tag is presented in Figure 5a,b, respectively. For the approach the total substrate thickness of the paint was 2 mm. The antennas were made using conductive copper painting and directly printing the elements onto the surfaces (*i.e.*, vehicle body and can body). The achievable gains and RL of the antenna are given in Figures 6 and 7 respectively, showing sufficient gain and bandwidth for the application.

(a) **(b)**

Figure 5

(a) The antenna printed on a car body and
(b) printed on a can body

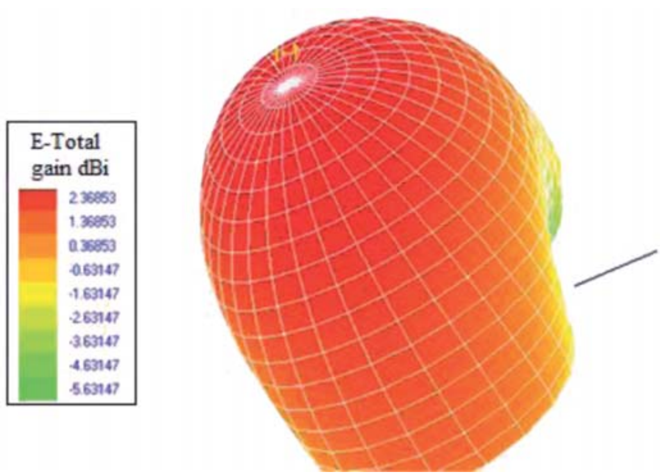

Figure 6

The radiation pattern of the proposed embedded RFID antenna,
E-Total, showing simulated gains, within the 2 dBi range

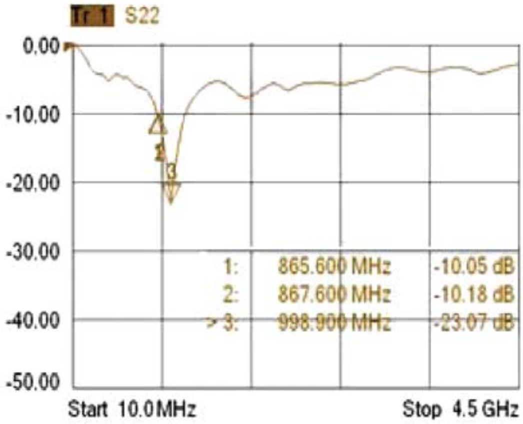

Figure 7

Measured return loss of the proposed embedded RFID antenna

Once the antenna parameters have been obtained, an analysis of the resulting link balance has been carried to determine acceptable antenna gains for the in-vehicle and 2 dBi seems to be adequate for the application; relatively low gain antennas imply smaller sizes and is seen attractive for physically optimising the antenna size. It was found that antennas with gains of 2 dBi and located in the middle of the ceiling of a vehicle are adequate to deliver a sufficient radio propagation field inside the vehicle with full power transmission at the transceiver [5]; any superior power beyond the total transmit power of +30 dBm would not be acceptable by the ETSI standard for in-door applications [15]. The antenna ensures good power distribution to likely RFID tag locations within the car while minimizing field exposure to potential occupants [17] (those assisting in the inventory distribution of goods). The resulting enhancement by using the novel antenna design is shown (Figure 8), where deterministic ray launching results, by means of in-house simulation code, have been obtained as compared with a commercial antenna for the cargo section of the vehicle. The power distribution reveals higher received power levels, which leads to improved interrogation distance from the in-vehicle RFID reader. It is worth noting that full complexity of the environment has been taken into account (*i.e.*, structure of the van enclosure as well as the existence of the transporting bins). To further highlight the complexity of the indoor cargo area environment and the strong topological dependence, Power Delay Profile (PDP) values have been estimated with the aid of the 3D Ray Launching algorithm for two different locations (bottom image, Figure 8). The PDP values, which is a metric to determine the influence of multipath propagation, is clearly different in both positions, which implies the need of precise radioplanning techniques in order to fully optimize the behavior of the deployed RFID system.

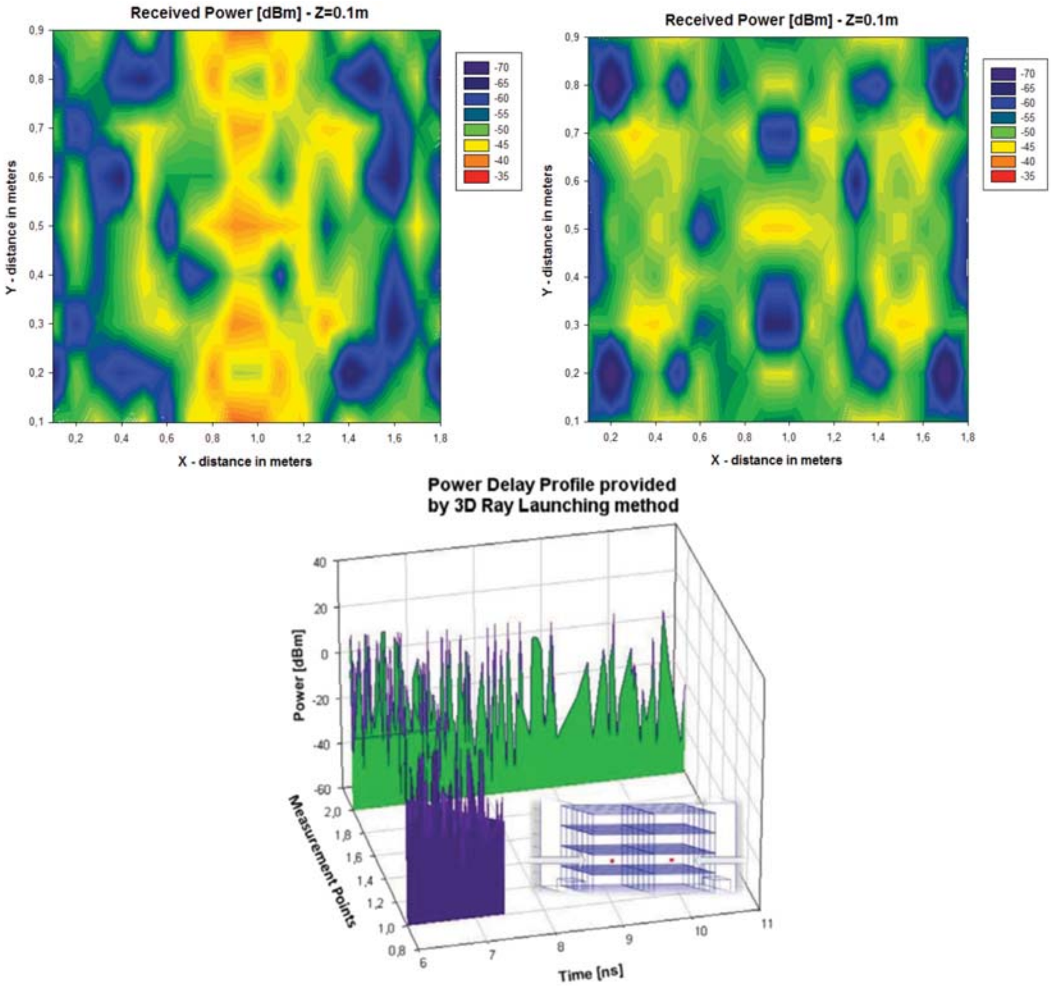

Figure 8

Simulation result of the resulting power distribution within the enclosed vehicle environment, obtained by in-house 3D ray launching code. The left hand figure is the result for the new embedded antenna, whereas the right hand figure corresponds to the conventional one. The bottom figure depicts estimated values of Power Delay Profiles for two different positions within the indoor cargo area of the Intelligent Van.

4. SYSTEM ARCHITECTURE

In order to fully exploit the benefits of the embedded RFID system, real time interaction with inventory as well as management is given by means of a supporting communication system. The core of the ubiquitous computing environment is given by the onboard system installed in the van. A specific communication middleware has been developed to connect this onboard system with the rest of modules that compose the system architecture (Figure 9). Taking advantage of the information exchanged with the rest of the systems and their additional processing capability, data gathered inside the vehicle can be enhanced. This becomes the van intelligent enough to report incidences in a completely autonomously way (without the aid of the carrier).

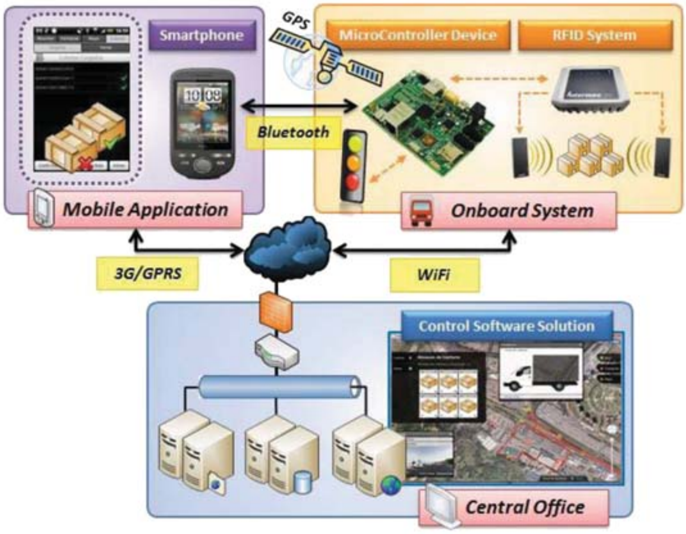

Figure 9

Description of the system architecture and possible interactions

This system can be decomposed into three different parts: the onboard system itself, responsible for bringing together the information obtained by the hardware components of the van; the mobile application and the control software solution. In this section we are going to describe each module of the system from a functional and technical point of view.

4.1. **Onboard System**

To deploy this solution it is necessary to integrate an onboard system in each vehicle in the distribution fleet. This system is responsible for identifying the load, validate transport tasks and communicate every incident that is detected. Therefore, the onboard system is the core of the intelligent cargo solution. When a vehicle enters the loading dock to start a new route, the onboard system connects to the warehouse central server via WiFi system in order to download an XML file that includes all necessary information about the route the vehicle will perform. This file updates the pharmacies in the route, their location and the EPC codes of the containers to be distributed.

Whenever the carrier opens the doors of cargo section of the vehicle, the system activates the RFID reader that performs continuous readings for validating the loaded containers. Through two lights, green and red, the system indicates whether the transport actions are executed properly. The green light indicates that the containers loaded on the vehicle conform to the current position, while the red light reports a deviation from the planned actions. Due to the uploaded data about the routes to follow, the sensors embedded within the vehicle and the integrated geopositioning capacities, the device also provides the van driver the necessary knowledge to optimize routes and therefore, the quality of the service. This procedure ensures, in a non-intrusive way, the proper execution of the routes assigned to the van driver. This is done taking advantage of the intelligence provided by the various hardware components involved (antennas, sensors, tags, etc.) intercommunicated via wireless technologies (WIFI, Bluetooth, RFID) and its associated information system. All these elements conform the system architecture of the proposed ubiquitous computing solution.

The main device used to implement all these features is an ISEE IGEPv2 MPU platform based on a DM3730, a System on a Chip (Soc) that integrates 1GHz ARM Cortex-A8 Core. This is a small size card (93 × 65 × 15 mm) that has all the communications modules and resources demanded by the project. Embedded platform runs under a Linaro distribution with a Linux kernel optimized for this specific board. It includes WIFI IEEE802.11b/g communication capability used for updating information at the warehouse and a Class 2 Bluetooth 2.0 module, capable of communicating with the mobile application of the driver. The platform provides several Global Purpose Input/Ouput pins (GPIO) that are used to activate red and green lights and detect when the vehicle wagon doors are opened. Furthermore, this board has two serial ports (UART type) which are used for communication with the RFID reader and an external GPS receiver (Fastrax i310). Finally, the embedded platform has an SD card that stores the historical data acquired during the development of the route that are subsequently transferred to the central server. The onboard system is powered through an independent battery which is charged from the supply system of the vehicle when the engine is running.

To facilitate future portability of the developed solution to other scenarios within the freight transport, a middleware has been developed through the use of static libraries that allow the programmer to access easily to key project resources. Thus the firmware programmer can be abstracted from the specifics in communication protocols with distributed modules and focus on application functionality. Figure 10 shows how the middleware is divided into four main libraries which provide the following services:

— *RFID services*: Provides functions to read locatable tags, verify access to a particular label and configure the power of the reader drive.
— *Geopositioning services*: Includes resources for locating the vehicle, calculate distance between different points and find the nearest stop on route.
— *Communication services with mobile device*: Includes authentication resources and functions for receiving and sending main communication frames.
— *Communication services with central server*: Provides functions for reading and unpacking the file route planning, dispatching urgent incidents and packaging and sending of developed route file.

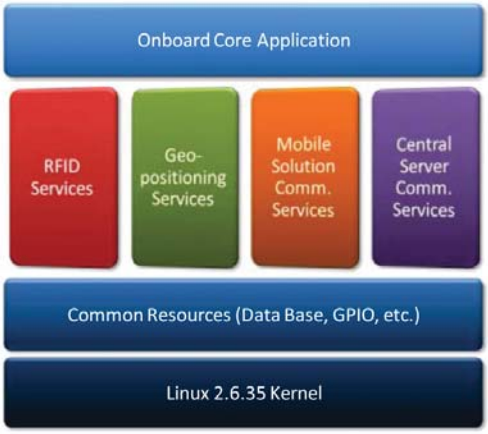

Figure 10

Middleware main modules

In deployment phase of the project the use of middleware will facilitate the replacement of peripherals used, allowing replace the RFID reader with a more economic one or GPS receiver with a more precise Global Positioning System without changing the core application. Similarly, integration with other ERP systems typical of other scenarios will require only the development of the specific module of the Middleware.

4.2. **Mobile Application**

The following extension of the system is the mobile application, which is installed on a Smartphone device. The van driver uses it to interact with the onboard system using a user-friendly graphic interface. The integration of a mobile device in the environment of the proposed solution can complement the system, serving the driver as an entry point to the knowledge offered by the system in a more direct and comprehensive manner [18], always maintaining the desired level of non-intrusiveness. This communication between the mobile device and the onboard system is established using Bluetooth technology at the start of each route.

Android OS has been used for the development of the mobile application. This decision was motivated by the opportunity offered by the pharmaceutical transport company CENFARTE (Centro Farmaceútico del Norte, S.A.) with whom an active collaboration has been established to enable the implementation of a real pilot of the solution. The company has the means to have an Android terminal for each route or carrier. As a result, the driver will carry a Smartphone to stay connected to the server application in order to know all specific needs on every transport service. The wide range of terminals and the variety of operating systems has forced us to develop a multiplatform application that works on the majority of newest existing smartphones, including

Android OS, Apple iOS and BlackBerry OS. To achieve this goal, the development has been focused towards a Service Oriented Architecture (SOA), in which most of the functionality is distributed in the server, freeing the mobile devices of processing load, that will access the logic through SOAP messages to a web service developed for the control software solution.

Once transportation is available to perform a delivery service, the mobile application displays the routes that are currently available. It does so through a WiFi connection to the server, accessing the web service responsible for obtaining the daily routes not yet started. In case of failure of the WiFi connection, the system offers continued support in communications through GPRS/HSPA connectivity, available in the mobile device. Once the route is established, the mobile device obtains data about the full path: distance, estimated duration, number of stops, addresses, *etc*. Similarly, for each of the established halts relating to the pharmacies on a route, specific EPC codes of containers to download are obtained. This information is accessible via another web service that fulfills the function of data-oriented middleware enabling the capture of real-time information from the ERP system implemented in the company. The developed system obtains the information in a transparent and non- intrusive manner, not being necessary expensive modifications in the legacy order management system. All this information is displayed to the carrier through a user interface designed with the purpose to enable maximum usability and minimize intrusiveness (Figure 11).

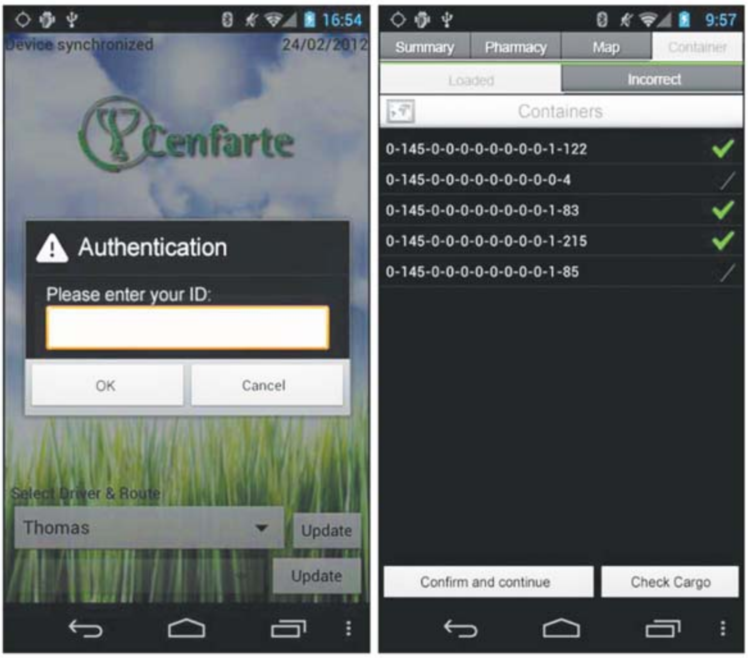

Figure 11

Developed mobile application interface

The application core functionality is the management of incidents, giving as an added value support for transport activities and navigation aid, as now will be described:

— *Management of incidents*: As discussed in previously, the proposed system is aimed to provide the van driver with an aid in his daily operations. One of the activities that is more prone to error is the loading and unloading of the containers and hence the developed system alerts the driver via a led indicator of its correct execution. However, other incidents that may occur must be taken into account, such as deviations in the estimated route time or the loss of containers in the pharmaceutical stores. It has been established that more than 10% of deviation in the estimated time for the delivery of an order or a non-conformity in the containers to download must generate an automatic incident. When the system detects a lost container, the embedded device sends by Bluetooth to the mobile application how many containers are missing in order to for them to be requested by the store administration. All these incidents are managed by the mobile application, simultaneously alerting both the carrier and control center. This is achieved by using communications established via GPRS/HSPA between the mobile device and the control software solution. The van driver will have the opportunity to see on the Smartphone at any moment which is the state of the route, which issues have been generated, and what are the activities to be undertaken to resolve them. As it can be seen, the mobile application helps the carrier in the development of daily activities, allowing reducing operational errors in the process significantly.
— *Navigation aid*: once in the course of the route and since these are changing according to the pharmacies involved in them, the mobile device offers integrated navigation service for helping the carrier. It shows the route, indicating the order in which the driver must make every stop on the planned route and if it is necessary, it assists delivery man in navigating from one point to another in that route.
— *Support for transport activities*: at each stop, the onboard system reads RFID tags and detects changes in the cargo that are sent via Bluetooth to the mobile application. This data relating to the operation of the carrier in the loading or unloading of containers, provides real-time information about possible deviations (human errors in cargo management) allowing warehouse staff to rectify the errors on delivery in minor time.

4.3. **Control Software Solution**

The control software solution relates to an application for monitoring medicine traceability, schedule optimized routes and locate different vehicles of the vans fleet. This includes the development of a control panel with three main functional features:

— *Medicine traceability*: the system has a robust database where all delivery information is stored, i.e., pharmacy office in which each medicine unit has been distributed, indicating batch number and expiry date. It allows user to search for a container even if it has been downloaded in a pharmacy office or if it is inside a van during a transport service.

— *Fleet management*: the system can locate different distribution vehicles on a map, it can store completed routes and the time spent on each stop. It contributes to the distribution company calculating an approximated time left to deliver a batch on a pharmacy office. It also calculates optimized routes taking into account delivery time, traffic and preemptive supply.
— *Optimized schedule fleet*: taking into account database stored information, using artificial intelligence techniques and the data provided by the ERP, the application generate routes for each vehicle optimizing the time of delivery.

The architecture of the control software solution installed at the servers of the central office is divided into functional layers following a modular structure that facilitates reuse, minimize the coupling and allow future functional enhancements to the platform, Figure 12.

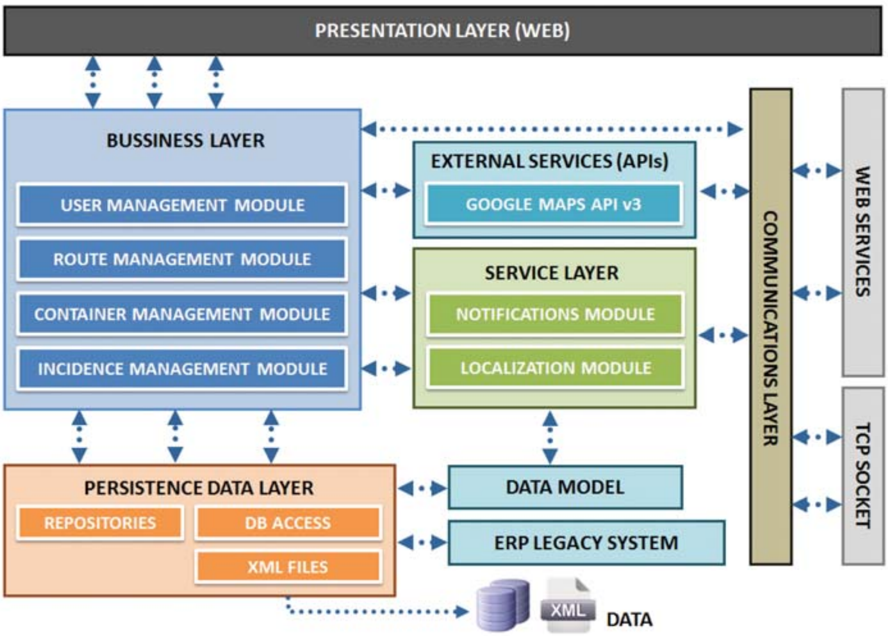

Figure 12

Architecture of the control software solution

Thus, different functional modules can be distinguished, whose characteristics are described below:

— *Business and service layer*: This module contains all the logic needed to meet the functional requirements previously stated. In addition it manages and gives the necessary permissions for the users of the system. It also manages the data relative to the geolocation of the routes, obtained through external services, in this case using the Google Maps Javascript API.

— *Persistence data layer*: In this layer data that should be stored by the application has been conceptually modeled. Microsoft SQL Server 2008 DBMS has been used in this context. The process of storing the operational data of transportation occurs at the end of the route. When this occurs, the embedded device is connected via WIFI to the server and sends a generated XML file which includes both the actual path followed by the vehicle and the incidences that may have occurred. This file is automatically treated by the system, generating the necessary entries in the DBMS so that the route is recorded at the time of its completion.
— *Communications layer*: Information relevant to the application is in the DB; however, access to such information is done through web services developed with Windows Communication Foundation (WCF) technology. This technical decision allows that both data and application logic can be accessed from other devices, thereby ensuring the scalability and interoperability of the whole system. Security also is increased because the data access does not occur directly but through the services, providing greater control over database queries. The network will be controlled at all times under a firewall that prevents unauthorized access. The set of services developed allows full interoperability between the different components of the system, which is a major benefit in broadening the number of devices compatible with it and enabling their development in the future.
— *Web presentation layer*: the development of the control solution is completed with the control panel web application which offers features beyond the typical application of fleet management. This application has been developed taken into account two fundamental characteristics: (1) maintain a friendly and attractive interface, (2) without prior installation or further configuration. The control panel, based on asp. NET development framework, has been implemented, making extensive use of technologies designed for creating Rich Internet Applications (RIA): JavaScript, CSS3, HTML5, Ajax and jQuery, along with the use of the tools offered by Google for displaying and processing of geographic and positioning information, Figure 13. This feature improves not only the final visual aspect of the application but also the overall usability. The whole site is based on an asynchronous behavior, so interaction eliminates the sense of loading data and responds instantly. All kind of choices as routes, stops or containers represent a dynamic and transparent loading of data and an almost immediately response to their interaction.

