Enhancing The CBTC System in Urban Rail Transit

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Abstract: In recent years, urban rail transit has developed rapidly around the world due to its safety, reliability, high capacity and energy efficiency. Furthermore, it is faster, safer, more comfortable and it has high capacity, which significantly related to communication based train control system (CBTC). That's how the demand for urban rail transit is increasing faster and lots of urban rail transit projects are constructed in especially big cities in order to reduce traffic and improve public transport quality. However, the majority of CBTC systems rely on Wireless Local Networks (WLAN) technology, which cannot fully provide data transfer during train operation at high-speed. Therefore, in urban rail transit, Long Term Evolution (LTE) has become a burden on the research communication technology due to a high transmission speed. Yet, there is a few study on the dependability of LTE based train ground communication systems. This study, will focus on the dependability of train ground communication, train ground communication performance parameters of based on LTE technology, the dependability analysis according to the experimental results, behaviour comparison, storage process and data observation of train data in operation in order to analyse the dependability of train data transmission. Its seems that the consistency of LTE-based train ground communication is important and fulfils CBTC requirements.

Keyword: CBTC, WLAN, LTE, Urban Rail Transit

1. Introduction

Operationally important roles must be recognized when deploying a Communication Based Train Control (CBTC) solution. These functions determine how a railroad works once the solution is deployed and if ignored the Operator should anticipate service delays, longer recovery times and irate commuters. Laser focus on the CBTC Solution's operational functions would ensure that the operational requirements of the Operator are met [1].

CBTC is often used in urban signalling system, which can control driverless high-frequency trains as soon as sixty seconds and helps safety and operations drivers such as doors start, accelerate, brake, stop, open and close. In order keeping the security of the system, using a bi-directional communication link, a CBTC system may detect the precise location of a train, independent of track circuits or axle counter [2].

CBTC benefits include integrated system based on state on the art CBTC with bi-directional radio communication, improved transport capacity to optimize use of the infrastructure: track and trains, enhanced system supervision and control from centralized automatic train control (ATC) location, thanks to bi-directional communication capabilities and integrated data network and reduce lifecycle and maintenance costs, including the result of wayside equipment being required [3].

Nowadays, CBTC systems are urgently used in the train control systems for city-based rail transit that aspects of rail especially the high tracing density and high speed. The forerunning train and the forward path conditions, the CBTC system carefully track the train process. The wireless communication system of the CBTC system ensure the reliability, safety and timely transmission of data. Communication is a prerequisite for CBTC system design. Currently, the urban rail transit system uses a wireless communication system based on WLAN. The present WLAN-based technology has among of the finest technologies for implementing high-density rail transit, high-security and high-speed although it does have certain drawbacks [4]. Therefore, this study is focuses on the CBTC system in urban rail transit which involved WLAN and Long Term Evolution (LTE) in order to highlight the technology performances in data communication.

2. Wireless Local Area Network (WLAN)

WLAN stands for "Wireless Local Area Network." A WLAN, or wireless LAN, is a network that allows devices to connect and communicate wirelessly. New devices are typically added and configured using DHCP. They can communicate with other devices on the network the same way they would on a wired network. The primary difference is how the data is transmitted [5].

As WLAN was outlined, the industry sponsored the creation of a new committee within the Institute of Electrical and Electronic Engineers (IEEE) in 1998. Committee 802.3 had defined the Ethernet LAN standards a few years earlier, so the new committee came to be called 802.11. The industry organised itself to looking for a brand name with more attractive than “IEEE 802.11” and called it “the Wi-Fi Alliance”, and “Wi-Fi” (standing for “wireless fidelity”) products started to hit the market in 1999.

The 802.11 standard actually defines a series of protocols to deliver a physical layer (PHY or OSI L1) and a media access control layer (MAC, included in OSI L2). Table 1 presents a summary of the different 802.11 PHY standards and some of their main characteristics. The initial 802.11-1997 standard defined two possible PHY multiplexing methods: Frequency Hopping Spread Spectrum (FHSS) and Direct-Sequence Spread Spectrum (DSSS), both for the 2.4 GHz band. This original standard was soon (1999) replaced by two new protocols: 802.11a, that specified an Orthogonal Frequency Division Multiplexing (OFDM) encoding over the 5 GHz band, and 802.11b, that defined a DSSS modulation over the 2.4 GHz band.

