Improving the Reliability of a Train Positioning System through the Use of Full Coverage Radio Communication Technologies

Performance Study of a TETRA Network to Transmit Position Information

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Abstract: Today, it is common for trains to incorporate autonomous positioning systems based on geo-location technologies similar to those used on road transportation. These positioning systems represent a cost effective solution for railway companies operating in not evolved regions. Furthermore, these positioning systems can enhance the reliability of positioning systems based on the occupation of the tracks (which are most used in the most developed regions). Autonomous positioning systems calculate the position of the train, but the position has to be sent from the train to the control center. GPRS/3G mobile technologies and WiFi radio technologies are the most common technologies for transmitting the position to the control centers. These technologies do not guarantee 100% coverage in certain areas such as tunnels or mountainous regions. This paper presents the results of the tests on an autonomous positioning system to add a new communications technology in order to increase its coverage. This technology is TETRA, which is a radio technology that has been traditionally used for voice transmission, but it can be a good complement to GPRS/3G when there is no coverage.

1 INTRODUCTION

Train positioning systems are a key element to ensure the safety of the rail system. Most positioning systems are based on electronic devices that are installed on the tracks. These positioning systems are very robust and reliable, but when they stop working, security levels are significantly reduced. In these situations the position of trains is done manually by live-voice communication between drivers and control centers. For this reason, in recent years, there have been many initiatives to develop backup positioning systems, in which the train becomes the protagonist (Jiang et. al., 2010) (Bai-Gen et. al., 2011). These positioning systems calculate the position of the trains by means of different position sources: GPS, MEMS gyroscope, maps, ATP, odometer, etc. Once the position is calculated, it is sent to the control center using a wireless communications network, usually GPRS or 3G. The main limitations of these systems are the coverage of mobile communications (tunnels, overgrown or isolated areas, etc.), and the cost of the communications (usually communications network belongs to a private operator). To tackle this limitation, this paper presents the results of tests performed with a train positioning system in order to improve reliability. The tests were focused on evaluating the improvement achieved by incorporating the TETRA as a backup channel in situations where there is no GPRS/3G coverage.

The paper is organized in 5 sections: Section 2 details the potential of TETRA technology for transmitting position information in the railways. Section 3 explains the underlying details of the positioning system and communications architecture to send the position from the trains to the control center. Section 4 shows the results of the tests; and finally, the paper concludes with Section 5 which details the conclusions and future lines of work.

2 TERRESTRIAL TRUNKED RADIO FOR DATA TRANSMISSION

TETRA (TErrestrial Trunked RAdio) is the communications standard, defined in 1999 by the

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European Telecommunications Standards Institute, for a generation of digital radio products. The main characteristics of TETRA are:

- It is an open standard air interface so it provides real interoperability with other communication systems.
- High spectrum efficiency with short bandwidth that allows creating private workgroups of users and high quality of services, for example at voice communications.
- It can be used on all frequencies below 1000 MHz frequency bands for Private Mobile Radio (PMR) and public safety applications are assigned on a national basis.
- In the railway context it offers encrypted and high-quality communications in noisy environments and whatever the signal conditions, providing up to 28Kbps bit rate.
- It is a mature technology with several suppliers of terminals.

At the beginning, TETRA was deployed to satisfy the needs of the Private Mobile Radio (PMR), Public Access Mobile Radio (PAMR), Land Mobile Radio (LMR) and the public applications for security and protection corps, guard coast, fire-fighter's services and ambulances. But later developments at the standard allowed Package Data Optimized (PDO) transmission mode and Short Data Services (SDS) that is comparable with the Short Data Message (SMS) of GSM.

Package Data Optimized is used by modern systems to transmit voice message, electronic mail, data interchange, and so on. In this regard, Enhanced-PDO known as DAWS (Digital Advanced Wireless Services) provides a 2Mbps bit rate to be used in combination with UMTS in high mobility scenarios as Railroad Digital Networks (Wenlong, Haige and Hongjie, 2002).

Short Data Services are transmitted over the control channel in a point-to-point or point-to-multipoint format without any reception acknowledgement. Two message formats are available:

- Status messages that only with 16 bits can represent 65,535 messages.
- User messages that use a variable package size from 16 to 2,047 bits.