5. SYSTEM VALIDATION

The solution has been tested in a pharmaceutical warehouse located in northern Spain. The embedded system has been deployed in a delivery vehicle owned by the company Cenfarte S.A. Figure 14 shows the onboard system installed inside this vehicle for testing purposes. The vehicle has an associated route that takes place up to three times a day. The route includes a maximum of 12 pharmacies and covers a distance of 26.4 km, when all pharmacies are included in the route. The tests were carried out for six days on which the route has been travelled 14 times. The average duration of the route during the tests was 1 h and 37 min.

Figure 13

Web interface of the control software solution

Figure 14

Onboard system deployed on a vehicle. The transport bins of green color with the corresponding RFID tags can be seen on the left hand side of the picture

To minimize the impact of the tests in the warehouse, the system evaluation was carried out in three phases. In a first stage the positioning system has been tested. This test was developed during the first two days of validation with five iterations of the route. The system has been continuously storing the location of the vehicle along the route. The information collected in this phase has been used to debug the recognition system of stops and their assignment to pharmacies included in the XML file with the planning of the route. In this stage the definition on how the system has to operate in areas without GPS coverage has also been performed. During one of the developed test routes, an extra stop was added to check the performance of the recognition system. In order to validate the system, an additional stop has been introduced and the corresponding incidence was logged into the XML file. As a result of this test, given the geographical nature of each pharmacy, some of which are located in pedestrian areas where it is impossible to park the Intelligent Van, highlighting the need to modify the structure of the database, including a field indicating the maximum parking distance for each pharmacy. As shown in Figure 15, which reflects the results of each route development in this phase of the system validation, parking distance

Variable	Warehouse	Pharmacy 1	Pharmacy 2	Unknown pl	Pharmacy 3	Pharmacy 4	Pharmacy 5	Pharmacy 6	Pharmacy 7	Pharmacy 8	Pharmacy 9	Pharmacy 10	Warehouse	*Avg*
Route 1														
Stop time	7m 35s	5m 24s	4m 10s	**9m 03s**	4m 22s	4m 38s			5m 30s	4m 13s	4m 22s		8m 23s	**5m 42s**
Relative distance	0m	18m	15m	**402m**	19m	17m			21m	32m	16m		0m	**54m**
Recognition of the stop[2]	YES	YES	YES	**YES**	YES	YES			YES	YES	YES		YES	**YES**
Route 2														
Stop time	7m 59s	5m 00s			4m 01s	4m 58s	6m 13s	6m 15s		5m 12s	3m 42s	5m 35s	7m 57s	**5m 36s**
Relative distance	0m	16m			13m	19m	25m	31m		12m	20m	28m	0m	**16,4m**
Recognition of the stop[2]	YES	YES			YES	YES	YES	YES		YES	YES	YES	YES	**YES**
Route 3														
Stop time	7m 16s	5m 45s	5m 02s	**9m 59s**	4m 21s			4m 34s	4m 48s		3m 55s	5m 15s	8m 31s	**5m 48s**
Relative distance	0m	24m	29m	**301m**	20m			13m	15m		12m	17m	0m	**43,1m**
Recognition of the stop[2]	YES	YES	YES	**YES**	YES			YES	YES		YES	YES	YES	**YES**
Route 4														
Stop time	8m 18s				3m 53s	4m 40s	5m 55s			4m 20s	4m 15s		7m 49s	**5m 25s**
Relative distance	0m				12m	15m	31m			18m	28m		0m	**14,8m**
Recognition of the stop[2]	YES				YES	YES	YES			YES	YES		YES	**YES**
Route 5														
Stop time	7m 45s	5m 39s	4m 31s		4m 08s	4m 56s	6m 06s	5m 30s		5m 05s	4m 01s	5m 22s	8m 12s	**5m 27s**
Relative distance	0m	14m	23m		15m	21m	29m	25m		27m	9m	20m	0m	**16,6m**
Recognition of the stop[2]	YES	YES	YES		YES	YES	YES	YES		YES	YES	YES	YES	**YES**

Figure 15

Results of the first phase of system validation: the positioning system. In the table, stop time row shows the duration of the stop from the van parked until the route resumes; relative distance row shows the distance between the position of the van at each stop and the nearest pharmacy on route; and recognition of the stop row indicates whether the stop is identified with the associated pharmacy.

varies significantly between pharmacies. This inhibits the allocation of each planned stop points in the route, especially when they are close and the detection of non-planned stops during the route performance.

In a second stage, tests have focused on the system for identification of the cargo. This test was conducted for six iterations of the route. During this test, the system has stored each cargo alteration detected during periods when the vehicle door remained open. During the development of this test 97 containers have been transported to the pharmacies included in the route. Similarly, 84 empty containers have been loaded and transported back to the warehouse. The analysis of the collected information has reported only one discordance with the actions carried out during the test. This error was due to an incorrectly labeled container affecting delivery at the 3rd pharmacy, as seen in Figure 16. It is worth noting that the system detects this change in the expected load and immediately informs the driver by switching the red traffic light, but corresponding incidence is reported at the exit from the warehouse.

Variable	*Warehouse*	*Pharmacy 1*	*Pharmacy 2*	*Pharmacy 3*	*Pharmacy 4*	*Pharmacy 5*	*Pharmacy 6*	*Pharmacy 7*	*Pharmacy 8*	*Pharmacy 9*	*Pharmacy 10*	*Warehouse*	*Total*
Route 1	●	●	●	●	●	—	—	●	●	●	—	●	
Average door-open time	6m 35s	4m 25s	3m 40s	3m 22s	3m 58s	—	—	4m 11s	3m 51s	3m 12s	—	6m 48s	**4m 26s**
Identified containers[3]	**16/17**	4/4	3/3	**2/3**	4/4	—	—	6/6	5/5	4/4	—	15/15	**59/61**
Cargo alteration[4]	**1**	0	0	**1**	0	—	—	0	0	0	—	0	**2**
Route 2	●	●	●	●	●	●	●	—	●	●	●	●	
Average door-open time	6m 35s	4m 25s	3m 40s	3m 22s	3m 58s	5m 20s	4m 26s	—	3m 51s	3m 12s	4m 26s	6m 48s	**4m 26s**
Identified containers[3]	20/20	6/6	7/7	3/3	3/3	4/4	3/3	—	4/4	5/5	3/3	17/17	**75/75**
Cargo alteration[4]	0	0	0	0	0	0	0	—	0	0	0	0	**0**
Route 3	●	●	●	●	●	●	●	●	—	●	●	●	
Average door-open time	6m 35s	4m 25s	3m 40s	3m 22s	3m 58s	5m 20s	4m 26s	4m 11s	—	3m 12s	4m 26s	6m 48s	**4m 26s**
Identified containers[3]	23/23	5/5	5/5	3/3	3/3	3/3	5/5	10/10	—	3/3	4/4	20/20	**84/84**
Cargo alteration[4]	0	0	0	0	0	0	0	0	—	0	0	0	**0**
Route 4	●	—	—	●	●	●	—	—	●	●	—	●	
Average door-open time	6m 35s	—	—	3m 22s	3m 58s	5m 20s	—	—	3m 51s	3m 12s	—	6m 48s	**4m 26s**
Identified containers[3]	15/15	—	—	3/3	5/5	6/6	—	—	5/5	5/5	—	15/15	**54/54**
Cargo alteration[4]	0	—	—	0	0	0	—	—	0	0	—	0	**0**
Route 5	●	●	●	●	●	●	●	●	●	●	●	●	
Average door-open time	6m 35s	4m 25s	3m 40s	3m 22s	3m 58s	5m 20s	4m 26s	4m 11s	3m 51s	3m 12s	4m 26s	6m 48s	**4m 26s**
Identified containers[3]	22/22	10/10	4/4	2/2	3/3	6/6	3/3	10/10	3/3	4/4	4/4	17/17	**88/88**
Cargo alteration[4]	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Ident. Containers in total	**96/97**	**25/25**	**19/19**	**13/14**	**18/18**	**19/19**	**11/11**	**26/26**	**17/17**	**21/21**	**11/11**	**84/84**	**360/362**

Figure 16

Results of the second phase of system validation: the identification system. In the table, average door-open time row shows the period in which the doors are open at each stop; identified containers row shows the number of containers identified in each stop with respect to the planning; and cargo alteration row indicates mismatches in the load to the schedule set.

Variable	Warehouse	Pharmacy 1	Pharmacy 2	Pharmacy 3	Pharmacy 4	Pharmacy 5	Pharmacy 6	Pharmacy 7	Pharmacy 8	Pharmacy 9	Pharmacy 10	Warehouse	Avg
Route 1	●	●		●	●			●	●	●		●	
Pharmacy assignment[5]	OK	OK		OK	OK			OK	OK	OK		OK	**OK**
Cargo identification[3]	OK	OK		OK	OK			OK	OK	OK		OK	**OK**
Incidences registered[6]	0	0		0	0			0	0	0		0	**0/0**
Route 2	●	●	●			●	●		●	●	●	●	
Pharmacy assignment[5]	OK	OK	OK			OK	OK		OK	OK	OK	OK	**OK**
Cargo identification[3]	OK	OK	OK			OK	OK		OK	OK	OK	OK	**OK**
Incidences registered[6]	0	0	0			0	0		0	0	0	0	**0/0**
Route 3	●	●	●	●	●	●	●	●		●	●	●	
Pharmacy assignment[5]	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	**OK**
Cargo identification[3]	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	**OK**
Incidences registered[6]	**1/1**	0	0	0	**1/1**	**2/2**	0	**2/2**	0	0	0	0	**6/6**
Incidence reported to CO[7]	**YES**				**YES**	**YES**		**YES**					
Delay time in Inc. Report.[8]	**2m 17s**				**31s**	**44s**		**42s**					**1m03s**

Figure 17

Results of the third phase of the system validation: the complete system. In the table, pharmacy assignment row indicates whether the stop is correctly associated to the corresponding stop; cargo identification row shows if the load carried at the stop is adjusted to the planning; and in incidences registered row, when the system detected an urgent incidence, the correct reception and the period from the reception until the reporting in the control center, are indicated.

Finally, the complete solution was tested during the development of three iterations of the route in the two last days of the system validation (Figure 17). In the first two iterations of the route, the courier was called to pay the maximum attention during the delivery in order to analyze the normal development of a route. In the 17 stops carried out during these first two iterations of the route, the system confirmed the process carried out by the courier, switching on the green light that validates the task. During the execution of the last repetition of the route undertaken to validate the system, the XML file containing the route information was altered manually including three differences with the order given to the courier. Changes included a container that was not ready at the dock of the vehicle (affecting delivery at the 4th pharmacy too) and the exchange between two pharmacies (5th and 7th in the figure) of two containers. The three incidents were detected and reported to the responsible for the warehouse by SMS and email.

6. CONCLUSIONS

The benefits that item-level traceability for pharmaceutical drugs provides to society in terms of public health and ensuring access to medicines enforces governments to require this feature of the different actors involved in the pharmaceutical supply chain in the short term. The reduction of profit in the pharmaceutical industry motivated by the imposition of certain public policies worsened because of the economic crisis affects not only the laboratories but also distributors of pharmaceutical products that are unable to afford the investment needed for these systems. Most of the initiatives to apply telematic technologies in order to fulfill requirements imposed by governments are being designed without considering the difficulties of deploying such systems in the warehouses currently in operation and in their impact in the activities of the pharmaceutical supply chain.

In this paper we have presented a system based on an intelligent van to improve the distribution of pharmaceutical drugs. The system is able to trace medicines over the delivery routes from warehouses to pharmacies, reporting incidences to carriers in case of anomalies in the distribution plan. This contributes, first to the reduction of the occurrence of errors during distribution and the required time for their recovering and second to locate a set of medicines in case of a mislead.

In order to achieve these tasks, the intelligent van has to identify its environment, including: its location, assets which are contained within the vehicle and the current delivery route. To meet the previous demands, current wireless technologies have been employed: RFID to provide with the cargo identification; GPRS/HSPA, WIFI and Bluetooth to achieve communication; and GPS for the geo- positioning provision. Moreover, interaction with the user has been provided through the integration of a Smartphone in the system.

In order to implement an optimized physical layer interface, detailed analysis of the complex electromagnetic environment given by the indoor cargo area of the vehicle loaded with transporting bins has been performed. Deterministic 3D ray launching simulations have been performed, by means of in-house developed code, which are key in order to estimate wireless link balance and hence performance of the on-board RFID system. The topology of the reader antenna configuration, the distribution of the bins and the properties of the tags can be optimized in order to increase readability and therefore reduce errors. This information has also been used in order to validate and propose a novel embedded antenna configuration, increasing the overall performance of the system.

One of the main contributions of this work is the use of telematic technologies for providing intelligence to a van; this is to improve the distribution of pharmaceutical drugs without altering the way carriers perform their normal tasks. Carriers using the intelligent van will not have to worry about registering (loaded or unloaded) pharmaceutical drug containers; they require no continuous supervision because the system validates every task they make, notifying them only in case of a deviation according to the planned route. It is a non-intrusive solution representing a successful case in using smart environments to resolve a real industrial need.

This has been possible due to first, the design of the technological solution and second, the characteristics of the scenario in which the systems is deployed. The "Good Distribution Practices for Pharmaceutical Products" drafted by the World Health Organization states that all pharmaceutical products should be stored and distributed in containers with no adverse effects on the quality of products, and offering adequate protection from external effects. Thanks to the standardization and reuse of these containers, the transportation of drugs is an ideal scenario for the implementation of RFID tags. The actual high cost of UHF tags is well amortized by a provided application capable of geo-locating the precise position of lost containers, allowing the costs of purchased tags to be affordable in a very short time investment, avoiding one of the biggest drawbacks of this technology (the cost). To summarize, by considering a holistic approach, from radiofrequency physical layer of the RFID system up to the System Architecture definition, a flexible, scalable and competitive solution for pharmaceutical drug delivery has been developed.

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REFERENCES

[1] US Department of Transportation Research and Innovative Technology Administration (RITA). Available online: http://www.its.dot.gov/faqs.htm/ (accessed on 16 May 2012).

[2] Commission Directive 2003/94/EC of 8 October 2003 laying down the principles and guidelines of good manufacturing practice in respect of medicinal products for human use and investigational medicinal products for human use. *Official J. Eur. Comm. L* 2003, 262, 22-26.

[3] José, R.; Rodrigues, H.; Otero, N. “Ambient intelligence: Beyond the inspiring vision». *J. Univ. Comput. Sci.* 2010, 16, 1480-1499.

[4] Jedermann, R.; Lang, W. “The Benefits of Embedded Intelligence: Tasks and Applications for Ubiquitous Computing in Logistics». In *IOT’08 Proceedings of the 1st International Conference on the Internet of Things*; Springer-Verlag: Berlin/Heidelberg, Germany, 2008.

[5] Finkenzeller, K. *RFID Handbook*; John Wiley & Sons, Inc.: Hoboken, NJ, USA, 2010.

[6] Gandino, F.; Montrucchio, B.; Rebaudengo, M.; Sanchez, E.R. “On improving automation by integrating RFID in the traceability management of the agri-food sector». *IEEE Trans. Ind. Electron.* 2010, 56, 2357-2365.

[7] Jedermann, R.; Lang, W. “The benefits of embedded intelligence: Tasks and applications for ubiquitous computing in logistics». *Lect. Notes Comput. Sci.* 2008, 4952, 105-122.

[8] Trebar, M.; Grah, A.; Melcon, A.A.; Parreno, A. “Towards RFID Traceability Systems of Farmed Fish Supply Chain». In *Proceeding of IEEE 19th International Conference on Software, Telecommunications and Computer Networks (SoftCOM),* Dalmatia, Croatia, 15-17 September 2011; pp. 1-6.

[9] ThingMagic, A Division of Trimble [online]. Available online: http://www.thingmagic.com/embedded-rfid-readers/mercury5e/1-embedded-rfid-readers/3-mercury5e/ (accessed on 16 May 2012).

[10] Finkenzeller, K. *RFID Handbook, Fundamentals and Applications in Contactless Smart Cards and Identification*, 2nd ed.; John Wiley & Sons, Inc.: Hoboken, NJ, USA, 2003.

[11] Hirvonen, M.; Jaakkola, K.; Pursula, P.; Säily, J. “Dual-band platform tolerant antennas for radio-frequency identification». *IEEE Trans. Antennas Propag.* 2006, 54, 2632-2637.

[12] Saez de Adana, F.; Blanco, G.; Diego, G.; Arriaga, P.; Cátedra, M.F. "Propagation model based on ray tracing for the design of personal communication systems in indoor environments». *IEEE Trans. Veh. Technol.* 2000, 49, 2105-2112.

[13] Applied Nanotech Holdings, Inc. Available online: http://www.appliednanotech.net/tech/inkjettable_metallic_inks.php/ (accessed on 16 May 2012).

[14] Koptioug, A.; Jonsson, P.; Olsson, T.; Sidén, J.; Gulliksson, M. "On the Behaviour of Printed RFID Tag Antennas, Using Conductive Paint». In *Proceedings of Antenn-03*, Kalmar, Sweden, 13-15 May 2003.

[15] *Technical Report Electromagnetic Compatibility and Radio spectrum Matters (ERM), Part 2 ETSI TR 102 644-2 V1.1.1*; European Telecommunications Standards Institute: Sophia Antipolis Cedex, France, March 2009.

[16] García Zuazola, I.J.; Elmirghani, J.M.H.; Batchelor, J.C. "High-speed ultra-wide band in-car wireless channel measurements». *IET Commun.* 2009, 3, 1115-1123.

[17] Hovinen, V.; Hamalainen, M.; Patsi, T. "Ultra Wideband Indoor Radio Channel Models: Preliminary Results». In *Proceeding of IEEE Conference on Ultra Wideband Systems and Technologies*, Baltimore, MD, USA, 21-23 May 2002; pp. 75-79.

[18] Lopez de Ipiña, D.; Vázquez, J.I.; García, D.; Fernández, J.; García, I.; Sainz, D.; Almeida, A. "EMI^{2}lets: A Reflective Framework for Enabling AmI». *J. Univ. Comput. Sci.* 2006, 12, 297-314.

Measurement and Modeling of an UFH-RFID system in a metallic closed vehicle

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Abstract

In this work, the characteristics radiopropagation of a wireless systems within an indoor vehicle is presented. An analysis of the physical radio channel propagation inside a van full of dielectric buckets is presented, based on 3D ray launching in house code. Simulation as well as measurement results from a real in-vehicle scenario confirm the topological dependence and impact on a RFID system is shown.

Keywords: 3D ray launchin; RFID system; intravehicular wireless channel.

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I. INTRODUCTION

The study of propagation of complex wireless channels has increased enormously in recent years because of the large amount of competition that exists in mobile communications at the moment. With the growing demand for wireless communications systems, a wireless concept for the data exchange between different system components inside vehicles becomes interesting. Channel performance directly determines the quality of the communication, in terms of sensitivity, capacity and latency. Therefore, a very clear understanding of the channel must be pursued in order to get high-quality and high-capacity transmission of the useful information by using the more limited base stations and hot-spots to give an efficient service, expected in systems like Long Term Evolution or vehicular Wi-Fi based on 802.11p standard. It is important to consider the phenomena that affects radio propagation in this particular case of vehicular communications, being the most relevant fast fading [1] [2] due to multipath propagation. Traditionally, empirical methods were used (such as COST-231, Walfish-Bertoni, Okumura Hata, etc.) for initial coverage estimation. They give rapid results, but require calibration based on measurements in order to give an adequate fit of the results , based on initial regression methods. On the other hand, deterministic methods are based on numerical approaches to the resolution of Maxwell's equations, such as ray launching and ray tracing (based on geometrical approximations) or full wave simulation techniques (MoM, FDTD, FITD, etc.) These methods are precise, but are time consuming to inherent computational complexity. As a mid-point, methods based on geometrical optics, for radioplanning calculations with strong diffractive elements, offer a reasonable trade-off between precision and required calculation time [3].

In the automotive sector, simulations by using full wave approaches like ray tracing method have been established to, e.g. optimize antenna positions in the vehicle under consideration of EMC problems and electromagnetic field exposure of the user [4-5]. Therefore, several ray tracing simulations and measurements have been made in metallic indoor scenarios, like the cabin of an aircraft [6-9] or enclosed spaces [10].

In this article, an analysis of the behavior of a RFID system [11] in a closed metallic van full of dielectric buckets (used for distribution of supplies, such as medicines) of a determined material has been done to verify that the variability and the topology of the environment affect the electromagnetic propagation. The main characteristics of the overall system are to control medical distribution all over the delivery route and to make carriers work easier among others. RFID technology is optimal to guarantee the traceability of all drugs delivered and allows van drivers to load and unload cargo from the vehicles with increased security and efficiency, due to automatic interrogation of the status of the whole load.

II. SIMULATION TECHNIQUE AND RESULTS

As stated in the introduction, a deterministic method based on 3D ray launching is used in order to analyze the metallic indoor scenario. A 3D ray launching algorithm has been implemented in-house, based on Matlab™ programming environment. Several sources can be placed within an indoor scenario, in which power is converted into a finite number of rays launched within a solid angle. Parameters such as frequency of operation, radiation diagram of the antennas, number of reflections, separation angle between rays and cuboid dimension can be fixed. Phenomena such as reflection, refraction and first order diffraction are considered, as well as the material properties for all of the elements within the scenario, given the dielectric constant and the loss tangent at the frequency range of operation of the system under analysis. Figure 1 shows a general indoor scenario (typical office of a department) that has been implemented in the simulator and the way which the rays impact with an object, storing the parameters in the different cuboids of the scenario.

The polypropylene material employed is characterized with a dielectric constant of 2.6, conductivity of 0.11W/mK and loss tangent of 0.0003 at the frequency of operation of 868Mhz-960Mhz (i.e., UHF RFID operation). The goal is to estimate the amount of buckets are within the closed vehicular environment in every moment. In order to achieve this, each bucket is characterized with a commercially available RFID tag. The transmitter antenna is fixed at the point (1.291m, 1.762m, 0.732m), corresponding to the central point of the roof of the vehicle. The parameters used in the simulation are the following: uniform cuboid resolution of 6cm, vertical plane angle resolution $\Delta\theta = \pi/180$, horizontal plane angle resolusion $\Delta\Phi = \pi/180$, maximum number of tolerated reflections N = 7 and frequency of operation 860-960MHz (UHF-RFID Technology) with transmission rate of 106Kbps and power transmission of -20dBm. In the first place, a circular polarized directional antenna is used for the transmitter, with a gain of 6dBi and horizontal beam width for -3dB of 67º and vertical beam width of 69º (model PATCH-A0025 from Poynting Antennas). Afterwards, a directional antenna with linear polarization is used, with a gain of 7dBi and providing a 60º horizontal beam width for -3dB and 74º vertical beam width (model PATCH-A0026 from Poynting Antennas). For the receiver, a RFID generic tag is used, with an omnidirectional radiation pattern and both cases of polarization, circular and linear are considered.

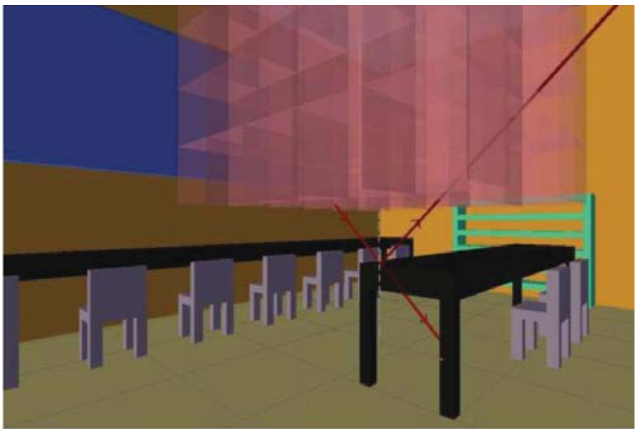

Figure 1

View of stored parameters of the ray in the indoor scenario

In this paper, the scenario under consideration is the case which the van is full of buckets of material polypropylene, stacked one above the others, as shown in Figure 2.

