Implementing Wireless Broadband Digital Network for the Railway Information System

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ABSTRACT

Broadband Railway Digital Network (BRDN) integrating the emerging broadband wireless access technologies will satisfy the requirements of next generation Railway Information System (RIS). This paper proposes an overall implementation scheme for BRDN with discussion on its main components, such as the intranet on train, train-ground internetworking and infrastructure of BRDN. The paper aims at enabling deployment of innovative, cost-effective, and interoperable multi-vendor broadband wireless access system for RIS on fleeting train.

Keywords : IEEE 802.11; 802.16; 802.20; Railway Information System; IPv6

1. Introduction

Railway Information System (RIS), in general, is built upon a computer based network to support railroad information collection, transmission, processing, and dissimilation in order to ensure safe and stable railway transportation and provide high quality operational services as well as passenger information services. Facing the rapidly increasing demand on “high-speed and high-density” railway transportation and to cope with the challenges from other transportation means, such as airlines and automobiles, the railway operators have to update their out-of-date RIS, which is characterized as offline or narrowband underpinned. As Yoichi et al. point out [1], the precondition of next generation RIS is the infrastructure – communications network, which should expand deployment both on train and ground, with the uninterrupted broadband connectivity between train and ground.

This paper is intended to address a new generation of RIS network technology - Broadband Railway Digital Network (BRDN), which utilizes the emerging broadband wireless network technologies as well as IPv6-based next-generation Internet technology to meet the requirements from the new generation RIS. Illustrated in Fig. 1, BRDN is composed of several components: the Wireless Vehicle Network (WVN) in each vehicle, the Wireless Train Network (WTN), the Train-Ground Internetworking (TGI), and the infrastructure of BRDN along the railway track. Based on an open architecture BRDN will enable the innovative, cost-effective, and interoperable multi-vendor applications for both transportation operation, production, and schedule, as well as passenger information services.

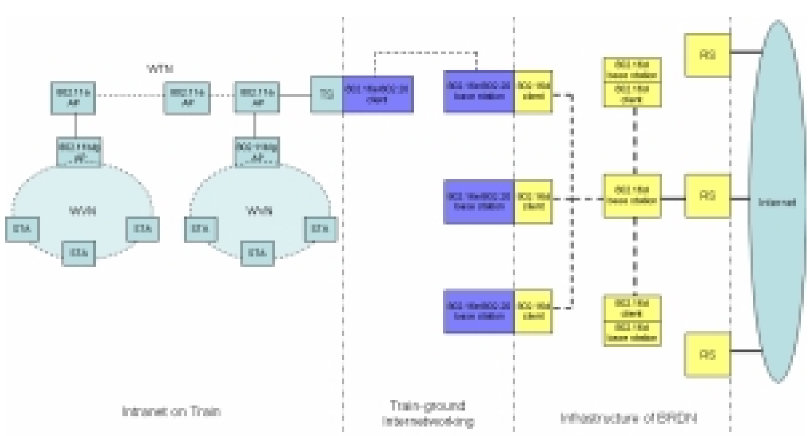

Fig. 1: A full view of BRDN

2. Broadband Wireless Technology

Great efforts have been done in deploying data communications network for RIS in adopting the latest broadband wireless technologies, such as IEEE 802.11x [2]. The IEEE 802.11 standard (nicknamed as Wi-Fi) came into use in 1997 for Wireless LAN. In 1999, the IEEE Standards Board enhanced the 802.11 standard: 802.11b working at 2.4 GHz with the data rate up to 11 Mbps, and 802.11a working at 5 GHz and supporting higher data rates up to 54 Mbps. In June 2003 IEEE approved 802.11g, which is compatible with 802.11b with the same data rate as 802.11a. 802.11a/b/g has become popular worldwide. However, due to limited coverage range of Wi-Fi, there are still some missing pieces for constructing a complete BRDN.

Since July 1999, the IEEE 802.16 Working Group has been developing a series of standards for Wireless Metropolitan Area Networks (MAN). In October 2004, P802.16-REVd/D5 has been approved as IEEE Standard 802.16-2004, a revision and combination standard of 802.16 and 802.16a [3]. In December 2004, IEEE 802.16e Task Group released the last draft 802.16e5a which defines air interface for fixed and mobile broadband wireless access [4]. Practically, Proxim Tsunami BWA Platform facilitates an industry mobile roaming capability up to 200 km/h [5].

