Towards a Train-to-Ground and Intra-Wagon Communications Solution Capable of Providing On Trip Customized Digital Services for Passengers

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Abstract. The widespread adoption of Smartphone by citizens represents a great opportunity to integrate such nomadic devices inside vehicles in order to provide new on trip personalized digital services for passengers. In this paper a proposal of communication architecture to provide the ubiquitous connectivity needed to enhance the concept of smart train is presented and preliminarily tested. It combines an intra-wagon communication system based on nomadic devices connected through a Bluetooth Piconet Network with a highly innovative train-to-ground communication system.

Keywords. smart train, ubiquitous communications, bluetooth piconet network, train-to-ground communication, context-aware services.

1 Introduction

The widespread use of wireless and Internet technologies in transport systems enables the provision of a large number of new intelligent services. Moreover, the presence of ubiquitous connected vehicles (trains, undergrounds, buses or cars), including intra and inter vehicular communications, as well as continuous connectivity with their traffic control centers, is a key factor for the new generations of Intelligent Transportations Systems (ITS). On the other hand, the rise of Smartphone adoption by citizens represents a great opportunity to integrate such nomadic devices inside vehicles in order to improve the services and quality of information provided to the passengers.

In railway industry, where our work is focused on, wired networks (such as Ethernet) for intra-train communications are commonly adopted. These networks are mainly used by safety and control systems hosted inside the train. The innovation of this work is to enhance the concept of ubiquitous connected smart train by contributing with advances in train-to-ground wireless communication systems [1] and taking advantage of the communication and interaction possibilities of Smartphones for communications inside the train. The combination of these two challenges, an intra-train communication system based on nomadic devices and a highly innovative train-to-ground communication system, will be able to improve the experience of passengers who could be provided with more customized information.

The rest of the paper is organized as follows. First, the current network architecture of the train where our proposed solution is being tested is described. Second, the train-to-ground communications design. Third, intra-wagon communications are proposed including several simulation results. Finally, the conclusions and future work.

2 Related Work

Nowadays the use of wireless and Internet technologies is increasing in the railway industry enabling bidirectional train-to-ground communications [2]. However these kinds of communications applied to this environment have to respond to several challenges related to aspects like coverage, bandwidth, communication disruptions, multiple network interfaces for communications and different priorities in the data transmission, responding at the same time to Quality of Service (QoS) [3] demanded by applications.

There are multiple works regarding communications optimization, including traffic prioritization and QoS control. However, these works are usually focused on networks instead of applications or services that use these networks [4]. In addition, there are industrial solutions designed to respond to these detected communications needs and challenges in transportation systems [1, 5]. But neither of these projects establishes a communication system that prioritize data transmissions dynamically, making at the same time a QoS control based on bandwidth availability. The solution proposed on this paper includes a train-to-ground communication system designed to respond to all these challenges.

3 Architecture of the Ubiquitous Connected Train

The proposed solution establishes a communication system that enables intra-train and train-to-ground connectivity. This work has been deployed in a train manufactured by CAF (one of the largest train manufacturers in the world). Concerning integration issues, trains connectivity architecture is one of the most important aspects of the work. Specifically, the train used to carry out our tests has two networks that connect all devices that are deployed on the train.

On the one hand, it is the control network known as Train Communication Network (TCN). This network was the result of the work of the most important railway manufacturers (mainly Bombardier and Siemens) and its architecture is based on IEC 61375 standard [6]. TCN is used to control and exchange of information among the most important elements of the train; basically those responsible for the movement and braking.

On the other hand, there is the Added-Value Network (AVN). This network architecture is very similar to a local area network. It is usually based on the Ethernet standard. The objective of this second network is the connection of the devices that support other essential components of the train, such as: people counting systems, air conditioning systems, infotainment systems.

