TOWARDS A WIRELESS ARCHITECTURE FOR THE DEPLOYMENT OF NEXT-GENERATION SERVICES IN THE RAILWAY INDUSTRY

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ABSTRACT

This paper describes a next-generation architecture for wireless communications, based on mobile phone carriers (GPRS) and broadband (WiFi), developed for the field of railways and allowing "train-to-earth" communications. This communication channel aims to complement traditional railway communication systems and its benefits make the deployment of new services, such as passenger oriented services, possible. Moreover, the result of this work is a framework for the addition of new on-board applications that have the capacity to connect the trains with control points. In addition, some planned improvements to this framework are described. Currently, as part of the architecture's validation, new digital services in the field of railways have been developed and are being implanted, and some others are being scheduled to be developed.

KEYWORDS

Wireless communications, railway, WiFi, GPRS, Web Services

1. INTRODUCTION

Since the origins of the railway in the XIX century most of the innovation and deployment efforts have been focused on aspects related to traffic management, driving support and monitoring of the train state [1]. The aim has been to ensure the safety of people and trains and to meet schedules, in other words, to ensure the railway service under secure conditions. To achieve this it has been necessary to establish a communication channel between the mobile elements (trains, infrastructure reparation machinery, towing or emergency vehicle, and so on) and the earth fixed elements (command posts and stations, signals, tracks, and so on) [2].

This article presents a specific communications architecture, also called wireless connectivity architecture. It is based on standard communication technologies and protocols to establish a bidirectional communication channel between fixed elements and the mobile elements of the railway system.

The second section of this paper includes a brief description of the state of the art in the field of communications in railways, then the third section describes the proposed solution, the fourth identifies new scenarios and services that arise as a result of this new communication architecture and the fifth section shows the future lines of work oriented to improve the proposed communication channel; finally, the sixth section of the article establishes the main conclusions of this work.

2. STATE OF THE ART

Railway communications emerged almost exclusively from the communication between fixed elements to carry out traffic management and circulation regulation. The technologies that communicate fixed elements with mobile elements (trains) are relatively recent, and they have contributed to improve and simplify the work required for rail service exploitation. Therefore, two subfields can be identified within the field of railway communications: a first one involving only fixed elements, and a second one involving both, fixed and mobile elements (called "train-to-earth" communications) [3]. For the former, the most efficient solutions are based on wired systems. The latter has undergone great change in recent years, requiring wireless and mobile communications [4].

Traditionally the communication between fixed elements and trains has been established using analogical communication systems, such as the traditional telephone or PMR (Private Mobile Radio) based on radio systems [5]. These analog systems are still used for voice communications and issues related with signaling. However, their important limitations in terms of bandwidth are causing the migration to digital systems, which offer a higher bandwidth.

Among the technologies of communication "train-to-earth", one of the most important advances of the last decade has been the GSM-R (Global System for Mobile Communications - Railway) [6]. This system is based on the GSM telephony, but has been adapted to the field of railways. GSM-R is designed to exchange information between trains and control centers, and has as key advantages its low cost, and worldwide support.

Another technology that provides a wide circulation in the rail sector is the radio system TETRA (Terrestrial Trunked Radio) [7]. TETRA is a standard for digital mobile voice communications and data communication for closed user groups. The system includes a series of mobile terminals, similar to walkie-talkies, which allow establishing direct communication between control centers, train drivers and maintenance personnel, in addition to being able to establish communications with earthlines and mobile phones. Being a private mobile telephone system, its implantation in the rail sector is very simple, because it is based on the placement of a series of antennas at stations or control centers along the route.

In addition, the special-purpose technologies mentioned so far include the growing use of wireless communication technologies based on conventional mobile telephony (GSM, GPRS, UMTS) and broadband solutions such as WiFi [8] or WiMax [9]. The wireless local area networks WiFi enable the exchange of information, at much higher speeds and bandwidths than with other technologies. The cost of deployment of such networks is very low, but these are limited in terms of coverage or distance they cover. To address this limitation, the WiMax technology has emerged extending the reach of WiFi, and is a very suitable technology to establish radio links, given its potential and high-capacity at a very competitive cost when compared with other alternatives [10].