In another aspect, the mobility-oriented wireless metropolitan area network standard, IEEE 802.20, has been initiated. In December 2002, the IEEE Standards Board approved the establishment of IEEE 802.20 Working Group. IEEE 802.20 promises to support various vehicular mobility classes up to 250 km/h in a MAN environment and targets spectral efficiencies, sustained user data rates and numbers of active users that are all significantly higher than achieved by existing mobile systems [6]. Practically, the Flarion RadioRouter base station based on the still-unratified 802.20 standard, is currently being trialed by a number of wireless operators including Nextel and T-Mobile International [7].

3. Implementing Intranet on Train

Fig. 2 illustrates one of possible network structures for the intranet on train. The WTN is the backbone of intranet on train, hooking up all vehicles together; in each vehicle, Wi-Fi access points (AP) are deployed to cover the whole area, allowing end users to access this WLAN via mobile devices, such as portable computer, PDA, mobile IP phone, etc. Train customers are connected to the Internet via an 802.16e/802.20 gateway, which resides both in the locomotive (or the first vehicle) and last vehicle of the train.

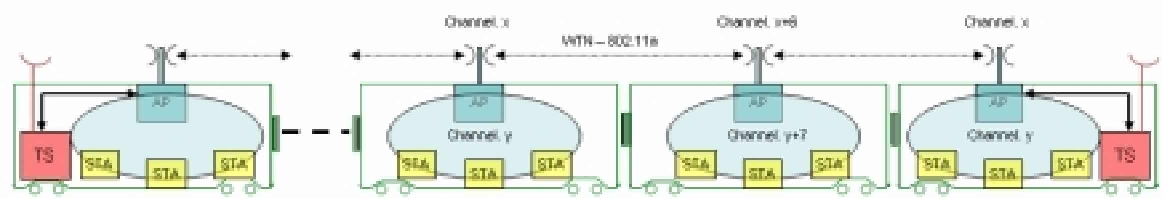

Fig. 2: Architecture of WTN and WVN

3.1. Wireless Vehicle Network

WVN is a wireless vehicle area network consisting of a few Wi-Fi APs in a vehicle. The idea has been implemented by one of European Union's FP5 projects [2]. Wi-Fi was the key technology because of its widespread market distribution: most of Wi-Fi enabled equipments such as portable computers and wireless sensors are able to access RIS via WVN on the fleeting train.

The allocation of the channel setting among APs needs artful design. Since 802.11b/g provides 11 channels each 22 MHz in bandwidth centered at 5 MHz intervals and only 3 channels do not overlap (channels 1, 6, 11), to eliminate the interference between the connected vehicles, the APs' channel among the immediate vehicles should not be overlapped (i.e. the select channels must be apart from at least five channels). Meanwhile, to minimize the interference between the meeting trains, the APs' channels for different running trains should be assigned premeditatedly. Based on these premises, the allocation of channels for the APs in different vehicles, presumably each vehicle having one AP, can be summarized as:

- If an AP's channel in a vehicle is y, the AP's channel for the next immediate vehicle is $0 < y \pm 7 < 12$;

- For the North-oriented and East-oriented trains, the initial $y_0 = 1$;
- Else the initial $y_0 = 4$.

3.2. Wireless Train Network

WTN is the backbone of the intranet on train to connect APs in each vehicle. There are several alternatives of the interconnection scheme between vehicles of a train: Wi-Fi, infrared light, and cable-wired. Fig. 2 presents the case using IEEE 802.11a with the following reasons:

- 802.11a work at different frequency (5 GHz) from that of 802.11b/g (2.4 GHz). Thus, this scheme can eliminate the interference between the AP for WTN and the AP inside the vehicle.
- 802.11a delivers increased data rates (up to 54Mbps) and improved degree of multipath repletion recovery by utilizing different PHY technologies than those used in 802.11b.
- 802.11a provides 12 channels and none of these channels overlap.

