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High Speed Railway Mobile Communication System based on 4G LTE technology

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ABSTRACT

With the change in time High speed railways (HSR) requires reliability, safety train operation and passenger communication. To make it happen HSR's system needs higher bandwidth and shorter response time, also the old technology in HSR's needs to develop new technology, improving the existing architecture and controlling costs. To fulfill this requirements HSR's adapt GSM-R technology which is evolution of GSM, but it fails to customer satisfaction. So the new technology LTE-R is adopted, which provides higher bandwidth as well as gives greater customer satisfaction at high speed. This paper introduces LTE-R give the comparison between GSM-R and LTE-R, also describes which technology is better at high speed in railway mobile communication system.

Keywords : High Speed Railway, LTE, GSM, Communication and Signaling System

I. INTRODUCTION

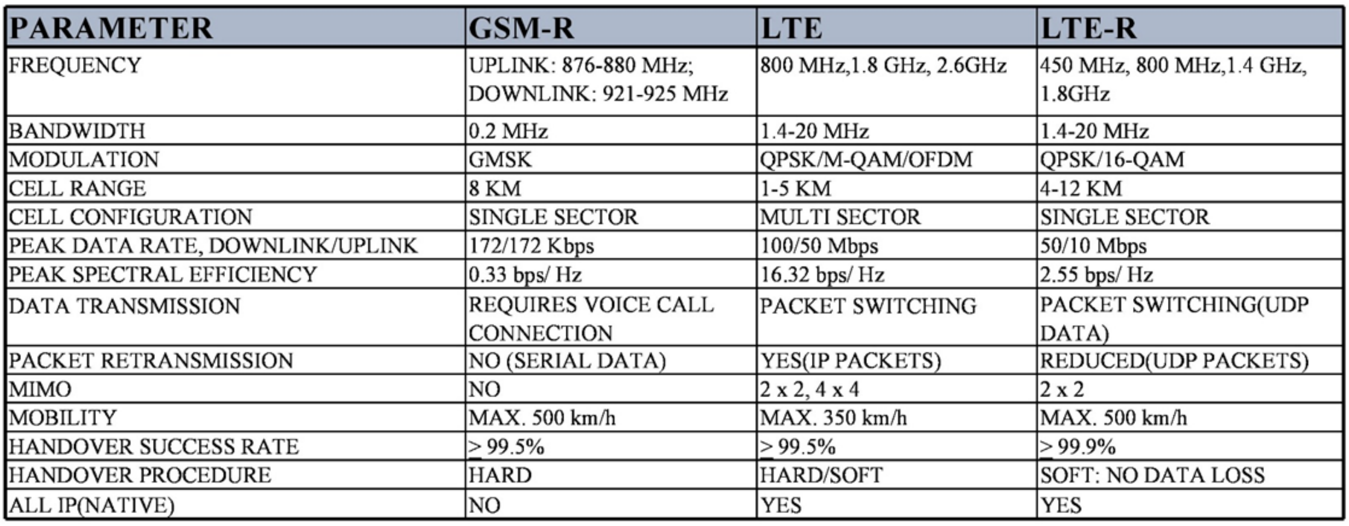
High speed railway needs to improve requirements for mobile communication system. With this improvement its network architecture and hardware devices must adapt to the train speed which reaches up to 500 km/h. HSR's also needs fast handover capability. So to solve all these problems HSR requires a new technology named as LTE-R, LTE-R based HSR provides high data transfer rate, higher bandwidth and low latency. LTE-R handles increasing traffic, ensures passenger safety and provide real time multimedia information.

With the increasing speed of train a reliable broadband communication system is essential for HSR mobile communication. HSR's applications quality of services (QOS) measures such as data rate, bit error rate (BER) and delay in transmission. To fulfil HSR operational needs a new system is thus required which have capability of being consistent with LTE, provides new services but still coexisting with GSM-R for a long period of time.

There are some issues like performance, services, attributes, frequency band and industrial support are needs to be consider to the selection of suitable wireless communication system for HSR's. 4G LTE system has a simple flat architecture, high data rate and low latency compared with third-generation (3G) system. In the scale of performance and level of maturity of LTE, LTE- railway (LTE-R) will likely be the next generation of HSR communication system.