All technologies discussed so far aim to establish a wireless communication channel between fixed elements and mobile elements of the railway field, but what happens with the services offered by means of this communication channel?, how can they have access to the channel?, how can they share it?. To address these questions, a categorization of railway services is necessary. Traditional applications or services of the railway field can be classified into two major groups: (1) services related with signaling and traffic control; and (2) services oriented to train state monitoring.

The first group of services is based on the exchange of information between infrastructure elements (tracks, signals, level crossings, and so on) and control centers, all of them fixed elements. Additionally, it uses voice communication between train drivers and operators in the control centers. Therefore, for this type of service, traditional communication systems based on analog technology remain significant.

The second group of services requires the exchange of information in the form of “data” between the trains and the control centers. In this case, the new services use any of the wireless technologies mentioned so far, but on an exclusive basis, which means that each application deployed on the train must be equipped with the necessary hardware for wireless communication, thus leading to trains having an excessive number of communication devices often underused. In addition, there are still many applications that require a physical connection “through a wire” between the train devices and a computer for information retrieval and updating tasks.

On the other hand, a new group of services is emerging that revolves around the railway end user (passenger or company that hires a transport service). These services are oriented to providing a transport service of higher quality that not only is safe, but provides additional benefits such as: detailed information about the location of trains and schedules, contextual advertising services, video on demand, and so on. All these services are characterized by their need of a wireless communication channel with large bandwidth and extensive coverage. As a result, the following needs are indentified: (1) to standardize the way trains and earth control centers communicate for applications related to monitoring train condition; and (2) to define a wireless communications architecture suitable for new services based on the railway end user [11].

3. “TRAIN-TO-EARTH” COMMUNICATIONS ARCHITECTURE

To address the needs of large bandwidth and coverage and general purpose communication channel in the rail sector, we turn now to present the results of our work which has been carried out in collaboration with companies in the railway sector of our country: EuskoTren and ETS (Basque Country), and Renfe (Spain).

As part of our work, we have defined a general purpose wireless communication channel, which allows the train to communicate with the Ground Control Panels in such a way that the applications or services are unaware of communication matters such as: establishment and closure of the communication, management of the state of connectivity, prioritization of information and so on.

The new wireless communication architecture has to respond to the demand for communication and transmission of information from any application, so it will have to take into account the nature of the information to be sent. The information exchanged between two applications (one on earth and the other on a train) may have different urgency degrees depending on their purpose or treatment with respect to the exchanged information.

In the field of railways, there is information that needs to be transmitted at the time that it is generated, for example in case of positioning information or alarms in some critical train operation elements. On the other hand, there may be less urgent information whose transmission can be postponed, such as train CCTV images, or audio files used by the background music. In addition, the urgent or priority information is usually smaller than the non-priority information.

For these reasons, the proposed communication architecture distinguishes two communication types:

- **“Light” communication:** this communication type enables the on-line exchange of information. It is called “light” communication because the size of the exchanged information will be small (bytes or Kbytes). The information transmitted using this communication mode is usually of high priority or urgent, therefore it must be transmitted immediately after its generation (real time). For example, in the case of a train positioning application, if the information about positions is not sent immediately after its generation, it loses all relevance.

- **“Heavy” communication:** there is a lot of no-priority information, which as such needs no real-time transmission. The “heavy” communication has been defined for this kind of information which involves the transmission of large quantities of information (Mbytes).

Thus, we have differentiated two transmission media one for each communication mode described above. Therefore, “heavy” communications will take place using WiFi technology whereas the technology selected for “light” communications is GPRS, enabling real time communication using the communication media offered by telephony providers and not having to install any type of new physical infrastructure element.

The selection of the WiFi and GPRS technologies does not guarantee the availability of communication coverage in the 100% of cases (for example, there is usually no coverage in many tunnels or mountain zones unless the telephone operators install specific antennas), but it is sufficient to respond to the communication demand of services deployed in the architecture, since combining the WiFi and GPRS technologies, a 100% coverage can be achieved. Although the initial selection of technology has been WiFi and GPRS, the use of standards makes the migration to other transmission technologies such as WiMax or TETRA possible. This could increase the communication coverage to about a 100%.

