4G LTE 기술을 적용한 고속철도 통신/신호 시스템 영향력에 관한 연구

Study on the Effectiveness of High-Speed Railway Communication and Signaling System Based on 4G LTE Technology

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ABSTRACT

Due to speed acceleration, higher requirements have been put forward to high speed railway communication and signaling system. The railway applications, including intra-train, train to ground and trackside networks, demand larger bandwidth, higher reliability and shorter response time from railway communication networks to ensure security operation and passenger communication. However, the current railway communication and signaling system has lagged behind the railway development, so advanced communication technologies are needed to improve the current situation. This paper presents high speed railway communication and signaling system based on 4G LTE technology, introduces its network architecture, key technology and analyzes its technical advantages compared with GSM-R system. According to analysis, LTE based high-speed railway communication network is more effective and reliable.

1. Introduction

With the increased demands of railway services, overall railway infrastructure has been developing in the last two decades, as well as transport capacity, especially the traveling speed is keeping increasing. Along with these developments, higher requirements have been raised to railway communication and signaling (C&S) system, such as reliability, safety train operation and passenger communication, etc. As a crucial part of railway system, C&S system is responsible to satisfy these requirements.

Communication based train control (CBTC) system is a widely used train communication system, providing a two-way continuous communication, safety control, speed control and other functions.[1] European rail traffic management system (ERTMS), which composes global system for mobile communications-railway (GSM-R) and European train control system (ETCS), addresses the efficient and effective management of rail traffic. GSM-R is introduced for internal voice and data communication in the railway environment, and ETCS is a signaling standard of control command system.[2] However, with travelling speed increased up to 500km/h, these

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systems are incompetent to deal with information lost, fast handover and Doppler shift problems to meet service requirement and ensure reliable train operation. So network architecture, hardware device and software algorithm are required to catch up with the increasing train speed.

Old fashioned train control and communication method relying on human operators has fallen far behind and the current applied railroad C&S systems are limited to their technical feature. For example, CBTC system is highly contingent on communication response time[3]and this feature constrains its application to high speed railway systems. Also, it is difficult for GSM-R system to deal with frequent handover and severe Doppler frequency shift problem when the travelling speed is high. Thanks to the fast development of wireless communication techniques, 3GPP long term evolution (LTE) is a good candidate to deal with these problems. It has many advantages, such as high throughput, low latency, plug and play, FDD and TDD in the same platform, an improved end-user experience and a simple architecture, etc. System architecture evolution (SAE) is the core network architecture of 3GPP's LTE wireless communication standard, which has a flat, all-IP architecture with separation of control plane and user plane.[4] LTE-SAE's new, flat architecture is based on and developing from existing GSM/WCDMA core network, so it is backward compatible to older network technology. Moreover, LTE-SAE architecture reduces operation expenses (OPEX) and capital expenditure (CAPEX), and features on simplified operation and smooth, cost-effective deployment.[5] Therefore, it is suitable to apply LTE technologies to high-speed railway C&S system to solve the facing high speed induced problem.

The rest of this paper is organized as follows. Section 2 will introduce some current applied C&S train operation and control system and some problems the current C&S system encountered. In section 3, we will compare the architecture of GSM-R and LET-SAE and present the proposed high speed railway C&S system based on LTE. Section 4 explains the key technology of LTE and its solutions for high speed railway C&S system. Finally, there are conclusions in Section 5.

2. Current applied C&S scheme of train operation and control system and some problems encountered

2.1 Current applied C&S train operation and control system

The major train management and communication systems are illustrated in Fig. 1. Among those systems, current methods of signaling and train control systems are: communication based train control (CBTC) systems, advanced train control systems (ATCS), and command, control and communications systems (CCCS). Incremental train control systems (ITCS), positive train control (PTC), positive train separation (PTS) and European train control system (ETCS) are the new systems developed to enhance the safety and security of train operations.

Communication technologies currently used in train control includes: GSM-R, terrestrially trunked radio (TETRA), enhanced position and location reporting system (EPLRS), inductive loop, satellite and few other proprietary systems. For more detailed information, you can refer to [2].

