QoS-Guaranteed Resource Scheduling For Broadband Communication In High-Speed Trains

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***Abstract*—In recent years, with the rapid development of high-speed train construction and operation, how to provide broadband mobile communication for high-speed train and meet the passengers' communication demand is receiving more attention. In order to fulfill the requirement of passengers, heterogeneous convergence network architecture is used for high-speed train communication system, where TD-LTE system is used to realize the train-ground communication and the vehicle-mounted communication supports various current communication modes (e.g. 2G, 3G and WiFi). This paper proposes a QoS-guaranteed resource scheduling algorithm and a railway resource grab mechanism in high-speed environment, which can ensure the Quality of Service (QoS) for users and the timely transmission for railway signal in this heterogeneous network. The proposal implements virtual resource mapping mechanism for 2G/3G/WiFi to TD-LTE and distributes the service waiting time according to the real-time demand of different service type. The simulation results show that the proposed algorithm vastly increases the throughput and reduces the packet loss ratio. Meanwhile, it improves the effectiveness and fairness of application service transmission.**

Keywords—QoS-guaranteed; resource allocation; high-speed; convergence network; broadcast and broadband communication

I. INTRODUCTION

With the development of economic society and rapid popularization of wireless portable terminal, users' communication requirement is more and more intensive [1]. The rapid development of high-speed railway makes wireless communication in high-speed mobile environment become more frequent. Instead of using fixed and low-speed pattern to access the communication network [2], people urgently want to contact with the world using the mobile terminal anytime in high-speed environment. The forthcoming high-speed communications are expected to provide a variety of services, from high-quality voice to high-definition videos. Furthermore, another application for the high-speed mobile broadband communication on trains is railway signal transmission. For the first time, the future mobile communication should provide low delay and high data rate. Broadband Internet access on trains can enhance the safety of the train by allowing an operation center to monitor train-related data in real time. Internet access on trains is already available today in the world. However the current railway communication system, such as GSM-R, can't meet the communication demand very well. TD-LTE (TD-SCDMA Long Term Evolution) system can meet the requirement and overcome the scarcity of frequency spectrum [3-5]. Through the special design, TD-LTE system would support high-speed data transmission services in the high mobility environment, which the speed of movement can reach more than 350 km/h.

TD-LTE system is used for the train-ground communication. The vehicle-mounted communication supports various current communication modes (e.g. 2G, 3G and WiFi), including the mainstream modes of three operators (e.g. China Mobile, China Unicom, and China Telecom) [6-7]. In order to fulfill the QoS requirement of passengers, increase spectrum efficiency, and balance between system throughput and users' fairness, rational resource management and schedule is an important and urgent problem to be resolved.

Compared with regular cellular mobile communication, high-speed railway communication environment becomes more complex and lots of questions need to be solved, such as serious channel distortion, enormous penetration loss, severe Doppler frequency shift, frequent cell handover, difficult resource management and so on. Resource allocation algorithm plays a key role in QoS guarantee，so the following two questions are addressed in this paper. First, QCI priority of users' data can't be considered in regular cellular mobile communication. Second, when railway signal is transmitted, all the users' data will be interrupted, which deteriorate users' experience.

It is the key to the question on how to allocate bandwidth rationally based on QoS guarantee for user equipments (UEs), mobile relay gateway and eNodeB (eNB) transmission. Conventional scheduling algorithms include round robin (RR) algorithm, max carrier to interference (Max C/I) algorithm and proportional fairness (PF) algorithm, etc.

This paper proposes a QoS-guaranteed resource scheduling algorithm based on virtual resource mapping in high-speed convergence networks. In this algorithm, we use multi-level scheduling to allocate RB to UEs with different communication modes, considering priority levels, SINR

(Signal to Interference plus Noise Ratio), QCI (QoS Class Indication) and latency of different services. Meanwhile, the proposed algorithm includes Virtual Resource Mapping Mechanism and Railway Signal Resource Grab Mechanism. Thus the proposed algorithm not only ensures the railway signal transmitting regularly and higher-level service transmits preferentially, but also considers the fairness principle for lower-level service.

The remainder of this paper is organized as follows. Section II introduces the system architecture and reviews the related works about resource scheduling algorithms. Section III describes the virtual resource mapping mechanism and railway resource grab mechanism. Section IV is the results and analysis of the simulation about packet loss rate and system throughput. Section V concludes this paper.

II. RELATED WORKS

A. System Architecture

In the specially designed heterogeneous convergence network structure with many communication modes co-existing for high-speed railway communication scenario is as follow. In the vehicle-mounted system, there is a 2G, 3G Femto and a WiFi AP in each train carriage. Users could access the network via 2G, 3G or WiFi. TD-LTE system is used for the train-ground communication. Femto and WiFi AP in each carriage are connected with Mobile Relay Gateway via wires. Mobile Relay Gateway converts 2G, 3G and WiFi data into TD-LTE data and transmits them to the two Mobile Stations which are installed in the train at both ends. The Mobile Station sends the data to ground eNB via TD-LTE system. The scenario is shown in Fig.1.