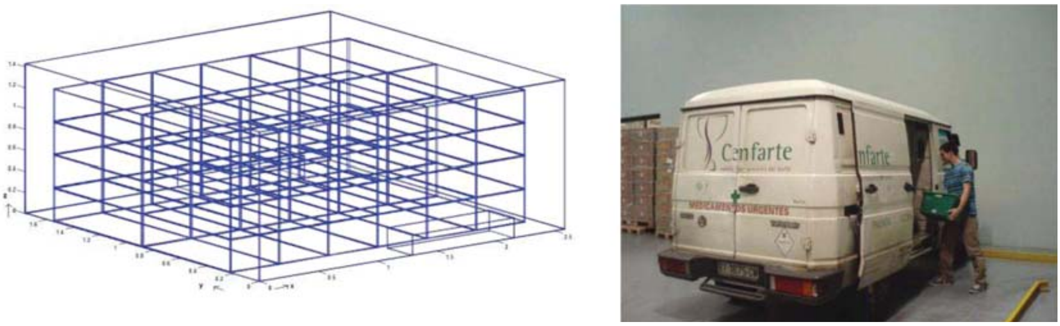

Figure 2

(a) Vehicular scenario under consideration: indoor van full of buckets. The material for the buckets is polypropylene and the walls of the van are metallic. (b) Image of the real vehicle modeled

A. Transmitter antenna with circular polarization

Figure 3 and Figure 4 show simulation results obtained by means of in house 3D ray launching algorithm for the received power using a transmitting antenna of circular polarization and both, circular and linear polarization, at the receiver point. It is observed

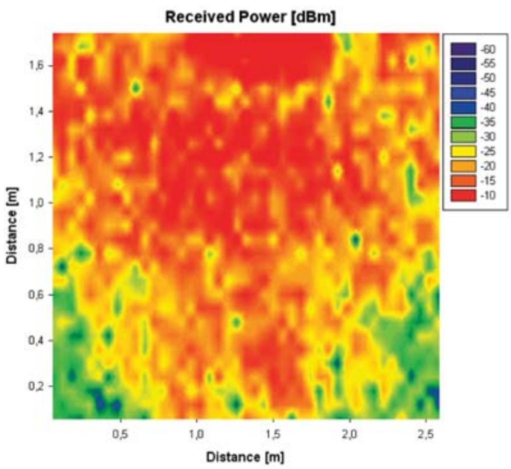

Figure 3

Received power [dBm] at half height of the first line of buckets (0.5m) with circular polarized transmitter antenna and circular polarized receiver antenna

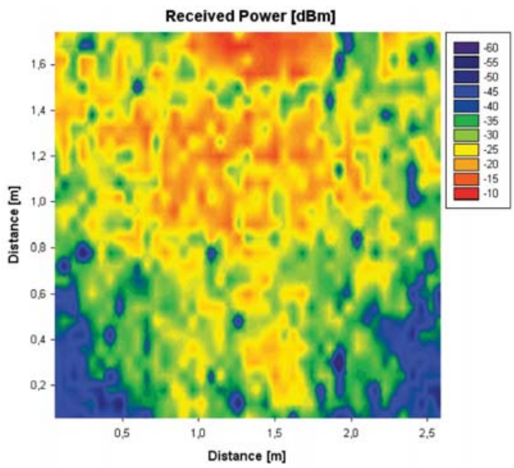

Figure 4

Received power [dBm] at half height of the first line of buckets (0.5m) with circular polarized transmitter antenna and linear polarized receiver antenna that the received power is greater in the first case, for circular polarization at the reception. This is due to the consideration as receivers all cuboids in the simulation space and linear polarization at reception is not capturing all the received power. From both figures it can be seen that spatial distribution of power is strongly dependent on the observation point, which stresses the influence of the morphology within the simulation result.

B. **Transmitter antenna with linear polarization**

Afterwards, similar simulations have been performed with the aid of 3D in house ray launching algorithm, but in this case changing the transmitting antenna by an antenna with vertical linear polarization. In the algorithm, the calculated electric field depends on the polarization of the transmitting antenna and hence it is calculated taking into account the vertical polarization. Figure 5 and Figure 6 show the received power for the half height (i.e., equivalent height within the vehicle of 0.5m) of the first line of buckets.

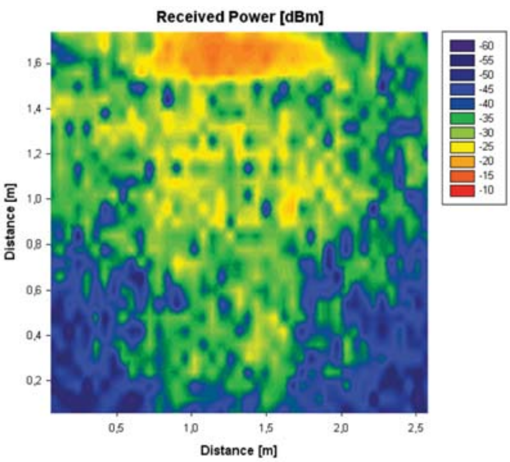

Figure 5

Received power [dBm] at half height of the first line of buckets with linear polarized transmitter antenna and circular polarized receiver antenna

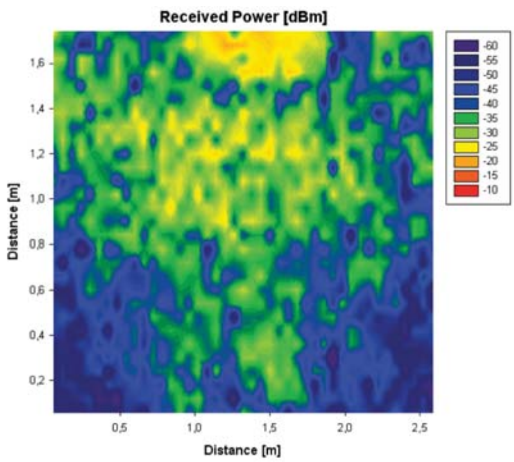

Figure 6

Received power [dBm] at half height of the first line of buckets with linear polarized transmitter antenna and linear polarized receiver antenna

As it can be seen from both figures received power level is, once again, strongly dependent on the position of the potential receiver element and the greatest values of power are obtained when the polarization of transmitting and receiving antenna is circular. For the other cases, no significant differences are observed in the received power. This is due to the fact that the fundamental propagation mechanism in a closed metal environment is multipath propagation, which is characterized by the temporal dispersion of the signal and the frequency dispersion due to temporal variations of the received amplitude [1]. To illustrate the relevance of this propagation mechanism the power delay profile for a given cuboid of the scenario has been obtained and is depicted in Figure 7. As it can be seen, there is a large number of echoes in the scenario within a time span of approximately 5ns to 20ns, corresponding to distances from 0.015 meters to 0.06 meters, which is coherent with the material properties at the frequency of operation within the vehicle.

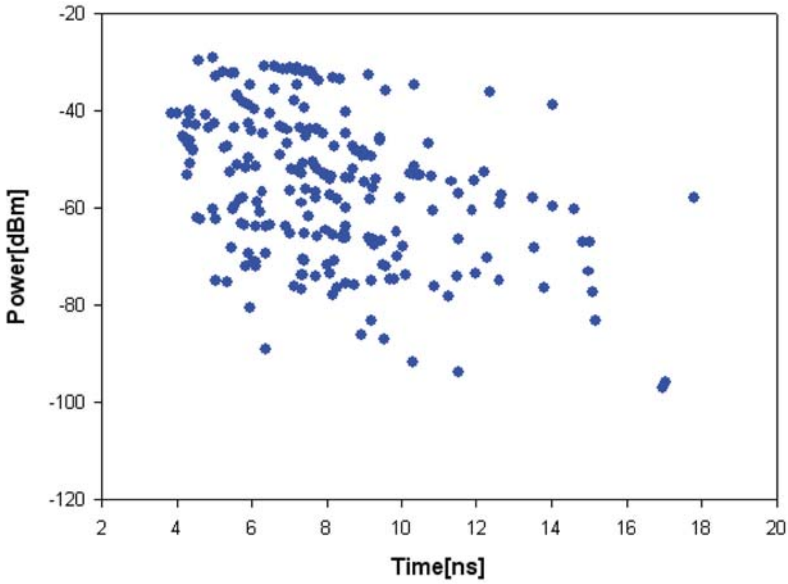

Figure 7

Power–Delay Profile at a given cuboid, located at the center (1.74m, 0.97m, 0.178m) in the indoor scenario

III. MEASUREMENTS RESULTS AND IMPACT ON RFID SYSTEM

In order to validate previous simulation estimations, measurements from a real vehicular indoor environment have been obtained. For this purpose, the indoor scenario of a van (Iveco Turbo Daily) used commercially for the distribution of medicines has served as environment for the measurement campaign. The goal is to characterize the different effects of electromagnetic propagation inside the van. A signal generator, a spectrum analyzer and a set of antennas (one transmitter and a receiver) in the range of 900MHz have been used. The transmitter antenna has been fixed in the position (1.402, 1.18, 1.4) m,. with a transmission power level of -20dBm (@868Mhz).

The signal generator is a network analyzer Agilent N1996A configured with a minimum sweep frequency to obtain a single- frequency pulse at the output. The analyzer spectrum is an Agilent N9912 FieldFox. The transmitter antenna PATCH-A-0026 with linear polarization has been used and the receiving antenna is a monopole (model FLEXI-SMA90-868) of small dimensions to interfere as little as possible with the scenario. The parameters used in the simulation are: cuboids resolution of 6cm, vertical angular resolution $\Delta\theta = \pi/180$, horizontal angular resolution $\Delta\Phi = \pi/180$, maximum number of reflections N = 7 and frequency of operation 860-960MHz (UHF-RFID Technology).

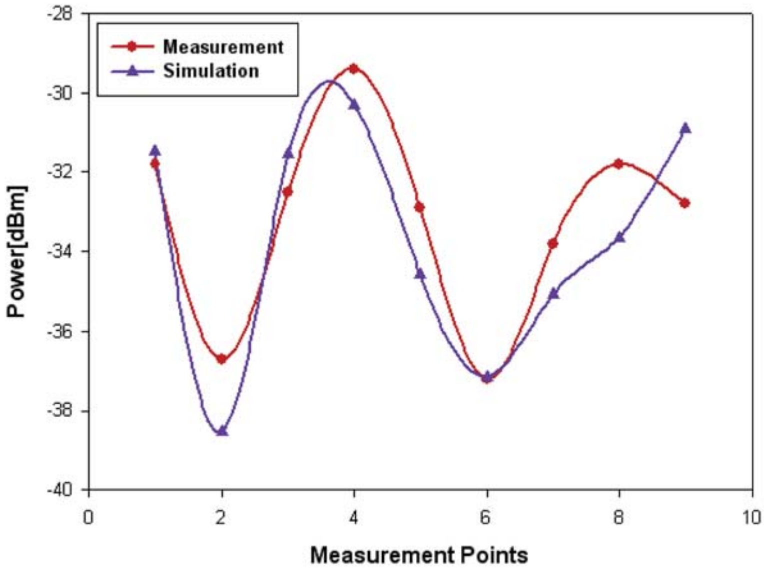

Figure 8

Comparison Simulation vs. Measurements

Figure 8 shows the comparison between simulation and measurements inside the van, exhibiting good agreement with a standard deviation of 0.686dB. The differences are due mainly to fast fading, which is the most relevant effect in this indoor scenario, that occurs due to the multipath components which are very significant.

The next step is to consider the impact of the indoor vehicular environment in the radio link budget of a RFID system. The most common RFID systems use passive tags. Tags communicate with the reader by modulating its reflection coefficient to incoming radiation from the reader, i.e., modulating its scattering/radar cross section [11]. Read range is the maximum distance at which the tag can be read by the reader. For a successful read, two conditions must be satisfied. First, the tag has to be powered up by the reader (the received power in the tag must be higher than the power up threshold, P_{th}). In second place, the reader must be sensitive enough to pick up the backscattered modulation from the tag. By means of 3D ray launching code, propagation losses can be estimated and become an input to a radio link budget for RFID in order to obtain effective read range. The power received in the reader in the backscatter communication radio link budget has been calculated as function of the differential reflection coefficient of the tag ($\rho' = \rho_1 - \rho_2$), where ρ_1 and ρ_2 are the 0 and 1 states of the chip reflection coefficient, which depend of the chip load [12].

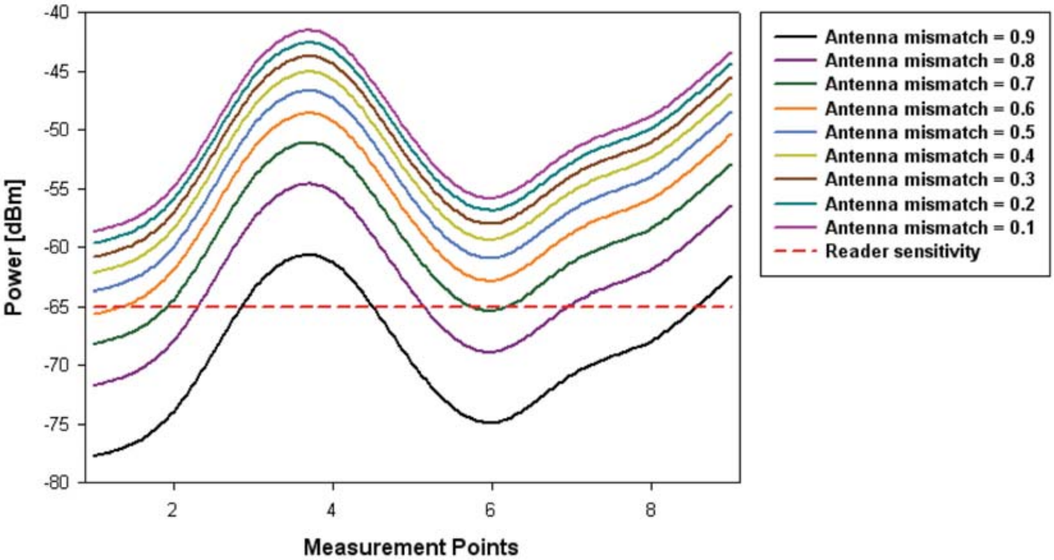

Figure 9

Received power in the reader in the backscatter communication radio link for different values of antenna mismatch

Figure 9 represents the UHF-RFID radio link budget. It is observed that for values of the antenna mismatch of the tag less than 0.6, the power received in the reader is greater than the reader sensitivity (-65dBm), so the budget is positive and the reader could read the information in the tag. For values of antenna mismatch bigger than 0.6, the reader couldn't read the tag because it would have not enough power. In all cases, the position of the reader and the tag plays a key role in the capability of reading the tag.

IV. CONCLUSIONS

In this paper, the demands for modeling the radio channel in enclosed spaces like they are found in vehicles are presented . The topological and morphological influence in the operation of a RFID system in a closed vehicle has been analyzed. The use of deterministic 3D ray launching algorithm implemented in house allows the optimization in the placement of transceivers to improve system efficiency and obtain overall enhanced performance. Simulation as well as measurement results have been presented, showing good agreement and of application to a link budget analysis of a RFID system. The results show that by considering radio planning in the vehicular scenario, the overall system performance can be strongly optimized, reducing power consumption as well as non desired interference levels.

ACKNOWLEDGMENTS

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REFERENCES

[1] H. Hashemi, "The indoor radio propagation channel". *Proc. IEEE,* vol. 81, pp. 943-968, July 1993.

[2] Hernández Rábanos, J.M., *Transmisión por radio*, Madrid: Ramón Areces, 2008.

[3] Iskander, M.F. and Yun, Z., "Propagation Prediction Models for Wireless Communications Systems". *Microwave Theory and Techniques, IEEE Transactions on*, vol. 50, nº 3, pp. 662-673, March 2002.

[4] P. Wertz, V. Cvijic, R. Hoppe, G. Wolfle, and F.M. Landstorfer, *Wave Propagation Modeling Inside Vehicles by Using a Ray Tracing Approach*, Vehicular Technology Conference, VTC Spring 2002, IEEE 55th, vol. 3, pp. 1264-1268.

[5] R. Wahl, M. Layh, T. F. Eibert, *Wave Propagation Inside and Around Vehicles in Dynamic Time Variant Scenarios*, Vehicular Technology Conference, VTC Spring 2006 IEEE 63rd, vol. 6, pp. 2883-2886.

[6] C. De Raffaele, C. J. Debono and A. Muscat, *Modeling Electromagnetic Interference Generated by a WLAN System Onboard Commercial Aircraft*, MELECON 2010 15th IEEE Mediterranean Eletrotechnical Conference, pp. 699-704.

[7] P. R. Sai Ananthanarayanan, Richard Alyssa Magleby and Cynthia Furse, "Measurement and modeling of multiuser antenna system in aircraft in the presence of electromagnetic noise and interference", *Microwave and Optical Technology Letters*, vol. 53, nº 5, Wiley Subscription Services, Inc., A. Wiley Company, pp. 1137-1144, May 2011

[8] R. Felbecker, W. Keusgen and M. Peter, *Ray-Tracing Simulations of the 60GHz Incabin Radio Channel*, XXIXth General Assembly of the International Union of Radio Science, URSI GA 2008.

[9] M. Peter, W. Keusgen, A. Kortke, M. Schirrmacher, *Measurement and Analysis of the 60GHz In-Vehicular Broadband Radio Channel*, Vehicular Technology Conference, VTC Fall – 2007 IEEE 66th, pp. 834-838.

[10] P. Wertz, G. Wolfle, R. Hoppe and F. M. Landstorfer, *Deterministic Propagation Models for Radio Transmission into Buildings and Enclosed Spaces*, Microwave Conference, 2003, IEEE 33rd European, pp. 1147-1150.

[11] K. Finkenzeller and D. Muller, RFID Handbook: *Fundamentals and Applications in Contactless Smart Cards, Radio Frequency Identification and Near-Field Communication*, Wiley, 2010.

[12] A. Lázaro, D. Girbau and D. Salinas, "Radio link budgets for UHF RFID on multipath environments", *IEEE Transactions on Antennas and Propagation*, vol. 57, nº 4, pp. 1241-1251, April 2009.

A telematics system for the intelligent transport and distribution of medicines

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Abstract

A growing demand for well-defined telematics systems in the intelligent transport distribution of pharmaceutical drugs is envisaged driven by legislative demands to enable the safe handling of medicines in automotive distributions. The provision is accomplished by providing virtual intelligence to vehicles designated for this form of smart freight transportation. The system provides anytime/anywhere assets tracking while on the move, from departure to destination, supporting reliable courier operation at low labour. The tracking and tracing system provides the vehicle with sufficient intelligence to: be located remotely, track and trace assets, and provide incidence reports. Our architecture is intended to automatically broadcast adaptive logistic-distribution-plans between a central office and a vehicle. The proposed system represents an inexpensive and non-intrusive solution that exploits advanced technologies such as smart environment sensing, RFID, WiFi, and GPS, to support modern industrial needs. The authors describe and discuss the motivation and the benefits of using the system, including new hardware and software developments.

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1. INTRODUCTION

Emerging demands for innovative pharmaceutical drug supply chains [1] require assets tracking solutions on moving vehicles alongside designated itineraries (pharmaceutical suppliers to end pharmacies). Enforced by the European Community (EC), the solution must provide traceability, secure delivery and healthy handling of medicines [2]. Due to the associated costs increase and the highly competitive industry, the solution must be inexpensive to allow profitable operation with low margins. Competitors offering low-price and efficient services are highly successful in attracting and retaining new customers.

Among the important attributes of the solution is the ability to provide distributors with a reliable, high quality of service (QoS) and satisfactory completeness of assigned freight distribution at a reasonable but nevertheless minimum time. In addition, the proposed telematics system should meet the European Union (EU) recommendations and provide relaxed human-computer interactions with simplified distributor's tasks.

To meet the above demands, a novel architecture is presented; in essence, it is envisioned as an inexpensive solution for the effective distribution of medicines that meets the requirements of the new regulations for the handling of medicines. It accomplishes this through the use of a range of relatively inexpensive technologies including typical mobile handsets (used by couriers) networked to a Central Office (CO). This allows for the traceability of journeys and assets remotely using human-to-computer interactions. Some potential applications of the telematics system include the ability to validate the cargo during distribution with minimum labour and the ability to identify and acknowledge responsibly any prospective failure of a committed distribution plan.

Following the introduction, the paper describes the key technical contributions of the proposed system and is organized as follows: Section 2 – describes the intelligent system, Section 3 – presents the Radio Frequency Identification (RFID) system and provides details of the antenna developments, Section 4 –summarises the key software advances and Section 5 –validates the system.

2. THE INTELLIGENT SYSTEM

The growth of telematics systems can contribute to the development of vehicles with sufficient artificial intelligence. The system should ensure safe transport of medical containers as approved by the World Health Organization (WHO) and be reusable [3] to minimise costs.

The vast number of containers that are expected in a warehouse would preferably favour an easy arrangement and low cost tagging solution; this is achievable using passive (uses no battery) transponders (tags). The containers are used in close loop with a value enhanced by their reutilisation to reduce waste and cost (permanent tagging). In addition, the system must be capable of automatically reading the tags; the use of handheld interrogators (readers) can lead to reading delays compared to an automatic solution.

Furthermore, it is essential to overcome any possible extended delivery and related expensive labour. For the solution, Radio Frequency Identification (RFID) technology is employed.

A high level block diagram detailing the proposed intelligent system architecture is depicted in Fig. 1. A description of the blocks is now detailed. Ultra High Frequency (UHF) RFID technology is employed; both the antenna interrogator and transponders are responsible for the wireless communication (the tracking and control of medicines). The interrogator is responsible for the requests and the processing of the replies made by the transponders allocated to individual containers; this is a more affordable technique than having each medicine tagged and is seen as an additional contribution to a cost-effective system. The "embedded system (ES)" is primarily responsible for the communication exchange between the RFID system and a Smartphone; the latter allows for real-time communications between the vehicle and a Central Office (CO). The hub of the "embedded system" provides the virtual intelligence to the vehicle (designated for this form of smart freight transportation) and interfaces the necessary hardware for the communication exchange. A simplified supply chain process of the intelligent system is given in Fig. 2, where, blocks marked as (*) indicate the origin-to-destination stages of the journey, and the halts otherwise.

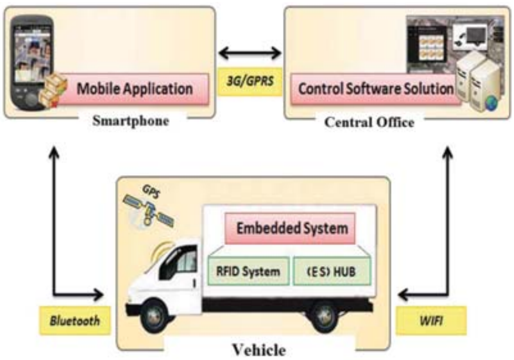

Figure 1

The intelligent system architecture

Figure 2

The supply chain process

Detail information on the intelligent system performance is now provided. First, a fully automated dispenser located at the CO receives prescription orders (from its enterprise resource planning (ERP) system and rapidly coordinates the medicines for transportation. The intelligent system organizes the requested medicines in containers that are dispatched immediately after validation.

WiFi - IEEE802.11b/g technology is used for the complete information provision of update itineraries from the CO to the vehicle; Bluetooth and General Packet Radio Service (GPRS) complement the operation. Although fast growing Automatic WiFi

Roaming can be used instead of 3G/GPRS, at present, the former is not as commonly deployed; 3G is typically a flat rate service used by couriers and therefore not seen as a cost increase. Although Bluetooth can in principle be replaced by emerging WiFi Direct, the earlier incorporates very robust security mechanisms [4]. The containers are manually packed inside the vehicles and an RFID interrogator (inside the vehicle) reads the corresponding transponders during packing (while the vehicle doors are open) with no intrusion to the courier's tasks.

The hub of the "embedded system", gathers, stores, and delivers the data as collected by the interrogator; In addition, it continuously monitors the courier's performance. The data is provided by an Electronic Product Code (EPC) allocated to each transponder. Each EPC global Gen2 using data content compliant with the ISO ISO18000-6C standard holds the necessary data for a bunch of prescriptions (medicines contained in a container) including recipient (end customers) destinations.

Using EPC, the total number of containers and accurate reception acknowledgments are systematically updated during the freight distribution. This allows for up-to-date distribution routes and track record of medicines, verifiable location, and assets tracing at unexpected situations.