II. LTE-R System Description

It is important to consider frequency and spectrum usage for LTE-R, to provide improved and more efficient transmission for High Speed Railway (HSR) communications. HSRs are important strategic infrastructure, so large spectrum chunks need to be allocated specifically for it. Some industry bodies, including the European Railway Agency (ERA), China Railway, are trying to obtain spectrum allocation for HSR use. Currently, most LTE systems work at the bands above 1 GHz, such as 1.8, 2.1, 2.3, and 2.6 GHz, although 700–900-MHz bands are also used in some countries. Large bandwidth is available in the upper bands, giving a higher data rate, whereas lower frequency bands offer longer distance. Since a high-frequency band has larger propagation loss and more severe fading, the radius of an LTE-R cell is suggested to be kept <2 km [due to the strict requirement of signal-to-noise ratio (SNR) in HSR], leading to frequent handovers and a requirement of investing more money for higher BS density. Therefore, the low-frequency bands, such as 450–470 MHz, 800 MHz, and 1.4 GHz, have been widely considered. The 450–470-MHz band is already well adopted by the railway industry. Furthermore, the carrier aggregation capability of LTE will permit the use of different bands to overcome problems of capacity. Figure 1(b) presents the detailed frequency allocation of 450– 470 MHz in China [12], and it is feasible to allocate enough bandwidth for LTE-R within this band. In Europe, the FRMCS of UIC would like to build on the current GSM-R investment by reusing the existing mast sites, which could save as much as 80–90% of the cost of a network. Railways are also concerned about continuing to make use of their GSM-R masts, and, therefore, a spectrum allocation under 1 GHz is more cost effective in Europe. However, the selection of frequency band depends on government policy and differs by country. Standard LTE includes a core network of evolved packet core (EPC) and a radio access network of Evolved Universal Terrestrial Radio Access Network (E-UTRAN). The Internet protocol (IP)-based EPC supports seamless handovers for both voice and data to cell towers, and each E-UTRAN cell will support high data and voice capacity by high-speed packet access (HSPA). As a candidate for the next-generation communication system of HSR, LTE-R inherits all the important features of LTE and provides an extra radio access system to exchange wireless signals with onboard units (OBUs) and to match HSR-specific needs. The future architecture of LTE-R according to [4] is presented in Figure 2, and it shows that the core network of LTE-R is backward compatible with GSM-R. Compared with the public LTE networks, LTE-R has many differences, such as architecture, system parameters, network layout, services, and QoS. Information of the train is detected by RBC and onboard radio equipment. This improves the accuracy of train tracking and the efficiency of train dispatchment. LTE-R also can be used to provide information transmission for future automatic driving systems.



PARAMETER	GSM-R	LTE	LTE-R
FREQUENCY	UPLINK: 876-880 MHz; DOWNLINK: 921-925 MHz	800 MHz,1.8 GHz, 2.6GHz	450 MHz, 800 MHz,1.4 GHz, 1.8GHz
BANDWIDTH	0.2 MHz	1.4-20 MHz	1.4-20 MHz
MODULATION	GMSK	QPSK/M-QAM/OFDM	QPSK/16-QAM
CELL RANGE	8 KM	1-5 KM	4-12 KM
CELL CONFIGURATION	SINGLE SECTOR	MULTI SECTOR	SINGLE SECTOR
PEAK DATA RATE, DOWNLINK/UPLINK	172/172 Kbps	100/50 Mbps	50/10 Mbps
PEAK SPECTRAL EFFICIENCY	0.33 bps/ Hz	16.32 bps/ Hz	2.55 bps/ Hz
DATA TRANSMISSION	REQUIRES VOICE CALL CONNECTION	PACKET SWITCHING	PACKET SWITCHING(UDP DATA)
PACKET RETRANSMISSION	NO (SERIAL DATA)	YES(IP PACKETS)	REDUCED(UDP PACKETS)
MIMO	NO	2 x 2, 4 x 4	2 x 2
MOBILITY	MAX. 500 km/h	MAX. 350 km/h	MAX. 500 km/h
HANDOVER SUCCESS RATE	> 99.5%	> 99.5%	> 99.9%
HANDOVER PROCEDURE	HARD	HARD/SOFT	SOFT: NO DATA LOSS
ALL IP(NATIVE)	NO	YES	YES

TABLE: System Parameters of GSM-R, LTE, and LTE-R

The preferred parameters of LTE-R are summarized in Table 1, based on the future QoS requirements of HSR communications. Note that LTE-R will be configured for reliability more than capacity. The network must be able to operate at 500 km/h in complex railway environments. Therefore, quadrature phase-shift keying (QPSK) modulation is preferred, and the packet number of retransmission must be reduced as much as possible.

III. LTE-R Services

HSR communications intend to use a well-established/ off-the-shelf system, where some specific needs should be defined at the service level. As suggested by the E-Train project [6], LTE-R should provide a series of services to improve security, QoS, and efficiency. Compared with the traditional services of GSM-R, some features of LTE-R are described.

1) Information transmission of control systems: To enable compatibility with the ETCS-3 or the Chinese Train Control System Level 4 (CTCS-4), LTE-R provides real-time information transmission of control information via wireless communications with a <50-ms delay. While the location information of the train is detected by a track circuit in ETCS-2/CTCS-3, in ETCS-3/CTCS-4 and LTE-R, the location information

of the train is detected by RBC and onboard radio equipment. This improves the accuracy of train tracking and the efficiency of train dispatchment. LTE-R also can be used to provide information transmission for future automatic driving systems.