In Railroad Networks basic TETRA Short Data Service for polling and transmitting GPS position in Location Information Protocol (LIP) format can be easily used with a high reliability in different scenarios because SDS messages can be send between subscribers, between subscriber and dispatcher and subscriber and fixed host in the network. Moreover, SDS messages can be sending to individual subscribers or broadcasted on a number of base stations to all subscribers using that base station.

In the railroad applications TETRA works in PDO or SDS modes. These systems are connection oriented so the mobile node installed in the train requires first a connection to a specific Base Station to start the data transmission. As the train is a moving node, fast handover techniques are needed to maintain the node connected to the network. This process produces a delay in the communication that can break down the link and cause the failure of the data transmission (Palit, Bickerstaff, and Langmaid, 2009). Moreover, railway networks may also suffer from the following problems caused by the handover applied techniques:

- Handover to a wrong cell, which has the same main control channel frequency as a neighbour cell. The Mobile Station (MS) then loses all sensible neighbours as it gets information on neighbours to the "wrong" cell.
- Cell dragging by an MS, where frequency reuse is reduced by interference of the transmitting MS with others that would otherwise be out of range.

3 POSITIONING SYSTEM ARCHITECTURE

Our positioning system (Carballedo et al., 2010) is organized conceptually into two functional blocks: (1) the positioning system itself, and (2) communications system. The positioning system is responsible for calculating the position, while the communications system sends the position from the train to the control center. Then the particularities of each are described.

3.1 Positioning System

Train positioning system is primary based on GPS data. This system is able to generate train positioning information applying a logical approximation algorithm for matching railway lines and GPS coordinates (Guan-Wei et al., 2009). To generate the most accurate positioning information, this system uses railway lines lengths (in kilometres) and traffic signals positions. Based on this information, the data extracted from the hardware (GPS, MEMS gyroscope, maps, ATP and odometer) and positioning algorithms, this system translates the train position to kilometric points. A kilometric point is a metric used by the railway company to tabulate the lines where its trains circulate.

Nowadays, GPS is a good and low cost positioning solution because of its reliability in railway environments (Bertran, and Delgado-Penin, 2004). But due to GPS inherent error (multipath, ionospheric propagation…), GPS only based systems have not enough accuracy. The reason is that 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. Therefore, in order to detect the exact track, 5 different position information sources area are used:

- *GPS Coordinates*. It provides absolute position data. The GPS chip is in the on board hardware. The development of the positioning system has been based on standards. Therefore, in the future, it would be possible to migrate to or integrate another navigation satellite system like Galileo.
- *MEMS Gyroscope*. It provides angular speed. It is also integrated in the on board hardware.
- *Maps*. They are organized as in (Guan-Wei et. al., 2009), (Saab, 2000a) and (Saab, 2000b) with coordinates information. Combining maps information with gyroscope data, it is possible to identify the exact track. All the maps are stored in the internal memory of the positioning systems.
- *Automatic Train Protection (ATP) Data*. They are an additional part of signaling systems. There are different kinds of ATPs, but all of them need beacons located in the infrastructure. These beacons provide a unique ID and are used to correct possible gyroscope-based track detection mistakes. Relation between tracks and beacon ID is also stored in the memory of the positioning system.
- *Odometer*. It provides relative position data. It is a covered distance register. It has an accumulative error due to wheels wearing away and wheels slide. But it is very useful when there is no GPS coverage. In fact, for tracks without GPS coverage, only distance and speed data are used to determine the exact position of the trains.

3.2 Communications System

The communications system that is used to transmit the position is based on a wireless communications architecture which allows a full-duplex transmission of information between trains and the control center (Gutiérrez et al., 2010). This architecture has been implemented and deployed on a router manufactured by Hirschmann which meets the specifications of the railways. In addition to the router, the communication system integrates two GPRS/3G modems and a WiFi radio interface.

Each train rides two communication systems (one at each end of the train) that operate according to a master-slave scheme. The master system manages communications with the control center, and the slave monitors its behaviour. If an abnormality is detected, the slave takes the role of the master.

The communications system is programmed to switch between the two communication technologies (mobile or WiFi) based on a number of parameters, such as: priority, volume of information, coverage and communication cost. On one hand, WiFi technology is used for transmitting large volumes of information, such as logs of operation or CCTV images. Furthermore mobile technology is used for transmitting information of small size and high priority, such as the position of trains.

