DECENTRALIZED SYSTEM FOR MONITORING AND CONTROL OF RAIL TRAFFIC IN EMERGENCIES

A New Distributed Support Tool for Rail Traffic Management

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Abstract: Traditionally Rail Traffic Management is performed automatically using centralized systems based on wired sensors and electronic elements fixed on the tracks. These systems, called Centralized Traffic Control systems (CTC) are robust and high availability, but when these systems fail, traffic management must be done manually. This paper is the result of 4 years of work with railway companies in the development of a distributed support tool for rail traffic control and management. The new system developed combines train-side systems and terrestrial applications that exchange information via a hybrid mobile and radio wireless communications architecture.

1 INTRODUCTION

Today, rail traffic management is performed automatically using Centralized Traffic Control systems (CTC) (Ambegoda, A., et. al. 2008). These systems are based on sensors and different elements fixed on the tracks. These systems allow real-time traffic management: (a) location of trains, (b) states of the signals, (c) status of level crossings and (c) orientation of the needles. Most of the infrastructure management entities have a CTC that handles centralized all these issues. The applications and systems that handle these tasks are very robust and have a performance index near 100%. Problems occur when these systems fail. In those situations, traffic management has to be performed manually and through voice communications between traffic operators and railway drivers (Sciutto, G., et. al. 2007).

The work presented in this article is the result of the work made during the last four years alongside a regional railway company of Spain. It defines a support tool to assist traffic operators in emergency situations in which CTC systems fail. The main objective of the new system is to reduce human error caused by the situations in which priority systems do not work properly.

The paper is organized into the following sections: the second section includes a brief description of the main functionality of the new system developed. The third section details the technical aspects of the work done. The fourth section presents the results the tests made. To close, the fifth section of the paper establishes the main conclusions of this work and the following steps to deploy the new system in a real scenario.

2 FUNCTIONALITY

CTC traditional systems are centralized and rely on wired communications. When CTC system or communications fail, no one knows the location of trains, thus increasing the chances of an accident. In these situations, the railway companies put into operation its security procedures that transfer the responsibility of traffic management to traffic operators, who are people that monitor traffic in the terrestrial control centers. These people should manage the traffic manually communicating through

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analog radio systems to the drivers of the trains. As people get nervous in emergency situations and that leads to mistakes, the new system aims to reduce these errors by creating a new tool to help traffic operators in emergency situations. This new tool must be based on different technologies to those used by traditional CTC systems so that failure in the former does not cause failure in the latter.

Taking into account the aspects mentioned above we have developed the *Backup Traffic Management Tool*. This system will assist traffic operators when the primary system fails. The main functions of this new system are:

- *Traffic situation representation for the track stretches where the main system do not provide information*. The new application represents the affected line stretches situation (train locations, track section occupation states, etc.) from information received from train-side systems through real-time wireless '*train-to-earth*' communications (see Figure 1).

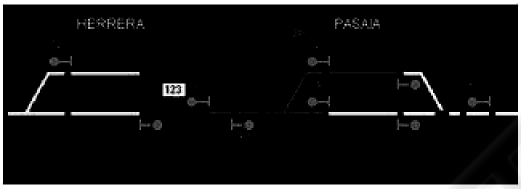

Figure 1: Traffic situation representation.

- *Traffic management environment*. The aim is to assist traffic operators in tasks related to traffic control when the main system fails partial or totally.
- *Statistical analysis* about aspects related to the system performance and reliability.
- *Control message sending from control centre to trains*. This functionality allows traffic operators to send messages to the train drivers in order to manage and control the traffic.

The *Backup Traffic Management Tool* provides a traffic assistance application that works independently of the main CTC System. Thus, the new system is based on an application that informs about the position of the trains on track and permits to make tasks related to traffic management and control in an easier way. Furthermore, this system permits a new way of communication between the traffic operators and the trains drivers: exchanging control messages.

It is important to point out that even if the main system is working without failure, our backup system stores train position information received from the boarded system, and analyzes the coherence between the information provided by this new system and the information provided by the primary system. This analysis is important to guarantee the reliability of the *Backup Traffic Management Tool*. Furthermore, all the stored information could be used for other external applications.

The *Backup Traffic Management Tool* is based on the following modules: (1) train positioning system, (2) statistical analysis, and (3) control message exchanged.