Compared to other comparable solutions [5-7], the proposed telematics system is seen as non-intrusive since it allows the couriers to be detached from the tasks associated with the recording of the loading and unloading of freight, and supports virtual intelligence to vehicles assisted with the ability to identify accurately a malpractice and have it reported in real-time to the CO autonomously. Any misplaced consignment is automatically registered and acknowledged where "lights" installed at the vehicle's carriage room (connected to the "embedded system") respond; a red light in case of failure and a green light otherwise.

Typically, couriers use Smartphones (no cost increase). Making use of the integrated Bluetooth technology (typical ranges of 10 meters) and a computer engineering solution (described in Section 4) the "embedded system" communicates to the Smartphone. This provides immediate up-to-date freight distribution information and stage progression to moving couriers who are warned in case of inaccuracies. Only the latter is immediately (real-time) reported to the CO via GPRS, Fig. 1. In addition, the intelligent system indicates which containers must be either collected or dispatched at the upcoming destinations. Once the freight distribution is completed, data is reported to the CO upon arrival, where WiFi is used for the communication exchange. The data is accordingly recorded in the developed "control software solution" for further analysis; this is introduced in Section 4.3.

Using existing Global Positioning System (GPS) technologies, an Assisted GPS (A-GPS) receiver, Fastrax IT310 [8], is connected to the hub of the "embedded system" for traceability, monitoring and itinerary predictions. The "embedded system", in addition, includes a variety of atmospheric sensors inside the vehicles to monitor and control the temperature, pressure and humidity of medicines; this is significant to preserve medicines in good conditions.

3. THE RFID SYSTEM

To meet the EU Governments strive for ensuring reasonable finances and fiscal sustainability in health care [9], the use of consistent and reusable (for economy and permanent tagging) containers for the transportation of goods is essential. This creates a perfect scenario for the attachment of RFID tags needed for the intelligent delivery of medicines to end customers.

The RFID system encompasses two basic communicators, a reader or interrogator and a tag or transponder. Specifically designed low-cost antennas for the application (reader and tag) are presented in the next sections; inexpensive antennas play a key role for maintaining a low-cost intelligent system.

3.1. **The RFID transponder design**

Certain materials pose challenges to passive RFID tagging, for instance metallic objects cancel electric fields and liquids absorb electromagnetic waves. In both cases passive tag antennas may not receive sufficient power to excite the RFID chip and suffer significant degradation in performance.

For use in this application, the UHF-RFID transducer should be thin, insensitive to detuning when attached to medicine containers, cheap, flexible, reliable and small in size (dimensions as low as 125 × 52 × 0.4 mm). A candidate tag has been presented in [10], Fig. 3, and has been filed as patent P40909GB. The tag was designed for optimum performance on the surface of any object, regardless of whether it is conductive or has high dielectric constant or loss, Fig. 4. This allows for read ranges close to the maximum quoted for a given system even when attached to the containers. For additional reliability, a Datamatrix (printed onto the tag label) can be used to complement the intelligent system in case of RFID failure. The tag is now customised to read at the 865.6-867.6 MHz frequency band using an EPC protocol

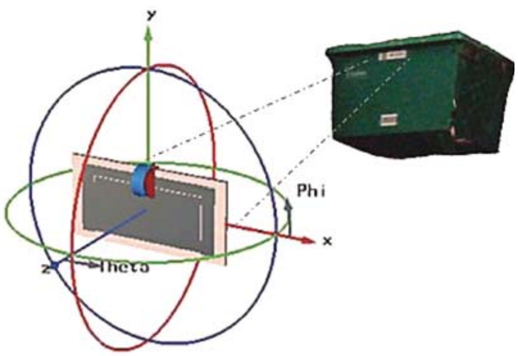

Figure 3

The RFID tag attached to the container

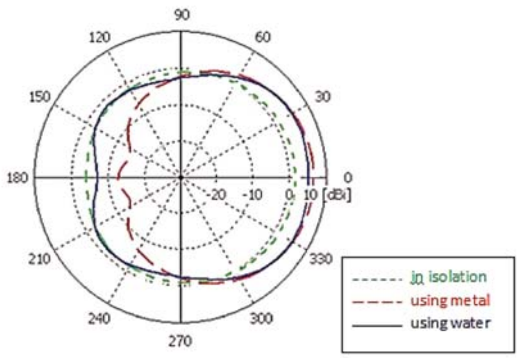

Figure 4

Simulated radiation pattern of the tag

for the air interface and has 4.3dBi directivity. A reading range of 2m using a 500mW reader was measured on all mounting surfaces (i.e.: metal and water container) in the laboratory environment and is adequate for the dimensions given by the vehicle.

3.2. **The RFID interrogator design**

The RFID interrogator was located inside a vehicle. An RFID Mercury5e development kit (DVK) from ThingMagic [11] was used as a base for the experiments. The DVK uses the UHF 865.6-867.6 MHz frequency band, provides a maximum power of 30dBm and a -65dBm receiver sensitivity; this is in accordance to the European Union regulatory body ETSI [12].

UHF is the preferred broadcasting approach to provide an effective interrogation zone as it is less restricted by line of sight compared to other higher bands. It supports ranges longer than those supported at other available low frequencies. To provide optimal interrogation zones within vehicles, interrogator antennas were designed and the strategic location inside the vehicle identified. Initial predictions using commercial software Zeland IE3D, based on the method of moments (MoM), indicated that an interrogator antenna, described in Section 3.3, is preeminent when located in the middle of the ceiling inside a vehicle.

The MoM was preferred over a Ray Tracing technique [13] since the first method accounts for any possible antenna performance deviation when implemented in a realistic scenario.

3.2.1. *The antenna development*

To meet with the demands of the RFID interrogator introduced in Section 3.2, and the economical constraints placed on the telematics system, Section 1, a customized interrogator antenna is preferred over commercially available antennas, and is introduced.

Among the devices that are capable of transmitting and receiving electromagnetic waves efficiently, miniature printed-planar inverted F antennas (PIFAs) are in great demand due to their relatively low profile design, easy fabrication, and low cost [14]. Typically, high gain antennas imply larger sizes when compared to less bulky but nevertheless efficient low profile antennas.

Presented simulated results indicate that optimized antennas having gains of 2dBi (measured at 1.92:1 VSWR) are adequate for in-vehicle applications. They can deliver a sufficient radio propagation field (within an interrogation zone) inside a vehicle, having a complete shield carriage room of $1.8 \times 2.6 \times 1.4$ m^3 with maximum power budget, Fig. 5; this assumes full power transmission at the transceiver [11]. The antenna interrogator was set in the middle of the ceiling of the car as a preferred location in vehicles [15]. This ensures good power distribution to likely RFID tag locations within the car while minimizing field exposure to the occupants (those assisting in the inventory distribution of goods). Antennas inside a metal shielding can in theory confine the antenna's radiated power within the car body with no power loss, no Doppler shift on moving vehicles. The power strength seen at the boundaries of the room, Fig. 5, guaranties RFID field coverage in all the corners of the vehicle.

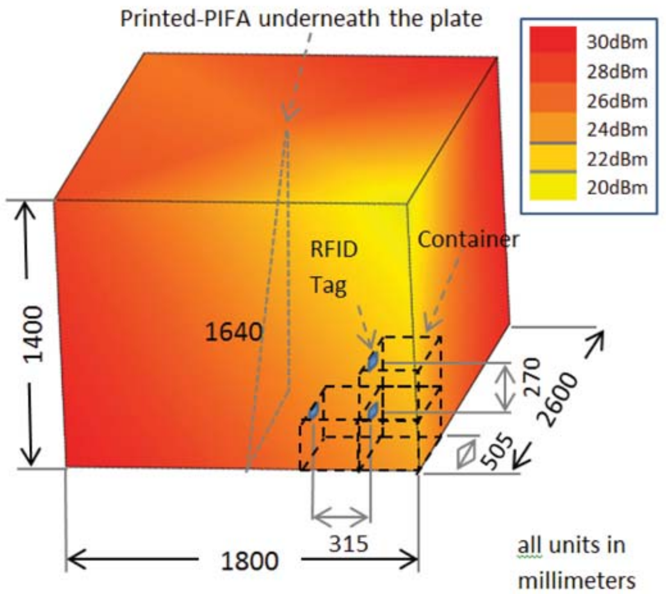

Figure 5

Received power at the boundaries of a car body

Directly printing (i.e.: electrically conductive paint) antennas onto suitable surfaces are encouraged as a desirable approach to provide relaxed and relatively inexpensive mass-produced antennas.

In addition, antennas that can be straightforwardly sprayed onto the coating of a vehicle body would further simplify the fabrication and costs; this is exciting to the automobile industry and for use in this application.

Owing to the reduced costs that are mainly achieved by the easy manufacturing process and the reduced amount usage of paint composite (i.e.: copper) needed for the deposition of the electrically conductive elements of the antenna, directly printing a radiator over the car body seems to be an efficient method for realizing a cheap antenna prototype. Recent advances in electrically conductive paints [16] can provide adequate sheet resistance for the development of cost-efficient antennas. Among the most remarkable conductors, silver and gold- based inks are expensive; copper is a more cost-balanced solution while providing a better electrical conductivity than gold. Other cheaper inks, such as aluminium and nickel can be used at a compromised performance.

The geometry of the proposed sprayed antenna (paint substrate 2mm) design is presented in Fig. 6. It depicts a relatively simple structure that enables easy fabrication.

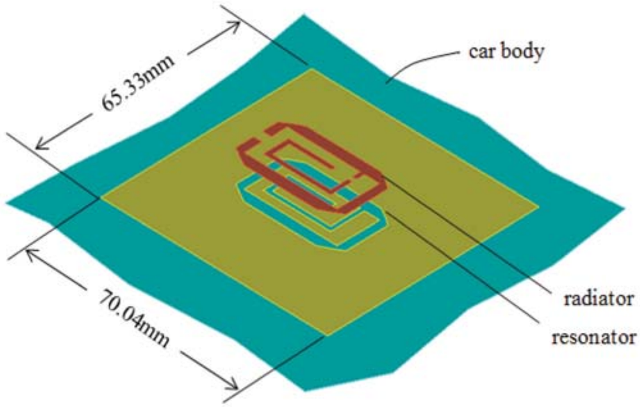

Figure 6

The miniature antenna design printed onto the car body

The antenna can easily be fed via-through a metal plate of the car body. The practical miniature antenna design is designed to be directly patterned onto the car body inside the carriage room of a van and is suited for use in radio frequency identification networks using the unlicensed RFID sub-band b2 (865.6-867.6 MHz) of the ETSI standard [12]. Because the antenna can be sandwiched in between paint layers, this can favour hidden antenna applications. In return, there would be no immediate information of the antenna interrogator location. Simulated results predict an antenna having a bandwidth of 2MHz (with tailored rejection to unwanted neighbouring frequencies) measured at the -10dB reflection coefficient and a 2dBi gain (this is a 46% radiation efficiency) when using copper ink. Recent studies show a similar performance using silver and a lower efficiency antenna using other conductive paints such as nickel [17]; copper is therefore the preferred ink for the antenna application. Radiation patterns having 60° beamwidth for both the azimuth and elevation planes are expected to positively contribute to effective radio coverage over the required interrogation zone; this directional antenna characteristic can be useful for in-vehicle applications [18] where the optimised pattern enhances the system coverage inside the vehicle, Fig. 5.

The results indicate an optimal radio propagation performance with potential reading range for the application; Multipath present in the enclosure (vehicle) is conjectured to have contributed positively.

In Multipath scenarios, the RFID interrogator antenna receives a direct component when the tag is directly visible and a great number of echoes with different amplitudes, phases and random arriving times otherwise [15]. Due to the expected reflections in Multipath, the tags are likely to be seen by the interrogator for any possible antenna orientation and Section 5 corroborates that all the tags were read.

4. THE COMPUTER ENGINEERING SOLUTION

A ubiquitous computer engineering solution aimed at supporting the necessary components of the intelligent system architecture of Fig. 1 is given in this section. For the solution, the embedded system set-up and related software control is subsequently explained.

In addition, a developed mobile application (designed for the Smartphone) and control software solutions (for governing the CO) are respectively given in Sections 4.2 and 4.3. Both, the mobile application and the control software are seen as relatively cheap solutions since they are deployed on typically encountered computers (handsets and desktops).

4.1. **The hub of the embedded system**

The hub of the "embedded system", Fig. 7, is given by a common shared commercially available stand-alone computer-on-module IGEPv2 from ISEE [19] and utilises existing interfaces to provide connectivity to the WiFi, the open-and-close of the vehicle´s door and control of the "lights" (using the General Purpose Inputs and Outputs (GPIOs)), the RFID, the GPS, and the Bluetooth (using the Universal Asynchronous Receiver Transmitter (UART)).

Other commercially available development kits might be used, however, the above was carefully chosen for its suitability and moderate cost. Specific embedded software was implemented to control the hub interfaces, Fig. 7. The solution is responsible for the

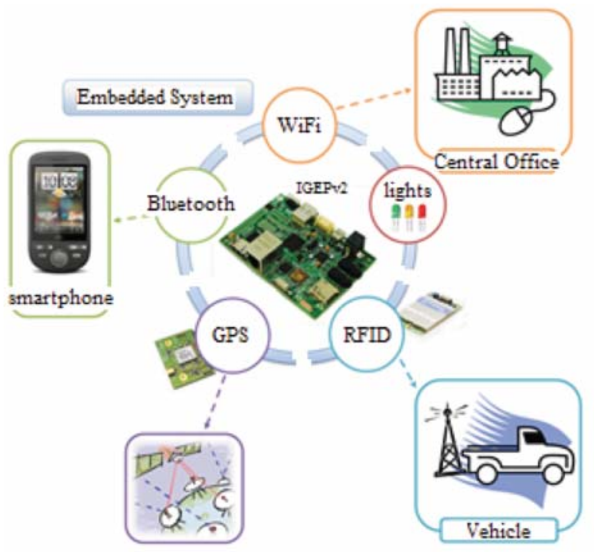

Figure 7

The "embedded system" hub

control of the intelligent system with responsibilities already described in Section 2 and allows for the data compilation of the “track and trace” in an XML file format; any assigned itinerary is download and encapsulated in the XML. The proposed mobile application is next introduced.

4.2. **The Mobile application**

The mobile application has the responsibility for presenting update data information regarding the containers and the prospective itinerary on the handset screen. For the realization, a Service-Oriented Architecture (SOA) is proposed; this provides maximum functionality distributed over a main server at the CO. Distributed Simple Object Access Protocol (SOAP) messages (text commands), based on the Extensible Markup Language (XML) syntax are sent across the Internet using Hypertext Transfer Protocol (HTTP); this allows relieve capacity processing for the terminals (Smartphones) accessing the logic of the control software solution, Section 4.3, in the CO via “web services”.

Even the market changes rapidly, at present smartphones are being customized on Android “software stack” solutions. For this reason, the Android’s mobile operating system, based on Linux kernel, is used for the solution and the resulting application design is presented in Fig. 8.

Following the establishment of a journey route, the Smartphone, receives the necessary data (via Bluetooth) for the predicted journey (efficient distribution of medicines), including: distance, duration, stopovers (pharmacies), addresses, and further information. At stopovers, EPCs containing detailed data of every container are downloaded and sent uplink for processing; the data is accessible via the mobile application interface, Fig. 8.

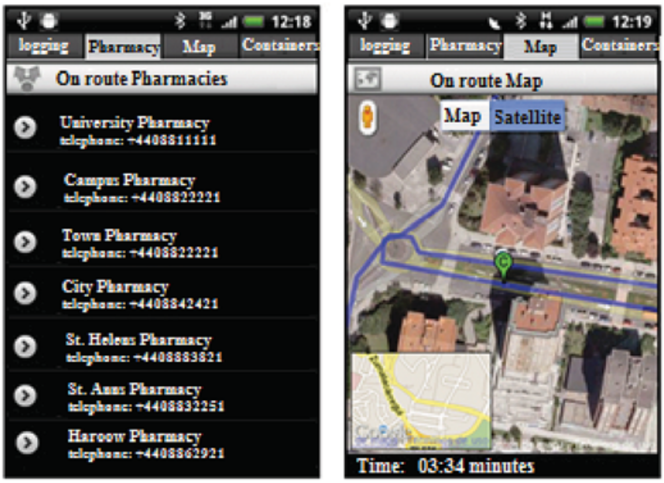

Figure 8

Mobile application interface

Among the potential functionalities of the mobile application are the management of incidences and the navigation assistance. These are described next.

4.2.1. *The management of incidences*

The management of incidences is responsible for the control of activities and warning of possible failures during transportation; this includes variations in the estimated time of a journey and left-behind containers. The alerts are sent to the courier (Smartphone) and the CO via GPRS.

In the system architecture, we assumed a 210% deviation in the estimated time, or any mislead container, for the system to automatically report an incidence. The warning alerts provide with the most recent number of containers; this leads to an improved QoS transport distribution system.

4.2.2 . *Navigation assistance*

The navigation assistance (uses Google Maps) is responsible for the alert warnings between the vehicle and the CO and is feasible using Bluetooth and GPRS, Fig. 7. It uses the Smartphone to provide the courier with any possible variation in the scheduled delivery immediately and assists the courier with real time and diverge routes (when necessary) and first-hand stopovers; and was highly accepted by the drivers.

4.3. **Control software solution**

The control software solution was developed for the monitoring and tracking of assets and centralised at the CO. It comprises the development of a control panel (web application), Fig. 9, with the following functionalities.

1. *The traceability of medicines*: The traceability system comprises a robust database with stored data information of the freight.
   This includes the distribution itinerary, the dispatch location, the batch number and the expiry date of nomadic containers at anytime/anywhere.
2. *Fleet management & optimization*: The fleet management system provides trace and tracking of moving vehicles using a web-map, Fig. 9. The computed routes with corresponding times (including stopovers) are recorded to assist in the prediction of appropriate time intervals for successive freight distributions. This leads to optimized routes with improved delivery time, traffic monitoring and a preventive transport distribution.

The architecture of the control software solution and corresponding architectonic layers (presents a modular arrangement prepared for ease reuse, minimize coupling

Figure 9

Web application interface at the Central Office

and prospect functionalities) is given in Fig. 10. The technical features of the layers are detailed next.

1. *Business and service layers*: This module contains the logic (treats and manages the routes) of the traceability of medicines and the fleet management. In addition it manages and give the necessary permissions (i.e.: user/password) to likely users at the vehicle and the CO, and makes use of the Google Maps Javascript API external services, Fig. 10, to provide with the itineraries.
2. *Persistence data layer*: "Microsoft SQL Server 2008" was used for the data storage of the applications related to the intelligent system. The data is stored at the completion of the entire transport distribution by generating the necessary entries in the Database Management System (DBMS) of the server. An XML file is automatically generated and sent from the "embedded system" hub to the main server at the CO. The file includes both, the completed itinerary of the vehicle and any detected incidence.
3. *Communications layer*: The communications layer utilises "web services" to retrieve the data (system information) as provided by the DBAccess, Fig. 10. The latter was developed using Windows Communication Foundation (WCF) technology. This ensures a high security, scalability and interoperability, and enables the access to the Persistence data and the Business (the logic) layers. Access to the control software solution is similarly made using a TCP sockets gateway operated by the communications layer; this enables XML files (with complete routes) to be driven via File Transfer Protocol (FTP).
4. Web presentation layer: A user-friendly graphic web application, Fig. 9, offers an easy use tool with unnecessary programming expertise. The application is aimed

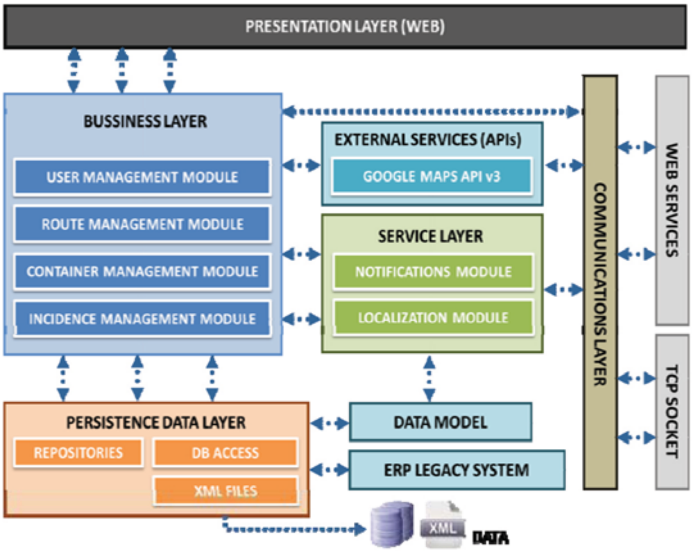

Figure 10

The control software solution architecture

for use in contemporary computers and is intended to be accessible worldwide via the Internet.

The control panel (web application) is based on the asp.NET development framework, and makes extensive use of the latest technologies for the Rich Internet Application (RIA).

The technologies include JavaScript, CSS3, HTML5, Ajax and jQuery, along with several tools offered by Google for the processing and display of the geo-spatial positioning of vehicles.

5. SYSTEM VALIDATION

As part of the evaluation of the system, the following set-up was arranged. The complete “embedded system” was installed inside an own vehicle, and the “mobile application” and “control software solution” debugged respectively in the Smartphone and the computer at the back-end of a CO.

The arrangement was made and vehicles run their daily itineraries (a real case) with arbitrarily distributions depending on pharmacy requests. A vehicle distributed a total of 97 containers [20] (dimension 665 × 415 × 315mm) along the distributed routes (26.4km total when all the pharmacies were covered) and was made 1-3 times/day, independently to the diverse destinations. The average time for a complete distribution was 1h-37min and the total number of stopovers (pharmacies) was 1-12. For consistency, the measurements were repeated over 6 consecutive days. The validation process was made gradually with the following progressions. First, the “track and trace” scheme was validated by successfully retrieving the data information of a previously recorded positioning of the moving vehicle in an XML file; for the test, software was implemented in the “embedded system”, Section 4. The resulted XML file provided with the necessary information to characterise uncovered areas of the GPS and the optimised location of the end customers (pharmacies). Second, the freight identification was validated by confirming the total number of containers contained inside a vehicle (non-intrusiveness to the courier was met). During the vehicle halts (pharmacies), the hub of the “Embedded system” received the XML file containing the number of containers that remained inside the vehicle; only once a single mislead was encountered and was due to a faulty tagged container. Finally, the complete solution as a whole was validated. In this case, the experiments were performed 3 times/day, were using the previous set-up and repeated for 2 days for consistency. For the first 2 attempts, the courier was given corresponding instructions to spot for any improper distribution of the freight; no discrepancies were seen as compared to the proposed system functionality. From the results, the system showed no misplaced consignments during the freight distribution; this was indicated (in green) by the “light” installed in the vehicle’s carriage room. For the 3^{rd} attempt, the XML file containing the itinerary was intentionally modified with the following inaccuracies: a wrong order, a misplaced container, and a wrong delivery; this was done intentionally to gain credibility in the results. All inaccuracies were tracked and subsequently received at the CO (on screen). There was no apparent delay in receiving the messages; however, the time response required by an operator (for misleads during the loading and the freight distribution) at the CO was not seen as a great impact when compared to the effectiveness in using the proposed system.

6. SUMMARY

A relatively cost-effective telematics system for the intelligent transport distribution of medicines has been presented. The solution meets with the European Community regulations and standards for the traceability, secure delivery and healthy handling of medicines. The proposed system was detailed and experimentally validated and is currently deployed in a Small and Medium Enterprise (SME) pursuing the urgent delivery of medicines.

The intelligent system exploits existing communication technologies and original software developments to provide an inexpensive solution. Advanced antennas were designed to further reduce the total costs of the system. For the validation, the intelligent system was set-up (using commercially available antennas) and tested accordingly.

The medicines were traced over a prearranged transport distribution itinerary showing no apparent disconformities; this verifies the system and validates the advanced hardware and software developments.