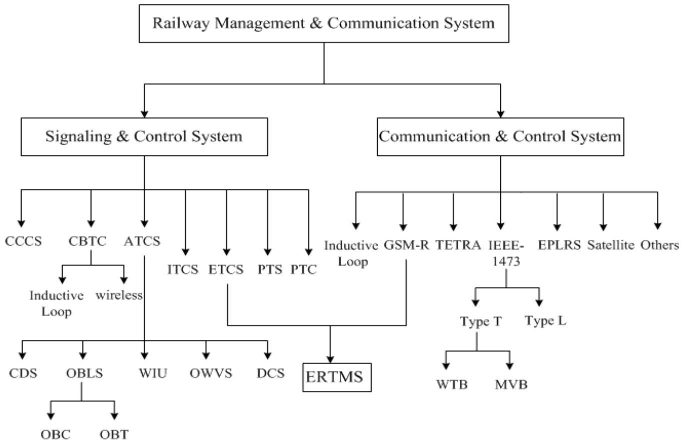

Fig.1 Major communication and signaling system for railway

2.2 Problems current C&S system encountered due to speed up

With the continuous speed increment, reliability of wireless data transmission of train operation and control system is a big challenge. It is urgently necessary to provide strong means to monitor the trains' real-time running status and train to ground conditions. Also, railway C&S systems have to provide higher level of service to keep pace of speed increment and customer expectations. Table.1 gives an overview of QoS requirement, passengers expect the travelling to be as fast as possible, as reliable as possible while enjoy the high data rate information services at the same time. This indicates high speed railway system requires shorter response time, higher level of security insurance and effective system to support large amount of data transmission.

Table.1 QoS overview

Quality of Service Description		
Character	**Service**	**Properties**
RT (real time)	Train operation, etc.	As fast as possible
HQ (high quality)	Safety operation, etc.	As reliable as possible
HDR (high data rate)	Video, internet, etc.	As much as possible

The following is some practical difficulties current C&S system encountered[6]:

1) Heavy information loss.

High-speed trains have a wholly-enclosed structure, and metal reflective glass is used for some models, with penetration loss reaching 24dB or higher. Signal information is hardly to be received or transmitted. To overcome penetration loss, outdoor signal transmitters need to provide stronger power, base station receivers need to have higher sensitivity or transmission equipment needs to provide a stronger signal.

2) High speed causes frequent handover

When the train's speed exceeds 250 km/h, passengers pass through multiple cells in a very short time. This causes a signaling storm, leading to call dropping.

3) Overlapping area can hardly meet requirements of handover and reselection

It takes at least 6 seconds for a mobile phone to complete handover between different base stations, while it often takes less than 6 seconds for high-speed train running at top speed to pass between two base stations. As a result, a mobile phone often cannot complete handover, leading to call drops.

4) It is difficult to overcome the Doppler Effect caused by high speed

At present, mobile communications terminals' carrier frequency uses the mechanism of tracing downlink air frequency. When on move, suppose the transmit frequency from base station is f_c, received frequency by terminal is $f_c^{'} = f_c - \Delta f$ and received frequency by base station is $f_c^{''} = f_c^{'} - \Delta f = f_c - 2 \cdot \Delta f$, $\Delta f = \frac{v}{\lambda} cos\theta$ is the frequency offset. This means the movement of terminals cause two times temporary Doppler frequency offset to f_c from base station. When passing base stations, uplink and downlink signals undergo strong changes, and in handover areas, down signals experience the mutation of Doppler frequency offset.

The incumbent general public network can't support both high speed and low speed scenarios at the same time. In order to achieve coverage effect, it is necessary to consider private network. However, the information loss problem needs to deploy base station as near as possible in order to provide strong power while frequency handover problem needs to keep base station distance as far as possible. This creates a dilemma. Even though high density base station deployment is employed, group handover problem will arise, and also it is difficult to develop algorithm to compensate frequency offset. The most important thing is no operator is willing to afford the tremendous cost.

3. Comparison of GSM-R and LTE-SAE and the proposed high speed railway C&S network based on LTE

GSM-R is similar to the basic network architecture of GSM, Fig.2 is GSM-R network infrastructure. MS (mobile station) indicates moving vehicle and radio terminals loaded on the vehicle. Several BTSs (base transceiver stations) deploy along the railway tracks, a BSC (base station controller) controls BTSs. The core component of GSM-R system is the network switch subsystem. It includes data gateways, SGSN (service GPRS supporting node) and GGSN (gateway GPRS supporting node), and MSCs (mobile switch centers). Information of users is stored in HLRs (home location registers) and VLRs (visitor locatin registers) assosiated with each MSC in the network. GCR (group call register) stores information about group calls, their configurations and users involved. OMC (operational and maintenance center) manages the entire GSM-R nentwork and billing center collects and records information about GSM-R network used for business and operational purpose.[7]

