Towards a Broadband Communications Manager to Regulate "Train-To-Earth" Communications

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***Abstract*—This paper describes an innovative broadband (WiFi) communications manager designed to manage "train-to-earth" communications. This communications manager aims to deal with applications communication needs and make decisions about what applications can communicate in each moment taking into account broadband features, application priorities and train connection states. Currently, as part of the architecture's validation, new digital services in the field of railways have been developed and they are being implanted, and some others are being scheduled to be developed.**

I. 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. 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 [1]. 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].

Nowadays the use of wireless technologies and Internet is growing in the railway industry which allows the deployment of new generation services that need to exchange information by "train-to-earth" communications [3]. In this sense, there are suitable solutions for other environments which permit to manage the bandwidth in terms of data rates. Therefore, these solutions are not designed for railway needs, and do not response all needs they have [4] [5]. This paper presents a Broadband Communications Manager developed taking into account railway communications needs and the limitations that have to be considered in terms of broadband network features.

The second section of this paper includes a brief description of the background of communications in railways, then the third section presents the proposed solution, the fourth one describes how this solution have been deployed and tested and the fifth identifies new scenarios and services that arise as a result of this new broadband wireless communication system; finally, the sixth section of this paper establishes the main conclusions of the work.

II. Background and Motivation

Railway communications emerged almost exclusively from the communication between fixed elements to carry out traffic management and circulation regulation [6]. The technologies that communicate fixed elements with mobile elements (trains) are relatively recent [7], and they have contributed to improve and simplify the work required for rail service exploitation. Therefore, focusing on the network topology, two categories 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) [8]. For the former, the most efficient solutions are based on wired systems. The latter has undergone great change in recent years, requiring wireless (WiFi/WiMax) [9] and mobile communications (GSM-R, GPRS, UMTS, HSPA, and so on) [10].

Furthermore, attending to functional purposes, traditional applications or services of the railway field can be classified into two major categories: (1) services related with signalling 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 centres, all of them wired fixed elements. Moreover, it uses voice communication between train drivers and operators in the control centres. Therefore, for this type of service, traditional communication systems based on analogue technology remain significant.

The second group of services requires the exchange of information in the form of "data" between the trains and the control centres. In this case, the new services could use any of the wireless technologies referred so far, but on an exclusive way, 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 identified: (1) to standardize the way trains and earth control centres communicate for applications related to monitoring train condition (and other future application which are developed); and (2) to define a broadband wireless communications architecture suitable for new services based on the railway end user [2].

According to the needs identified previously, nowadays new wireless communication architectures are being deployed enabling real-time bidirectional "train-to-earth" connectivity. However, within these wireless communications, there is need of voluminous information exchange for providing some kind of services, which require greater bandwidth and do not necessarily require real-time communication. This kind of communications will enable "train-to-earth" information exchange for onboard applications update/maintenance and multimedia information download/upload such as videos or pictures.

Therefore, at this point it has to be into account aspects such as bandwidth, coverage or communications priorities. However, the existing broadband based information exchange management systems, which are used in other environments, do not satisfy the requirements and use that this kind of communications has in the railway industry [4] [5]. In order to fulfil these requirements, it is necessary a smart intermediate element which manages when the final applications can communicate each other taking into account these aspects.

III. Broadband Communications Manager

With the purpose of providing an innovative broadband communications architecture suitable for the railway, 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 broadband communications are designed to update large volumes of information, which, theoretically do not need to take place in real time.

Furthermore, some additional problems have to be solved on this environment. First, it is 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.

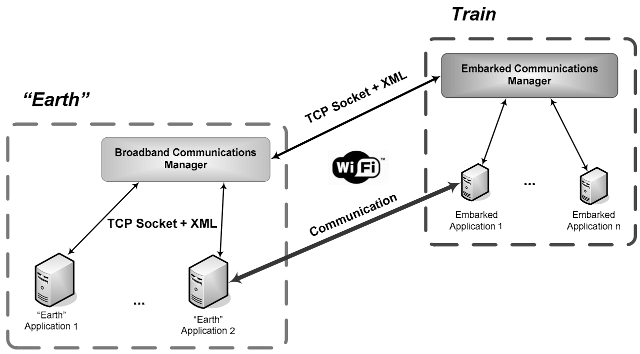

Fig. 1. Broadband Communications Manager arbitrating the communications between "earth" and train applications

To tackle these problems a Broadband "Train-To-Earth" Communications Manager has been developed. Its design and functional architecture is described below.

A. Design of the Communication Regulation

The Broadband Communications Manager is a system that arbitrates and distributes shifts to communicate "earth" applications and train applications (see Fig. 1); 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.

1) Protocol for communication establishment: when the 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.