2) Real-time monitoring: LTE-R provides video monitoring of front-rail track, cabin, and car connector conditions; real-time information monitoring of the rail track conditions (e.g., temperature and flaw detection); video monitoring of railway infrastructures (e.g., bridges and tunnels) to avoid natural disasters; and video monitoring of cross tracks to detect freezing at low temperatures. The monitoring information will be shared with both the control center and the high-speed train in real time, with a <300-ms delay. Although some of the aforementioned surveillance can be conducted by wired communications, the wireless-based LTE-R system is more cost effective for deployments and maintenance.

3) Train multimedia dispatching: LTE-R provides full dispatching information (including text, data, voice, images, video, etc.) of drivers and yards to the dispatcher and improves dispatching efficiency. It supports rich functionalities, such as voice trunking, dynamic grouping, temporary group call, short messaging, and multimedia messaging.

4) Railway emergency communications: When natural disasters, accidents, or other emergencies occur, establishment of immediate communications between accident site and rescue center is required to provide voice, video, data, and image transmissions. Railway emergency communication systems use the railway private network to ensure rapid deployment and faster response (with a <100-ms delay) compared with GSM-R.

5) Railway Internet of Things (IOT): LTE-R provides the railway IOT services, such as real-time query and tracking of trains and goods. It helps to enhance transport efficiency and extend service ranges. Moreover, railway IOT could also improve train safety. Most of today's trains rely on trackside switches located in remote areas. With the IOT and remote monitoring, it is possible to remake trackside infrastructure from switches to power lines, which could automate many of the routine safety checks and reduce the costs of maintenance.

In addition to the features listed previously, some other services of LTE-R should be included, such as dynamic seat reservation, mobile e-ticketing and wireless interaction of passenger information.

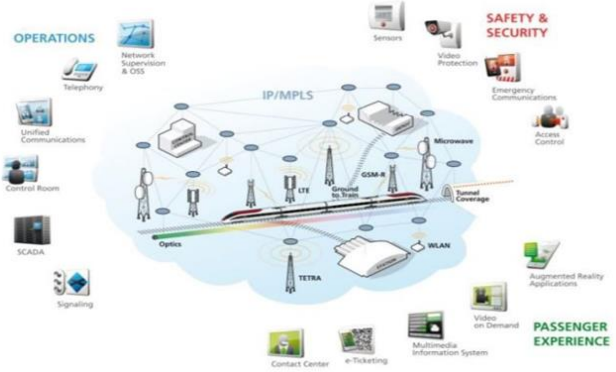


Figure 3 summarizes the future possible services provided by LTE-R, which is based on the technical reports of the UIC, China Railway, and ERA. It is noteworthy that broad-band wireless access for passengers inside high-speed trains is not provided by LTE-R because of its limited bandwidth. Some candidates for broad-band wireless access for train passengers have been discussed, such as Wi-Fi, Worldwide Interoperability for Microwave Access (WiMAX), 3G/4G/5G, satellite communications, and radio-over-fiber (RoF) technology [13].

IV. LTE-R Challenges

There are several challenges associated with LTE-R.

1) HSR-specific scenarios: In the LTE standard of [14], a channel model for HSR is presented that only includes two scenarios, open space and tunnel, and uses a nonfading channel model in both scenarios. However, as indicated by [15], the strict demands (high velocity, rail track flatness, etc.) of HSRs lead to many HSR-specific environments, such as viaducts, cuttings, and tunnels. The propagation characteristics in those scenarios are

distinct from traditional cellular communications and may significantly impact the system performances of GSM-R and LTE-R. In the past, some measurements were conducted to characterize the HSR channels for GSM-R band, and a scenario-based path loss and shadow fading model has been proposed in [16] and [17] for GSM-R at 930 MHz. However, this work is still ongoing, and many scientific issues are yet to be solved at LTE-R band, e.g., propagation loss, geometry distribution of multipath components (MPCs), and two-dimensional/three-dimensional angular estimation in those HSR-specific environments. It is necessary to develop a series of channel models for the link budget and network design of LTE-R, and extensive channel measurements are needed.

