Test of Integrated Urban Rail Transit Vehicle-to-Ground Communication System Based on LTE-U Technology

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Abstract. With the continuous promotion of LTE in urban rail transit, the authorized spectrum resources of LTE-M system are limited, which limits LTE's ability to meet the data transmission requirements of urban rail transit. LTE-U, an emerging wireless technology which use an unauthorized spectrum to achieve LTE, can effectively alleviate the pressure of spectrum resource shortage. In this paper, we analyze the technical advantages of LTE-U in urban rail transit applications. By building an LTE-U test network and simulating the radio channel characteristics at the equipment work site in the laboratory, the LTE-U system is tested for its ability to carry services such as CBTC, CCTV/PIS, emergency text and train operation status information in urban rail transit. The test results show that LTE-U system can meet the demand of carrying urban rail transit services and is a feasible solution to the existing problems of urban rail transit.

Keywords: LTE-U · CBTC · CCTV · PIS

1 Introduction

With the continuous development of urbanization in China, urban rail transit has gradually become a fast and convenient mode of public transportation, playing an important role in solving urban traffic congestion and driving the development of intercity industries. In order to improve the quality of operation service and safety guarantee ability, Communication Based Train Control (CBTC) system, Passenger Information System (PIS) and Closed-circuit Television (CCTV) monitoring and control (CCTV) system are used. These systems become an important part of the urban rail transit system [1]. CBTC is a signalling system based on radio communication, which achieves precise closed-loop control of trains through two-way, real-time data transmission between on-board equipment and ground equipment. PIS and CCTV systems also require vehicle-to-ground communication for information exchange between trains and the ground, also PIS and CCTV services require high transmission rates. Therefore, the car-to-car communication system should comprehensively carry the urban rail transit service with CBTC signal

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system as the core, which can provide effective bandwidth for PIS and CCTV services while meeting the low delay, high reliability and priority transmission of CBTC service [2].

Long Term Evolution-Metro (LTE-M) is an LTE system based on Long Term Evolution (LTE) radio communication technology, customized to meet the service needs of urban rail transit. LTE-M system fully takes into account the requirements of urban rail transit service for reliability and real-time, which can realize the comprehensive bearing of single system for multiple services. LTE-M system has the ad-vantages of high communication rate, high spectrum utilization, mature multiservice priority scheduling mechanism and so on [3]. However, LTE-M technology works in the 1785–1805 MHz dedicated frequency band, in addition to urban rail, the frequency band has been widely used in airports, oil, power, heavy railways and other fields, these application areas may overlap with LTE-M system operating area, resulting in co-frequency interference. And with the significant increase in the demand for data transmission between trains and land, the current spectrum resources have restricted the network capacity of the urban rail transit wireless communication system. Not only a large number of data between trains and land cannot be timely up-loaded and downloaded, but also restrict the choice of urban rail transit wireless communication system construction plan. The introduction of LTE technology into the 5.8 GHz open band (LTE in Unlicensed spectrum, LTE-U) can alleviate or even solve the problem of insufficient frequency resources for urban rail communications and meet the demand for data transmission between trains and land with higher spectrum utilization on the basis of richer spectrum resources [4, 5].

As a complementary technology to LTE in licensed bands, LTE-U was first introduced by Qualcomm at the 3GPP RAN62 summit in December 2013, and 3GPP introduced it as a key technology in LTE R13 [6]. Cagri investigated the modes that affect the performance of downlink scheduling algorithm, and proposed a novel QoS-aware downlink-scheduling algorithm, which increased the QoS-aware fairness and overall throughput of the edge users [7]. Li investigated the effect of MU-MIMO enabled WiFi AP on the performance of traffic offloading in LTE-U, the paper suggested that adaptive utilization of antenna numbers on the MU-MIMO enabled AP based on SNR, and deciding CSI feedback length were critical to achieve high rate performance for traffic offloading in LTE-U [8]. Liu proposed a unified hybrid adaptive channel access scheme, which takes advantages of both the DCM and LBT mechanisms. It can adaptively adjust the important parameters, such as the back-off window size and the duty-cycle time fraction based on the WiFi traffic and the available licensed spectrum resource while guaranteeing the fair coexistence between the WiFi and LTE-U systems [9]. Manzoor investigated the problem of unlicensed spectrum sharing among WiFi and LTE-U systems, then they proposed a fair time-sharing model based on the ruin theory to share redundant spectral resources from the unlicensed band with LTE-U without jeopardizing the performance of the WiFi system [10].