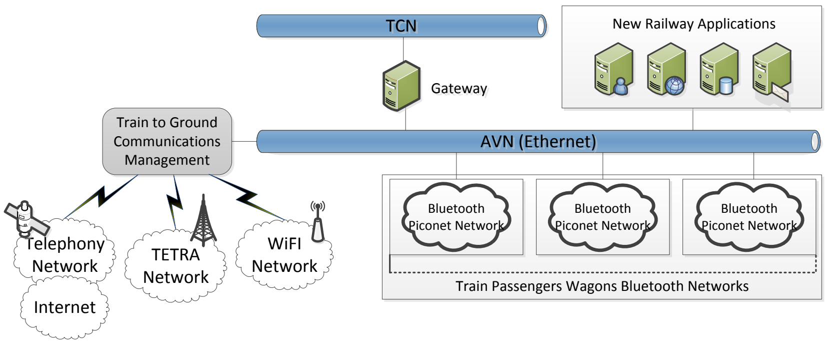


Fig. 1. Network architecture of the ubiquitous connected train

Taking into account this train network architecture (Fig. 1), firstly, the solution presented in this paper proposes the creation of a Bluetooth Piconet Network (BPN) [7] inside each passenger wagon. These BPN enable to share and distribute information and contents with passengers' devices, allowing the establishment of ad-hoc operation between dynamic users, which can change along a variable time-span within the proposed scenario. Individual dongles could also be employed, which in principle would not modify the results in radioelectric terms. Secondly, in our approach a reliable train-to-ground communication system is developed which integrates the on-board communication network, GSM radio links, TETRA network and Internet technologies. It becomes the key element to offer ubiquitous remote access to on-board equipment and distribute applications from transportation ground systems.
So, this solution deploys a BPN on each wagon. BPNs are interconnected each other through train Ethernet network (AVN), which enables an information channel along the train. AVN is also integrated with the train-to-ground communication system in order to achieve external connectivity.

This approach will allow the railways companies to exchange information with their trains and distribute contents and information to the users. Thus, this kind of communications enables the development of new on trip personalized digital services for passengers (e.g. trip information, weather forecast or train connections in destination).

4 Train-to-Ground Communications

In order to respond to train-to-ground communications challenges, we propose a communication middleware that aims to enable several physical network links between train and ground system (3G, WiFi, etc.). It chooses the network link considered as the best at every moment according to the bandwidth availability.

This middleware has been designed to respond to several requirements:

1. *Dynamic and efficient communication request management:* this system prioritizes train-to-ground communications requests taking into account communication urgency criteria, as well as previous performance logs.
2. *The best bandwidth:* the system always selects the physical link considered as the best taking into account the bandwidth in order to respond to final applications communication requirements.
3. *Quality of Service:* this solution aims to make a service quality management too. Therefore it is necessary to know the bandwidth availability offered by the network link which is active at every moment, as well as the bandwidth offered by the rest of communications links (although they are not being used). At this point it is essential to establish a set of connection procedures which enable to reserve a certain bandwidth for a particular communication.

This middleware is composed of two software elements (Fig. 2); one in the terrestrial side (Ground Communication Manager, GCM), and the other boarded in trains (Train Communication Manager, TCM). The former manages terrestrial aspects of the architecture and the latter train-side issues. They interact with each other in order to control and manage train-to-ground communications. In addition, this system includes a Bandwidth Measurement Service (BMS) that notifies available links bandwidth values to the GCM at every moment.

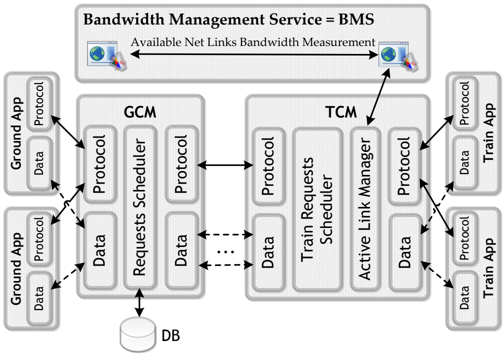
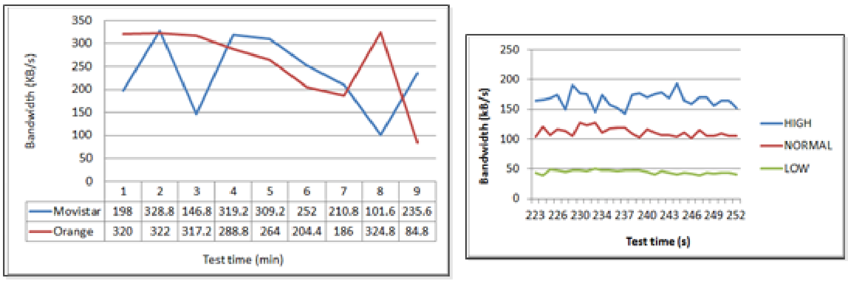