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

- Firstly, an "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 Broadband 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.

It is important to emphasize that the manager does not set any limitation or condition in the final communication between the “earth” application and the train. The manager's work focuses on defining the time at which this final communication must be carried out, and warns of this fact the “earth” application and the train. 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.

2) *Multithreading management:* To carry out its work, the manager must establish connections with multiple “earth” applications and trains at the same time. To manage all these communications efficiently has chosen to make multithreaded design of the management of connections, so every communication that the Broadband Communication Manager performed with existing external elements (“earth” applications and trains) are carried out independently and concurrently, using a dedicated thread in each case. Fig 2 shows the outline of the multithreaded architecture of the Broadband Communication Manager.

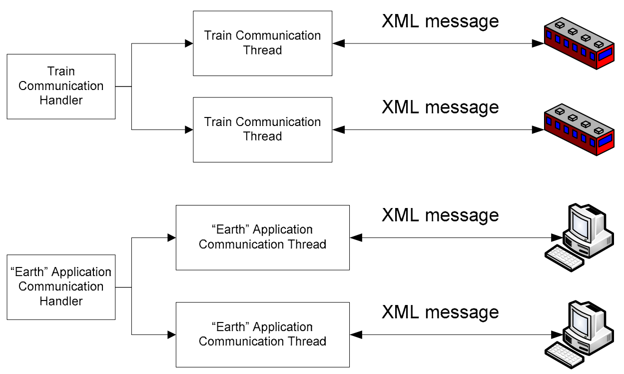

Fig. 2. Multithreading architecture

Both the Train Communication Handler and the “Earth” Application Handler are separate threads that are responsible for receiving connections from external agents. Upon receiving the connection message specified in the protocol, generate a separate communication thread with the element which has sent the message, an “earth” application in case of “Earth” Application Handler, or a train in case of the Train Communication Handler.

3) *Protocol for data transmission based on XML:* All the communications are done through an architecture based on TCP sockets (one for applications and another for the trains) and exchange of XML messages. A message will be defined for each requests/responses exchanged between the three elements that form the architecture: “earth” applications, trains and Broadband Communication Manager. Fig 3 shows a XML sample message.

```
<?xml version="1.0" encoding="UTF-8"?>
<request>
    <application name="CCTV" ip="130.88.10.56" />
    <train name="UT204" />
    <port number="3556" priority="1" />
</request>
```

Fig. 3. An XML message with a request from an “earth” application to the Broadband Communication Manager, asking a communication with an on board application installed in the train number UT204.

A protocol has been defined for the communication with the manager by sending and receiving XML messages, so that both “earth” applications and these ones installed on the train can communicate with it. It is important to emphasize that the added value services that finally are developed are responsible of creating and maintaining the communication infrastructure and protocol with the Broadband Communication Manager.

The choice of the TCP Socket schema and XML documents was taken due to the simplicity of the solution, the flexibility for expansion and addition of functionality, and simplicity of implementation (independent of platform and language programming).

Moreover, all the data handled by the Broadband Communication Manager are stored in a relational database. These data contain information about the communication requests, trains and “earth” applications to manage, and the available communication ports between them. The Broadband Communication Manager’s design contains a data layer that abstracts the data source of the business layer, so that the change of this data source for one with more capacity would not create any problem in the correct functioning of the Broadband Communication Manager.

4) *Port to IP address translation schema:* To finish the design of communication description, we would like to make a brief introduction on the management of the applications installed on the trains, which are the target of communication from “earth” applications. These applications on board are implemented on a computer that will have a private IP address (within the Ethernet network loaded) and is not accessible from outside. Therefore, it has been defined an addressing scheme to allow access from IP address of the “earth” application to the IP address of the boarded application. This is achieved through filtering PAT, associating each private IP address of the Ethernet shipped to a port number. Thus, whenever a train acquires an IP address from a WiFi network, the port number becomes the way to access the boarded application.

Boarded in each train there is a Communications Module which is the responsible for performing this filtering of port numbers to IP addresses within the trains. This boarded module is also responsible for communicating directly with Broadband Communications Manager, and manages the opening of the ports that are associated with IP address of the boarded applications.

B. Functional Architecture

Functional architecture of Broadband Communication Manager is based on message exchange between the manager itself and two types of external entities such as “earth” applications and trains.

The Broadband Communication Manager is divided into 5 modules (Fig. 4) that handle processing and deployment of all the functionality that has been developed.

