Railway Signaling Systems and New Trends in Wireless Data Communication

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***Abstract*—With the increment of passenger railway traffic especially in high speed lines, improvements in railway transportation safety become even more crucial. This paper presents technological and commercial trends in this area, enumerates innovative on-going related projects and proposes the application of new wireless communication standards such as, DSRC – WAVE (Dedicated Short Range Communications and Wireless Access in Vehicular Environment) or 802.11p; 802.16 or WiMAX; and MBWA (Mobile Broadband Wireless Access) or 802.20, in train control communications networks. In order to validate this proposal, we have designed a model for a wireless communication system deployed in a fully redundant configuration. The application of these new open-standard technologies will allow an affordable deployment, ubiquitous, always-on and interoperable muti-vendor mobile broadband train control communication system that supports new safety services and applications.**

Railway, signaling, wireless, 802.11b/g, MBWA

I. Introduction

Recent studies regarding technological trends in the transportation industry, point out safety as the priority target. This concern about improving safety is shared not only by users but also by logistics operators and equipment manufacturers [1]. At the same time, the necessity for developing transportation infrastructures that make full use of the newest advances in IT and telecommunication is specially emphasized. However, the railroad industry, very conservative, takes much longer than other industries to take profit from the latest information and telecommunication advances.

In the last few years a set of new wireless communication standards and pre-standards with high mobility support, low latency and high data rate has appeared. Some of these technologies include: DSRC – WAVE (Dedicated Short Range Communications and Wireless Access in Vehicular Environment) or 802.11p; 802.16 or WiMAX; and MBWA (Mobile Broadband Wireless Access) or 802.20. In USA, a nationwide roadway-based communications network using DSRC is planned to be created [2]. All new vehicles would be equipped with DSRC at 5.9GHz. This vehicular network can enable a wide range of safety and mobility applications such as intersection collision avoidance, traffic management, traveller information or weather sensing.

In this paper we propose the application of new wireless communication standards in the railway industry. There are some initiatives to use these technologies in high speed trains but for commercial and not for operational use.

This paper is organized as follows. In section II, the railway scenario and some market and technological trends in railway industry are described. Section III presents signaling systems and train control communication systems evolution. Section IV identifies the new standards for wireless communications technologies. In Section V, the most innovative projects in this area are enumerated. And finally the main findings and further steps can be found in the last sections.

II. Railway Scenario and Trends

Operational railway communication network can be grouped in locomotive, wayside and train control communications networks. This paper focuses on the application of new wireless communication standards in train control communications networks. There are some security and safety issues that have to be taken into account. In this section, we present some technical trends in the current railway industry.

Cables and data communication equipment installed between the tracks are eliminated. Although there is a series of advantages in the use of cables, inductive loop CBTC, like for example: the technology has been proved and in good condition for over 30 years; it is easy to install; it uses cables without protection and of low cost; it is easy to repair in the field, etc.. in almost all new CBTC (Communication Based Train Control) systems RF technology is applied.

Those who defend RF-CBTC point out that the cable may be vandalized and sabotaged. Furthermore, it is important to take into account that systems based on radio frequency are cheaper and easier to install and maintain than cable conventional systems. A significant movement occurred with the introduction of wireless communications for trains. It opened up a channel for direct communications between the control center and the trains in motion [3].

Making use of high IP interoperability and standard/open technology, thus avoiding protocols and proprietary solutions. Unfortunately, nowadays each train control equipment manufacturer uses a proprietary solution in such a way that

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prevents a resource, as a locomotive equipped with a device from a given manufacturer, from operating in a line with equipments from other maker. Interoperability of a data transmission system is a basic assumption for considering a system inter operational.

Using technologies that have been tested and proved in another markets. A great offer of equipments from many manufacturers will allow a cost reduction in the earth-train communication systems deployment as well as a reduction in time.

In this industry, the high cost of a telecommunication system deployment along a railway network makes necessary that the equipments and systems installed have a working life of around 30 years. Therefore, one of the requirements of project and selection of the equipments involved is trying to minimize their obsolescence along that period of time.

Bandwidth requirements for existing train control systems are not quite significant but additional services that can improve safety as train health and events communication etc… demands much more bandwidth than 2G technologies can offer. We refer to others non-ATC (Automatic Train Control) services such us Telecommunication services, Supervisory Control and Data Acquisition (SCADA) subsystems and Platform CCTV.

III. SIGNALLING SYSTEMS AND TRAIN CONTROL COMMUNICATION SYSTEMS EVOLUTION

Over the past years a great number of signaling strategies have been developed in order to keep a safe distance between trains. This safe distance is determined by the current train position, its speed compared to other trains in the same area, the direction of movement, etc… The mechanisms used for determining till what point a train can circulate, can be based on the track being subdivided into fixed-block lengths (fixed-block signaling systems) or variable block lengths (moving-block signaling systems) [4].