Fig. 2. Train-to-ground communication middleware architecture

In order to establish train-to-ground communications, TCM and GCM can communicate through different communications network physical links. The TCM is who selects the active link considered most favourable for communications based on available links bandwidth measurements notified by BMS, and then establishes active link connection with GCM. Two kinds of flows are involved in these communications: data and control. Thus, GCM and TCM on each train communicate each other and exchange commands in order to establish active links and manage the prioritization of train and ground final applications requests. These priorities are managed using specific queue scheduling techniques. The control protocol is defined using XML messages where information is exchanged via TCP/IP sockets.

At this moment, all these abilities are being successfully tested through preconfigured scenarios which includes a set of known communication requests (generated both on ground side and on trains) and network conditions.



(a) (b)

Fig. 3. Middleware tests results: (a) network bandwidth conditions along the test, (b) middleware communications management performance applying different request priorities

5 Intra-Wagon Communications

Our approach proposes an intra-wagon communications network establishment based on Bluetooth Piconet Networks (BPN), which enable the users' ubiquitous interaction with the train information systems. So, Bluetooth devices are organized in small networks (piconets) with one device acting as the master and up to seven others acting as active slaves, at any given time [7].

Piconet [8] is a general-purpose, low-power ad hoc radio network that provides a base level of connectivity to even the simplest of sensing and computing objects. It provides a broad range of mobile and embedded computing objects with the ability to exploit an awareness of, and connectivity to, their environment.

Sensors can use piconet to relay information about the state of the local environment or of a particular device. Personal connectivity is improved because the multitude of mobile and fixed devices commonly used by an individual can be connected by piconet; it might be used to personalize things nearby or allow two devices near each other to interoperate. Embedded networking is also suitable for smart information services: active diaries, alarms, information points, and electronic business cards, for example. The proximate connectivity that piconet provides means these applications can be context-aware [9].

Therefore, the proposed solution applies intra-wagon communications creating a BPN inside each passenger train wagon. The tests have been based on three devices, one master unit and two slaves. The master unit device is collocated just below the ceiling in the central part of the wagon, and the two slaves are just above the seats, emulating a real person who is sitting in the wagon sending information with a mobile device.

In addition, simulations have been made using the indoor wagon passenger train as scenario. The wagon has been modeled as a metallic cube, with rows of seats with a polycarbonate base. Simulations are based on the deterministic method of a 3D beam source, with the aid of an in-house developed ray launching code [9-11] to analyze the complex scenario of the indoor wagon passenger train. This approach is based in Geometrical Optics and Uniform Geometrical Theory of Diffraction. It is important to emphasize that the topology and morphology of the indoor section of the vehicle have a significant impact in the response of the system. Reflection, refraction and diffraction phenomena have been taken into account, as well as all the material parameters (given by dielectric constant values as well as conductivity values at the operational frequency of the system). The passenger seats are made of polycarbonate, the floors and walls of aluminum and the windows of glass. Simulation parameters are shown in **Table 1**. The cuboids resolution and the number of reflections have been set to 10cm and 5, respectively, to balance accuracy with simulation time.

Table 1. Parameters in the ray launching simulation

Frequency	2.4GHz
Vertical plane angle resolution $\Delta\theta$	1º
Horizontal plane angle resolution $\Delta\varphi$	1º
Reflections	5
Transmitter Power	0dBm
Cuboids resolution	10cm

Fig. 4 shows the power distribution inside the wagon for a height of 1.5meters. As it can be seen, morphology as well as topology of the considered scenario has a noticeable impact on radio wave propagation.

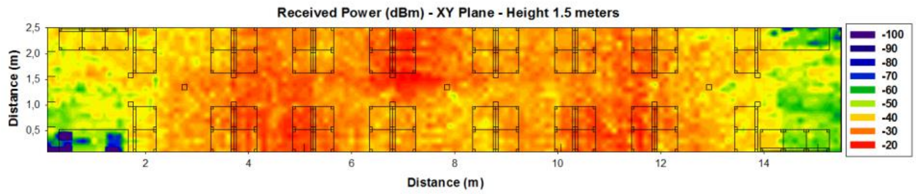


Fig. 4. Estimation of received power (dBm) on the indoor passenger wagon train for a height of 1.5m, obtained by full 3D Ray Launching algorithm.