Figure 1 shows the communications architecture of the positioning system. As can be seen, the trains are connected to the control center via two GPRS/3G links (each with a different phone operator, to ensure maximum coverage and robustness) and a WiFi link (which is only active in the stations). All subnets (GPRS/3G and WiFi) are integrated into the Ethernet network of the control center by means of firewalls, ensuring the security of the information transmitted from the trains. Finally, the figure also illustrates the future integration of the TETRA network in the communications architecture.

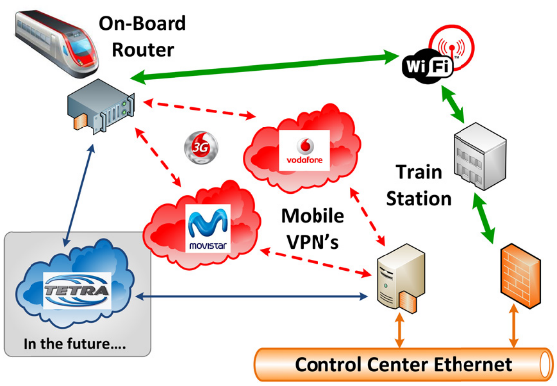

Figure 1: Communications architecture.

Currently the communication system is operational, but mobile technology has the following limitations:

- There is only 80% of coverage. This is because the railway line which is using the communications system goes through mountainous areas, with lots of vegetation, and also there are many tunnels.
- The transmission of information via the mobile network, has a cost, which depends on the volume of information transmitted.

These two constraints, makes the positioning system not very reliable. For this reason, extensive work was done to analyze the simplest way to increase coverage in the transmission of information from the trains to the control center. This is the reason for carrying out the work presented in this paper.

The line on which the positioning system is being used, has a TETRA network for voice communication. This communication network has 100% of coverage and it has no cost associated with the volume of information transmitted. This was the motivation for the study of communication delays presented below.

4 TEST AND RESULTS

In this fourth section we present the field tests done in a real life scenario and analyse the results obtained. The main objective of the tests was to determine whether a TETRA network is a valid alternative for the transmission of the positions from the trains to the control center.

The tests have been done on a railway track that goes from Bilbao to San Sebastian (in the north of Spain). The route is about 140 km. and runs through a mountainous area (with lots of vegetation) and numerous tunnels. Because of the terrain, the GPRS/3G coverage reaches only 80% of the track. Furthermore, the line has a TETRA network, which for the moment is used only for voice communications. Currently, the communications architecture of the positioning system is based primarily on GPRS/3G communications. So, all the tests have been focused on comparing the performance of the current solution (GPRS/3G) with a new solution that integrates the transmission of the position through a TETRA network. To make this comparison three different scenarios have been defined, as detailed below:

In the first scenario (which corresponds to the current version of the positioning system), the position is transmitted via GPRS/3G technology. To establish communication, the mobile phone provider has defined a virtual private network (VPN) in its communications network. This VPN is integrated with the Ethernet network of the control center. Thus, train positions are transmitted securely from the trains to the control center.

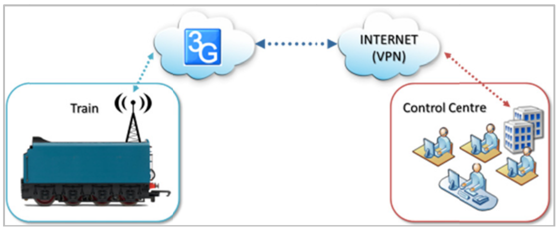

Figure 2: Scenario 1.

In the second scenario, both the train and the control center are equipped with a TETRA radio. Thus, all communications are made through the TETRA network, without the intervention of other networks. This second scenario analyses the performance of the communications between two TETRA radios. The main objective of this test scenario is to improve the positioning system in the future. In order to increase safety levels, the trains running on the same section, could exchange their positions. Thus, each train would know the location of nearby trains (like radar).