LTE-U is basically the same as LTE-M in the network architecture, only the RF work unit of the frequency band is not the same. The network architecture includes Evolved Packet Core (EPC), Base Band Unit (BBU), Radio Remote Unit (RRU) and User Equipment (UE). LTE-U system has excellent mobility and switching performance, which can support high-speed (160 km/h above) environments such as urban rail fast lines, with small switching time delay and strong service continuity. It is conducive to the transmission of highly reliable service data such as urban rail CBTC and traffic dispatching. It also has the advantages of strong anti-interference ability, large coverage radius, strong maintainability, flexible deployment, good QoS guarantee and high network security [11].

This work tests the proposed LTE-U system based on LTE-U technology to verify the performance of the LTE-U system for carrying integrated urban rail transit services. While ensuring the high reliability of CBTC service transmission, it can meet the transmission requirements of emergency text dispatching and train operation status information services, and provide an effective transmission channel for CCTV and PIS services.

The structure of this paper is as follows: Sect. 1 introduces the research back-ground, network architecture and advantages of LTE-U technology; Sect 2 introduces the test objectives and test contents; Sect. 3 introduces the test environment; Sect. 4 draws the results of this system test; and Sect. 5 is a summary.

2 Test Objectives and Contents

2.1 Test Objectives

The purpose of this test is to simulate the field wireless channel characteristics in the laboratory environment, and to verify that the LTE-U system is capable of carrying CBTC services, CCTV/PIS services, emergency text and train operation status information in the urban rail transit environment (80 kmh, 120 kmh, 160 kmh, 200 kmh).

2.2 Test Contents

In order to verify the availability of LTE-U system for wireless communication in urban rail transit vehicles, the LTE-U communication system is tested. The test consists of the following four main parts:

- The capability of LTE-U system to carry CCTV/PIS services
- The capability of LTE-U system to carry CBTC services
- The capability of LTE-U system to comprehensively carry CBTC, CCTV/PIS, emergency text and train operation status information services
- Transmission performance testing of LTE-U systems

3 Test Environment

The core network ZXTS eTC500, the LTE baseband processing unit ZXSDR B8200, and the 5725–5850 MHz band Radio Remote Unit 8504-S5800 were used in this test to build the LTE network. The train access unit (TAU) is also required, as well as a client and server that can run CCTV and PIS service simulation software simultaneously. The ACE MX wireless channel simulator was used to simulate train speed and multipath, and the EUBUS tunable attenuator was used to support large scale switching channel simulation at 5.8 GHz.

The channel simulator is able to simulate the small-scale radio decay characteristics of LTE in the 5.8 GHz band, and support no less than 4 paths, the maximum delay of the path is not less than 1 μs, and the maximum speed of the supported Doppler frequency deviation of the train is not lower than 200 km/h.

Tunable attenuators are mainly used to simulate the ability to switch cells at certain speeds, and are capable of simulating large scales decay characteristics at 5.8 GHz LTE frequency.

The service performance test software is Ixchariotv6.7, which is installed on the service server and service client to test the basic LTE performance. The statistical interval for all test metrics is 1 s. For performance such as transmission delay, it is necessary to support timestamping on simulated service packets and to calculate latency by performing timestamp analysis on the end. Also, latency estimation is not allowed in the form of ping packages.

Figure 1 shows the connection performance test of the system.

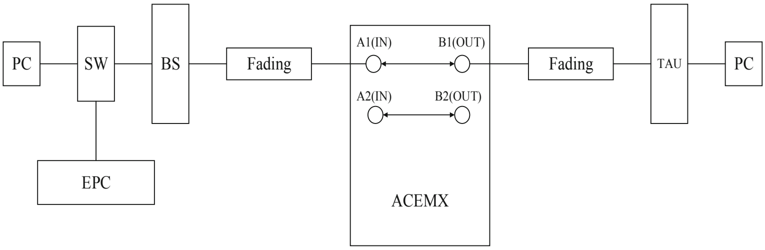

Fig. 1. Testing the connectivity performance of LTE-U system

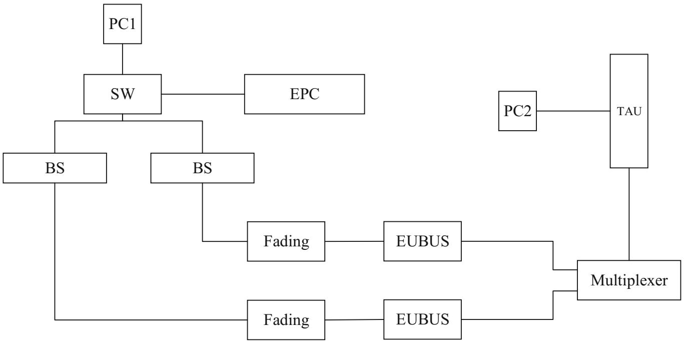

Fig. 2. Testing the switchover interrupt of LTE-U systems under static channel model.