The position of a given moving train in the railroad network is continuously relayed wireless to other trains. By using continuous digital wireless signals, it is possible to reduce the interval between trains, increasing traffic capacity without huge infrastructure investments.

As long as better performance is pursued by the railway operators, the present tendency among many railway engineers is the use of Communication Based Train Control Systems. CBTC systems, relying on two-way continuous communications, safety control a train's position, speed and other functions. The way to do this, is through control and telemetry data interchange between the train and the wayside equipment. Communication between wayside and train can use either inductive loop or radio frequency transmissions.

The use of advanced communication for location reporting and the issuing of movement authorities to trains is the basis for modern signaling systems, which are becoming more and more sophisticated. CBTC systems highly demand communication availability: if there is any communication loss, CBTC is disrupted and trains stop. The typical accepted communication loss rate is once every 10 years/train. CBTC systems, in operation now, use mostly inductive loop communication and a few of them use radio communication link. The typical bandwidth need demanded by top performance CBTC Radio Link is by 40 kbps in a control area with 8 trains, [5] although there is more and more emergent requirement for video monitoring of trains.

It is worth pointing out the recent NAJPTC program that is the collective effort of the North American railroad industry and the USA government to develop a standard, interoperable CBTC system. As it is indicated by this program's scientist: the main reasons for developing a CBTC system are to prevent train accidents, to facilitate high-speed passenger trains operating on the same lines as freight trains, and to evaluate potential productivity benefits. [6]

The technologies currently in use for train control communications are GSM for Railway; Terrestrially Trunked Radio (TETRA); Enhanced Position and Location Reporting System (Nishinaga, Evans & Mayhew 1994); Inductive Loop; Satellite; and a range of proprietary systems. Obviously, the necessary investments infrastructure will vary for each of the mentioned, but not only that. The volumes of traffic differ from case to case, so conditioning levels of assurance regarding security and prioritization of messaging, as well as quality of service guarantees.

The use of closed systems for safety critical applications in railways is a practice commonly and traditionally spread in this industry. However, systems are expensive to deploy, maintain and operate.

In 1994, European Union launches the industry standard for signaling and management system for Europe, enabling interoperability throughout the European Rail Network (ERTMS). GSM-R was the chosen radio communication technology for voice and data communication. There is, nowadays, some concern regarding the GSM-R capacity to provide enough circuit channels in congested crossings (Jones, Porter & Waboso, 2003) [4]. On the other hand, the future GSM-R deployments within the Trans-European Network Transport (TEN-T) are being postponed due, in part, to investment problems [7]. In the United States there is a merge of proprietary close communication solutions.

IV. NEW TECHNOLOGIES, NEW OPPORTUNITIES

Until recently, there was no technology capable of covering environments with high mobility of vehicles holding high data transmission rates. However, a group of technologies and communication standards that has as functional requirement to provide high transmission rate and low latency in high speed environments has appeared. As we mention before, some of these technologies include: DSRC – WAVE (Dedicated Short Range Communications and Wireless Access in Vehicular Environment) or 802.11p; 802.16 or WiMAX; and MBWA (Mobile Broadband Wireless Access) or 802.20. Some commercial pre-certified 802.20 equipment – such as iBurst, that has been recently launched in Australia- are many times more effective than the GPRS/UMTS standards. Mobile broadband wireless access (MBWA or 802.20) takes-off may affect several areas, one of them microwave backbones.[8]

The standard specifies a transmission speed superior to 1Mbps by user and support to mobility up to 250Km/h and a number of active users significantly superior to that one obtained by the existing movable systems. In order to fulfil the specific demands of the high mobility users of applications that demand great bandwidth, new air interfaces throughout the entire protocol stack including level MAC and network level must be designed and optimized. [9] The first example of this type of optimization has arisen with the name of Flash-OFDM (Fast Low-latency Access with Seamless Handoff Orthogonal Frequency Multiplexing Division) of the Flarion company. Flash-OFDM is a special type of OFDM that has specifically been developed for services of great bandwidth and high mobility users.

Enhanced 802.16e or WiMAX supports vehicular mobility up to 200km/h. with a high throughput up to 30 Mbps. Both of these technologies are suitable for metropolitan wireless access services in a cell size of 15km. with a good performance [10]. These specifications complete the existing gap between the services of high speed of transmission and low mobility of 802.11b/g systems and the high mobility but low speed of transmission of the cellular networks

V. New Projects, New Initiatives.

In this section, some current research efforts in applying new telecommunications technologies in earth-train internetworking are enumerated.

Alcatel radio CBTC, open-standard and with overlapping radio coverage has entered in revenue services in Las Vegas Monorail. All the equipment used is Commercial-Off-the-Shelf (COTS). The security systems make use of IPSec protocol along Internet Key Exchange (IKE) protocol for dynamic key exchange [11]. Some tests have also been carried out in Hong Kong and Metro Paris. As a requirement for a high speed metro line, data communication system offers seamless handover between cells at speeds of up to 150km/hr without significant data loss [12].