Table 1 802.11 PHY Standards [6]

Release	Band [GHz]	Bandwidth [MHz]	Codification
802.11	2.4	20	DSSS/FHSS
802.11a	5	20	OFDM
802.11b	2.4	20	DSSS
802.11g	2.4	20	DSSS/OFDM
802.11n	2.4/5	20/40	OFDM
802.11ac	5	40/80/160	OFDM

802.11b was the most successful protocol in the family, and nearly all the Wi-Fi access points deployed between 1999 and 2003 used the 802.11b protocol. Part of the reason for the success of 802.11b over 802.11a was that the 2.4 GHz band provided much better propagation characteristics in office and domestic environments, where obstacles like walls and furniture would limit the effective range of 802.11a devices working on the 5 GHz band to a few meters. Therefore, the first CBTC applications to make use of a Wi-Fi radio bearer network were based on the 802.11b protocol.

3. Long Term Evolution (LTE)

Long Term Evolution (LTE) that was developed by the 3rd Generation Partnership Project. LTE is a particular type of 4G that is designed to deliver a fast mobile internet experience—10 times faster than 3G speeds—for mobile devices such as smartphones, tablets, notebooks and wireless hotspots. In 2008, the International Telecommunications Union required all services using 4G to adhere to a set speed and connection standards, making the gap between 3G and 4G enormous in terms of service and capability. To bridge the gap, LTE was created to represent a "long-term evolution" toward the 4G standard [7].

In February 2014, Huawei announced that the new LTE network deployed in Zhengzhou’s metro Line 1 would be part of a trial to transmit CBTC over LTE. If the trial were successful, CBTC operations could be switched from Wi-Fi to LTE by the end of 2014[8]. In August 2014, Alstom and Huawei publicly announced a joint project to test CBTC over LTE, together with voice communications and CCTV transmission, at an

Alstom test facility in Valenciennes, France. Alstom has stated that Urbalis CBTC over LTE could be available by the end of 2014 [9]. During the August 2014 Australasian Railway Association Telecommunications and Train Control Conference in Sydney, GE Transportation announced that the Tempo CBTC platform had been successfully trialled over a commercial LTE network in Hong Kong, using an Ericsson eNodeB and a Huawei on board data radio. All these developments point very clearly at the supplier industry’s conviction that the CBTC market is ready for an alternative to Wi-Fi such as an LTE network.

The implementation of LTE in the CBTC system will fairly use the relatively low frequency of 1.8 GHz and the issue of leakage cable of radio frequency as the transmission medium, in order to increase the efficiency of the CBTC system's train-ground communication significantly. In addition, this literature was introduced the two important performance indicators for the delay in the train communication system and packet loss rate. Because of packet failure, the efficiency of the train service would be seriously impaired if the control data cannot be transmitted to the train.

At a certain range, the packet delay need to be controlled in order to prevent the data provides by the train is not real-time data that affected on the accuracy of train operations. In the CBTC systems of the wireless network, literature examined the train control issue. In China, within a broader range of urban rail transport, the use of LTE-based wireless communication technology are their best option. Several studies on LTE technology, which few of it indicates studies have been carried out regarding the reliability of experimental data-based LTE-based CBTC train ground communication systems [9].

4. CBTC Structure

A CBTC system consists of Zone Controller (ZC), Data Communication System (DCS), Automatic Train Supervision (ATS), Automatic Train Operation (ATO), Automatic Train Protection (ATP), Computer Interlocking (CI) and Database Storage Unit (DSU). Therefore, Fig. 1 shows the influnces of wireless communication reliability on the performance of CBTC systems [10].

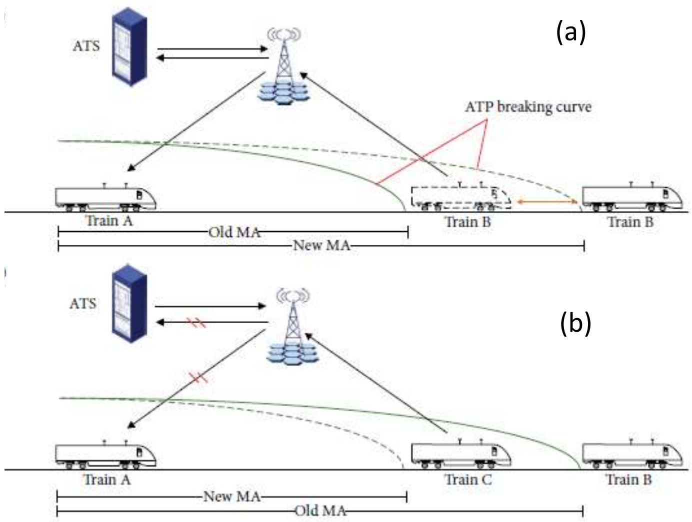

Fig. 1 Influences of wireless communication reliability on the performance of CBTC systems [10]