In accordance with the above discussion, the wireless communications infrastructure proposed here includes two communication modes: light and heavy, each of them supervised in the “earth”, by the Light Communications Manager and Heavy Communications Manager respectively.

3.1. Light Communications

Light Communications have been designed to enable real time communication between the “earth” and train applications giving a transparent communication channel that is independent of the functionality of other already existent or potential individual applications.

Due to the necessity of delivery of information in real time, for this kind of communication it is indispensable to choose a mobile technology that enables the communication between the trains and a central system at all times. To do this the technology that has been selected is GPRS (depending on the infrastructures of the company it could be substituted for a private network such as TETRA or GSM-R). To increase coverage availability, the hardware installed in each train has two phone cards belonging to different telephone providers. This allows switching from one to the other depending on coverage availability. Therefore, the idea is to have a predetermined operator, and only switch to the second when the former is unable to send. .

In addition to the hardware equipment, in order to make the communication in train and in “earth” possible, it is required the installation of software that manages such communication and the reception and dispatch of information from and to the train or “earth” applications, depending on the case. Figure 1 shows the two elements that have been defined, one in earth and the other in the trains: *Light Communications Manager* and *Train Communications Manager*.

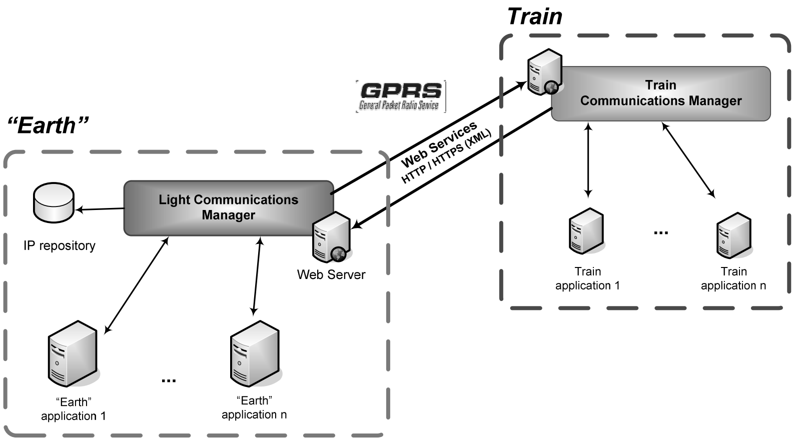

Figure 1. Light Communications Architecture

Each train has a Train Communications Manager (in each locomotive) that communicates with the Light Communications Manager situated in the central command post (in "earth"). The communications between these modules are performed over HTTP via REST Web Services exchanging XML information. The use of this kind of technology offers scalability, interoperability, development independence, and facilitates the use of intermediate systems to reduce the interaction time and improve security, among other things.

The responsibility of the Light and Train Communications Manager will be to receive and send information between "earth" and train applications. To do this, the applications' information includes a header that identifies the origin and the destination of the information (simulating the sending of information by e-mail where the origin and destination are identified). How to identify the different applications is totally transparent to the final applications, being the Train Communications Manager and the Light Communications Manager responsible for doing the translation from "application names" to IP address.

An important feature of the infrastructure is the physical location of trains which involves obtaining the IP address of each train. The Light Communications Manager is able to identify and locate the Train Communications Manager of the destination train reading the header data of the exchanged information. At this point it is important to remember that each train is equipped with two phone cards, each of them with a different IP address. In order to control this and to perform adequate train location, the Light Communications Manager has a repository that contains the IP address associated with each train. Thus, when the Light Communications Manager receives an information request, it obtains the data about the destination train, identifies the corresponding IP address, and sends the information to the Train Communications Manager which identifies the destination application for the information and then proceeds to deliver it.

It can be seen that every communication has to go through two core elements that can result in the loose of channel availability in case of failure. This problem is tackled by means of the use of web services. This solution deploys support web services in a way similar to traditional web architectures. Furthermore, the use of the HTTP communication protocol would facilitate the incorporation of a secure communication channel, moving the solution to the HTTPS protocol [12].