2.1 Train Positioning Module

The *Backup Traffic Management Tool* is always receiving and storing positioning information generated by the train-side systems. Furthermore, the *Backup Traffic Management Tool* can receive positioning information generated by the traffic management main system due to the existence of an *External Positioning Information System* that publishes the information generated by the main system via JMS based Messaging System. This storage tasks are performed even when the primary CTC system is active because the information collected will be used for statistical analysis module.

Therefore, this module stores the information that receives from the main and the backup systems. This stored information is basic on the generation of statistics related to the *Backup Traffic Management Tool* reliability. These statistics will be used for the improvement of the system. Furthermore, this information may be exploited and used by future applications and systems.

2.2 Statistical Analysis Module

Using the information stored by the positioning system on a data base, the *Backup Traffic Management Tool* can make statistical analysis related to the system's reliability level, GPS and GPRS coverage, and other system functionality aspects.

Then, one of the main objectives of this module is to compare the received information, determining if the positioning provided by the train-side systems agrees with the information generated by the main CTC system.

2.3 Control Message Exchanged Module

This module allows the procedural alarms transmission to the train-side systems.

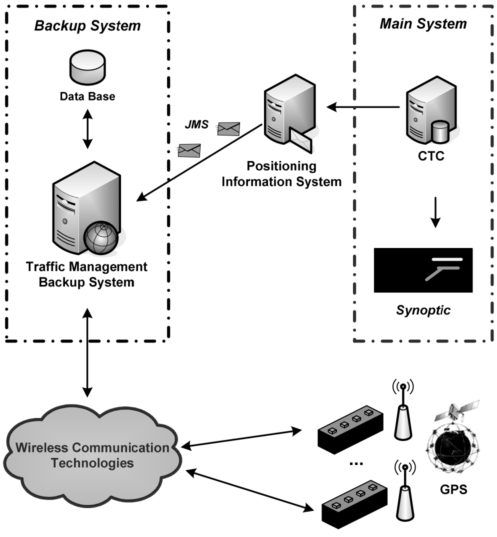

Figure 2: Backup Traffic Management Tool.

The procedural alarms indicate anomalous situations: main system failure, signal exceeds authorization to a certain point as a consequence of a failure of any electro-mechanical track component, etc.

Moreover, taking into account the different circumstances that can occur, and notifications given to engine drivers, there are two types of messages:

- *Messages generated by the traffic operator:* the traffic operator in the terrestrial control centre can select and send messages manually to a train driver. These messages must be confirmed immediately by the driver when they read them on the HMI.
- *Temporal speed limitations:* these messages are predefined by a circulation inspector and they have greater validity than the others. Once the message is created, it is sent to all the trains immediately.

3 TECHNICAL DESCRIPTION

In this section, we describe the most important technical aspects about the proposed system. The main aspects are related to (1) trains positioning and (3) wireless '*train-to-earth*' communications. Both issues are described below.

3.1 Train Positioning Information Generation and Management

The *Backup Traffic Management Tool* permits a new way of train positioning which works independently of the main system operation. This system receives and stores positioning information generated by the hardware (accelerometers, gyroscope, odometer, etc.) and GPS modules boarded on the trains. Furthermore, the *Backup Traffic Management Tool* communicates with an external positioning information system which permits the reception of train positioning information generated by the main CTC system.

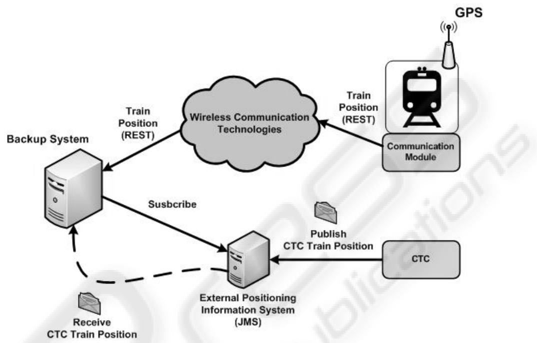

Figure 3: Train Positioning Reception in the Backup Traffic Management Tool.

3.1.1 Train Positioning Generation Based on GPS

In order to enable a new way of train positioning generation and management, the presented system aims to board a new hardware/software module on each train. This system is based on GPS data and it is able to generate train positioning information applying a logical approximation algorithm for matching railway lines and GPS coordinates (Wei, S.G., et. al. 2009). Then this positioning information is sent to the control center in real-time, so that the backup application can represent the train location in a synoptic.