Fig. 1(a) shows that the communication is possible, the modified location of train B, whose position is located in the figure far from train A, will be transmitted to the following trains during each communication cycle using the communication network. Until the MA is modified, the following train will act as the braking curve and will never reach the MA limit. However, if the communication disruption or delay in data communication systems is too substantial, ZC may not be able to transmit the newest MA point for a certain time to the following train. As is seen in Fig. 1(b), the old MA is still used by the following train until the new MA arrives. It will determine a new breaking curve when the ATP receives the modified location and the train will return to the new optimized ATO-controlled guidance trajectory.

Based on the condition of the precursor train and the forward track, the CBTC system will trace the train operation closely. The minimum train tracking interval will then hit the 90s or less, which can shorten the train tracking interval easily and greatly increase the quality of transport. The CBTC system's wireless communication system must ensure accurate, safe, and timely transmission of data. An essential precondition for the design of CBTC systems is the high efficiency of train-ground communication [10].

A. Design of Long Term Evolution (LTE) on CBTC

Particularly Time Division-LTE (TD-LTE) has greater spectrum efficiency, quicker data rate, and shorter time delay than the existing 2G/3G system [11]. Accordingly, the LTE for Metro (LTE-M) is recommended to be the wireless communication device for urban rail transit in the future, in order to meet the safety-critical, high-speed, and high-throughput requirements. QoS performance, such as transmission delay, packet drop rate, and handoff success ratio, are also included in the LTE-M system study [12].

On the other hand, in the conventional LTE-M based CBTC system, the train status data can first be sent to the eNB wayside, and then the eNB wayside transfers the data to other trains [13]. Therefore, in the CBTC scheme, careful design is pursued for a novel wireless communication method of direct data transfer between trains. Fig. 2 shows the traditional LTE based CBTC system.

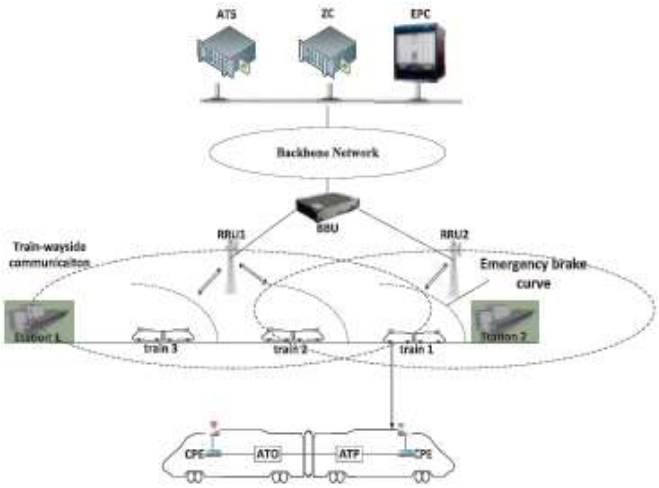

Fig. 2 Traditional CBTC system [13]

The consequent of many technological advancements, the evolution of communication-based signalling for transit rail applications outline into four basic signal system generations of train control. Each signal system generation shows an increase in operational protection and efficiency to accommodate more demanding user requirements as shown in Fig. 3 [14].

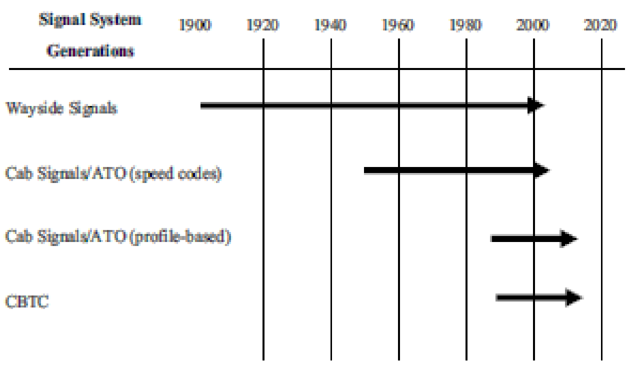

Fig. 3 Signal System Generation [14]

The CBTC systems provide the utmost operating elasticity and can accommodate the highest train throughput, restricted only by the rolling stock efficiency and the physical track alignment limitations. The high level of control offered by CBTC systems in particular, makes this the technology the preferred mode for train operations that are driverless / unattended [15]. Fig. 4 shows operations of CBTC system.