3.2. Heavy Communications

For Heavy Communications defined in the architecture, a number of WiFi networks have been settled in places where the trains are stopped long enough to ensure the discharge of a certain amount of information, this is: stations in the header that starts or ends a tour, workshops and garages. In this way, we can say that the WiFi coverage is not complete, but it is important to say that Heavy Communications are designed to update large volumes of information, which, theoretically do not need to take place in real time. Moreover, migrating the solution on a WiMax network type, could guarantee coverage in virtually all of the line, so that even the resolution of Light Communications, could also be channeled through the WiMax network.

The functional pattern for this type of communication is very similar to that of Light Communications (see Figure 2). In this case it is also necessary to find a mechanism to locate the trains, with the difference that the trains will not have an IP address known at all times, but instead the IP address will be obtained from the WiFi network within which they are connected, and such IP may change. On the other hand, there are various “earth” applications to communicate with train units, and the fact that the volume of information transmitted in these communications is large, implies the existence of a bandwidth monopolization problem with the communication channel.

To tackle these problems the figure of the Heavy Communications Manager is introduced. This is a system that arbitrates and distributes shifts to communicate “earth” applications and train applications; in this way, the “earth” applications request a turn when they want to establish a heavy communication with a train. This distribution shift is managed on the basis of the state of the train connection to a WiFi network (known at all times) and a system of priorities, which are allocated according to the “earth” application that wants to communicate with the train.

When the Heavy Communications Manager decides to give a shift for a “earth” application and a train to begin a communication, it sends an authorization to each part so that it is carried out. To do this, the manager establishes a communication with each “earth” application and each train Communications Manager through TCP Sockets. Within these, a series of messages in XML format that act as communication protocol, are defined.

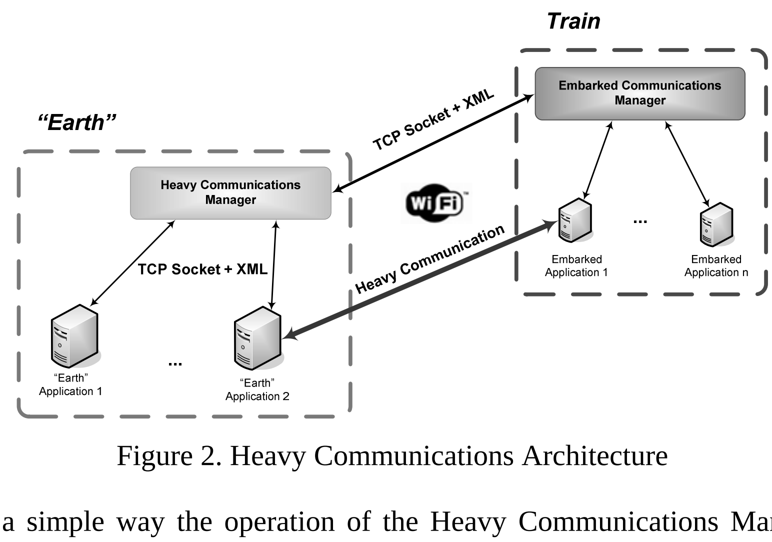

Figure 2. Heavy Communications Architecture

To explain in a simple way the operation of the Heavy Communications Manager, here is a representation of a typical scenario:

- Firstly, a “earth” application designed to communicate remotely with a train application is connected to the Manager through a TCP Socket.

- The “earth” application will make a request for communication, and will give it the appropriate priority. By the time the manager receives the request, it orders the request in the queue of the request of a certain train. The manager, on receiving the request, orders the queue of pending requests for the train.

- When a train arrives at a station, connects to the WiFi network getting a new IP address, which is supplied by the Embarked Communications Manager to the Heavy Communications Manager. If the train has pending requests for communication, the “earth” application and train application are notified so that they start the communication.

- At this moment there is direct communication between the “earth” application and the train application, through the WiFi network. The responsibility for initiating the communication relies on the “earth” application because it knows the IP address of the train.

- When the communication ends, the “earth” application is the one to inform the Updates and Downloads Manager, which is available to serve the next request for more urgent communication, if any.