In order to generate the most accurate positioning information, this system parts from a railway lines different tabulation ways. In this case, the tabulation is related to lines lengths (in kilometers) and the traffic signals positions. Based on this information, and the data extracted from the hardware and software modules boarded on trains (including GPS), this system translates this information to *kilometric points*. A *kilometric point* is a metric used by the railway company to tabulate the lines where its trains circulate. So, it can be said that this system is capable of making a translation of GPS positions to *kilometric points* tabulated by the railway company.

The transmission of train positions to the terrestrial control centre depends on the communication availability. Therefore, all the positions generated by the boarded system are stored locally on the trains in log files. These log files will work as a registry that permits to know what positions were not sent due to communication and coverage problems. Furthermore, the information contained by these logs can be integrated offline with the *Backup Traffic Management Tool* in order to guarantee system reliability.

Besides the position of trains, it is also necessary to know the exact track each train takes. This is especially complex because the GPS positioning accuracy is around three meters, and the tracks are separated by less than 2 meters. To achieve the exact track that occupies a train inertial sensors are used. These sensors allow the detection of tack changes.

Finally it is noteworthy that for sections of track without GPS coverage distance and speed data are used to determine the exact position of the trains.

As it can be guessed, the positioning module has been the most complex to develop because we have had to perform multiple tests outside the laboratory to refine the different types of positioning and to combine them appropriately.

It is important to remark that this positioning system has been developed based on standards; therefore, it is possible a migration to another navigation satellite system like Galileo, or the combination of GPS and Galileo in the future, creating an even more accurate global navigation satellite system.

3.1.2 Communication with the External Positioning Information System

The external positioning information system's aim is to provide train positioning information generated by de main CTC system to other external systems. This system is based on JMS (Java Massaging System) in a publish/subscribe schema. So, the messages published by the CTC system can be received by the subscribed applications.

In order to generate reliable statistics about the proposed system with respect to the original system, the *Backup Traffic Management Tool* subscribes to the *External Positioning Information System* to receive positioning information generated by the CTC.

3.2 'train-to-earth' Communications Module

The system presented on this paper permits a real-time train traffic management, so it is necessary to enable a wireless communication channel between the *Backup Traffic Management Tool* installed on the control centre and the trains. For this reason, the system that we propose in this paper uses a '*train-to-earth*' wireless communications architecture based on mobile and radio technologies (Salaberria, I., Carballedo, R., Gutierrez, U., Perallos, A., 2009). Figure 4 shows the basic protocols and communication technologies applied in the communications architecture.

3.2.1 Protocols

The communication between the terrestrial and the on-board system is based on REST (Representational State Transfer) technology. This communication technology uses the HTTP (HyperText Transfer Protocol) protocol and XML formatted messages. This solution is similar to traditional XML Web Services but with the benefit of a low overload and computational resources consumption (Pautasso, C., Zimmermann, O., Leymann, F. 2008). Although the information interchanged between the Terrestrial and the On-Board Communication Managers is encrypted, using the HTTP protocol allows the easy migration to HTTPS (HyperText Transfer Protocol Secure) that offers encryption and secure identification.

It is important to point out that REST is not a standard; it is an architecture style that is based on standards (HTTP, URL, XML/HTML/GIF/JPEG/.. resource representations, MIME types, etc.).

In addition, it can be said that the selected technologies are well known and broadly used in different application areas or contexts, but they are novel in the railway *train-to-earth* communication field.

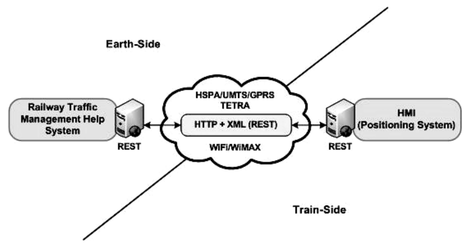

Figure 4: 'train-to-earth' Communications Architecture.

3.2.2 Communication Technologies

In order to establish '*train-to-earth*' communications, the system presented in this paper combines mobile (GSM/GPRS) and radio technologies (WiFi). In this case, according to the transmission characteristics (information volume, real-time communications needs, coverage and communications costs), the system combines these technologies selecting the best way of communication in each moment, taking into account train locations, and its connectivity state (Shafiullah, G., Gyasi-Agyei A. and Wolfs, P. J., 2007).