3.1 Channel Environment

The channel model is simulated using a channel simulator, and the model should be able to represent the wireless decay characteristics in a typical urban rail transit scenario. The channel model is divided into a static model and a dynamic model, in which the static model includes three points, far, medium and near, and the default speed model is loaded at 200 km/h with the following power ranges for the far, medium and near points:

- far point: [−85, −100) dBm;
- medium point: [−75, −85) dBm;
- near point: > −75 dBm.

Figure 2 and Fig. 3 show the switchover interrupt test in static and dynamic mode respectively.

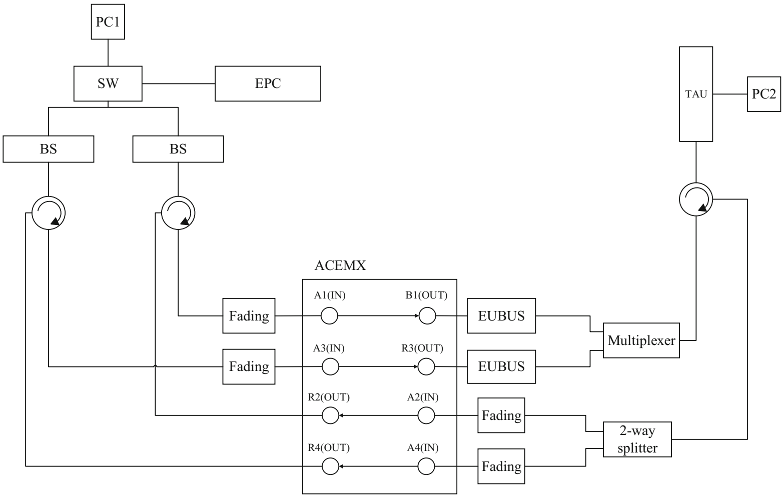

Fig. 3. Testing the switchover interrupt of LTE-U systems under dynamic channel model.

The switchover model includes underground tunnel segment as well as surface segment. Laboratory switching channel characteristics are simulated using programmable attenuators, while small-scale decay (e.g., multipath decay, Doppler frequency bias) is loaded using a channel simulator. Table 1 and Table 2 show the relative delay and relative decay of the tunnel and surface channel models, respectively.

Table 1. Tunnel channel model

Tap	Relative latency (ns)	Relative decline (dB)
1	0	0
2	90	−4
3	180	−8

Table 2. Ground channel model

Tap	Relative latency (ns)	Relative decline (dB)
1	0	0
2	180	−8

Underground Tunnel Segments In the underground tunnel segment switching test, taking into account the simulation efficiency of multiple switching, the ITU-R tunnel correction model is adopted:

$$PL_{total} = 20\lg f + 30\lg d - 28 \tag{1}$$

the train triggers the switch when the receiving power is −70 dBm, the received power of the train at the edge of the cell is −77 dBm. When the speed is 200 km/h, 220 km/h, the attenuation values is 10 dB, 5 dB, 4 dB, 3 dB, 3d 2 dB per second, assuming a switch every 6 s, at which point the train's strongest received power is − 50 dBm.

Above Ground Segment. In the ground segment switching test, taking into account the simulation efficiency of multiple switching, the WLAN attenuation model is adopted:

$$PL_{total} = 40\lg f + 50\lg d - 2\lg(h_r h_t) \tag{2}$$

the train triggers the switch when the received power is −70 dBm, and the received power of the train at the edge of the cell is −82 dBm. When the speed is 220 km/h, the attenuation value is 10 dB, 8 dB, 5 dB, 4 dB per second, assuming a switch every 4 s, at which point the train's strongest received power is −55 dBm.

3.2 Service Model

The CCTV system service is variable video surveillance analog data with uplink transmission rate of 4 Mps in 2 channels. The data packet adopts the RTP protocol and the data size is 1400 bytes.

The PIS service is a channel of video analog data with variable speed of 2–8 Mbps downlink. The data packet adopts RTP protocol with the size of 1400 bytes.

The distribution of loading services should be able to reflect the service requirements of the docked CBTC system. The data packets of each service flow adopt UDP or RTP (only used when testing the performance of packet loss) protocol with the size of 400 bytes, and the data rates of downlink and uplink are 256 kbps and 256 kbps, generating 4 service streams. The type of CBTC service is QCI1, GBR.

The type of train operation status information service is QCI 2, GBR with uplink rate of 100 kbps. The data packet adopts UDP protocol with the size of 400 bytes.

The type of emergency text service is QCI 2, GBR with downlink rate of 10 kbps. The data packet adopts UDP protocol and its size is 400 bytes.