The priority system, takes into account the number of attempts to start communication, to avoid blocking the communication channel by any request. In addition, to provide an extra level of security, each “earth” application uses a specific port for communication with the train applications. This is accomplished by the Manager of Communications board which is used to make a PAT mapping from port to IP address, so that the IP addresses of the train applications are not known from the outside.

It is important that the Heavy Communications Schema makes no restriction with respect to the final communication between the “earth” applications and the train applications. It does not define any structure or format of the information being exchanged; it only establishes a mechanism to know the IP address of the destination train (because it is dynamic), and regulates or controls the transmission shifts to prevent the monopoly of the communication channel.

4. APPLICATION SCENARIOS AND SERVICES

The implementation of the wireless communications architecture described in this article would be the basis for various digital services development that would make daily work easier in the rail sector increasing the quality of service provided. These services could be classified into three different groups (Figure 3) depending on their objective:

1) **Services related to monitoring the condition of the train:** this group would focus on services that would carry out maintenance, management, traffic control and security. Thanks to the possibility of being able to connect wirelessly with the corresponding units, it is easy to know the state of the train at all times, not just its location at any given moment, but also the check that all critical elements are functioning properly. It also could help in the process of maintaining these critical elements in a more efficient way, because the information could be collected faster, saving resources, both human and technological.

2) **Services oriented to final users:** railway companies can deploy end users oriented services being it beneficial from the point of view of the company and also from de point of view of the users. The purpose of these services is to enhance the feeling of quality that users can appreciate offering a higher quality of rail service.

3) **Services oriented to the driver:** the driver is a key element in the rail system since he is responsible for steering the train. Therefore, the main objective of this group of services is to improve the security and to reduce fuel consumption.

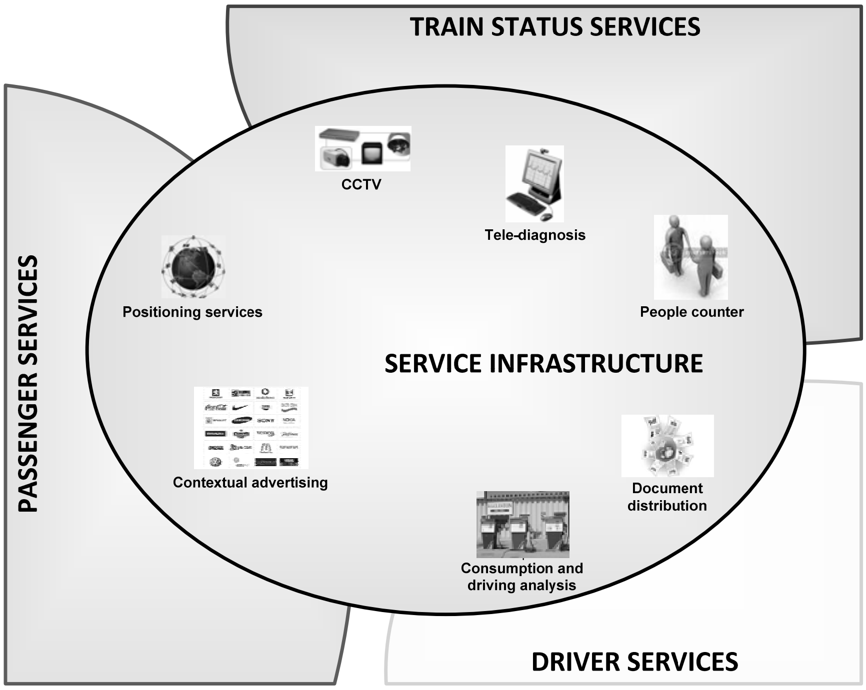

Figure 3. Digital services

Figure 3 shows some services that could be developed in each category. At this point it is important to say that the *positioning* and the *document distribution* services have already been developed and successfully tested. Rest of services is scheduled to be developed in the future.