A future development will see us design cost-effective and advanced intelligent systems to automatically broadcast update distribution plans between a central office and a vehicle and with the capability to trace individual medicines that are packed inside a container (i.e.: Datamatrix which is at present cheaper than RFID tags). Inexpensive RFID tag antennas (including the transducer chip) can guarantee the solution.

6. ACKNOWLEDGMENTS

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7. REFERENCES

[1] Huang, G.Q, Zhifeng Qin, Ting Qu, Qingyun Dai, "RFID-enabled pharmaceutical regulatory traceability system", *IEEE International Conference on RFID-Technology and Applications (RFID-TA),* pp. 211, 17-19 June 2010.

[2] "Commission Directive 2003/94/EC of 8 October 2003 laying down the principles and guidelines of good manufacturing practice in respect of medicinal products for human use and investigational medicinal products for human use", *Official Journal of the European Union*, ISSN 1725-255, L 262, Volume 46, 14 October 2003.

[3] "Medical Device Regulations: Global overview and guiding principles", World Health Organization WHO Library, ISBN 9241546182, 2003, available [online], http://www.who.int/medical_devices/publications/en/MD_ Regulations.pdf

[4] C. Merloni, L. Carettoni, S. Zanero, "Studying Bluetooth Malware Propagation The BlueBag Project", The IEEE Computer Society, pp. 1-25, 2007.

[5] Jedermann, R., Lang, W., "The Benefits of Embedded Intelligence - Tasks and Applications for Ubiquitous Computing in Logistics", *International Conference on The Internet of Things IOT,* LNCS 4952, pp. 105-122, Springer, Berlin, 2008.

[6] Snow, J., "Guidelines for the Storage of Essential Medicines and Other Health Commodities", World Health Organization and U.S. Agency for International Development, 2003.

[7] Trebar, M., Grah, A., Alvarez Melcon, A., Parreno, A; "Towards RFID traceability systems of farmed fish supply chain", *IEEE 19th International Conference on Software, Telecommunications and Computer Networks (SoftCOM),* pp. 1-6, Nov. 2011.

[8] Fastrax Corporate [online] available at http://www.fastraxgps.com/showfile.cfm?guid=840b6b1b- be4e-43c8-9359-34dd8216d4d7

[9] Thomson, S., Foubister, T., Mossialos, E.; "Financing Health Care in the European Union, Challenges and Policy Response", *Observatory Studies Series*, No. 17, WHO Regional Office for Europe, 2009.

[10] Ziai, M.A., Batchelor, J.C., "Thin Ultra High- Frequency Platform Insensitive Radio Frequency Identification Tags", *IET Microwaves, Antennas & Propagation*, Vol. 4, Issue 3, pp. 390-398, 2010.

[11] ThingMagic Corporate [online] available at http://www.thingmagic.com/embedded-rfid-readers/mercury5e/1-embedded-rfid-readers/3-mercury5e [12] Technical Report Electromagnetic compatibility and Radio spectrum Matters (ERM); Part 2 ETSI TR 102 644-2 V1.1.1 (2009-03).

[13] Zhijun Zhang; Sorensen, R.K.; Zhengqing Yun; Iskander, M.F.; Harvey, J.F.; "A ray-tracing approach for indoor/outdoor propagation through window structures", *IEEE Transactions on Antennas and Propagation*, Vol. 50, Issue: 5, Page(s): 742-748, 2002.

[14] I.J. García Zuazola, J.C. Batchelor, "Compact multiband PIFA type antenna"; *IET Electronic letters*, vol 45, Issue 15, Page(s): 768-769, July 2009.
[15] I.J. García Zuazola, J.M.H. Elmirghani, and J.C. Batchelor, "High-speed ultra-wide band in-car wireless channel measurements"; Communications, IET, Volume 3, Issue 7, Page(s):1115-1123, July 2009.
[16] Applied Nanotech Holdings, Inc [online] available at http://www.appliednanotech.net/tech/inkjettable_metallic_i nks.php
[17] A. Koptioug, P. Jonsson, T. Olsson, J. Sidén, M. Gulliksson; "On the behaviour of printed RFID tag antennas, using conductive paint", *Proceedings of Antenn-03*, Kalmar, Sweden, 2003.
[18] Hovinen, V., Hamalainen, M., Patsi,T., "Ultra wideband indoor radio channel models: preliminary results", *IEEE Conference on Ultra Wideband Systems and Technologies*, Wyndham Baltimore Inner Harbor. Baltimore, Maryland USA, pp. 75-79, 21-23 May 2002.
[19] ISEE Corporate available [online] http://www.igep-platform.com/index.php?option=com _content&view=articl e&id=46&Itemid=55
[20] Commercially available containers, available [online], http://media.ssi- schaefer.de/fileadmin/ssi/documents/navigationsbaum/lager n_und_foerdern/kaesten_und_behaelter/produkte/nestbare_ behaelter/englisch/nesting_storage_containers_kmb_00_a_ en.pdf

Conferencias

Towards an improved RFID anti-collision algorithm

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Abstract

RFID is an emerging auto identification technology that provides great features to ambient intelligence environments. It poses a number of research challenges such as interference decrease, security over the RF channel and throughput increase. When there are more than one tag responding to a reader, a collision can occur decreasing system's throughput. That is called "the tag collision problem". This problem is going to be analyzed in order to optimize system throughput. Reducing the total number of collisions, average throughput can be improved, and power consumption decreased. Thus, main anti-collision algorithms are presented and analyzed.

Keywords: RFID, passive tag, anti-collision algorithm, tag collision.

1. INTRODUCTION

A radio frequency identification system (RFID) is an auto identification method that reads codes stored into small tags using radio frequency waves (RF). The main idea of this technology is to attach a tag to the objects that want to be monitored and identified without an existing line of sight.

This technology fits very well into ambient intelligence philosophy which is a model of human-computer interaction. This paradigm is also described as ubiquitous computing and it could be defined as "machines that fit the human environment instead of forcing humans to enter theirs". If every object in the world is tagged, everything could be identified, creating tremendous benefits in a very different kind of applications like traceability of goods, baggage management, livestock tracking, and supply chain management. This fact made RFID a unique technology making ubiquitous identification possible.

RFID is increasingly being used as an auto identification (autoID) technology and is coexisting with actual technologies like bar codes. RFID not only has the same functionality as bar codes but also improves it as well. It does not require human intervention to scan an object and RFID tags have much more storage memory (64 bits, 96 bits and some kind of tags have more) than bar codes. As passive tags are much cheaper than actives and do not use batteries they are spreading in tracking and controlling applications.

In this document a survey of RFID anti collision algorithms is presented with the main objective of improving one of the methods to get a better performance on its execution. This is going to be performed analyzing different algorithm behaviours and developing a new algorithm that minimizes the main problem presented in the next section. The rest of the document is organized as follows: Section 2 defines RFID technology and what the research question is. Section 3 describes the existing solutions for that question. Section 4 presents work done and research objectives and Section 5 contains conclusions.

2. RFID TECHNOLOGY CHALLENGES

An RFID system is composed of three main components (Finkenzeller-2003):

- One or more tags, also known as transponders. These include a microchip and a patch antenna and are attached to the objects to count or identify. Tags can be active or passive. Active tags are battery powered. Passive tags obtain power from reader's signal and their main purpose is to store data and communicate with the reader. They need a stronger signal from the reader and answer weaker than active tags reaching less distance.
- A reader or transceiver. This device is made up of an RF module, a control unit and one or more antennas. It offers a bidirectional communication with tags, a basic processing of the received information from them and data transfer to external subsystems.

— A data processing subsystem. Connected to the reader, it can implement a final application or store identified tags into a database.

With RF signals, RFID sends energy to tags and in the meanwhile, each tag answers their unique identification code (ID) backscattering those signals. The reader collects that information and sends it to the data processing subsystem.

2.1. **The Research Questions**

RFID systems allow multiple configurations. The coexistence of more than one reader or more than one tag with the same identification zone leads to some problems known as "the reader collision problem" and "the tag collision problem" (Yang et al.-2010).

When reader's interrogation zones intersect can interfere with one another. Interference detected by one reader and caused by another one is referred to as reader collisions (Engels & Sarma-2002). On the other hand, "the tag collision problem" occurs when there is one reader and more than one tag. As all tags transmit in the same channel, an arbitration method must be used. Otherwise without any coordination, collisions may occur and messages from different tags may cancel each other out at the reader. That leads to a retransmission of tag IDs, which results in a loss of bandwidth and an increase of delay in identifying all the objects. To avoid it, a multi-access protocol is needed. It can be defined as a special case of multiple access communication problem, but anti-collision protocols that solve network collisions cannot be directly applied to "the tag collision problem" (Abraham et al.-2002). There are various constraints which make this problem unique:

— Power source: Passive tags do not have batteries so they need to be powered by reader's signal.
— The number of tags is unknown.
— Tags cannot communicate with each other. The reader has to control the collision resolution process.
— Limited capabilities and memory of the tags. Therefore the resolution protocol has to be simple.

Various multi-access procedures have been developed in order to separate the individual participant signals from one another in the same channel. There are three different procedures:

— Space Division Multiple Access (SDMA): These techniques reuse channel capacity in spatially separated areas. In RFID, it can be used with an electronically controlled directional antenna on the reader. It points the beam at different zones to be read.
— Frequency Division Multiple Access (FDMA): These techniques split up the transmission channel into different carrier frequencies that are simultaneously available. In RFID it can be used with tags that have a freely adjustable harmonic transmission frequency.

— Time Division Multiple Access (TDMA): These techniques use the entire available channel divided between the participants chronologically. In RFID are the most used techniques.

3. TIME DIVISION MULTIPLE ACCESS ANTI-COLLISION TECNIQUES

In RFID systems, TDMA procedures are the largest group of anti-collision methods. There are two main types of protocols in RFID: Aloha based protocols which are probabilistic and Tree based protocols which are deterministic.

3.1. **Aloha Based Protocols**

Aloha is a probabilistic communication protocol that is the origin of all these protocols. It has evolved into slotted-Aloha where time is divided into slots and improves its throughput. After that, framed-slotted-Aloha (FSA) is developed. In FSA all nodes must respond choosing a slot into a fixed length frame (a group of slots). As the throughput of the FSA decreases with the increase of the total amount of nodes, a dynamic- framed-slotted-Aloha (DFSA) is developed. This one changes length of the frame on each read cycle adjusting to the aumount of tags at any time. Because of the probabilistic nature of Aloha based protocols, a specific tag may not be identified for a long time, what is called “the tag starvation problem”. DFSA doesn’t work properly when tag population is larger than the maximum frame size available, becouse DFSA’s frame size is bounded. Enhanced DFSA (EDFSA) is developed to solve that problem. The main Aloha based algorithms applied to RFID are: I-Code and Q algorithm.

— *I-Code:* It is based in framed-slotted Aloha (FSA) concept. Reader transmits a command with the data requested (what determines the size of the slot), a random number for the tag to select a slot position and the frame length (Vogt-2002). Then tags start answering data requested in their selected slots. With the information of the slot population, the reader estimates a new frame length and chooses the optimal from specific ranges that have been found on experiments. This is a fast algorithm that doesn’t guarantee the detection of all the tags on each run.
— *Q algorithm:* EPC Class1 Gen2 protocol adopts a variation of DFSA algorithm, the Q algorithm (EPC Global-2008). The main difference with DFSA or I-Code is that Q algorithm is slot based, so the total length of the frame is calculated on each tag answer. Q algorithm uses 16 bits random numbers (RN16) instead of sending the tag IDs on each slot which improves security, privacy and reduces considerably the amount of transmitted bits. What makes this algorithm dynamic is the Q parameter. It is updated on each tag response and determines the length of the new frame (2^Q) used by tags to arbitrate their answers. Q is increased with a collision response or decreased with a success response. Also, slot duration is controlled by the reader and it doesn’t depend on any synchronized clock. Thus, the reader makes a slot finish its duration when the slot is empty, and makes the

next slot start for reducing the waste of time caused by the empty slot occurring in the middle of a frame. An enhancement of these methods is proposed by (Kim & Kim-2011) where tags are divided in groups to improve throughput when the population is bigger than the maximum frame available.

3.2. **Tree Based Protocols**

The main characteristic of this kind of protocols is that all tags in the reader's interrogation zone will be identified. These protocols usually have low complexity tags and work well with uniform set of tags but are slower than Aloha based protocols. The most known algorithms are: the Tree Algorithm, Query Tree (QT) and Bitwise arbitration (BTA).

— *Tree Splitting:* It uses a virtual tree to organize and identify each tag (Hush & Wood-1998). The reader starts identification, and all tags send their IDs. On each tag collision, the algorithm splits the set of tags in B subsets (B > 1). These subsets become increasingly smaller until they contain one tag. This algorithm doesn't need clocking circuitry but they must maintain a counter, so if a tag get discharged, it loses cycle information. En enhancement of this algorithm is the Adaptive Binary Tree Splitting (ABTS) by (Myung et al.-2006) where it reduces not only collisions but also unnecessary idle slots with an additional counter.
— *Query Tree (QT):* Proposed by (Law et al.-2000). Reader starts arbitration sending a query (q). Tags matching that 'q' answer the reader. When a collision occurs, the reader adds 1 or 0 to q, obtaining 2 new querys (q1, q0) per collision and sending each at a time. In case of a single tag response, tag is identified and it will not respond until a new inventory round. The process need to go through all the possible *q*'s to detect all the tags.
— *Bitwise arbitration (BTA):* These algorithms operate requesting tags to respond bit by bit. ID-Binary Tree Stack (ID BTS) by (Bo-2006) uses a binary tree which height is the maximum tag ID. A path from the root node to a leave node represents each ID and using a stack the reader can store tags position on the tree. Another algorithm proposed by (Kim et al.-2007) is Bit Query (BQ) where tags answer to a query sent by the reader with their next adjacent bit to the requested prefix. If a tag answers successfully, the reader continues with that bit into the query, and if not it changes to a '0' bit. Then the algorithm will come back to that node and change query to a '1' bit continuing the identification process.

3.3. **Hybrid Protocols**

Combining advantages of Tree and Aloha, some protocols have been proposed that try to fully exploit their performances. There are mainly two kinds of this combination. One is using randomized divisions in tree- based algorithms and another is using tree strategies when a collision occurs in Aloha-based algorithm.

— *Aloha in Tree based:* Proposed protocols in this category are Tree Slotted Aloha (TSA) developed by (Bonuccelli et al.-2006) which uses a tree structure but in each node response tags are sequenced in slots as in a FSA. Query Tree Aloha by (Shin et al.-2007) that sends a prefix and a frame size to tags, and those that match the prefix answer using FSA. In (Namboodiri & Gao-2007) three Hybrid protocol are introduced: Multi Slotted (MS) that uses multiple slots per query to reduce collisions, Multi Selective Sleep (MSS) that sleeps identified tags of the previus protocol and the MS with Assigned Slot (MAS) which assigns slots in a query frame.
— *Tree in Aloha based:* Protocols proposed in this category are Framed Query Tree by (Shin et al.-2007) where the reader transmits a frame to tags and they choose a slot randomly. Within each slot, QT is used to identify tags. In (Eom & Lee-2007) Framed Slotted Aloha based is presented. The difference with FSA is that when tags are collided in a timeslot, the reader resolves the collision using Tree Algorithm. (Makwimanloy et al, 2011)

4. RESEARCH OBJECTIVES

Related to this research area, some RFID work has been done for 1 year in Mobility research group from DeustoTech. One of the topics of this research has been the traceability of medicines making drug containers ubiquitous by attaching them passive RFID tags on each (Moreno et al.-2011). Some identifying tests have been done in different scenarios to analyze different aspects of RFID taking advantage of the passive tags benefits: their low-prize, the absence of battery, their long useful life and their small size.

Moreover, this research is gradually becoming more focused on the algorithms showed in the previous section. Each anti collision algorithm has its pros and cons and the research is being focused on improving some aspects. While the ultimate aim of a multi-access protocol is to increase throughput, minimize packet delay and improve stability, RFID collision resolution algorithms are focused on reducing total tag identification time and consumed power. Aloha based algorithms are used when there are not many tags in the interrogation zone because of the increase in the probability of collision, what decrease their speed. However, they are very popular in applications with few tags. On the other hand Tree based algorithms are much more effective when the number of tags is large.

Both types of algorithms have been researched extensively. One of the most important research issue in Aloha based is in DFSA algorithm estimating the frame size so that it improves its speed in large groups of tags because the throughput of these algorithms is maximum when frame size equals the number of tags. Nevertheless, further research is needed to reduce their tag and reader complexity and requirements. In case of tree based protocols, QT simpler tag designs are an advantage but when tag ID’s size increases this issue becomes critical. Hybrid protocols are becoming very popular, and an interesting research direction is determining which combinations have a better behaviour in power consumption, average throughput, number of slots and identification time. To perform this, comparisons between specific algorithms have to be done as in (Bagnato et al.-2009). So each of the algorithms implemented must be compared with existing ones on the same conditions.

5. CONCLUSION

RFID is increasingly being used as an autoID technology because it fits very well into ambient intelligence philosophy. It is a unique technology that makes ubiquitous identification possible. Due to the restrictions imposed by passive tags such as low complexity and inability to communicate with each other, readers should take the brunt of anti-collision algorithms. These should improve some aspects like average throughput, power consumption, identification time, reliability and scalability.

The main objective of this starting research is to make a survey of different anti-collision algorithms to develop a solution for "the tag collision problem" improving some of the weaknesses of existing ones. If the total number of collisions is reduced, average throughput will be improved, and power consumption and identification time will be decreased. So as to reduce collisions estimation methods must be analyzed too and then an anti collision algorithm that matches application needs should be developed taking advantage of existing ones.

REFERENCES

Book

EPC Global, 2008. *EPC™ Radio-Frequency Identity Protocols Class-1 Generation-2 UHF RFID Protocol for Communications at 860 MHz – 960 MHz Version 1.2.0.*

Finkenzeller, K., 2003. *RFID Handbook: fundamentals and applications in contactless smart cards identification*. John Wiley. New York, USA.

Journal

Kim, S. and Park, P., 2007. "An efficient tree based tag anti-collision protocol for RFID systems". *IEEE Commun. Lett*. vol. 11, pp. 449-451.

Makwimanloy, S. et al, 2011. "A Novel Anti-Collision Algorithm for High-Density RFID Tags". *ECTI Transactions on Electrical Eng., and Communications*. pp. 33-39.

Myung, J. et al, 2006. "Adaptive binary splitting for efficient RFID tag anti-collision". *IEEE Communications Letters*. Vol 10, no. 3, pp. 144-146.

Conference paper or contributed volume

Abraham, C. et al., 2002. *Inventory Management using Passive RFID Tags: A Survey*. Department of Computer Science, The University of Texas at Dallas. Richardson, Texas.

Bagnato G. et al., 2009. “Performance analysis of anti-collision protocols for RFID systems”. *Network Vehicular Technology Conference, 2009. VTC Spring 2009. IEEE 69ths*. Barcelona Spain, pp. 1-5.

Bo F. et al., 2006. “ID-binary tree stack anticollision algorithm for RFID”. *Proc. 11th IEEE Symposium on Computers and Communications*. Sardinia Italy, pp. 207-212.

Bonuccelli M. A. et al., 2006. “Tree slotted Aloha: a new protocol for tag identification in RFID networks”. *International Symposium on World of Wireless, Mobile and Multimedia Networks*. Niagara-Falls USA, pp. 603-608.

Engels, D. and Sarma, S., 2002. “The Reader Collision Problem”. *IEEE International Conference on Systems, Man and Cybernetics*. Vol. 3, pp. 6.

Eom, J. and Lee, T-J., 2007. “Framed-Slotted ALOHA with Estimation by Pilot Frame and Identification by Binary Selection for RFID Anti-Collision”. *ISCIT ‘07. International Symposium on Communications and Information Technologies*, pp. 1027-1031.

Hush, D. and Wood, C., 1998. “Analysis of tree algorithms for RFID”. *IEEE Symposium on Information Theory*, pp. 107.

Kim, S. and Kim, S., 2011. “An enhanced anti-collision algorithm for EPC Gen2 RFID System”. *5th FTRA International Conference on Multimedia and Ubiquitous Engineering*. Loutraki, pp. 293-296.

Law, C. et al., 2000. “Efficient memory-less protocol for tag identification”. *Proceedings of the 4th International Workshop on Discrete Algorithms and Methods for Mobile Computing and Communications*. Boston, Massachusetts, USA, pp. 75-84.

Moreno, et al., 2011. “Easily deployable solution based on wireless technologies for traceability of pharmaceutical drugs”. *2011 IEEE International Conference on RFID-Technologies and Applications (RFID-TA)*. Sitges, Spain, pp. 252-258.

Namboodiri, V. and Gao, L., 2007. “Energy-Aware Tag Anti-Collision Protocols for RFID Systems”. *Proceedings of the 5th Annual IEEE International Conference on Pervasive Computing and Communications*. NY, pp. 1-14.

Shin, J.D. et al., 2007. “Hybrid Tag Anti-collision Algorithms in RFID systems”. *ICCS ‘07 Proceedings of the 7th international conference on Computational Science, Part IV*. Springer-Verlag Berlin Heidelberg, pp. 693-700.

Vogt, H., 2002. “Multiple object identification with passive RFID tags”. *Proceedings of IEEE International Conference on Systems, Man and Cybernetics*. Hammamet, Tunisia, pp. 6.

Yang, L. et al, 2010. “Revisting Tag Collision Problem in RFID Systems”. *39th International Conference on Parallel Processing*, pp. 178-187.

Intelligent Van Based on Wireless Technologies for Pharmaceutical Drugs Traceability and Incidences Reporting

A successful experience of using smart environments to resolve a real industrial need

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Abstract

This paper describes a telematic system based on an intelligent van which is able to trace pharmaceutical drugs over delivery routes from a warehouse to pharmacies, without altering the carriers daily tasks. The intelligent van understands its environment, including: its location, the assets and the predefined delivery route; and can report incidences to carriers in case of failure according to the established distribution plan. It is a non-intrusive solution which represents a successful experience of using smart environments and a RFID in a viable way to resolve a real industrial need.

Keywords: intelligent van, pharmaceutical drugs traceability, incidences reporting, non-intrusive, RFID, wireless technologies.

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I. INTRODUCTION

Pharmaceutical drug supply chain, from an economic and health perspective, requires controlling all stages of distribution: from drugs are produced in a laboratory until they reach the pharmacies. This requirement is reflected by the Ministry of Health and Consumption of Spain through the new Royal Decree of drugs traceability, redacted in accordance to Directive 2003/94/EC of the Commission of the European Communities [1].

Adapting to the changes required by regulation imposes severe changes in the business model of different actors involved in the pharmaceutical sector. Moreover associated costs are hardly feasible in a highly competitive industry where profit margins often are set by administration.

The features of the existing application scenario in drug delivery from the warehouse to the pharmacy carry particular difficulties. The huge competition between pharmaceutical distributors forces them to preserve a high quality service in terms of delivery time and reliability. Inside a market where all competitors are offering the same products at similar prices, service quality is a decisive factor because an incomplete or incorrect shipment can result in the loss of a client. These requirements fall on the carrier which is required to complete the route in minimum time without making any mistakes during delivery. For these reasons the need to deploy a system that meets the new regulations should be carried out through a system that does not complicate current tasks of carriers. The installation of a system that requires the carrier to use hardware devices such as handheld RFID readers or Datamatrix adds new tasks in a job already stressful enough. Generally, each route is conducted at least four times a day and a significant delay or wrong delivery often results in the loss of a pharmacy that changes of dealer. Therefore, the job of the carriers should be thoroughly reviewed to avoid mistakes and if they commit to define responsibilities. This scenario causes significant disagreements between staff transport and store.

This paper presents a system designed to adapt the distribution of drugs to the new regulatory environment that does not alter the behavior of workers involved in it. The onboard module in each delivery truck will collect all the information required for traceability without any interaction. Furthermore, this system is responsible for validating all actions which vary the cargo during development of a route by interfering with the activity of the carrier only if it detects a deviance with respect to planning.

This paper is divided into three main parts. Initially indicate the functional characteristics of the system presented, then be described in depth the container identification system inside a van and later detail the architecture of the modules necessary to provide intelligence to vehicles used. Finally through the conclusions will show the results of implementing the system in a real warehouse for distribution of pharmaceuticals in the north of Spain.