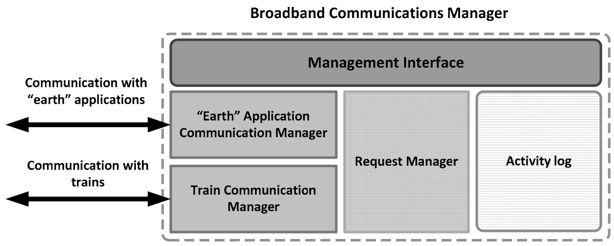

Fig. 4. Functional architecture

To have a global vision of the performance of the manager, we focus on three modules which develop the most important functionality: "Earth" Application Communication Manager, Request Manager, and Train Communication Manager.

1) "Earth" Application Communication Manager: It will be responsible for managing all the messages exchanged between each "earth" applications and Broadband Communication Manager. Basic functionality is to receive the XML messages coming from "earth" applications and generate an appropriate response. This communication is bidirectional, and it is responsibility of the "earth" extreme to start and finish it.

To streamline the management of communications between "earth" applications and Broadband Communication Manager, the connections are managed independently (through a dedicated thread of execution). The main functionality offered by this module would be the next one:

- Establish and close the connection between "earth" application and Broadband Communication Manager.
- Receive request for communication with a port of a train.
- Send a message to an "earth" application to start a previously requested communication.
- Receive a communication completed message from an "earth" application.

2) *Train Communication Manager:* It will be responsible for managing all the messages exchanged between the communication module of each train and Broadband Communication Manager.

This manager works much like the module described in previous paragraph, receiving XML messages from the communication module of each train and generating a response. In this case, the primary goal of the module is to indicate when a train is connected to a WiFi network and what it is its IP address. This data is very important for "earth" applications to communicate with train boarded applications. The basic functionality is setting a connection with the train, and sending messages to open or close a port so that an "earth" application can communicate with the train through it.

There is a very important task that Train Communication module manages, the disconnection or closure of communication between trains and the Broadband Communication Manager, where two scenarios can occur: in the first one, the train that is connected to the WiFi network and has established communication with the Broadband Communication Manager has got no communication request for it. In this case, the manager sends a ending request message to the train and closes the connection. In the second scenario, a train is disconnected from the WiFi network because of the movement of the train or a communication error. In this case the manager checks every often if the connection with the train is lost. There is a big problem when the connection fails in the middle of a communication between the "earth" application and the train, because the request of this communication has not been completed correctly. To solve this, the next time that the train connects to the Broadband Communication Manager; it sends back a start message of the broken communication to the "earth" application and a opening port message to the train.

3) Request Manager: It will be responsible for managing requests for communication between "earth" applications and the trains, and to control when and under what circumstances they need to be attended.

As discussed above, the Broadband Communication Manager splits communication shifts to "earth" applications based on requests that they have performed. These requests are grouped by train, so the manager handles requests addressed to each train independently. Furthermore, requests are sorted so that stipulates the order in which applications communicate with the trains. The management of requests associated with each train is based on the following criteria: (1) priority, which represents the "urgency" with which a request must be addressed; (2) retries, it is taken into account the number of attempts to start communication, to avoid blocking the communication channel by any request; and (3) parallelism, the manager can handle communications from multiple applications simultaneously with several trains, with the some limitations:

- A train can communicate with only one application at any time.
- An "earth" application can communicate only with one train at a time.
- In a station, it can only be established a single communication at any time.

The priorities associated with the requests, are managed centrally and Broadband Communication Manager assigns these priorities to "earth" applications. In addition, the manager also controls the boarded applications that can communicate with each single "earth" application, identifying the train communication module ports that can be accesses by each of those "earth" applications.

4) *Management Interface and Activity Logs:* As for the remaining two modules, the Management Interface contains a small management window which monitors the status of existing requests in the tracker, and may even cancel or change the priority of unserved if necessary. Through this interface is possible to configure parameter and information settings of the Broadband Communication Manager such as "earth" applications with which it communicates or through which port and priority will communicate with the trains. It is important to say that is respected standard design patterns like MVC (Model View Controller) so that in future the

presentation layer can be replaced by a more suitable or interesting one at any time without interfering with the core functionality described a few paragraphs earlier. The other supporting module, the Activity log, contains each of the activities undertaken by Broadband Communication Manager.

IV. TESTING AND DEPLOYMENT

The Broadband Communication Manager is currently being tested within the infrastructure of a railway company in the north of Spain. These tests are carried out within the maintenance installations of the company, using a new generation train equipped with the necessary technology to communicate with the architecture of connectivity deployed, being the Broadband Communication Manager part of it.

Broadband Communication Manager has been installed on a dedicated server for its work, and is located in a local network designed to communicate it with different deployed "earth" applications. Today we can find two of these services, also in test phase, relying on the Broadband Communication Manager in the local network installed: a video download application, and a document updating and downloading application.