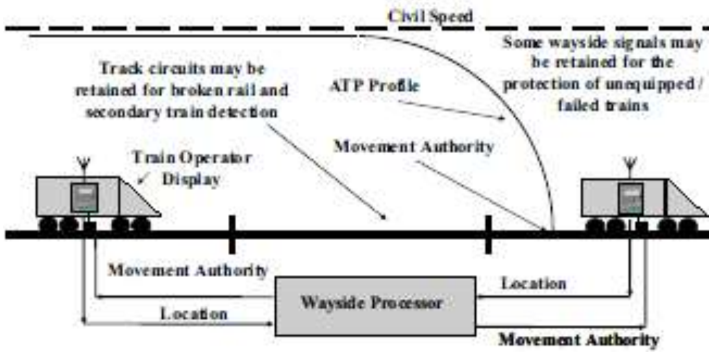

Fig. 4 CBTC Operations System [15]

In contrast with conventional 2G/3G networks, the LTE network architecture is flat. Node B is the only feature called eNode B of the LTE system on the wireless connectivity side of the E-UTRAN. This means that, owing to the elimination of the transmission node, the transmission delay would be shorter. The LTE network architecture is seen in Fig. 5 [16].

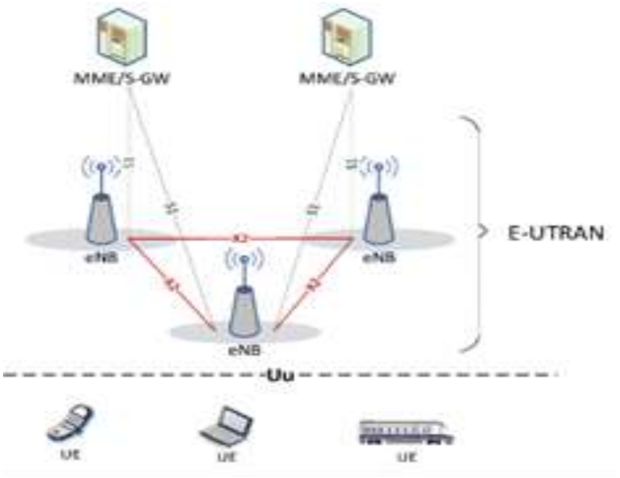

Fig. 5 System architecture of LTE [16]

To minimize wireless interference and enhance the device in the LTE-M based system, stability and dedicated frequency range are used. An advanced train-ground communication system based on TD-LTE is planned for urban rail transit/metro (LTE-M) systems.

B. System Structure

TD-LTE base stations consisting of the Building Base Band Unit (BBU) and the Remote Radio Unit (RRU) are referred to as the wayside equipment. The optical fibre connects the BBU and RRU, the RRU and the train equipment connect via air interface with each other [16]. Two Customer Premise Equipment (CPEs), PIS screens, IMS cameras, and train state sensors compose the train equipment. The two CPEs are mobile stations in the LTE-M networks, and all the equipment is connected by switches. This is shows in Fig. 6 [12].

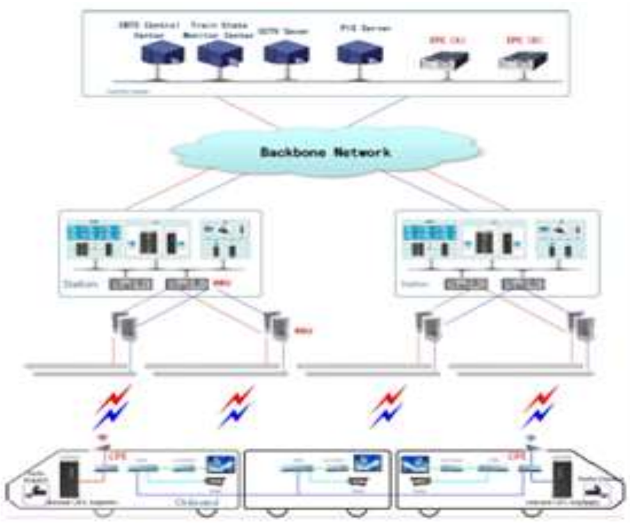

Fig. 6 The designed LTE System [12]

5. Results and Discussions

The field test and the simulation results for the transmission delay are reviewed in this section. The field test was performed in conjunction with the delay in transmission of WLAN and LTE-M on the Beijing Yanfang subway line. For LTE-M and WLAN, the average transmission delay without handoff is around 24ms and 60ms, respectively. Meanwhile their maximal handoff latency will exceed 225ms and 406ms, respectively. The efficiency of the constructed LTE-M system meets the standards for urban rail transit communication, according to test findings. It guarantees a stable transmission of CBTC traffic, also provide IMS and PIS traffic with an effective transmission path [14].