As the 802.11a APs work outdoor without masking, the interference between 802.11a APs deployed in meeting trains is critical. The channels of 802.11a can be allocated as the following:

- The interval of APs' channels in immediate vehicles is 6, presented as x and $0<x\pm6<13$;
- For the North-oriented and East-oriented trains, the initial $x_0=1$;
- Else the initial $x_0=2$;
- For different classes of trains, we can set different value of the initial x_0 with an offset.

Guaranteed by the channel allocation, the interference of wireless data transmission between adjacent vehicles can be eliminated. Meanwhile, the interference between two passing trains can also bee eliminated.

3.3. Onboard Proxy Server (OPS)

An OPS serves as the gateway between the Internet and the intranet on train. It also provides the NAT (Network Address Translate) and DHCP services for WVN. Moreover, An OPS can be equipped with several additional functionalities such as caching and pre-fetching capabilities, which are illustrated in detail in [8], to minimize the outage in presence of disconnection periods.

There are two OPSs with 802.16e/802.20 clients deployed on the first vehicle and the last vehicle respectively. This deployment will facilitate the handoff of Mobile IP when train running from one network to another. Pivotally, this configuration minimizes the outage in the presence of blind area (primarily caused by the temp coverings which shielded the propagation) by a negotiation mechanism between the two OPSs. Even the whole train entering into the shadow area, the dwell time will be deceased significantly.

4. Train-Ground Internetworking

A diagram of TGI is depicted in Fig. 3. IEEE 802.16e/802.20 base stations are deployed along the railway track with complete coverage including tunnels which are involved by using satellite link, etc. TGI plays the role of bridge between intranet on train and Internet when trains are fleeting in the wireless overlay network, with the provision of reliable broadband internetworking based on enhanced Mobile IPv6, which support the rapid mobility for train scenario.

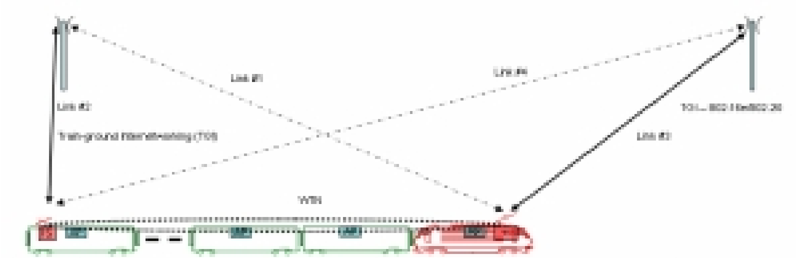

Fig. 3: Architecture of TGI

4. 1. Key technology of TGI

As the key component of BRDN, TGI has attracted a lot research effort (e.g. [9-10]). Although traditional narrowband technology and newer Wi-Fi technology have been tested for train-ground internetworking, they are not competent enough: 2G (GSM-R), GPRS and 3G technologies lack of supporting multimedia streams because of the limited bandwidth capacity; and Wi-Fi technology only provides a small cell size (150m typically) that is not enough for a fleeting train

(train's dwell time is less than 4 seconds at the speed of 80m/s).

Fortunately, the broadband wireless technologies for mobile access - IEEE 802.16e and 802.20 are emerging as the promising technologies. Enhanced 802.16e supports the vehicular mobility up to 200 km/h with a high throughput up to 30 Mbps; 802.20 supports rapid mobility up to 250 km/h with data rates up to 16 Mbps. In addition, both of them are suitable for metropolitan wireless access services in a cell size of 15 km with a good performance [4, 6]. Apparently, IEEE 802.16e/802.20 technologies satisfy the requirements of broadband train-ground internetworking for the fleeting train.

4. 2. Rapid Mobility

To provide reliable Internet connections for a train running at a high speed, rapid mobility is the key issue. Mobile IPv6 is the proposed standard for IP mobility support by the Internet Engineering Task Force (IETF). Although Mobile IPv6 represents a promising solution, its performance under "extreme" mobility is questionable. This standard for mobility assumes relatively low speeds, which makes it very suitable for macro-mobility and nomadic environments. However, high-speed trains move at speed up to 360 km/h (0 to 100 m/s) which drastically reduces the effectiveness of the Mobile IPv6 protocol and diminishes the quality of its services. Edwin simulated a train scenario in [11] and found that generally Mobile IP is not appropriate for the applications when the speed is higher than 20 m/s. In order to realize seamless handoff, Zou et al propose a Predictive Pre-Handoff (PPH) algorithm based on the high predictability of train's switching from one network to the neighboring network [12].