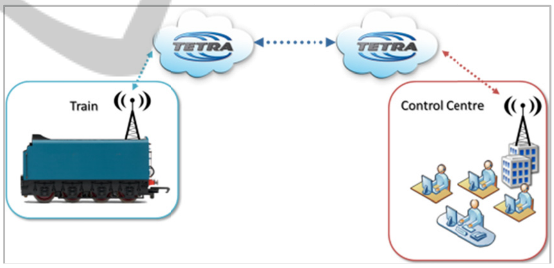

Figure 3: Scenario 2.

The third scenario is the one to be implemented in the final solution. A TETRA radio will be installed on the train. This radio transmits the position to the TETRA network. And finally, the position will reach the control center through a VPN that integrates the TETRA network and Ethernet network of the control center. Note the TETRA radios mentioned in the second and third scenarios are dedicated exclusively for the transmission of the position.

With the three scenarios, several tests batteries have been developed. The tests have consisted of sending position messages between a train and the control center. The messages have a size of 572 bytes and their content describes the train itself, the position where the train is located and the quality (source) of the position. During testing, the time it takes to get messages from the train to the control center has been measured. To ensure that the time was correct, both the train positioning system as the control center have been synchronized using NTP client. All transmissions have been made through TCP sockets; so that the messages were received in the same order they were sent. To cover all the possibilities, the two modes of data transmission that offers TETRA (SDS and PDO) have been tested. In this sense, since PDP mode has a communications set-up time and an expiration time, the messages have been sent at different intervals of time to force the closure and opening of the PDO connection. Finally, note that only correctly transmitted messages have been posted, that is, the message data lost due to lack of coverage, have not been taken into account in the analysis.

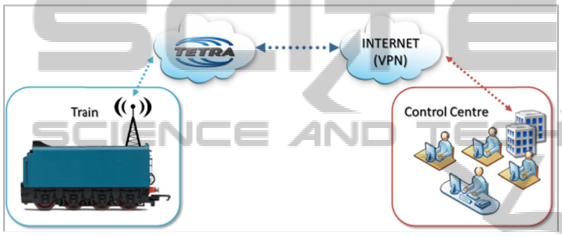

Figure 4: Scenario 3.

Table 1 shows the results of the tests. Each of the columns in the table represents: (1) the test scenario, (2) TETRA communication mode, (3) the size of the message sent, (4) the average delay since the message is sent from the train until it is received at the control center (the smaller the better) and (5) the percentage of messages received at the destination.

As it was expected, the results of the first scenario (where information is transmitted via 3G), are best ones. In this scenario the average delay is 1.28 seconds. Although this delay is the best, the problem of this scenario is that 20% of messages are lost due to lack of coverage.

Table 1: Tests results.

Scenario	Mode	Msg. Size (bytes)	Received %	Delay (seconds)
Scenario 1 (3G --> VPN)	---	572	80,12%	1,279
Scenario 2 (Tetra --> Tetra)	PDP	572	99,75%	4,851
Scenario 2 (Tetra --> Tetra)	SDS	572	99,80%	4,040
Scenario 3 (Tetra --> VPN)	PDP	572	99,87%	3,510
Scenario 3 (Tetra --> VPN)	SDS	572	99,68%	4,090

In relation to the results obtained in the scenarios 2 and 3, which are those that use TETRA for transmitting position information; as can be observed the delays are between 3 and 5 seconds. The best results of TETRA technology are achieved in scenario 3 (using PDO). Furthermore, the worst results are obtained in stage 2 (also with PDO). Another important issue is the fact that in scenarios 2 and 3, no messages are lost. This is because the TETRA network has a coverage of 100%.

Although the delay of TETRA is 3 times the delay of GPRS/3G, this technology is still valid for our positioning system. The justifications for this statement, are:

- The average speed of the trains using our positioning system is about 85 km/h. This implies that in 3 seconds, the train could move about 70 meters.
- The most critical areas with regard to safety are the stations. The stations are usually located near urban centers. In these areas there is mobile phone coverage and so, GPRS/3G transmission can be used.

In conclusion, TETRA technology provides acceptable results despite having a delay higher than GPRS/3G. The main advantage of TETRA technology is that 100% of messages sent, arrive at the destination. Therefore, these tests confirm that adding to our communications architecture, the possibility of transmitting information through a TETRA network, will make it more robust. Accordingly, this will increase the reliability of the positioning system proposed.