II. INTELLIGENT VAN

The intelligent container concept is not new in logistics and distribution processes. However the specific needs of the scenario corresponding to the distribution chain of medicines requires the development of a customized solution. Furthermore the high cost of RFID tags impedes implementation of such systems in real applications specially in scenarios with heterogeneus load [2]. The use of tags 13.56 MHz HF frequency range with limited reading distance, limit the identification of the packets to the moment they are loaded or unloaded. The proposed system uses long- distance UHF tags to know the vehicle cargo at any time.

Two of the main characteristics of this project are to control medical distribution all over the delivery route and to make carriers work easier among others. An intelligent system has been established introducing Radio Frequency Identification technology (RFID) in drugs distribution. This technology is optimal to know the traceability of all drugs delivered and facilitates the drivers to load and unload the cargo because if something goes wrong, the system will alert indicating the failure.

Focusing on the general process, in the beginning, automated medical dispense robots have to coordinate orders for each pharmacy. This system organizes all requested medicines in containers, and then all of them are sent to the dock ready for loading vans. There is a passive transponder attached to each container so its EPC code can be related to what drugs are on each container and the pharmacy destination for each one. Spanish law will allow the use of two technologies, Low Frequency RFID and DataMatrix for the identification of individual packages of medicines. A second phase of this project that will begin in the fourth quarter of 2011, will implement a robot that can dump the contents of a container and validate, based on identification technologies approved, the packaging of medicines contained within. Thus the system will meet the requirements of traceability required by law.

Fig. 1 shows the process flow indicating the communication established between the three main parts of the system: embedded platform (EMB PLA), mobile device (MOB DEV) and central server (CTR SRV). When the delivery van arrives at the warehouse, the embedded device installed on each truck is connected to the network of the warehouse via WiFi and is allowed to download from the corporative Enterprise Resource Manager (ERP), all the necessary information about the next route the vehicle must perform. This info includes the number of containers that must be loaded into the wagon and the Electronic Product Code (EPC) of each transponder attached to containers that have to be distributed along the route.

At this point, carriers start to load vans with their corresponding containers. An RFID reader module is located inside the van and each container has attached a passive tag so that it can detect each container that enters or leaves the wagon. It is very important to emphasize that this is a non- intrusive system. The carrier does not have to be worried about registering loaded or unloaded containers because the RFID of the proposed system does it automatically. RFID module detects transponders EPCs and transmits them to the embedded platform connected. This device stores all the information needed for a correct delivery and monitors what the carrier is doing at anytime.

If the carrier makes a mistake loading or unloading a wrong container a red light will switch on in the wagon and he will know that there is something wrong. Since all van drivers carry a Smartphone with them, an application for it has been designed, so the

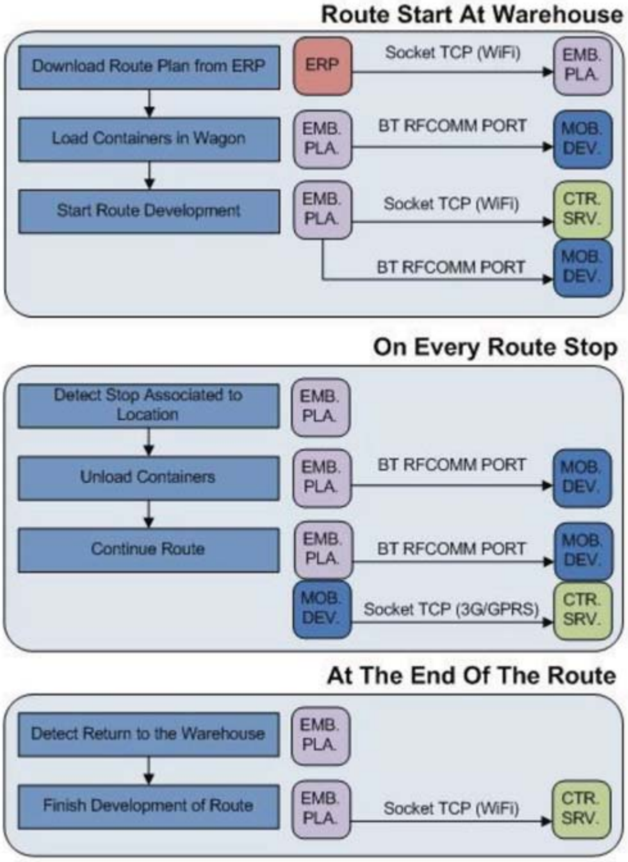

Figure 1

Process flow diagram of the system

Smartphone is considered an element of the proposed system. That mobile is connected by Bluetooth to the van's embedded platform, so it knows the list of containers to load into their vans and which containers are being loaded or unloaded. Therefore when the red light switches on, the carrier will get an error message generated by the proposed system in his Smartphone. He will try to solve it by himself and if he cannot do it, the Smartphone will send an incidence to the warehouse manager and that incidence will be registered in the embedded device too. The mobile application runs resident on the smartphone and is only accessed by the carrier when the red light indicates an error, so the app shows the description of undertaken mistake. In the event that the development of the transport process is executed as planned the carrier does not need to open the application and adds no new tasks to usual job.

Once the van is loaded, the van driver starts the delivery. He has a route of pharmacies where he must unload some containers at each time. With the Global Position

System (GPS) transceiver incorporated within the embedded device, the van knows its rough location every time. So the intelligence of the system calculates which containers to unload in the next pharmacy and in the other ones. When the van stops and the wagon door is opened the system detects the nearest pharmacy included in the route accessing which containers should be unload at this point. When the carrier unloads all containers associated with that stop and no more, the system activates the green light, indicating that unload is correct. If after downloading all containers, the red light remains on, the carrier must enter the mobile application to detect the cause of the error. If there is any divergence that cannot be solved, the carrier can continue to the next stop and the system immediately reports an incidence to the warehouse manager.

As it is a non-intrusive system, the carrier must do his job as usually. He will not realize that behind him, there is a system controlling every movement that he makes, and only he will be notified in case of an error.

The system in addition includes atmospheric sensors inside the wagon for temperature, pressure and humidity control transported goods.

The embedded platform saves in a Secure Digital (SD) card, at regular configurable intervals, the location of the van, EPCs of containers loaded and the values of the atmospheric sensors. When the route ends and the van returns to the pharma warehouse, the device connects to the network of the warehouse via WIFI and sends an XML file through File Transfer Protocol (FTP) containing all the information stored during the development of the route. This allows the warehouse manager may subsequently review the development of a route through the control panel and look for causes of undertaken errors and delays.

III. CARGO IDENTIFICATION SYSTEM

According to the OMS drugs must be stored and transported under certain conditions. One of them is the need to use standardized and reusable containers to transport those drugs from warehouses to each pharmacy office.

This fact constitutes a perfect scenario for RFID technology and this project in particular. It can be controlled what drugs go to each pharmacy if they are inside a registered recipient. And working with a GPS, the system knows the place where containers have left the van. Attaching one passive tag to each container, not only it can be monitored when the containers enter or leaves the van, but it also makes the investment in tags to be easily affordable in a very short time, avoiding one of the biggest drawbacks of this technology. Carrying drugs into containers that have attached a transponder also allows its tracking and the traceability of each medicine.

The intelligent system designed is based on several technologies, but one of the most important is RFID. This technology uses two basic elements, a reader or interrogator and a tag or transponder. As already mentioned, passive transponders have been attached to containers exploiting its reusability, and an RFID reader has been placed inside each van.

To enhance the reader's gain, several tests have been made with different antennas and with different antenna locations. Some of them will be described.

A. **RFID tag**

A Confidex's Carrier Tough (Fig. 2) tag has been chosen to be attached to a container. It is a passive tag (do not have any batteries) covered in hard plastic and resistant to mechanical stress, friction and shock. It also has a paper with a 2-D Data Matrix that is useful for other applications in other parts of this supply management.

Figure 2

Confidex's Carrier Tough passive tag

It works using EPC Class1 Gen2 protocol, its frequency range is from 860 – 960 MHz and its reading range is from 4 to 6 m, enough for a wagon van.

The price of tags is decreasing year by year, but it still remains a problem for many companies to adopt this technology. The reusability of these transponders thanks to the fact that they are stuck on the wall of the containers and not on each drug box, makes RFID an adequate technology for the project because of its easy investment recovery.

B. **RFID reader**

An RFID reader is located into each delivery van. This is in constant communication with the embedded device next to it and tells the reader to read tags and send received EPCs of the transponders inside the wagon when the system needs it. This reader module has on one side, RS-232 communication with the embedded device, and on the other side, wireless communication with the passive transponders attached to containers.

It has been used a Thing Magic's Mercury5e-EU RFID Reader [3]. This works at the UHF range of frequency to improve interrogation distance and bears EPC Gen2 protocol, more robust against noise and reading interferences. It has 30 dBm of read gain at the range of 865.6-867.6 MHz according to the European Union regulatory support ETSI (EU) EN 302208. With an antenna of at least 6dBi, it can read tags in 9 m because of its sensitivity of -65 dBm.

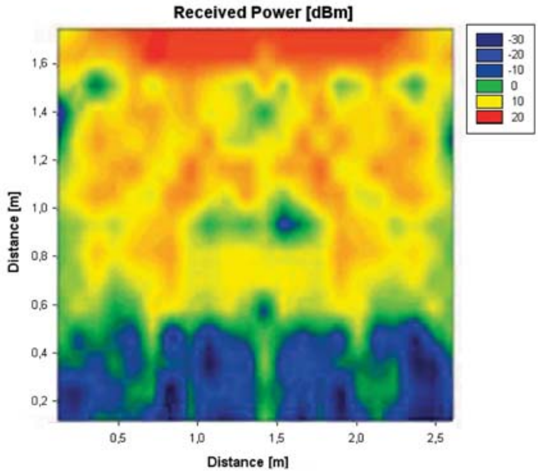

Figure 3

Estimation of received power [dBm] on the second floor of containers, obtained by full 3D ray launching algorithm

The working procedure of this system starts with the embedded device. It asks for the information of tags inside the van sending a request through serial port. The RFID reader starts generating a continuous wave to power up the tags stored into the van and these tags answer their EPC codes (96 bits) modulating the continuous wave generated by the reader [4]. To detect all those backscatter signals generated by transponders [5], a high gain antenna is connected to the reader and is strategically located into the van. In this manner the reader improves its reading range against low power answering of transponders and enlarges covering inside wagon. Once it has completed a read cycle, the reader sends back through serial port all EPCs stored in its internal buffer to the device.

For tests, some useful parameters have been used to improve detection of the tags. When the reader communicates with a tag it stores the received signal strength indicator (RSSI) of the tag read. And it also stores the time the tag was read, relative to the time the command to read was issued (Timestamp). Those parameters have helped to take a decision on where to locate the antenna to get the best tag detection results.

C. **RFID antenna**

To enhance coverage over the wagon an antenna for the reader is needed. As it has been said, with a 6 dBi antenna, the wagon of a standard van can be covered. Some tests and simulations have been made with different commercial antennas of at least 7 dBi of gain and a self-designed one.

These simulations have been made using the van as scenario to see commercial antennas behavior. The wagon has been modeled as a metallic cube full of polypropylene containers and the antenna has been placed at different locations in the ceiling of the van. Simulations are based on the deterministic method of a 3D beam source [6] to analyze the inside of a van full of containers. A linearly polarized PATCH-0026 and a circularly polarized PATCH-0025 have been used. Both ones have very similar parameters except their polarizations.

Both antennas have a similar reading range behavior because the van is a closed metallic environment so there is multipath propagation. The RFID reader will receive a direct component, if there is direct visibility, or there will be a great number of echoes with different amplitudes, phases and random arriving times. The circularly polarized antenna has been chosen because it has the best coverage over the wagon. Figs. 3 and 4 show the power distribution inside the van using the latter antenna. They respectively depict an estimated power received by likely tagged containers that are located at the second row of the packing distribution and that in an isotropic view. It has been placed at the back of the van in the middle of the ceiling offering the best results of the simulations done. Because of its polarization, tags can be read in any orientation. In an environment like this one, the transmission power decreases with distance with a lot of variations, due to the number of multipath components.

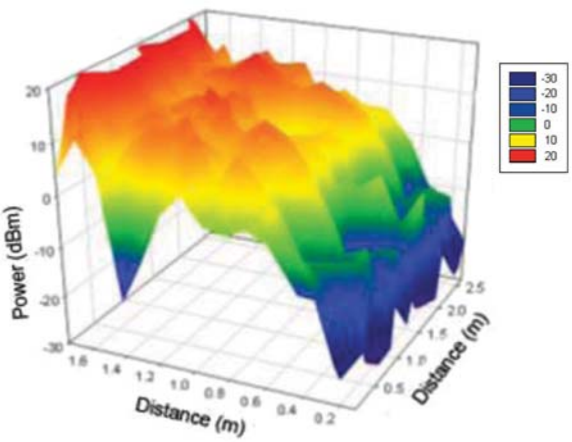

Figure 4

Volumetric view of simulated values of received power [dBm] on the second floor of containers seen from the side

D. **Antenna design**

To meet the demands of the proposed system in section III, utilising RFID, a customized antenna interrogator design is preferred over the commercial required. Typically, high gain antennas imply larger sizes Current simulated results indicate that antennas having gains of 2dBi are adequate for in-vehicle applications. They can deliver a sufficient radio propagation field inside a vehicle; this assumes full power transmission at the transceiver [3]. The antenna interrogator is being set in the middle of the ceiling of the car as a preferred location in vehicles [7]. This ensures good power distribution to likely RFID tag locations within the car while minimizing field exposure to potential occupants (those assisting in the inventory distribution of goods). Antennas inside a metal shielding can theoretically confine the antenna's radiated power within the car body with no power loss, no Doppler shift on moving vehicles. Directly printing (i.e: electrically conductive paint) antennas onto suitable surfaces are encouraged as a great opportunity to provide relaxed and relatively inexpensive mass-produced antennas. Recent advances in electrically conductive paints [8] can provide adequate sheet resistance for the development of cost-efficient antennas.

The geometry of the sprayed antenna design is presented in Fig. 5. It depicts a relatively simple structure that encompasses an easy fabrication and is suited for use in radio frequency identification networks using the unlicensed RFID subband b2 (8.656-8.676 GHz) of the ETSI standard [9].

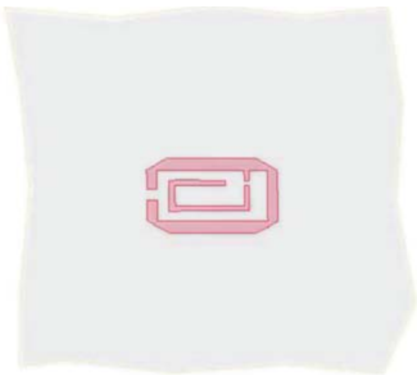

Figure 5

The antenna printed onto a car body

Simulated results expect an antenna having a sufficient bandwidth for the application and a 2dBi gain when using copper ink. Recent studies show a similar performance using silver and a lower efficiency antenna using other conductive paints such as nickel [10]; copper is therefore the preferred ink used for the antenna application. Radiation patterns show a directional antenna characteristic that can be useful for in-vehicle applications [11]; as a result, the antenna enhances the system coverage inside a vehicle.

IV. SYSTEM ARCHITECTURE

System architecture is structured on the basis of the embedded device installed in the van. Because of the capacities of this device and its wireless communication with other resources (both individuals and hardware resources) we can base on it our proposed intelligence system.

This system can be decomposed into three distinct parts: the embedded device itself, responsible for bringing together the information obtained by the hardware components of the van; the mobile application and the control software solution. In this section we are going to describe each module of the system from a functional and technical point of view.

A. **Embedded device**

The Embedded Device is the main communications system and thus, the core of the intelligent cargo solution. It detects containers using RFid technology, and communicates with the central server and the mobile unit with its embedded Bluetooth and WIFI modules.

Due to the incorporated data about the routes to follow, the sensors embedded, and its integrated geopositioning capacities, the device also provides to the van driver the knowledge necessary to optimize routes and therefore, the quality of the service.

Warehouse automated dispensing robots made the coordination of the orders of each pharmacy. In the moment a new order arrives, the system stores all the medicines required within a container that will be sent to the dock ready for loading vans. When the truck arrives at the warehouse a WiFi connection is initiated between the embedded device, installed in each vehicle, and the server. The device download all the necessary information and updates the EPC of the containers to be distributed along the path. It also updates the location, the number of stops and what are the containers to unload at each stop. With its RFid module, it can detect tags attached to each container loaded into the van, so that it can warn the dealer with a red or green light if there are errors or not in the process of loading and unloading the cargo.

This procedure ensures, in a non-intrusive way, the proper conduct of the routes assigned to the van driver. This is done using the intelligence provided by the various hardware components involved (antennas, sensors, tags, etc.) intercommunicated via wireless technologies (WIFI, Bluetooth, RFID) and its associated information system. All these elements conform the system architecture of the proposed ubiquitous computing solution.

The main device used to implement all these features is an ISEE IGEPv2 based on an 1GHz ARM Cortex-A8 processor stand-alone computer-on-module. This is a small size card (93x65x15mm.) that has all the communications modules and resources demanded by the project. Embedded platform runs under a Linaro distribution with a Linux kernel optimized for this specific board. It includes WIFI IEEE802.11b/g communication capability used for updating information at the warehouse and a Class 2 Bluetooth 2.0 module with a range of 10 meters, able to communicate with the mobile application of the driver. Platform provides several Global Purpose Input/Ouput pins (GPIO) that are used to activate red and green lights and to detect when the wagon door is opened. Furthermore, this board has two serial ports (UART) which are used for communication with the RFID reader and an external GPS receiver (Fastrax i310). Finally, the embedded platform has an SD card that stores the historical data acquired during the development of the route that are subsequently transferred to the central server.

Figure 6

Embedded device conectivity

The RFid reading system is composed of a Mercury5e-EU RFid Reader, two commercial high gain antennas and passive UHF tags attached to each container. The reader works at the UHF frequency range to improve interrogation distance and bears EPC Gen2 protocol, more robust against noise and reading interferences. To detect all signals generated by transponders, two high gain antennas are connected to the reader and are strategically located into the van. In this manner the reader improves its reading range against low power answering of transponders and enlarges covering inside wagon.

B. **Mobile application**

Installed on a Smartphone. Van driver uses it to interact to the embedded system using a user-friendly graphic interface. The integration of a mobile device in the environment of the proposed solution can complement and supplement the system, serving the driver as an entry point to information is accessible via another web service that fulfills the function of data-oriented middleware enabling the capture of real-time information from the ERP system implemented in the company. The developed system obtains the information in a transparent and non-intrusive manner, not being necessary expensive modifications in the legacy order management system. All this information is displayed the knowledge offered by the embedded system in a more comprehensive manner, always maintaining the desired level of non-intrusiveness .

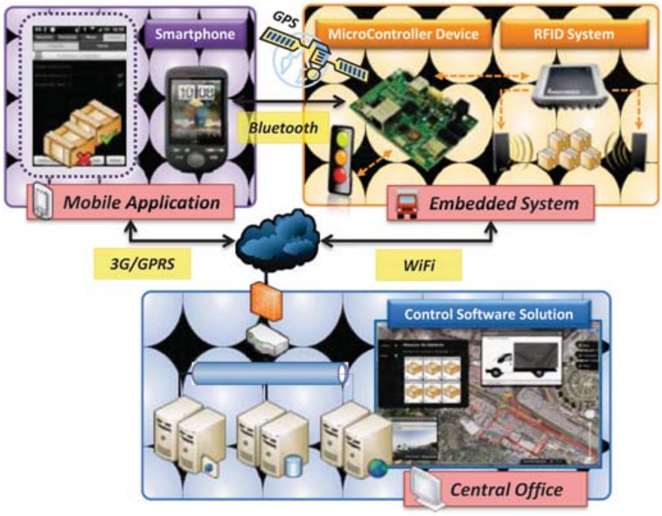

Figure 7

System architecture and interactions

Android technology has been used for the development of the mobile application. This decision is motivated by the opportunity offered by the pharmaceutical transport company CENFARTE (Centro Farmaceútico del Norte S.A) with which it has been established an active collaboration to enable the implementation of a real pilot of the solution. The company has the means to have an Android terminal for each route or carrier. As a result of that, each driver carries a Smartphone to stay connected to the server application in order to know all his needs on every transport service.

The wide range of terminals and the variety of operative systems has forced us to develop a multiplatform application that works on the majority of newest existing smartphones, including Android OS, Apple iOS and BlackBerry OS.

To achieve this goal, the development has been focused towards a SOA (Service Oriented Architecture), in which most of the functionality is distributed in the server, freeing the processing load to other devices that will access the logic through SOAP messages to a web service developed for the control software solution.

Once transportation is available to perform a service, the application displays the routes that are currently available. It does so through a WIFI connection to the server, accessing the web service responsible for obtaining the daily routes not yet started. In case of failure of the WiFi connection, the system offers continued support in communications through GPRS/HSPA connectivity present in the mobile device.

Once the route is established, the mobile device obtains data about the full path: distance, estimated duration, number of stops, addresses, etc. Similarly, for each of the established stops relating to the pharmacies on a route, are obtained concrete EPC codes of containers to download. This information is accessible via another web service that fulfills the function of data-oriented middleware enabling the capture of real-time information from the ERP system implemented in the company. The developed system obtains the information in a transparent and non-intrusive manner, not being necessary expensive modifications in the legacy order management system. All this information is displayed to the carrier through an user interface designed with the intent to facilitate maximum usability and minimize intrusiveness.

The application core functionality is the management of incidences, giving as an added value support for transport activities and navigation aid:

1) *Management of incidences*: As discussed in previous sections of this document, the proposed system intended to give the van driver an aid in its daily operations. One of the activities that is more prone to error is the loading and unloading of the containers, and hence the developed system alerts the driver via a led indicator of its correct execution.

However, other incidents that may occur must be taken into account, such as deviations in the estimated route time or the loss of containers in the pharmaceutical stores. It has been established that more than 10% of deviation in the estimated time for the delivery of an order or a non-conformity in the containers to download must generate an automatic incidence. When the system detects a lost container, the embedded device sends by Bluetooth to the mobile application how many containers are missing in order to request for them to the store administration.

All this incidences are managed by the mobile application, simultaneously alerting both the carrier and control center. This will be achieved using communications established via GPRS/HSPA between the mobile device and control software solution.

The van driver will have the opportunity to see on the smartphone at any moment which is the state of the route, which issues have been generated what are the activities to be undertaken to resolve them. As seen, the mobile application helps the carrier in the development of daily activities, allowing to reduce operational errors in the process significantly.

Navigation aid: once in the course of the route and since these are changing according to the pharmacies involved in them, the mobile device offers integrated navigation service for helping the carrier. It shows the route, indicating the order in which the driver must make every stop on the planned route and if it is necessary, it assists delivery man in navigating from one point to another in that route.

2) *Support for transport activities*: at each stop, embedded device reads RFID tags and detects changes in the cargo that are sent via Bluetooth to the mobile application. This data relating to the operation of the carrier in the loading or unloading of containers, provides real-time information about possible deviations (human errors in cargo management) allowing warehouse staff to rectify the errors on delivery in minor time.

C. **Control software solution**

It has been developed an application for monitoring medicines traceability, to schedule optimized routes and to locate different vehicles of the vans fleet.

This software solution includes the development of a control panel that includes three main functional features:

— Medicines traceability: the system has a robust database where all delivery information is stored. That is, pharmacy office in which each medicine unit has been distributed, indicating batch number and expiry date. It allows user to search for a container even if it has been downloaded in a pharmacy office or if it is inside a van during a transport service.
— Fleet management: the system can locate different distribution vehicles on a map, it can store completed routes and the time spent on each stop. It contributes to the distribution company calculating an approximated time left to deliver a batch on a pharmacy office. It also calculates optimized routes taking into account delivery time, traffic and preemptive supply.
— Optimized schedule fleet: taking into account database stored information, using artificial intelligence techniques and generating information by ERP, the application generate routes for each vehicle optimizing time of delivery.