To make this communications possible, the trains have been equipped with the necessary connectivity hardware/software system. Furthermore, taking into account mobile communications coverage aspects, to enhance trains GPRS connectivity, the communication system boarded on trains allow GPRS communications within two different telephony providers, working one of them as main provider, and the second one as the secondary when the first one is not operative.

So, in this system movable technologies such as GPRS/UMTS/HSPA are used for the Real Time Communications. These technologies do not offer either a great bandwidth or 100% coverage, and they have a cost associated to the information transmission. Despite this, these technologies are a good choice for the delivery of high-priority and small sized information. The selection of the specific technology (GPRS/UMST/HSPA) depends on whether the service is provided or not, (by a telecommunications service provider), and the coverage in a specific area.

On the other hand, this system use WiFi radio technology to realize '*train-to-earth*' communications on WiFi connectivity equipped railway infrastructure points (a private net of access points is needed). What is more, this technology allows the transmission of large volumes of information and does not have any costs associate to the transmission (for example log information stored on trains, or train services information that is uploaded on train periodically).

For a correct and optimized used of the communication architecture, we have defined two types of transmission. These two types take into account characteristics of both information and communication technologies, such us: the volume and the priority of the information, the existence of coverage, and the cost of the communication. Considering these aspects, we have defined: *Slight* and *Heavy Communications*.

- *Slight Communications*: This type of communication is for the transmission of small volumes of information (few kB.) and with high priority. In general, information that has low latency (milliseconds or a pair of seconds) and needs to be transmitted exactly when it is generated or acquired (for instance, the GNSS location of a train, or a driving order to the train diver).
- *Heavy Communications*: This type of communication is tied to the transmission of large volumes of information (in the order of MB) and with low priority. The importance of this information is not affected by the passage of time, so it doesn't need to be transmitted at the exact time it is generated. The management of this type of transmission is the core of this paper.

It is important to point out that although each separate technology can't achieve 100% coverage of the train route, the combination of both comes very close to complete coverage. As the application layer protocols are standard, other radio technologies such as TETRA or WiMAX can easily substitute the ones selected now. These technologies can achieve a 100% coverage and neither one has a transmission cost. However, there are certain limitations such as the cost of deploying a private TETRA network, and the cost and the stage of maturity of the WiMAX technology (Aguado, M., et. al. 2008).

4 EXPERIMENTAL RESULTS

The work that has been presented on this paper is the result of almost three years of joined efforts with a railway transportation company.

Currently this system is on real deployment phase. Thus, the system has been deployed in a passenger train and in two freight transportation locomotives, allowing the sending of GPS based positioning information from trains to terrestrial control center.

We have performed test on laboratory and also in real scenarios. Laboratory tests have been satisfactory. Test on real settings have also been successful except for mountainous landscapes with numerous tunnels where wireless mobile communications were affected by the insufficient coverage related to these kind of technology. However, this difficulty can be easily overcome using a communication technology with a greater coverage. Furthermore, in order to ensure security on traffic management, coverage in all stations is guaranteed. So that, the Backup Traffic Management Tool is able to recognize when a train enters or leaves a station, helping to prevent conflicting movements (interlocking).

It is important to point out that during the system real tests, there has been improvements on the GPS based position generation and management. This work has been focused on what it is the best way to relation the position provided for CTC (track sections) and the position generated by GPS based boarded system (*kilometric points*). So, the CTC provide positions as a track sections where the train is. This track section is a range of kilometer points. Therefore, when the backup system receives train boarded system's position, it calculates what track section corresponds to the kilometer point provided by this position. However, while CTC generates track section based positions when the train enters or leaves this track sections, the boarded system provides the kilometric point calculated by the GPS module on the main coach where the engine driver is. Thus, it is possible that the backup system interprets that there is no correspondence between both positions when really there is. So, these aspects have been considered to make improvements to achieve a better fit between the positions provided by both systems.

5 FUTURE WORK

In the future our efforts will be focused on (a) the improvement of GPS based positioning system enabling a more accurate position calculation, (b) improvement of communication capabilities and (c) system deployment and integration with new train series and other railway lines topology.

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