5. FUTURE LINES OF WORK

As future lines of work, the major efforts are focused in providing the communication channel described in this paper with:

- **Communication network virtualization.** Where the technology and the terrestrial platform which takes part in the digital contents interchange are selected transparently to the front-end back -end applications depending on which technology suits better the communication features (transferred information volume, nature/priority, cost, coverage, and so on). Nowadays, the wireless technologies available for this kind of communication between the railway and the terrestrial platform are: WiMax, WiFi, GPRS, UMTS, TETRA or GSM-R. Nevertheless, the channel design has to be compatible with any other future communication technology.

- **Hybrid self-managed and shared communication channel.** The idea is to deploy a shared channel to be used for all the applications independently of their present or future functionality. These applications would connect a horizontal service and they only indicate the information and the destination (hiding protocols and communication complexities). The channel would decide when the proper time is and which one is the best technology to send the information.

Apart from this, a framework for vertical services deployment could be developed. This framework would offer an easy and seamless integration of new applications with the wireless communication infrastructure and with other future horizontal services. This infrastructure is based on standards and technological paradigms which are highly/ long enough proved in different environments. Furthermore, their interoperability and integration benefits are sufficiently contrasted; one example is the SOA (Service Oriented Architecture) paradigm case. It would be interesting to intend to move good communication solutions in other areas to the railway area.

Finally, the proposed infrastructure would boost the development of new vertical services which can be classified in four categories: (1) driver assistance services, (2) services for passengers, (3) freights trazability services (based on RFID technology), (4) services for train health monitoring. All these services have in common the digital and multimedia (often) content exchange necessity between the train and terrestrial platforms. Besides, the ubiquitous connectivity given by the developed infrastructure helps to improve present services in the railway area introducing new ones which are context aware or adaptive and personalized for each user. These advanced features would derive in crucial improvements in the railway area services.

6. CONCLUSIONS

In the rail industry, communications were born almost exclusively for the purpose of managing and regulating traffic flow, requiring by the mobile nature of this sector two modes of communication: those that occur between fixed elements of the rail infrastructure, which are based mainly in wired systems; and those which participate in the fixed and mobile elements (communications known as "train-to-earth"), which require a wireless communication channel and traditionally have materialized on the use of analogical communication systems such as traditional phone or radio .

Such channels of communication have been used traditionally in this sector to provide services mainly related to signaling and traffic control and to provide services for monitoring the condition of the train. Today, despite the maturity of the industry and the spectacular advances in terms of wireless communications, the rail industry continues to base the operation of its primary services on these types of communication systems, already belonging to the past. Specifically, the technologies of new-generation wireless communication, such as those based on conventional mobile technology (read: GSM, GPRS or UMTS), or broadband solutions (such as WiFi or WiMax), open countless possibilities of implementation in a sector like the railroad, as the cost of their deployment is very low, they perfectly complement traditional communication systems, and they have wide bandwidth and wide coverage that enable the deployment of new services in this area, and other services directly related to the end user that achieve a top quality transport service.

It is precisely this opportunity that led to the realization of the job described in this article: architecture of next-generation wireless communications for the rail industry to establish a bi-directional communication channel "train-earth." This architecture is a single channel of communication between all train applications and those in the control centers, standardizing in this way data transmission between them. Thus, this channel is a resource shared by all the applications that simplifies the complex details related to communications and provides advanced services oriented to communication, such as the selective treatment of the transmissions based on the nature of the information to transmit (urgency) and its volume, the location of the messages destination based on mappings of IP addresses, the management of priorities and arbitration of shifts of information communication, attempts management, and so on. This architecture will allow the addition of new services, making it a very appropriate framework for enabling new types of user-oriented services, which usually require mobility and bandwidths much higher than those offered by traditional communication systems.

The implementation of the architecture of wireless communications described here is being the basis for new digital services currently under development, with very diverse nature and purpose: from services for monitoring the condition of the train, to final user services, and services oriented to assist train drivers.

As future lines of work, we highlight: (1) the proportion of channel with communication network virtualization being a hybrid, self-managed and shared communication channel, (2) the development of a framework for vertical service deployment and (3) the development of new vertical digital services. Therefore, the objective is the adoption of best practices on Software Engineering and standards of interoperability to enable and integrate easily the implementation of other potential services and applications into the architecture.

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