All this functionalities have been developed on a Rich Internet Application (RIA). Below are listed the technical characteristics of each of the parts that compounds the traceability control service: the data model, the web services and the web application.

1) *Data Model*: data that should be stored by the application has been conceptually modeled. Microsoft SQL Server 2008 DBMS has been used in this context. The process of storing the operational data of transportation occurs at the end of the route. When this occurs, the onboard device is connected via WIFI to the server and sends a generated XML file which includes both the actual path followed by the vehicle and the incidences that may have occurred. This file is automatically treated by the system, generating the necessary entries in the DBMS so that the route is recorded at the time of its completion.

Figure 8

Mobile application interface.

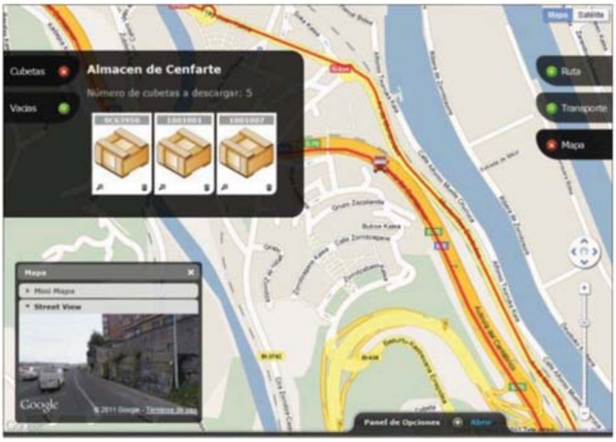

Figure 9

Web application interface

2) *Web Services*: information relevant to the application is in the DB; however, access to such information is done through Web services developed with WCF technology (Windows Communication Foundation). This technical decision allows both data and application logic can be accessed from other devices, thereby ensuring the scalability and interoperability of the whole. Security also is increased because the data access does not occur directly but through the services, providing greater control over database queries. The network will be controlled at all times under a firewall that prevents unauthorized access. The set of services developed allows full interoperability between the different components of the system, which is a major benefit in broadening the number of devices compatible with it and facilitate their development in the future.

3) *Web Application*: the development of the control solution is completed with the web application which offers features beyond the typical application of fleet management. This application has been developed taken into account two fundamental characteristics: (1) to maintain a friendly and attractive interface, (2) without prior installation or further configuration. This Web application approaches usability to a modern desktop application but with all the advantages that such implementation offers, being available globally via the Internet to a vast number of devices supported.

The Control Panel, based on asp.NET development framework, has been made extensive use of technologies designed for creating Rich Internet Applications (RIA): JavaScript, CSS3, HTML5, Ajax and jQuery, along with the use of the tools offered by Google for displaying and processing of geographic and positioning information. This feature improves not only the final visual aspect of the application but also the overall usability. The whole site is based on an asynchronous behavior, so interaction eliminates the sense of loading data and responds instantly. All kind of choices as routes, stops or containers represent a dynamic and transparent loading of data and an almost immediately response to their interaction.

V. CONCLUSION AND FUTURE WORK

Profits that item-level traceability for pharmaceutical drugs provides to society in terms of public health and ensuring access to medicines enforces governments to require this feature to the different actors involved in the pharmaceutical supply chain in the short term. The reduction of profit in the pharmaceutical industry motivated by the imposition of certain public policies hardened because of the economic crisis affects not only to laboratories but also to distributors of pharmaceutical products that are unable to afford the investment needed for these systems. Most of the initiatives to apply telematic technologies in order to fulfill requirements imposed by governments are being designed without considering the difficulties of deploying such systems in the storehouses currently working on and in their impact in the activities of the pharmaceutical supply chain.

In this paper we have presented a system based on an intelligent van to improve the distribution of pharmaceutical drugs. The system is able to trace medicines over the delivery routes from warehouses to pharmacies, reporting incidences to carriers in case of anomalities in the distribution plan. This contributes, first to the reduction of the occurrence of errors during distribution and the required time for their recovering, and second to locate a set of medicines in case of a mislead.

In order to achieve these tasks, the intelligent van has to identify its environment, including: its location, assets which are insides, and the current delivery route. To meet the demands above, current wireless technologies were used, it includes: RFID to provide with the cargo identification; GPRS/HSPA, WIFI and Bluetooth to achieve communication; and GPS for the geo-positioning provision. Moreover, interaction with the user has been provided through the integration of a Smartphone in the system.

The main technological contribution of this work is the use of telematic technologies for providing intelligence to a van; this is to improve the distribution of pharmaceutical drugs without altering the way carriers do their tasks. Carriers using the intelligent van will relax from worries about registering (loaded or unloaded) pharmaceutical drug containers; they require no continuous supervision because the system validates every task they make, notifying them only in case of a deviation according to the planned route. It is a non-intrusive solution representing a successful case in using smart environments to resolve a real industrial need.

This has been possible due to first, the design of the technological solution and second, the characteristics of the scenario in which the systems is deployed. The "Good Distribution Practices for Pharmaceutical Products" drafted by the World Health Organization states that all pharmaceutical products should be stored and distributed in containers with no adverse effects on the quality of products, and offering adequate protection from external effects. Thanks to the standardization and reuse of these containers, the transportation of drugs is an ideal scenario for the implementation of RFID tags. The actual high cost of UHF tags is well amortized by a provided application capable of geo-positioning the precise location of lost containers. It makes the costs of purchased tags affordable in a very short time investment, avoiding one of the biggest drawbacks (the cost) of this technology.

Finally, among the future prospects to improve the proposed intelligent system, we can highlight the following. First, after several tests using different commercial antennas and locations inside the van, the next challenge is to design a customized antenna. Ongoing development of a miniature antenna that is aimed to be printed onto the car body seems to be an efficient technique to simplify the fabrication and reduce costs; this is exciting to the automobile industry. Second, in order to improve the reliability of the system we are designing a validation device able to dump the content of a container (loaded of medicines) and pick-up its content through the identification of a 2D bar code. The device should be integrated into an automated robotic dispensing system of pharmaceutical products for warehouses and aimed to guarantee the right content of containers that are to be packed in the van.

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REFERENCES

[1] "Commission Directive 2003/94/EC of 8 October 2003 laying down the principles and guidelines of good manufacturing practice in respect of medicinal products for human use and investigational medicinal products for human use," in *Official Journal of the European Union*. ISSN 1725-255. L 262, Vol. 46, 14 October 2003.

[2] R. Jedermann, W. Lang, "The benefits of embedded intelligence: tasks and applications for ubiquitous computing in logistics", *IOT'08 Proceedings of the 1st international conference on The internet of things*, Springer-Verlag Berlin, Heidelberg ©2008, ISBN:3-540-78730-5 978-3-540-78730-3.

[3] ThingMagic, A Division of Trimble [online] available at http://www.thingmagic.com/embedded-rfid-readers/mercury5e/1- embedded-rfid-readers/3-mercury5e.

[4] Klaus Finkenzeller, *RFID Handbook, Fundamentals and Applications in Contactless Smart Cards and Identification*, 2nd ed., Jhon Wiley & Sons Ltd., 2003.

[5] Mervi Hirvonen, Kaarle Jaakkola, Pekka Pursula, and Jussi Säily, "Dual-Band Platform Tolerant Antennas for Radio-Frequency Identification", *IEEE Transactions on Antennas and propagation*, Vol. 54, No. 9, pp. 2632-2637, Sept. 2006.

[6] Saez de Adana, F. and Blanco, G. and Diego, G. and Arriaga, P. and Cátedra, M.F., "Propagation Model Based on Ray Tracing for the Design of Personal Communication Systems in Indoor Environments" *Vehicular Technology, IEEE Transactions on*, vol. 49, no. 6, pp. 2105-2112, November. 2000.

[7] I.J. García Zuazola, J.M.H. Elmirghani, and J.C. Batchelor, "High- speed ultra-wide band in-car wireless channel measurements"; *Communications, IET*, Vol. 3, Issue 7, July 2009, pp. 1115-1123

[8] Applied Nanotech Holdings, Inc [online] available at http://www.appliednanotech.net/tech/inkjettable_metallic_inks.php

[9] *Technical Report Electromagnetic compatibility and Radio spectrum Matters (ERM); Part 2* ETSI TR 102 644-2 V1.1.1 (2009-03)

[10] A. Koptioug, P. Jonsson, T. Olsson, J. Sidén, M. Gulliksson, “On the behaviour of printed RFID tag antennas, using conductive paint”, *Proceedings of Antenn-03*, Kalmar, Sweden, 2003.
[11] Hovinen, V., Hamalainen, M., Patsi,T., “Ultra wideband indoor radio channel models: preliminary results”, *IEEE Conference on Ultra Wideband Systems and Technologies*, 21-23 May 2002, Wyndham Baltimore Inner Harbor. Baltimore, Maryland USA, Page(s):75-79.

Análisis de funcionamiento de un sistema RFID en un entorno vehicular cerrado

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Resumen

In this work, a ray-tracing technique to predict the propagation channel parameters in indoor scenarios is presented. An analysis of the physical radio channel propagation inside a van full of buckets is presented. The propagation model is a deterministic technique, based on 3D ray launching. The results show the dependence of the scenario in the performance of the system, revealing that the consideration of the topology of the wireless system prior to deployment leads to an optimal final configuration.

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I. INTRODUCCIÓN

El estudio de la propagación radioeléctrica en entornos interiores ha aumentado considerablemente en los últimos años debido a la competencia que existe en comunicaciones móviles. Por ello, es importante tener un método de predicción de la propagación para poder analizar el entorno, y así mejorar la eficiencia minimizando el número de estaciones base requerido y ofreciendo un servicio eficiente, con el ahorro económico que esto representa. Es importante conocer los fenómenos que afectan a la propagación radioeléctrica. El más importante es el desvanecimiento rápido (*fast fading*) [1] [2] debido a la propagación multitrayecto. Tradicionalmente se usaban los métodos empíricos, eficientes y fáciles de usar, pero sólo válidos cuando el entorno posee las mismas características donde se han realizado las medidas para obtener las ecuaciones (algunos ejemplos son COST-231, Walfish-Bertoni, Okumura-Hata, Anderson 2D, etc.). Por otro lado, están los métodos deterministas basados en métodos numéricos como el método de trazado de rayos, el método de diferencias finitas en el dominio del tiempo (FDTD) o el método de los Momentos (MoM). Estos métodos son mucho más precisos, pero la desventaja es su coste computacional, que puede llegar a ser muy grande para entornos complejos. Como punto medio, están los métodos deterministas basados en técnicas de trazado de rayos [4], en los que se adquiere un compromiso entre precisión y tiempo de simulación. Existen varias técnicas dentro de estos métodos, como son el método de las imágenes, lanzado de rayos, métodos híbridos, etc. [3].

En este trabajo, se va a analizar el comportamiento de un sistema RFID [5] en un entorno vehicular cerrado lleno de cubetas de un cierto material para comprobar que la variabilidad y la topología del entorno afectan en la propagación electromagnética, y este análisis de propagación permitirá una configuración óptima en la configuración de los sensores.

II. ALGORITMO DE LANZADO DE RAYOS EN 3D

El modelo de propagación que se utiliza en este trabajo está basado en el método determinístico de lanzado de rayos en 3D para analizar el interior de una furgoneta llena de cubetas. El procedimiento básico de este método consiste en lanzar un rayo de la antena transmisora (Tx) y trazar el rayo en el escenario para ver si choca con algún objeto o si se recibe por alguna antena receptora (Rx). Cuando choca con interiores ha aumentado considerablemente en los últimos algún obstáculo, se analizan los fenómenos de la reflexión, transmisión y primer orden de la difracción, dependiendo de la geometría y de las propiedades eléctricas del objeto, teniendo en cuenta la constante dieléctrica del material y la tangente de pérdidas. El algoritmo de lanzado de rayos en 3D está implementado en *Matlab*^{TM} . Se pueden colocar varias antenas transmisoras en un escenario, y la potencia transmitida por cada una de ellas se convierte en un número finito de rayos que se lanzan en un ángulo sólido que se puede definir. Los parámetros que se pueden variar en el algoritmo son: la frecuencia de operación, el diagrama de radiación de las antenas, el número de reflexiones, la separación entre ángulos en los rayos lanzados y la dimensión de los cuboides en los que dividimos el escenario. En la Figura 1 podemos observar el escenario que vamos a simular, el interior de una furgoneta llena de cubetas, y en la Figura 2, vemos una representación de cómo se van a lanzar los rayos con nuestro algoritmo de lanzado de rayos en 3D.

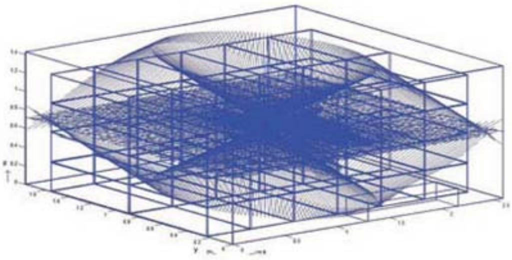

Figura 1

Representación del lanzado de rayos para el escenario del interior de la furgoneta

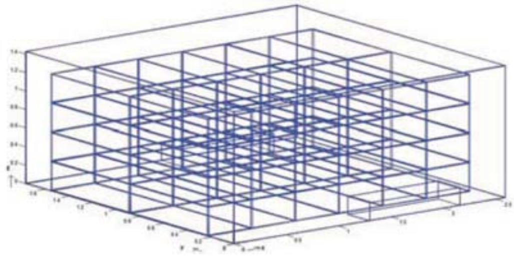

Figura 2

Escenario propuesto de simulación: interior de una furgoneta llena de cubetas. El material considerado para las cubetas es polipropileno y las paredes de la furgoneta son metálicas

III. RESULTADOS DEL ESCENARIO DE SIMULACIÓN

El escenario considerado es el caso en que la furgoneta va llena de cubetas de material polipropileno, apiladas unas encima de otras, como mostramos en la Figura 1. El objetivo es saber en todo momento cuántas cubetas se encuentran dentro del entorno vehicular cerrado. Para ello, cada cubeta llevará una etiqueta RFID cuya sensibilidad es de -65dBm. En primer lugar, se coloca la antena en la parte del fondo de la furgoneta, arriba a la derecha (*Punto (0.05,1.750,1.400)m)*, y después, se realiza la simulación colocándola en la posición central arriba a la derecha *(Punto (1.291,1.762,0.732)m)*. Los parámetros utilizados en la simulación son: resolución de cuboides de 12cm, incremento de ϕ y θ de $\pi/180$, número de rebotes igual a 5, frecuencia de operación 860-960MHz (Tecnología RFID) con tasa de transmisión de 106Kbps, y potencia de transmisión de 26.9dBm (500mW). En primer lugar, se utiliza una antena directiva con polarización circular, y después una antena directiva con polarización lineal.

A. **Antena con polarización circular**

Los resultados obtenidos con el algoritmo de lanzado de rayos en 3D para la potencia recibida colocando la antena en la parte de atrás de la furgoneta (*Punto (0.05,1.750,1.400) m)*, se pueden ver en la Figura 3 y Figura 4 en la que representamos la potencia recibida para la altura mitad de la segunda fila de cubetas en el interior de la furgoneta y el perfil de potencia recibida para esta misma altura a lo largo de la distancia.

Para la antena colocada en la parte central de la furgoneta *(Punto (1.291,1.762,0.732)m)*, podemos observar los resultados en la Figura 5 y Figura 6.

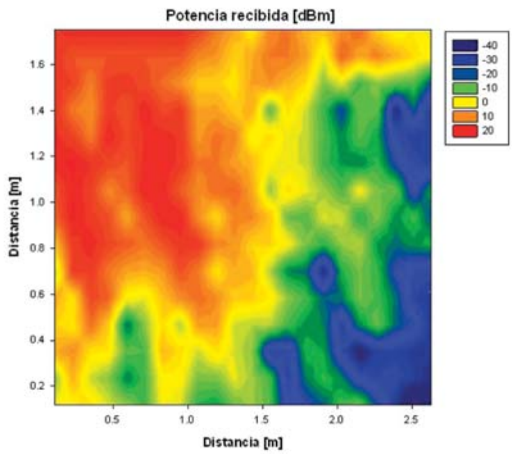

Figura 3

Potencia recibida [dBm] a la altura mitad de la segunda línea de cubetas con la antena de polarización circular colocada atrás

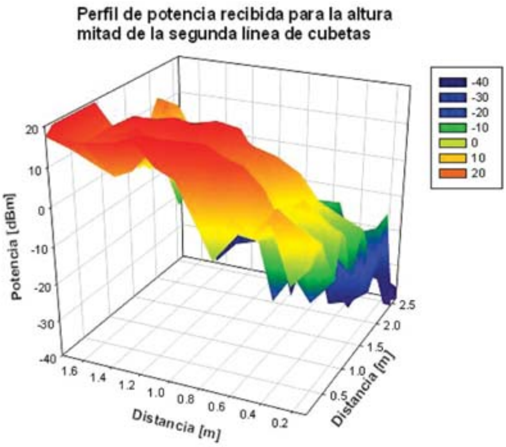

Figura 4

Perfil de Potencia recibida [dBm] a la altura mitad de la segunda línea de cubetas con la antena de polarización circular colocada atrás

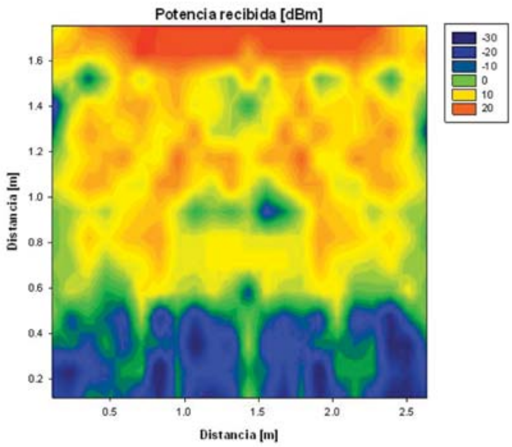

Figura 5

Potencia recibida [dBm] a la altura mitad de la segunda línea de cubetas con la antena de polarización circular colocada en la parte central

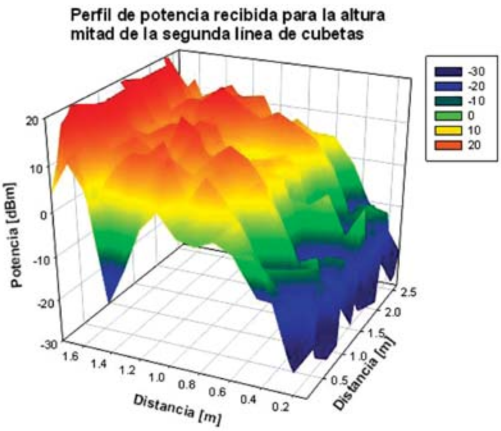

Figura 6

Perfil de Potencia recibida [dBm] a la altura mitad de la segunda línea de cubetas con la antena de polarización circular colocada en la parte central

Sabemos que la sensibilidad de las etiquetas RFID que lleva cada una de las cubetas es de -65dBm, por lo que todas las etiquetas de las cubetas se leerán porque a la vista de los resultados, en las dos posiciones de la antena, se obtiene más potencia en todos los puntos del interior de la furgoneta. Sin embargo, observamos después de la simulación que se obtienen mejores resultados con la antena colocada en la posición central de la furgoneta, ya que en esta posición se alcanza más cobertura, y son menos los puntos en los que la potencia es menor de -40dBm.

B. **Antena con polarización lineal**

Ahora realizamos las mismas simulaciones con el algoritmo de lanzado de rayos en 3D, pero cambiamos la antena transmisora, utilizando ahora una antena con polarización lineal. En las Figuras 7 y 8 vemos la potencia recibida con la antena situada en la posición de atrás, y en las Figuras 9 y 10 con la antena en la posición central.

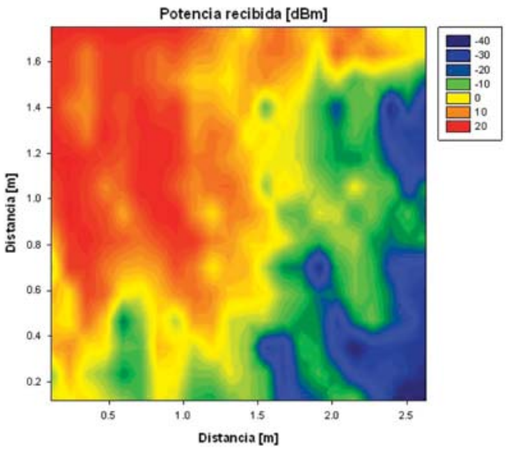

Figura 7

Potencia recibida [dBm] a la altura mitad de la segunda línea de cubetas con la antena de polarización lineal colocada atrás

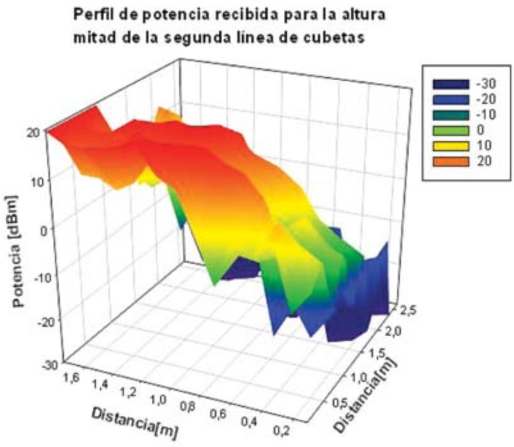

Figura 8

Perfil de Potencia recibida [dBm] a la altura mitad de la segunda línea de cubetas con la antena de polarización lineal colocada atrás

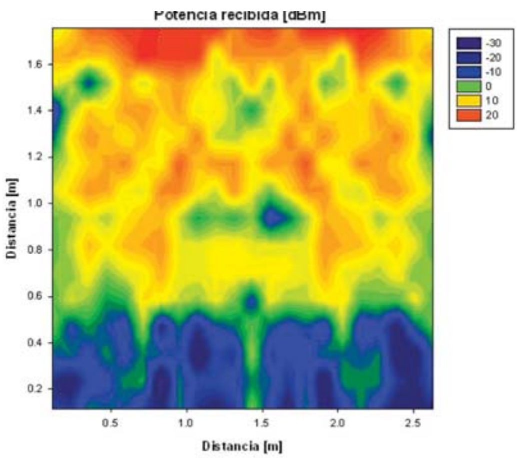

Figura 9

Potencia recibida [dBm] a la altura mitad de la segunda línea de cubetas con la antena de polarización lineal colocada en la parte central

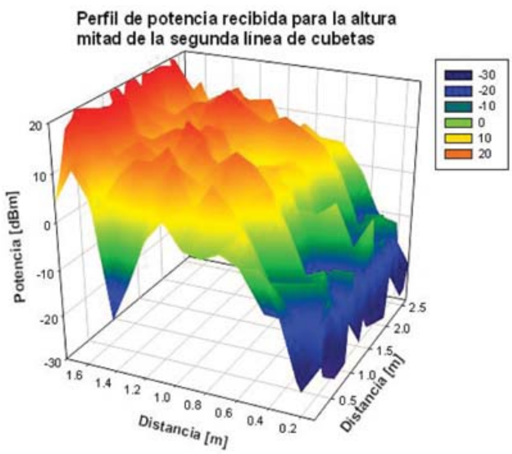

Figura 10

Perfil de Potencia recibida [dBm] a la altura mitad de la segunda línea de cubetas con la antena de polarización lineal colocada en la parte central

A partir de los resultados se observa que las diferencias entre la utilización de una antena de polarización circular y otra de polarización lineal no son significativas en este entorno vehicular cerrado. Esto es debido a que al tratarse de un entorno metálico cerrado la componente fundamental es la propagación multitrayecto. Ésta se caracteriza por los parámetros de dispersión temporal de la señal, consistente en que al receptor le llega una componente directa (si hay visibilidad directa) y múltiples ecos con amplitudes, fases y tiempos de llegada aleatorios, y por la dispersión en frecuencia debida a las variaciones temporales de la amplitud recibida [1].

En las gráficas de los perfiles de potencia se observa que la potencia disminuye con la distancia con mucha variabilidad debido a la cantidad de componentes multitrayecto localizadas en este entorno.