In this paper, we are to propose further a Dual-Subscriber-Station (DSS) scheme as depicted in Fig. 3 for the reliable seamless handoff. Let the first subscriber station (SS) located in locomotive (or the first vehicle) as SS A, and another as SS B. When train departs from station, both SS A and B are link to the same base station as link #1 and #2. The two links act as the backup for each other via a negotiation mechanism according to the signal quality of links, for the blind area protection. As the train approaches the next base station, link #1 will be disconnected from the former base station, leaving link #2 as the principal. Immediately, SS A will hook up to the new base station as link #3. In the case of bestriding (i.e., SS A and B link up the adjacent base station simultaneity), handoff is triggered. Within the dwell time of crossing the overlapping coverage, link #2 is interrupted and link #4 is established and the handoff is accomplished. The Mobile IP handoffs happen in the same way when the train arrives at the following base station.

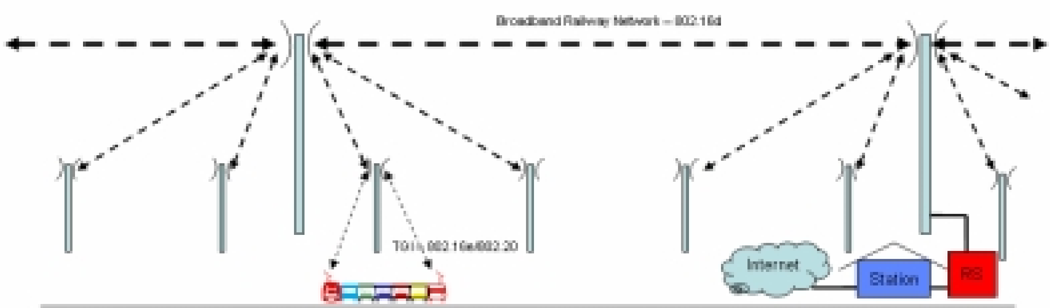

Fig. 4: The Backbone of BRDN

5. The Backbone of BRDN

One of the configurations for BRDN (IBRDN) is shown in Fig. 4. IEEE 802.16d base stations are deployed along the railway track with the provision of broadband wireless access for the non-mobile equipment, which connect to the 802.16e/802.20 base station directly. 802.16d base stations are working together as a data bus by each 802.16d base station also acting as the client of the adjacent base station integrating with an 802.16d SS. This data bus is hooked up to the Internet via the gateways hosted by train stations.

5. 1. IEEE 802.16d for IBRDN

The active 802.16d standard addresses the frequencies between 2 and 60 GHz that support line-of-sight (LOS) and non-line-of-sight (NLOS) communications, with the provision of data rates per sector up to 120 Mbps, range up to 60 km even more with Quality of Service (QoS) support.

According to the range of 802.16d and 802.16e/802.20, each 802.16d base station is hooked up with four 802.16e/802.20 base stations. Thus, the distance between the adjacent 802.16d base stations is recommended as 60 km. Because the clients of 802.16d base station are still, the base stations can be configured as directional antenna to enhance the quality of signal and extend the transmitting distance.

5. 2. IP Mobility

Due to the predictive feature of train movement, the mobile IP mechanism can be implemented in the enhancement of the routers in the backbone of BRDN. The DSS scheme of train-ground internetworking as the specialty of the proposed BRDN will be taken into account for the implementation of Mobile IPv6. Therefore, current mobile IP scheme conceived in late 1990s will be modified for the implementation. The details are not covered in this paper due to the limit of the size.

6. Conclusion

This paper proposes the architecture and implementation of BRDN, which will be built upon IEEE 802.11x, IEEE 802.16x and next generation Internet technologies. The further research work will be focused on the implementation of mobile IPv6 in conjunction with the DSS scheme at data link layer.

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