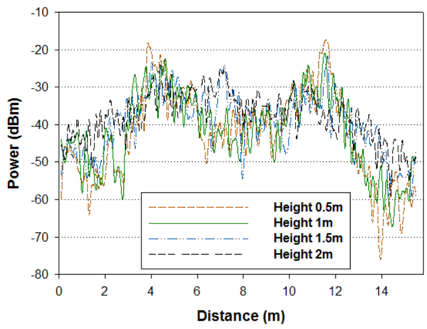
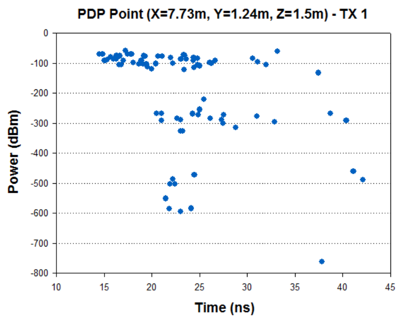


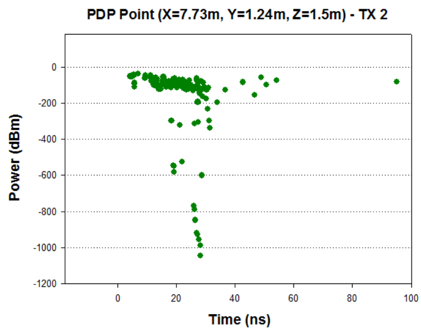
Fig. 5. Estimation of radials of received power (dBm) along the X-axis for Y=1.25m along the indoor passenger wagon train.

Fig. 5 depicts the radials of power along the wagon train (X-axis) for a fixed value of Y, which is Y=1.25m, for different heights. It is observed that the distribution of power has a lot of variability due mainly to the strong influence of multipath components.

As stated above, in this type of environment, the fundamental radioelectric phenomenon is given by multipath propagation. To illustrate this fact, the power delay profile for the passenger wagon in a central location has been obtained and is shown in Fig. 6 for each transmitter of the BPN. As it is observed, there are a large number of echoes in the scenario due to this behavior of multipath channel.



(a)



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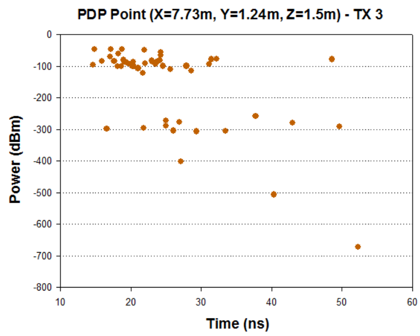

(c)

Fig. 6. Power Delay Profile at a given cuboid, located at the central location in the indoor wagon train (a) Transmitter 1 (master unit) (b) Transmitter 2 (slave 1) (c) Transmitter 3 (slave 3).

6 Conclusion and Future Work

This paper has proposed a solution to provide the ubiquitous connectivity needed to enhance the concept of smart train. It includes not only train-to-ground communication systems, but also intra-wagon connectivity which integrates passengers' devices in the environment.

Regarding the last challenge, results of several radioelectric simulations have been presented in order to analyze the viability of the applications of Bluetooth Piconet Networks inside train wagons, using an indoor wagon passenger train as test scenario. On the other hand, a research work focused on the development of a train-to-ground communication middleware designed to respond to communication requirements demanded by railway applications was presented. It manages aspects related to QoS, uses multiple radio and mobile interfaces (GPRS, UMTS, WLAN, etc.) and adopts an "always best connected" approach to enhance communications availability and obtain the best bandwidth capabilities, by selecting always the most favorable network link. Finally, future work relative to the exploitation of this communication system by the development of on trip customized added value services for passengers will be explored.

Acknowledgments. This work has been funded by the Ministry of Science and Innovation of Spain under INNPACTO funding program (RailTrace project, IPT-370000-2010-036). Special thanks to Eusko Trenbideak - Ferrocarriles Vascos S.A. for their support.

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