5 CONCLUSIONS AND FUTURE WORK

This paper presents the results of the tests performed to increase the reliability of a train positioning system. The train positioning system tested uses different sources of information to calculate the position of the train: GPS, MEMS gyroscope, maps, ATP and odometer. After calculating the position, it is sent to the control center using a wireless communications architecture based on GPRS/3G. Due to the nature of the railway line, the coverage of the communications architecture only reaches 80%. This implies that the positioning system is not very reliable. The railway line in which the positioning system is deployed has a TETRA communications network that is used for voice communications. The TETRA network has a coverage of 100%. This network could be a good alternative for areas where there is no GPRS/3G coverage, but currently there are no studies to confirm this hypothesis.

The aim of the work done has been to confirm whether the TETRA network is a valid alternative to improve the reliability of the positioning system. For this, a series of tests were done. The tests have been focused on measuring the delay in sending the position from the trains to central control. It has also been counted the number of messages sent successfully.

The results of the tests confirmed the initial hypothesis. Therefore, TETRA technology is a good alternative to increase the coverage of the communications architecture.

In the future, efforts will focus on the integration of the TETRA network in the current communication system. To do this, we must modify both the hardware and software of the communications architecture. On the one hand, we must connect two new TETRA stations to the router that manages the communications between the train and the control center. On the other hand, we must define a scheme for selecting the right communications technology (GPRS/3G or TETRA) according to the existing coverage.

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REFERENCES

Bai-Gen, C., Yi, A., Guan-Wei, S., Jiang, L. and Jian, W. (July 2011). Application simulation research of Gaussian particle filtering in train integrated position system. *Prof of IEEE International Conference on Service Operations, Logistics, and Informatics (SOLI)*, ISBN: 978-1-4577-0573-1, pp. 527-531. Beijing, China.

Bertran, E. and Delgado-Penin, J. A. (September, 2004). On the use of GPS receivers in railway environments. *IEEE Transactions on vehicular technology*, vol. 53, no.5.

Carballedo, R., Salaberria, I., Perallos, A., Odriozola, I., Gutierrez, U. (September, 2010). A Backup System Based on a Decentralized Positioning System for Managing the Railway Traffic in Emergency Situations. *Proc. of 13th International IEEE Conference on Intelligent Transportation Systems - On the Way to Intelligent Sustainable Mobility (ITSC)*, ISBN: 978-1-4244-7658-9, pp. 285-290. Madeira Island, Portugal.

Guan-Wei, S., Bai-Gen, C., Jian, W. and Jiang, L. (June, 2009). Research of Train Control System Special Database and Position Matching Algorithm. *Proc. of the IEEE Intelligent Vehicles Symposium*. pp. 1039-1044. Xian, China.

Gutiérrez,U., Salaberria, I., Perallos, A., Carballedo, R. (April, 2010). Towards a Broadband Communications Manager to Regulate ‘train-to-earth’ Communications. *Proc. of the 15th IEEE Mediterranean Electrotechnical Conference (MELECON)*, ISBN: 978-1-4244-5794-6, pp. 1600-1605. Valletta, Malta.

Jiang, L., Bai-Gen, C., Tao, T. and Jian, W. (August, 2010). A CKF based GNSS/INS train integrated positioning method. *Proc. of International Conference on Mechatronics and Automation (ICMA)*, ISBN: 978-1-4244-5140-1, pp. 1686-1689. Xi’an, China.

Palit, S. K., Bickerstaff, S. and Langmaid, C. (March, 2009). Design of wireless communication sensing networks for tunnels, trains and building. *International journal on Smart Sensing and Intelligent Systems*, Vol. 2, No. 1.

Saab, S. S. (Mar. 2000). A map mathing approach for train positioning part I: Development and analysis. *IEEE Transactions on Vehicular Technology*, vol.49, no 2, pp. 467-475.

Saab, S. S. (Mar. 2000). A map mathing approach for train positioning part II: Application and experimentation. *IEEE Transactions on Vehicular Technology*, vol.49, no 2, pp. 467-475.

Wenlong, X., Haige, X. and Hongjie, Y. (2002). TETRA protocol interfaces features and potential applications in railway. *Proc. of the IEEE Region 10 Conference on Computers, Communications, Control and Power Engineering (TENCON)*. ISBN: 0-7803-7490-8, pp. 1086-1088. Beijing. China.