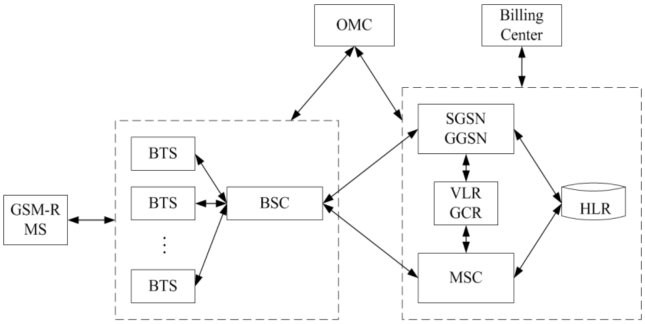

Fig.2 GSM-R network architecture

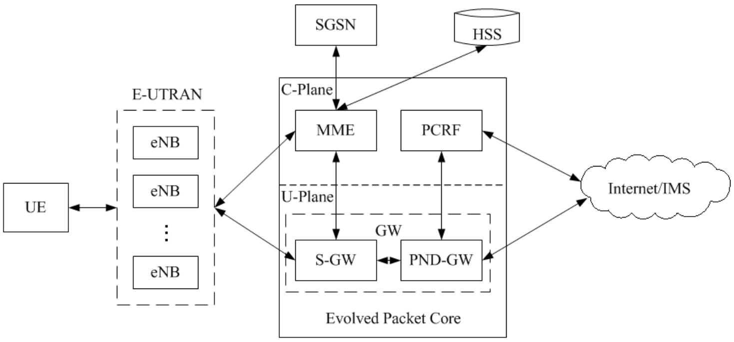

Fig.3 LTE-SAE network architecture

Fig.3 illustrates LTE-SAE network architecture. The access network of LTE-SAE is E-UTRAN (evolved-UMTS terrestrial radio access network). The only network equipment in the whole network is eNB (evolved-NodeB), which transmit or receive signals from terminals in one or more cells. Evolved-NodeB has Functions which are similar to that of BTS and BSC in GSM-R network, such as radio interface of transmission and reception at physical layer, including modulation and demodulation, channel coding and decoding, radio resource control, wireless mobility management and wireless interface protocol. C-plane (control plane) and U-Plane (user plane) are split to MME (mobility management entity) and the gateway in EPC (evolve packet core). MME performs the role of SGSN (service GPRS supporting node) in GPRS networks. Within U-plane there are two specific gateway nodes, S-GW (service gateway) and PDN-GW

(Packet data network gateway). S-GW is the user plane gateway to the E-UTRAN and PDN-GW serves as the user plane gateway to the internet or the IP Multimedia subsystem (IMS). It should be noted that it is possible for both S-GW and PDN-GW co-exist within a single gateway element. PCRF (policy and charging rules function) is the policy and charging control element. HSS (home subscriber system) is responsible for both updating and storing the database containing all the user subscription information.[8][9]

Compared with GSM-R, LTE-SAE has a flatter network architecture, which can improve data latency and support interactive and real-time communications which are inherently delay sensitive, whilst providing both voice and data services over a single all-IP network. Also, due to its simple deployment and backward compatibility, it is suitable for operators to evolve GSM-R to cost-effective LTE generation, in order to match current network, spectrum, and business objectives for railway services.

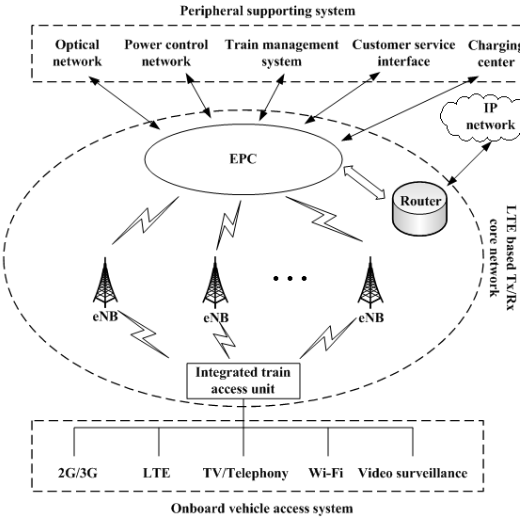

Fig.4 High speed railway C&S network architecture based on LTE

The proposed high speed railway C&S network based on LTE in Fig.4 are composed by three subsystems, including onboard vehicle access system, LTE based Tx/Rx core network and peripheral supporting system. Onboard vehicle access system can support multiple wireless accesses, such as GSM, CDMA, LTE and Wi-Fi, and other services like TV/telephony and video surveillance are also provided. LTE based Tx/Rx core network, which deals with all the transmission and reception work, is made up of integrated train access unit, eNB, LTE-EPC and a router. The peripheral supporting system is a important backing system, though which we can operate, control and monitor the whole network.