4 Results

(1) The capability of LTE-U system to carry services

Projects	Index	Results
CCTV/PIS operational functionality testing	CCTV/PIS rate meets requirement	PASS
Transmission Latency Performance Test for CCTV and PIS Services	The maximum latency for CCTV and PIS services is less than 300 ms	PASS
Packet Loss Performance Test for CCTV and PIS Services	The rate of packet loss of CCTV and PIS services is less than 1%	PASS
Switching Latency Performance Test for CCTV and PIS Services	The maximum switching latency for CCTV and PIS services is less than 500 ms	PASS
Ultimate Performance Testing	The test results meet the RSRP boundary values and SINR values for service metrics	PASS

(2) The capability of LTE-U system to carry CBTC services

Projects	Index	Results
Transmission Latency Performance Test for CBTC Services	The maximum latency for CBTC services is less than 150 ms	PASS
Packet Loss Performance Test for CBTC Services	The rate of packet loss of CBTC services is less than 0.5%	PASS
Switching Latency Performance Test for CCTV and PIS Services	The maximum switching latency for CBTC services is less than 150ms	PASS
Switching Packet Loss Performance Test for CBTC Services	Switching packet loss rates meets the requirements	PASS
Probability of Transmission Outage Test for CBTC Services	The probability of transmission interruption which less than 2.4 s is 100%	PASS
Carrying CBTC Service Test in Congestion Scenarios	Under conditions of data saturation, it is able to meet the requirements of CBTC service and train status information service in priority	PASS
Carrying CBTC Service Test under Interference Environment	Latency and packet loss rate meet the requirements when SINR is reduced to − 2 dB	PASS

(3) The capability of LTE-U system to comprehensively carry CBTC, CCTV/PIS, emergency text and train operation status information services

Projects	Index	Results
Average Performance Metrics Testing for Integrated Services	CBTC, train status, emergency text, CCTV/PIS service index meet the requirements	PASS
Performance Metrics Testing of Integrated Services in Switch Scenarios	The switching latency of each service meets the requirements	PASS
Carrying Integrated Service Test under Interference Environment	The latency and packet loss rate of CBTC, train status, emergency text, CCTV/PIS service meet the requirements	PASS
Carrying CBTC Service and CCTV Service Test in Congestion Scenarios	CBTC, train status, emergency text, CCTV/PIS service index meet the requirements	PASS
LTE-U Network Transmission Capability Testing Under Extreme Conditions	Loaded with 4-channel CBTC service, 1-channel train status information service, 1-channel emergency text service, 2-channel 2 Mbps CCTV service and 1-channel 6 Mbpss PIS service, the system's ultimate RSRP is −98 dBm and SINR is 18 dB	PASS

(4) Transmission performance testing of LTE-U systems

Projects	Index	Results
20 MHz Co-frequency Uplink Throughput Test	Co-frequency networking; With 80 km/h, 120 km/h, 160 km/h, 200 km/h channel simulator and switchover simulator;	PASS
20 MHz Co-frequency Downlink Throughput Test	Co-frequency networking; With 80 km/h,120 km/h, 160 km/h, 200 km/h channel simulator and switchover simulator;	PASS
20 MHz Inter-frequency Uplink Throughput Test	Inter-frequency networking; With 80 km/h, 120 km/h, 160 km/h, 200 km/h channel simulator	PASS
20 MHz Inter-frequency Downlink Throughput Test	Inter-frequency networking; With 80 km/h,120 km/h, 160 km/h, 200 km/h channel simulator and switchover simulator;	PASS

(*continued*)

(*continued*)

Projects	Index	Results
40 MHz Co-frequency Uplink Throughput Test	Co-frequency networking; With 80 km/h, 120 km/h,160 km/h, 200 km/h channel simulator and switchover simulator;	PASS
40 MHz Co-frequency Downlink Throughput Test	Co-frequency networking; With 80 km/h, 120 km/h,160 km/h, 200 km/h channel simulator and switchover simulator;	PASS
40 MHz Switching Uplink Throughput Test	Co-frequency networking; No Channel Simulator; With switch simulator; Simulation of leaky cable and waveguide scenarios with no Doppler effect	PASS
40 MHz Switching Downlink Throughput Test	Co-frequency networking; No Channel Simulator; With switch simulator; Simulation of leaky cable and waveguide scenarios with no Doppler effect	PASS
80 MHz Switching Uplink Throughput Test	Co-frequency networking; No Channel Simulator; With switch simulator; Simulation of leaky cable and waveguide scenarios with no Doppler effect	PASS
80 MHz Switching Downlink Throughput Test	Co-frequency networking; No Channel Simulator; With switch simulator; Simulation of leaky cable and waveguide scenarios with no Doppler effect	PASS

5 Conclusion

The LTE-U vehicle-to-ground communication system can meet the needs of urban rail transit comprehensive carrier CBTC, CCTV, PIS, emergency text and train operation status information services. In particular, the wide bandwidth and high throughput of the LTE-U system is a viable solution to meet the capacity requirements of PIS and CCTV in the future.

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Conflicts of Interest. The authors declare that they have no conflicts of interest to report regarding the present study.

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