IV. CONCLUSIONES

Se ha presentado un método determinista de análisis de la propagación electromagnética basado en trazado de rayos en su variante lanzado de rayos y se ha realizado el análisis de la propagación de un sistema RFID en un entorno vehicular cerrado. La utilización de esta herramienta de simulación en 3D nos permite observar la influencia de la morfología y de la topología de un escenario dado en una red inalámbrica. Esto permitirá la optimización en la colocación de los sensores en el escenario para ofrecer un servicio mejor y ofrecer una buena calidad de señal.

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REFERENCIAS

[1] H. Hashemi, "The indoor radio propagation channel" *Proc. IEEE*, vol. 81, pp. 943-968, July 1993.
[2] Hernández-Rában os, J.M., *Transmisión por radio,* Madrid: Ramón Are- ces, 2008.
[3] Iskander, M.F. and Yun, Z., "Propagation Prediction Models for Wireless Communications Systems" *Microwave Theory and Techniques, IEEE Transactions on*, vol. 50, no. 3, pp. 662-673, March. 2002.
[4] Saez de Adana, F. and Blanco, G. and Diego, G. and Arriaga, P. and Cátedra, M.F., "Propagation Model Based on Ray Tracing for the Design of Personal Communication Systems in Indoor Environments" Vehicular Technology, IEEE Transactions on, vol. 49, no. 6, pp. 2105–2112, November. 2000.
[5] Finkenzeller, K. and Mu¨ ller, D., *RFID Handbook: Fundamentals and Applications in Contactless Smart Cards, Radio Frequency Identification and Near-Field Communication,* Wiley, 2010.

Easy to Deploy Solution for Pharmaceutical Drugs Traceability in Distribution Warehouses

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Abstract

Enormous profits that item-level traceability for pharmaceutical drugs provides to society in terms of public health and ensuring access to medicines enforces some governments to require this feature to the different actors involved in the pharmaceutical supply chain. Other existing works have been designed without considering the difficulties of deploying traceability systems in the storehouses currently working. The system described in this paper is based on ITS technologies and aims to meet, specifically, the requirements set by the Ministry of Health of Spain, but minimizing the impact of deployment in existing pharmaceutical distributors.

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I. INTRODUCTION

There is a growing need for smart solutions in logistics to improve the supply chain. However, most existing commercial applications focus on generic needs of transport operators and are not adaptable to the specific needs that arise in certain sectors which are intended to improve service or adapt to new demands required by law. Through this paper we describe a system that facilitates the adaptation of distribution depots of pharmaceuticals to the new regulations demanded by the Ministry of Health in Spain by combining different intelligent transportation technologies.

Pharmaceutical drug supply chain, from an economic and health perspective, requires control all stages of distribution: from drugs are produced in a laboratory until they reach the pharmacies. This requirement is reflected by the Ministry of Health and Consumption of Spain through the new Royal Decree of drugs traceability, redacted in accordance to Directive 2003/94/EC of the Commission of the European Communities [1].

Adapting to the changes required by regulation imposes severe changes in the business model of different actors involved in the pharmaceutical sector. Moreover associated costs are hardly feasible in a highly competitive industry where profit margins often are set by administration [2].

In a scope of application where reliability and delivery time are the main differentiating factors, installing a system that slows the work of the carriers, forcing them to use portable RFID or B2B readers is operationally unfeasible. The main advantage of this system is that it is completely transparent not only for carriers but also for warehouse staff.

Besides, in a market where all competitors are offering the same products at similar prices, service quality is a decisive factor because an incomplete or incorrect shipment can result in the loss of a client. The presented system can also detect all issues that arise in the transportation of drugs and minimize the time involved in its management.

II. RELATED WORK

Last years there has been a considerable rise in the global concept of traceability of products and materials. Several research projects have been developed and a lot of research papers have been published which explore different aspects of traceability of goods [3] [4] applied to different types of industries [5] [6] and needs [7].

Even more important has been the interest shown by companies related to fields where traceability is not only a productive benefit, but a health or safety necessity: areas such as food or pharmaceuticals. Given this social need, have been the institutions which have claimed traceability systems for those industries.

As a practical example, in Europe, Regulation 178/2002 requires the traceability of all food from farms to the end of the supply chain [8]. While in countries such as Spain, through a traceability pilot [9] which involves the most relevant actors in the pharmaceutical industry: laboratories and distributors, legislation in the same direction for the comprehensive control of drug transport is being promoting. Moreover, several European projects are being developed, such as BRIDGE FP6 Project [10] in pharmaceutical traceability topic.

As it can be concluded in this kind of projects, adopting a complete system of traceability of goods is a challenge for the industry due to multiple risk factors. In fact, have been published a lot of research papers examining some of these risks. Some of these papers have been used as reference for implementing the system presented in this paper.

One of the highlights is the need to monitor the drugs traceability at item-level in order to prevent counterfeiting and guarantee transparency and safety in the drug flow.

Other papers focus on another key issue: the choice of technology that makes possible the identification of products. Technologies such as DataMatrix or RFID has been taken into consideration [11] [12] looking for the best solution for all the participants in the supply chain. This choice is a source of conflict between actors involved: laboratories and distributors. Laboratories cannot bear the cost of RFID tags associated with individual packages, while 2-D printed Barcodes can cause mandatory changes in the operational model of distribution depots involving the alteration of existing distribution system to pharmacies and cause significant delivery delays [13]. Also, has been conducted in-depth analysis about the type of RFID tags to use [14] [15] to ensure an accurate reading in presence of critical operating conditions. Other studies have also focused on the evaluation of the potential effects of drugs on RFID systems [16]. The experimental results are strongly encouraging the use of RFID-based technologies for item-level tracing systems in the pharmaceutical supply chain.

The result of our work, therefore, is an ICT solution that considering all the above studies and associated risks provides a functional overall-process platform based on UHF RFID tags in conjunction with a mobile application for support real-time management and complete traceability of the pharmaceutical drugs supply chain.

III. INTELLIGENT DRUGS TRACKING SYSTEM ARCHITECTURE

There are three well differentiated parts in this system: the embedded device, the mobile application and the control software solution. We are going to describe each module of the system from a functional and technical point of view.

A. **Embedded device**

It is the main communications device. It detects containers using RFid technology, and communicates with the central server and the mobile unit with its embedded Bluetooth and WIFI modules. Automated medical dispense robots have to coordinate orders for each pharmacy. This system organizes all requested medicines in containers,

Figure 1

System architecture

and then all of them are sent to the dock ready for loading vans. When the delivery van arrives at the store, a WIFI connection starts between the embedded device, installed into each van, and the Server. The embedded device downloads all needed information and updates the number and EPC of containers to be distributed along the next route. It also updates place and number of stops and which container to deliver. With its RFid module, it can detect tags attached to each container, loaded into the van, so that it can warn delivery man with a red or green light if all containers are inside. If there is a lost container, the embedded device sends by Bluetooth to the mobile application how many containers are missing in order to request for them to the store administration.

The main device used to implement all these features is an ISEE IGEPv2 based on an ARM Cortex-A8 processor stand- alone computer-on-module. The main characteristics of this board are:

- Micro-SD with OS: it contains a Linaro distribution with a Linux kernel optimized for this specific board.
- WIFI IEEE802.11b/g: implemented on a chipset based on Marvell 88W8686 and used for updating information at the warehouse.
- Bluetooth 2.0: it is Class 2 with a power of 2.5 mW (4 dBm). With a range of 10 meters, it sends information to the mobile application of the driver.
- GPIO pins: these pins are connected to two green and red high brightness LED diodes that inform the driver if the load or unload of containers has been done correctly.
- Serial ports: two of the serial ports are connected to the GNSS receiver and to the RFid reading system.

1) *GNSS receiver*: Since most of the routes are developed in urban areas where coverage is limited, an ultra high sensitivity GPS receiver module is used. Furthermore, as the module is fed from the main battery of the van it must be low power consumption. GPS receiver supports WAAS / EGNOS / MSAS to improve the accuracy and cold start. The receiver module (Fastrax i310) is connected to the embedded device through an UART port.

2) *RFid reading system*. This sub-module is composed of a Mercury5e-EU RFid Reader, two commercial high gain antennas and passive UHF tags attached to each container.

The reader works at the UHF frequency range to improve interrogation distance and bears EPC Gen2 protocol, more robust against noise and reading interferences. To detect all signals generated by transponders, two high gain antennas are connected to the reader and are strategically positioned into the van. In this manner the reader improves its reading range against low power answering of transponders and enlarges covering inside wagon.

B. **Mobile application**

It is installed on a Smartphone. The van driver uses it to fill in the work schedule using a user-friendly graphic interface. Android technology has been used for the development of the mobile application. This decision is motivated by the opportunity offered by the pharmaceutical transport company "Cenfarte, Centro Farmaceútico del Norte S.A" with which it has been established an active collaboration to enable the implementation of a real pilot of the solution. The company has the means to have an Android terminal for each route or carrier. As a result of that, each driver carries a Smartphone to stay connected to the server application in order to know all his needs on every transport service.

The big terminal offering and the variety of operative systems has forced us to develop a multiplatform application that works on the majority of newest existing mobiles supporting WIFI, Bluetooth, GPS and GPRS/HSPA, including Apple iOS and BlackBerry OS. To achieve this goal, the development has been focused towards a SOA (Service Oriented Architecture), in which most of the functionality is distributed in the central server, freeing the processing load to other devices that will access the logic through SOAP messages to a web service developed for the control software solution.

The mobile application helps the carrier in the development of daily activities, allowing to reduce operational errors in the process significantly. Thereby this subsystem seeks to improve the overall productivity of transport.

Once transportation is available to perform a service, the application displays the routes that are currently available. It does so through a WIFI connection to the server, accessing the web service responsible for obtaining the daily routes not yet started. In case of failure of the WiFi connection, the system offers continued support in communications through GPRS/HSPA connectivity present in the mobile device itself.

Application makes extensive use of Google Maps API in order to obtain all possible information about the route. Thus, once the route is established, the mobile device obtains data about the full path: distance, estimated duration, number of stops, addresses, etc. Similarly, for each of the established stops relating to the pharmacies on a route, are obtained concrete EPC codes of containers to download. This information is accessible via another web service that fulfills the function of data-oriented middleware enabling the capture of real-time information from the ERP system implemented in the company. The developed system obtains the information in a transparent and non-intrusive manner, not being necessary expensive modifications in the legacy order management system.

All this information is displayed to the carrier through an user interface designed with the intent to facilitate maximum usability. As a result of that, the application offers navigation help, support for transport activities and incident management.

1) *Navigation help:* once in the course of the route and since these are changing according to the pharmacy establishments involved in them, the mobile device offers integrated navigation service for helping the carrier. It shows the route, indicating the order in which the driver must make every stop on the planned route and if it is necessary, it assists delivery man in navigating from one point to another in that route.

2) *Support for transport activities*: at each stop, embedded device reads RFID tags and detects changes in the cargo that are sent via Bluetooth to the mobile application. This data relating to the operation of the carrier in the loading or unloading of containers, provides real-time information about possible deviations (human errors in cargo management) allowing warehouse staff to rectify the errors on delivery in minor time.

Figure 2

Mobile application interface

3) *Incident management*: incidents are considered as, significant deviations in the planned route. It has been established that in more than 10% deviation in the estimated

time for delivery of an order or a non-conformity in the containers to download, an incidence must be generated. The incidents are managed by the mobile application, simultaneously alerting both the carrier and control center. This will be achieved using communications established via GPRS/HSPA between the mobile device and control software solution.

C. **Control software solution**

It is used to monitor medicines traceability, to schedule optimized routes and to position different vehicles of the vans fleet. This software solution includes the development of a control panel to manage all system. It includes three main features:

- Medicines traceability: the system has a robust database where all delivery information is stored. That is, pharmacy office in which each medicine unit has been distributed, indicating batch number and expiry date. It allows user to search for a container even if it has been downloaded in a pharmacy office or if it is inside a van during a transport service. The control software also controls containers situation, allowing users to locate them if one of them gets lost.
- Fleet management: the system can position different distribution vehicles on a map, it can store completed routes and the time spent on each stop. It contributes to the distribution company calculating an approximated time left to deliver a batch on a pharmacy office. It also calculates optimized routes taking into account delivery time, traffic and preemptive supply. And the software solution controls shipping delay, monitoring routes and stops that have been occurred during a penalized transport service.
- Optimized schedule fleet: taking into account database stored information, using artificial intelligence techniques and generating information by ERP, the application generate routes for each vehicle optimizing time of delivery.

All this functionalities are developed using this control software solution where we can find three distinct parts: the data model, web services and web application. Below are listed the technical characteristics of each of the parts composing the control system.

1) *Data Model:* data that should be stored by the application has been conceptually modeled. Microsoft SQL Server 2008 DBMS has been used in this context. Entities are collected as part of the functional structure of the application: drivers, routes, pharmacies, buckets, etc. The process of storing the operational data of transportation occurs at the end of the route. When this occurs, the onboard device is connected via WIFI to the server and sends a generated XML file which includes both the actual path followed by the vehicle and the incidences that may have occurred. This file is automatically treated by the system, generating the necessary entries in the DBMS so that the route is recorded at the time of its completion. This route can be accessed later using the historic route.

2) *Web Services:* information relevant to the application is in the DB; however, as discussed in previous sections, access to such information is done through Web services developed with WCF technology (Windows Communication Foundation). This technical decision allows both data and application logic can be accessed from other devices, thereby ensuring the scalability and interoperability of the whole. Security also is increased because the data access does not occur directly (accessing the DB) but through the services, providing greater control over database queries. The network will be controlled at all times under a firewall that prevents unauthorized access. The set of services developed therefore allows full interoperability between the different components of the system, which is a major benefit in broadening the number of devices compatible with the system and facilitate their development in the future.

3) *Web Application*: the development of the control solution is completed with the web application which offers features beyond the typical application of fleet management. This application has been developed taken into account two fundamental characteristics: (1) to maintain a friendly and attractive interface, (2) without prior installation or further configuration. In these terms this Web application approaches usability to a modern desktop application but with all the advantages that such implementation offers, being available globally via the Internet to a vast number of devices supported**.**

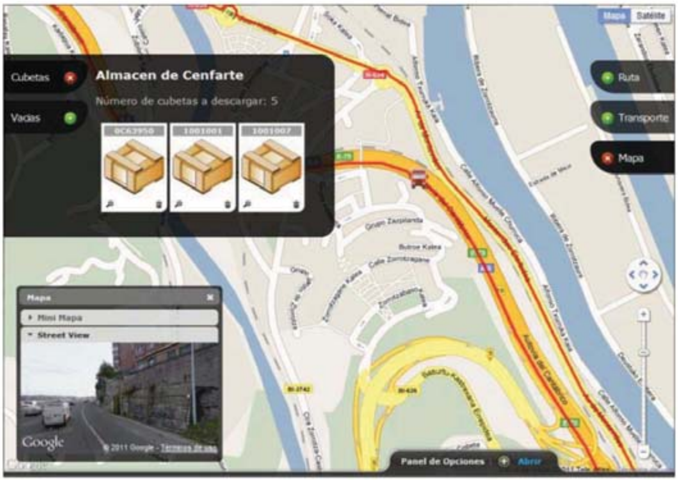

Figure 3

Web application interface

The Control Panel, based on asp.NET development framework, has been made extensive use of technologies designed for creating Rich Internet Applications (RIA): JavaScript, CSS3, HTML5, Ajax and jQuery, along with the use of the tools offered by Google for displaying and processing of geographic and positioning information. Thus, the designed user interface lets you use the application as if it were a regular desktop application, making use of in frequent UI elements in an application of this kind, such as dialogues, menus, tabs, etc. This feature improves not only the final visual aspect of the application but also the overall usability. The whole site is based on a synchronous behavior, so interaction eliminates the sense of loading data and responds instantly to user actions. All kind of choices as routes, stops or containers represent a dynamic and transparent loading of data and an almost immediately response to their interaction.

IV. CONCLUSIONS

Profits that item-level traceability for pharmaceutical drugs provides to society in terms of public health and ensuring access to medicines enforces governments to require this feature to the different actors involved in the pharmaceutical supply chain in the short term. Many of the studies and initiatives referred on the section related work have been designed taking into account only the requirements imposed by governments but without considering the difficulties of deploying such systems in the storehouses currently working and supporting the pharmaceutical supply chain. The reduction of profit in the pharmaceutical industry motivated by the imposition of certain public policies hardened because of the economic crisis affects not only to laboratories but also to distributors of pharmaceutical products that are unable to afford the investment needed for these systems. The system described by this paper aims to meet the requirements set by the Ministry of Health of Spain minimizing the impact of their deployment in existing pharmaceutical distributors.

Therefore, rather than impose a technology for the item- level identification of medicines, it is proposed combining the two technologies predominantly used in the pilots carried by the same scope: RFID and 2-D Barcodes.

The “Good Distribution Practices for Pharmaceutical Products” drafted by the World Health Organization states that all pharmaceutical products should be stored and distributed in containers which do not have an adverse effect on the quality of the products, and which offer adequate protection from external influences. Thanks to the reuse of these containers, the transportation of drugs is an ideal scenario for the use of RFID tags. The high current cost of UHF tags used by the system is amortized by an application capable of geo-positioning last location of each lost container.

This system performs container-level tracking since the containers are loaded in a pharmaceutical warehouse until they are delivered in pharmacies. In this way the technology used by pharmaceutical laboratories will not interfere in the process. The system must collect the containers loaded by the automated dispensing robot installed in drug warehouse, validates the loading of each container, using technology agreed upon by the laboratories (2-D barcodes), and is responsible for carrying out the traceability of the last step in the supply chain.

On the other hand, this system offers some additional features of great interest for pharmaceutical warehouses manage: (1) the monitoring system of routes allows the depot manager to identify the causes that have led to irregularities in the execution of a route; (2) the assistant device of the van driver notifies immediately when significant delays are produced or errors in delivery are detected; (3) the device of container tracking indicates the position of all containers that have not been returned to the warehouse enabling their recovery.

V. FUTURE WORK

The work presented in this paper describes the first part of a project currently underway and is scheduled to end in December 2012. There are three additional challenges to carry out in the future:

1) Pilot test of the complete system using commercial wide range antennas for the detection of tags inside the wagons of delivery vans. This pilot will be implemented during the first half of 2011.
2) Custom Antenna design to minimize errors in the detection of containers. This part of the project is scheduled to Be Performed during the second half of 2011. Upon completion of this part is scheduled to deploy the system in the warehouse that the distributor of pharmaceutical products Cenfarte SA owns in the Basque country.
3) During the course of 2012 is scheduled to design and implement a validation system able to dump the contents of a container loaded of medicines and pick out its content through the identification of 2D bar codes. This system should be integrated into automated robotic dispensing of pharmaceutical products manufactured by Cenker Robotics, a company that collaborates on the project.

With the development of these parts, the system meets the requirements set by the administration and allows easy deployment in the distribution of stores currently in operation.

REFERENCES

[1] "Commission Directive 2003/94/EC of 8 October 2003 laying down the principles and guidelines of good manufacturing practice in respect of medicinal products for human use and investigational medicinal products for human use," in *Official Journal of the European Union*. ISSN 1725-255. L 262, Volume 46, 14 October 2003.

[2] S. Morgana, M. McMahonb and D. Greysonc, "Balancing health and industrial policy objectives in the pharmaceutical sector: Lessons from Australia" in *Health Policy*, Volume 87, Issue 2, August 2008, Pages 133-145.

[3] V. Kapsalis, C. Fidas, L. Hadellis, C. Karavasilis, M. Galetakis, C. Katsenos, "A networking platform for real-time monitoring and rule- based control of transport fleets and transferred goods," in *Intelligent Transportation Systems (ITSC) 2010 13th International IEEE Conference*, Funchal, 19-22 Sept. 2010, page 295.

[4] J. Cleland-Huang, R. Settimi, E. Romanova, R. Berenbach, S. Clark, "Best Practices for Automated Traceability," *inComputer*, Vol. 40, Issue 6, 2007, pp. 27-35.

[5] DianminYue,Xiaodan Wu,JunboBai, "RFID Application Framework for pharmaceutical supply chain," in *Service Operations and Logistics, and Informatics 2008 IEEE International Conference*, Beijing, 12-15 Oct. 2008, page 1125.

[6] T. Kelepouris, K. Pramatari, G. Doukidis, "RFID-enabled traceability in the food supply chain," in *Industrial Management & Data Systems*, Vol. 107 Issue: 2, 2007, pp. 183-200.

[7] Guidong Liu, Wensheng Yu, Yu Liu, "Resource Management with RFID Technology in Automatic Warehouse System," in *Intelligent Robots and Systems 2006 IEEE/RSJ International Conference*, Beijing, 9-15 Oct. 2006, page 3706.

[8] F. Schwägele, "Traceability from a European perspective," in *51st International Congress of Meat Science and Technology (ICoMST), Meat Science*, Vol. 71, Issue 1, 2005, pp. 164-173.

[9] "Análisis del Pliego de Prescripciones Técnicas que ha de regir en el procedimiento abierto para la realización del proyecto piloto que determine el sistema de identificación automática más adecuado para la trazabilidad de los medicamentos," in *Trazabilidad de Medicamentos de Uso Humano Conference*, Madrid, 26 May 2009.

[10] J. Jenkins., J. Barnett, P.Mills, "Pharma Traceability Business Aplication, Building Radio frequency IDentification for the Global Environment (BRIDGE Project Report)", *WP06, European Commission contract* No: IST-2005-033546, 2007.

[11] M.P. Schapranow, J. Müller, A. Zeier, H. Plattner, "Sustainable Use of RFID Tags in the Pharmaceutical Industry," in *RFID Systech 2010 European Workshop on Smart Objects: Systems, Technologies and Applications*, Ciudad Real, Spain, 15 June 2010.

[12] U. Barchetti, A. Bucciero, M. De Blasi, L. Mainetti, "RFID, EPC and B2B convergence towards an item-level traceability in the pharmaceutical supply chain," in *RFID-Technology and Applications (RFID-TA) 2010 IEEE International Conference*, Guangzhou, China, 17-19 June 2010, pp 194-199.

[13] UAN Zhi-peng,KUAI Li-ping,SHU Li-xin,CHENShen-xin, "Joint application of 2D barcode and RFID technology in medical logistics tracking system" in *Journal of Pharmaceutical Practice*, 2009-05-16.

[14] D.D. Uysal, J.P. Emond, D.W. Engels, "Evaluation of RFID Performance for a Pharmaceutical Distribution Chain: HF vs. UHF," *in RFID 2008 IEEE International Conference,* Las Vegas, NV, 16-17 Apr. 2008, page 27.

[15] L. Catarinucci, R. Colella, M. De Blasi, V. Mighali, L. Patrono, L. Tarricone, "High performance RFID tags for item-level tracing systems," in *Software, Telecommunications and Computer Networks (SoftCOM) 2010 International Conference*, Split, Dubrovnik, 23-25 Sept. 2010, pp 21-26.

[16] R. Acierno, M. Maffia, L. Mainetti, L. Patrono, E. Urso, "RFID-based tracing systems for drugs: Technological aspects and potential exposure risks" in *Biomedical Wireless Technologies, Networks, and Sensing Systems (BioWireleSS) 2011 IEEE Topical Conference*, Phoenix, AZ, 16-19 Jan. 2011, page 87.

El ámbito de aplicación abordado en este trabajo es el de la sanidad, desarrollando una solución viable en coste y operativa que implementa un sistema de trazabilidad de productos farmacéuticos durante la fase de transporte, desde el distribuidor hasta los puntos de venta en las farmacias. El resultado es un piloto que posibilita un análisis del proceso de distribución y una gestión en tiempo real de incidencias, apoyada en una serie de servicios de soporte al transportista que son provistos de forma no intrusiva en su modelo operacional.

Así, la solución tecnológica combina un sistema telemático capaz de conectar en tiempo real las flotas de furgonetas encargadas de la distribución con el centro de gestión del distribuido farmacéutico; y un sistema automático de identificación de cubetas contenedoras de medicamentos basado en tecnología de identificación por radiofrecuencia (RFID).

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