4. Key technology of LTE and its solusion for high speed railway C&S system

4.1 Key technology

The E-UTRA (evolved universal terrestrial access) is the air interface of LTE. OFDMA (orthogonal frequency division multiple access) is used for downlink and SC-FDMA (single carrier frequency division multiple access) for uplink. LTE supports FDD (frequency division duplex) and TDD (time division duplex). With FDD, downlink and uplink are transmitted simultaneously in separate frequency bands. With TDD, the transmission in downlink and uplink is discontinuous within the same frequency band. It also support multi-antenna scheme, by using MIMO (multiple input multiple output), Tx/Rx diversity and spatial multiplexing can be achieved.

4.1.1 Physical access of downlink and uplink:[10]

OFDM is a frequency division multiplexing (FDM) scheme utilized as a digital multi-carrier modulation method. The basic principle of OFDM is to split a high-rate data stream into a number of lower rate streams that are transmitted simultaneously over a number of subcarriers. Because the symbol duration increases for the lower rate parallel subcarriers, the relative amount of dispersion in time caused by multipath delay spread is decreased. Intersymbol interference (ISI) is eliminated almost completely by introducing a guard time in every OFDM symbol. In the guard time, the OFDM symbol is cyclically extended to avoid intercarrier interference (ICI).[11] OFDMA is a multi-user version of the popular OFDM, which provides flexible scheduling in the time-frequency domain. Based on frequency channel response, users are assigned to different subcarrier, which are able to avoid frequency selective fading. Due to different service requirement and channel conditions, downlink data is time-frequency scheduled to be transmitted to different users on different subcarriers in various modulations, such as QPSK (quadrature phase shift key), 16QAM (quadrature amplitude modulation) and 64QAM.

For uplink, OFDM is not appliable because of PAPR (peak-to-average power ratio) problem. It is difficult for user equipment to have power amplifier to overcome PAPR. Also frequency offset cause problem in uplink transmission because multiple users, using very adjacent subcarriers, will send data to eNB simultaneously, so single carrier FDMA (SC-FDMA) is adopted for uplink transmission. As in OFDM, SC-FDMA system systems use different orthogonal frequencies to transmit information symbols, but in a sequential manner. Compared to OFDMA, this arrangement significantly reduces the envelop fluctuations in the transmitted waveform. Therefore, a SC-FDMA signal has a lower PAPR than that of a FDMA signal. This in return resolves the challenges required with regard to limiting the physical size, high power consumption and cost-effective design of user equipment power amplifiers.

4.1.2 MIMO

MIMO offers significant increase in data throughput and link range without additional bandwidth or transmit power, which is achieved due to high spectral efficiency and space diversity. To meet the needs of high data rate transmission and high system capacity, LTE supports multi-mode adaptive MIMO for downlink and uplink.

4.2 LTE's solution of high speed railway C&S system from technical point of view

Heavy information loss due to specific enclosed structure of high speed train can be overcome by installing roof-top antenna on the train, which is an element of integrated train access unit. And antenna technology is an advantage of LTE, it can support the increasing demand of large data throughput. Roof-top antenna collects information from (distributes information to) onboard devices by onboard vehicle access systems, without information loss.

The proposed high speed railway system based on LTE can deal with frequency handover problem. According to network architecture, 2G/3G devices access network though integrated train access unit, this makes them free from frequency handover between cells and signaling storm caused by group handover can be avoided.

Overlapping area to meet handover and reselection in LTE network can be easily deployed, because LTE's flat network architecture and its lean signaling process ensures that handover can be completed in several hundred milliseconds.

The basic LTE subcarrier spacing of 15 kHz facilitates enough tolerance for the effects of implementation errors and Doppler effect without too much degradation in the subcarrier orthogonality [12]. In addition, some other technique scheme such as HARQ (hybrid automatic repeat request) and iterative residual frequency offset correction algorithm [13] can be applied to mitigate Doppler frequency shift.

5. conclusions

According to analysis, we can conclude that LTE technology is the solution for high speed railway system. Compared with GSM-R, it can solve the urgent encountered problems and it is more effective to provide strong support for safety operation while offering passengers multi-services during high speed travelling. In addition, the easy deployment and low cost provide operators an optimum option and it is also applicable to other high speed travelling method, urban rapid rail, Maglev, etc.

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