In the case of the train, it has been installed a WiFi network in the maintenance station which can connect the Communications Module of the train. Thus, it can be tested in a direct way one of the basic action scenarios of the Broadband Communication Manager: the communication between "earth" applications and the train when is in the garage, ideal moment for many of these applications to perform their work, as might be downloading the surveillance video of the day.

New tests are planned in the coming months with the train making a journey through a series of stations where WiFi networks are installed. This will test the other Broadband Communication Manager's application scenario: a train arriving at a station, connecting to the Broadband Communication Manager through the WiFi, and losing that connection in the middle of a communication with an "earth" application because the station has been abandoned by the train.

Finally, it remains tests with multiple trains simultaneously, a fact that is for the last stage of the testing phase. Note that tests performed so far have been successful, solving either quickly and effectively the problems encountered.

V. APPLICATION SCENARIOS

The implementation of the system that manage the broadband communications in the railway industry 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 (Fig. 5) 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 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 very often, in order to 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.

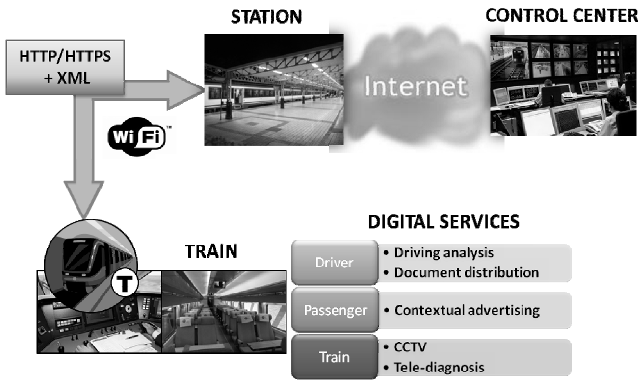

Fig. 5. Digital Services

As shown in Fig. 5 and relating to the three groups of services described above, some kind of services that could be developed are:

- CCTV: it consists in the downloading of the recordings made by the CCTV video surveillance system installed in each train wagon. Thus, a "earth" application located on the outside could download and store the contents of the recordings made by security cameras in a fast and comfortable way, thanks to wireless communication, which in this case would be heavy (through WiFi), considering the volume of information to be transmitted.
- Tele-diagnosis: remote diagnosis permits to save technological and human resources. The idea is to receive information about trains "health" (or status) very often (daily) which enables the realization of diagnosis about different aspects related to the functionality of them.
- Contextual advertising: the objective is the introduction of contextual advertising in the train carriages which would be updated with information about the sites where the train is passing by, or with ads from shops in the area.
- Document distribution: in regard to services oriented to the driver or train staff, one of the most relevant utilities to develop would be a system for download and/or update documents with relevant information for the staff embarked on the train. This information would be coming from an application from the outside. This system would be

of great help because the driver could obtain updated information on any item he would like (from route itineraries to security protocols) fast, thus facilitating his work. This utility would free the driver from the burden of carrying information on paper, and even allows the on-line notification of such documentation updates.

- Consumption and driving analysis: the energy cost of the train is originated from the internal wagons elements that are usually fixed and constant, and from the variable costs of locomotives. The locomotives' consumption depends on the drivers' driving patterns. The objective is to look for driving patterns in order to try to reduce the locomotives energy consumption.

At this point it is important to say that the CCTV and the document distribution services mentioned above have already been developed and successfully tested.

VI. Conclusion

New generation of wireless communications technologies [11] opens countless possibilities of use in the railway industry. 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 generation services in this area, some of them directly related to the end user, in order to provide a high quality transport service.

The broadband based information exchange management systems existing at present do not satisfy the railway industry requirements for this kind of communications. This paper describes a wireless communication architecture designed for railway industry and focused in "train-to-earth" information exchange that requires larger bandwidth and not need a real-time communication. Thus, the presented solution aims to (1) resolve the limitations/problems of the used of a shared communication channel and (2) to constitute an alternative to WiFi traffic control management existing solutions that are not adjusted to railway requirements. This solution allows to strength the railway oriented communication possibilities permitting to develop new services that exploit information that could be uploaded or downloaded by "train-to-earth" communications.

In the future, our efforts will be focused on (a) continued work in the implementation of the platform to refine it and improve it; and on the other hand (b) continued development of added value services supported on the platform. At this point, one new service is planned for the short term: the establishment of a multimedia information channel for passenger oriented services.

Besides, the design and implementation of this type of architecture by independent research organizations and using standards protocols and technologies, will allow for numerous technology provider companies to supply this type of services to the railway industry. In turn, railway companies will cease from being coupled to just a few specific suppliers. This is one of the key reasons railway companies are interested in contracting the design presented in this paper.

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