2) High mobility: High-speed trains usually run at a speed of 350 km/h, and LTE-R is designed to support 500 km/h. The high velocity leads to a series of problems. First, high velocity results in a nonstationary channel because, in a short time segment, the train travels over a large region, where the MPCs change significantly. Characterization of nonstationary is of special importance as it affects the BER in single-carrier and multicarrier systems. Second, high velocity leads to a shift of the received frequency, called the Doppler shift. For example, if the frequency is 2.6 GHz, the maximum Doppler shift at 350 km/h is 843 Hz, whereas it is only 24 Hz for a pedestrian mobile speed of 10 km/h. The large Doppler shift leads to phase shift of the signal and can impair the reception of angle-modulated signals. However, because the high-speed train mostly moves along a scheduled line with a known speed, it is possible to track and compensate for the Doppler shift by using the real-time recorded information of speed and position. Third, a large Doppler spread is expected in HSR environments owing to the high velocity. For LTE-R (broad-band system), Doppler spread typically leads to loss of signal-to-interference-plus-noise ratio and can hamper carrier recovery and synchronization. Doppler spread is also of particular concern for orthogonal frequency division multiplexing (OFDM) systems, because it can corrupt the orthogonality of the OFDM subcarriers. Several approaches such as frequency domain equalization and the intercarrier interference self-cancellation scheme should be considered [18].

3) Delay spread: Delay dispersion leads to a loss of orthogonality between the OFDM subcarriers, and a special type of guard interval, called the cyclic prefix (CP), should be employed. The delay dispersion determines the required length of CP. LTE supports both short (4.76 ms) and long (16.67 ms) CP schemes. For the short CP scheme, the corresponding maximum difference of path length between two MPCs is 1.4 km. Because railway communications aim to provide linear coverage, directional BS antennas with main lobes along the rail track are widely used, so transmit power is focused on the narrow-strip-shaped regions. Intuitively, we would anticipate that the short CP scheme is sufficient for LTE-R. This is especially true because high-speed trains mostly travel in (semi)rural/suburban environments, where there are few scatterers. However, in some special environments with rich multiple reflections, such as cuttings, a large delay spread is expected (note that a measurement-based validation is required), and the long CP scheme should be used. Another example for large delay spread occurs in the presence of mountains along the rail track [19], especially before and after the train enters and leaves tunnels. More measurements are required to address the behaviors of delay spread in HSR environments, and the CP needs to be adjusted to the environment, just as with general LTE.

4) Linear coverage: In HSRs, linear coverage with directional antennas along the rail track is used, where the directional BS antennas orientate their main lobe along the rail track so that it is power efficient. The linear coverage brings some benefits, e.g., with the known location of a train, it is possible to design distance/ time-based beamforming algorithms with good performance. However, it is noteworthy that the link budget and performance analysis of linear coverage are different from the circular cell of cellular systems, e.g., for the determination of the percentage of coverage area. It is well known that, due to the

effect of shadow fading, some locations within the coverage area will have a received signal below a particular threshold. Computing how the boundary coverage relates to the overall percentage of coverage area is very useful for link budget and network planning. In Figure 4, we compare the determination of percentage of coverage area for linear and circular cells [20] using the Hata-based link budget model, where we can see that the linear coverage in HSRs generally has a higher percentage of coverage area. This should be carefully considered when designing LTE-R networks to avoid an over deployment of BSs.

5) Sparse multipaths: Sparse multipath channels represent a sparse distribution of resolvable paths in the angle-delay-Doppler domain. As in some open areas of HSRs, for example, viaducts and rural areas, there are few scatterers. The linear coverage of HSR also reduces the number of the scatterers that can be seen by transmitters/receivers. It is possible to have a sparse multipath channel in those environments. However, support for multiple-input, multiple-output (MIMO) transmission will be an integral part of LTE-R. The performances of multi antenna solutions, such as spatial diversity and spatial multiplexing, depend on the scattering richness in the environments. If the HSR channel turns out to be sparse in those open areas, the clear line of sight and few scatterers lead to a strong correlation between the signals of two antennas and reduce both diversity and spatial multiplexing gain. There is an indication that, in certain sparse environments, a reconfigurable antenna array [21] can improve system capacity.

6) Impact of train car: A high-speed train usually is over 200 m long and made of metal. The static high-speed train acts as a scatterer with strong reflection and increases the delay spread, whereas the dynamic nature of the high-speed train significantly increases the nonstationary aspect of channels. The large metal roof of the train also increases reflections and scatterings near the transmitters/receivers and significantly affects the pattern of the transmitters/receivers antenna on the roof. Moreover, propagation into the interior of the high-speed train leads to large penetration loss and reduces the SNR. The coverage inside the train car could be improved with moving relays, similar to fem to cell access points.

V. CONCLUSION

In this paper we have summarized the full description of LTE-R system, which includes comparison between GSM-R and LTE-R systems on the basis of certain parameters. It also describes how LTE-R fares better than the GSM-R system. LTE-R provides different services to HSR communication to make easier to communicate at high speed. With the even side LTE-R also has odd side means have some challenges which is elaborated in the paper, but with this challenges LTE-R further prove that it will be able to fulfil the requirements of a high speed railway mobile communication system.

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