Another radio based CBTC project is being installed in NYCT Carnaise Line where SIEMENS is installing its 2.4 GHz spread-spectrum radios with discrete antennas in outdoor and tunnel area (more flexible than leaky cables/guides) and using TDMA MAC layer and cellular architecture focused on a deterministic behaviour. It uses train localization when available for cell handover. The bit rate is low[5].

LOCOPROL is another project, this time relying on an innovated cost-effective satellite based vital fail-safe train location system as the core of a train protection, control and command system is. It aims a significant reduction of the costs and also to short term applications for low density traffic railway lines [13].

The Cooperative Research Centre for Railway Engineering and Technology (RailCRC) is jointly conducting a project with the Queensland University of Technology (QUT) to evaluate secure communications in the Australian rail Network. They propose to deploy a more economic multipurpose broadband communications infrastructure, capable of meeting the signalling and business application needs of rail stakeholders [4].

There are some other initiatives that are not focused on communications for operational purposes but on providing an infrastructure to offer broadband access to internet and m-commerce for high speed train passengers.

One of this initiatives is the “FIFTH” (Fast Internet for Fast Train Hosts) project. The passengers reach on-board servers using 802.11b/g cards and an on-board gateway is connected via satellite link to the outer (Internet) world [13].

The German railway company Deutsche Bahn has recently announced the project “Railnet” that will offer to its passengers broadband Internet connection beginning in 2006. In order to do that, several wireless technologies will be used such as UTMS and Wi-Fi. The lines where the trains reach speeds close to 300 km/hr will join the project in a following phase. The project has been qualified as a “technical challenge” and the need, for instance, for a working Internet connection even in tunnels is stressed.

Another telecom company, T-Mobile, is testing a Wi-Fi/WiMax train network solution in the UK that utilizes a pre-certified version of Wimax to offer broadband on the train. Users get Wi-Fi in cars via a pre-WiMax equipment on the roof, which in turn connects to 37 operational base stations along the track.

Other world pioneer project, TEBATREN by InfoGLOBAL, consists of a broadband wireless solutions set developed for Metro Madrid that incorporates a wide range of technologies in radio systems such as band translators, cable radiating systems, data flow management including bandwidth assignment for QoS guarantee, security, etc,. Its main objective is, in the second phase of the project, a digital broadband wireless train-centre transmission communication system that will be focused on video and data transmission from and towards trains moving in that line. Vodafone is also testing a pre-certified 802.20 commercial equipment Flash-OFDM from Flarion in Metro Tokyo.

VI. FURTHER STEPS

This paper proposes the application of new wireless communication standards in train control communications networks. In order to validate this proposal, we have designed a model for a wireless communication system deployed in a fully redundant configuration. Fixed clients on the wayside will have double coverage and also a dual subscriber scheme at data link layer to increase redundancy.

Our next step is to use simulation tools such us Network Simulator 2 (NS-2) to validate this proposal and realize performance studies. We will identify which one of these technologies better performs in this environment, especially from the security point of view, and will propose a network data level optimization specific for railway security requirements. It is necessary to take into account message authentication, message integrity and message vitality requirements. Special attention has to be paid to diminish latency caused by handover since mobile client is on moving when train is in operation switching from one network to another over time. Finally, a testbed with pre-standard commercial equipment is planned to be mounted to validate this architecture.

There are several studies about seamless handover for MBWA or 802.20, in an open and no railway scenario. Some researchers apply mobility predictive or mobility detection. An intrinsic characteristic in railroad scenario is that train and then the mobile client switches from one network to another at a fixed trajectory. The period of handover and even the next router address are predictive by the train schedule.

Other challenging aspects of this project are to demonstrate that IP networks are able to provide the service assurance that is required to support safety-critical applications, and to test their behaviour with voice communication. Voice communication is a fundamental service demanded for railway communication systems. This requirement includes priority management, urgent call support, broadcast, multicast and quick establishment for call. Wireless communication standard, 802.11b/g, has demonstrated support for this requirement in some studies. [15]

VII. CONCLUSIONS

Traditionally, each advance in mobile telecommunication technology has enabled an advance in railway communication systems [16]. Mobile communications have advanced since the first generation till what nowadays is understood as B3G (Beyond 3G) or 4G. And the same thing has happened in the railway communication systems: since those systems based on analogical communications such as UIC751-3, through systems based on 2G as GSM-R (UIC), Iden (from Motorola) and TETRA (ETSI). A forward step, getting closer to 3G technology, it appears in GT800 system (from Huawei)[17]. B3G technology has to allow a new revolution in railway communication systems, more specifically because these technologies have been designed to support high speed (up to 250km/h), low latency, high transmission rate, QoS (Quality of Service) and security protocols. The use of these new open-standard technologies will enable an affordable deployment, ubiquitous, always-on and interoperable muti-vendor mobile broadband wireless earth-train communication system and support to new services and applications that improve safety in signalling systems.

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