Thus, transmission delay will meet the CBTC condition without handoff, but there is still a lot of delay-violation during handoff. As a result, even if LTE-M offers lower transmission latency, handoff latency, and delay-violation periods than WLAN, there is still some deficiency. In addition, the handoff affects both WLAN and LTE-M. There is a significant handoff delay in WLAN and LTE-M when the handoff happens. The train-ground communication round trip response time is less than 300 ms, indicating that the train-ground communication system based on LTE technology can stably transmit data and data. The estimates show that the near-point response time is frequently less than the far-point response time. The test results shown that the transmission delay and packet loss rate of train-ground contact are below a specific amount in a variety situation.

Besides, even under an unfavourable 1.4MHz bandwidth, it can be see that the train ground contact system also has very high reliability and is equipped with a low RSRP, and meets the specifications of CBTC urban rail transit networks. As a conclusion, CBTC urban rail transit networks can be extended to the train-ground communication system with LTE technology. The performance metrics tested in the field test including the transmission delay, handoff delay, throughput, and system stability. This be shown in Fig. 7, Fig. 8, Fig. 9 and Fig. 10. [12].

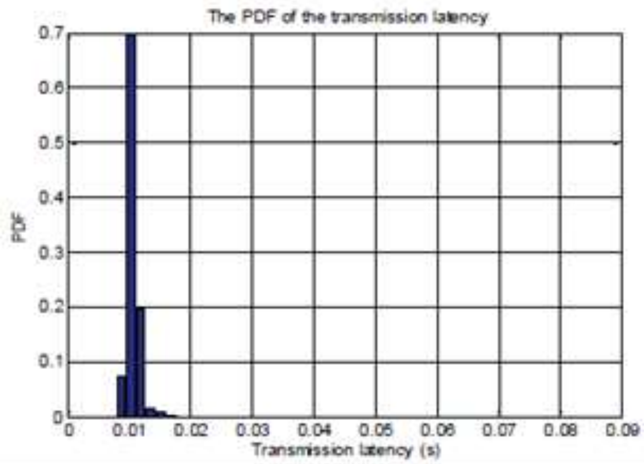

Fig. 7 Transmission delay [12]

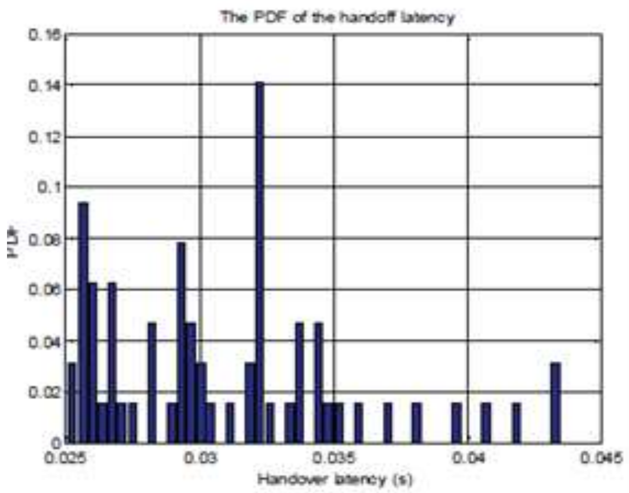

Fig. 8 Handover latency [12]

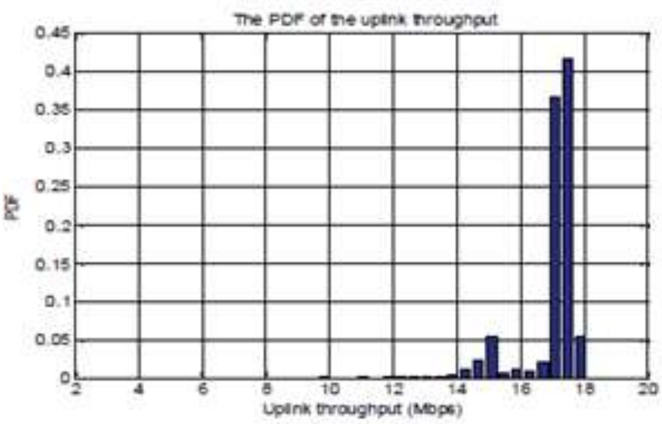

Fig. 9 Uplink throughput (15MHz Bandwidth)[12]

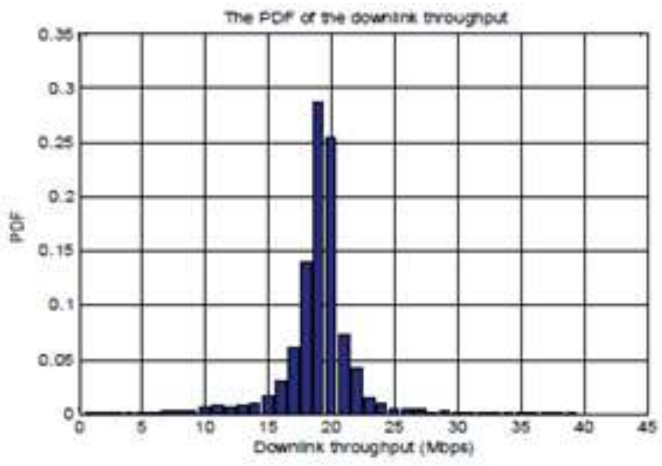

Fig. 10 Downlink throughput (15MHz Bandwidth) [12]

In railway operations, the train is still protected by the LTE communication network system and the behaviour of the train transfers in-memory data to the cloud concept at any time. The in-memory data also will observe from any location via one or more critical networks in order to facilitate and provide high-capacity with the efficient data storage. LTE communication technology is use in order to ensure a high data transfer rate. As a result, using LTE-based networking technologies to relay data from the event recorder to the cloud in real time is very safe. The data is sent to the cloud in real time via LTE wireless networking technology, and employees may access the appropriate modules based on their needs and obtain the most up-to-date data [12]. Table 2 shows the differences between WLAN and LTE.

Table 2 Differences between WLAN and LTE

	WLAN (Wireless Local Area Network)	LTE (Long Term Evolution)
Advantages	-It is a reliable type of communication. -As WLAN reduces physical wires so it is a flexible way of communication. -It is easier to add or remove workstation. -It provides high data rate due to small area coverage. -Easy installation and you need don't need extra cables for installation.	-Data as well as voice can be exchanged between participants. This is because LTE supports packet switching. -High amounts of data can be transferred between the sender and the receiver. -It has high speed of the file upload and download. -It releases the network usage faster. This decreases the load on the network. -This decreases the traffic and moves towards lesser crashes in the service.
Disadvantages	-It has a limited area to cover. -If the number of connected devices increases then data transfer rate decreases. -Signals may be affected by the environment as compared to using fibre optics. -Communication is not secure and can be accessed by unauthorized users. -It is required to change the network card and access point when standard changes.	-This service is not currently available in all cities. -More towers and fresh technologies need to be developed for better signals while in transit. -LTE being complex needs only skilled people to manage the system. They even need to be paid a higher salary. -This technology cannot be used in old versions of smartphones. -Buying new smartphones for LTE is a costly affair.

With the knowledge of rail operational demands as well as rail passenger rising demands, LTE (Long Term Evolution) emerges to fulfil the requirements of high data rates, low latency, wide-area coverage, backwards compatibility, and high device capability that are far beyond the capabilities of GSM-R (Global System for Mobile Communications Railways). LTE-SAE (System Architecture Evolution) provides an end-to-end Quality of Service (QoS) architecture offering support for IP-based protocols, roaming, and mobility. In this arrangement, the network reserves the resources dependent on service features. Service distinction is crucial for the proper implementation of railway communications, allowing for discerning the minimum access levels required by control mechanisms and alarms while providing excellent service availability.

5.0 CONCLUSION

In conclusion, it is clear that Wi-Fi will become less and less fit for the purpose of carrying CBTC data over the next years as CBTC applications expand into the suburbs and as the 2.4 GHz and 5 GHz bands become more and more crowded. Its shortcomings in range, mobility, media access control, quality of service and resistance to interference pose a danger to the future reliability of CBTC systems everywhere. Clearly showing that LTE will replace Wi-Fi in coming years. It is now up to the operators to realise that the clouds are gathering over Wi-Fi, that these problems are only going to get worse, and need to overcome the problems.

ACKNOWLEDGEMENTS

This research study was funding by Universiti Tun Hussein Onn Malaysia (UTHM) under TIER 1 grant vot H859. The authors thank to the colleagues from UTHM who provided insight and expertise that greatly assisted the research.

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