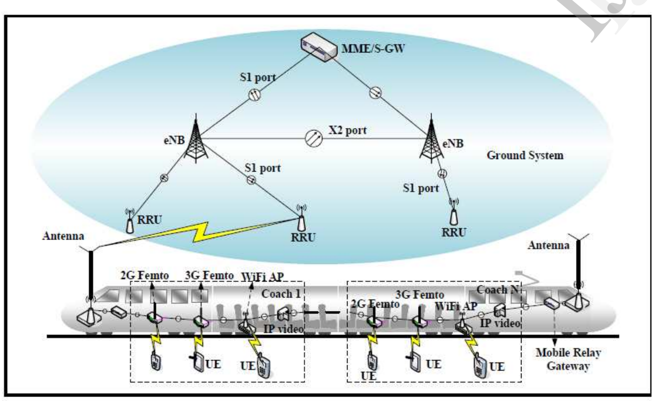

Fig.1.System Application Scenario

User data is transmitted to mobile relay gateway. In mobile relay gateway, this data will enter into scheduling queues and wait for QoS mapping. Idle TD-LTE resources are gathered and ready at the same time.

Then according to the traffic and idle resources, 2G/3G/WiFi data will be transferred into TD-LTE format in mobile relay gateway. At the end, TD-LTE data which has been allocated resources will be sent to ground eNB. The proposed resource scheduling algorithm is mostly used in MAC layer of 2G/3G/WiFi nodes port and TD-LTE port.

The system structure of the heterogeneous network is shown in Fig.2 and data flow in mobile relay gateway is shown in Fig.3.

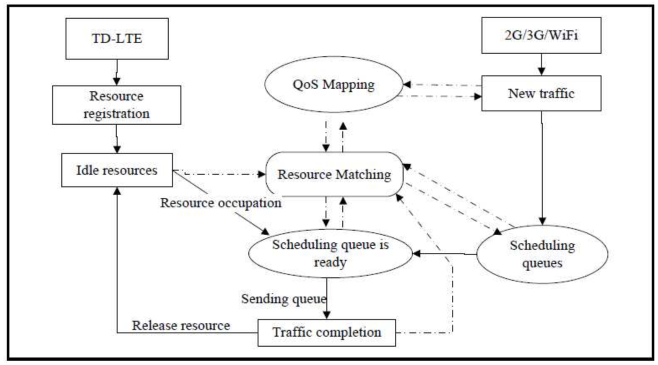

Fig.2.System Structure in Heterogeneous Network

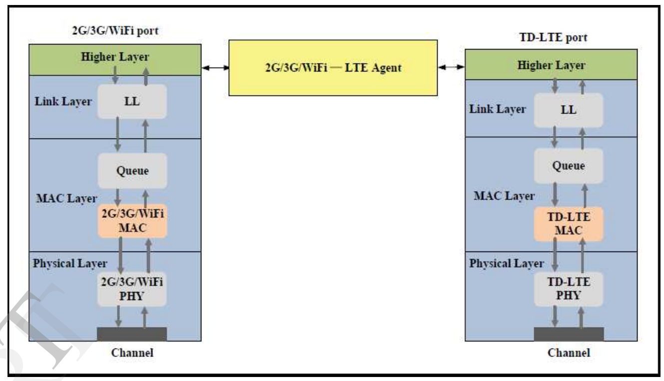

Fig.3.Data Flow in Mobile Relay Gateway

B. Conventional Resource Scheduling Algorithms

In RR algorithm [8], eNB calls each UE circularly and ensures all users could communication with equal probability. However, UE will get resource blocks (RBs) even if the channel condition is very poor, which will cause low throughput rate.

In Max C/I algorithm [9], eNB always calls the UEs, which have the best channel condition, and distributes resources to them. So the UE, which is close to the eNB or has good channel condition, will always have RBs to transmit, but the UE which is far from eNB will have less opportunity to get resource. It cannot guarantee the fairness of all UEs.

In PF algorithm [10], the channel condition in current and throughput in the past are considered to seek the balance between system throughput and fairness. But it brings large scheduling latency and enormous processing overheads to the eNB. If appearing high load, it is also cannot guarantee the QoS.

M-LWDF (Modified Largest Weighted Delay First) algorithm [11] considers the wireless channel condition, service fairness and latency. But this algorithm ignores the service priority and cannot guarantee the QoS requirement in TD-LTE system.

III. RESOURCE SCHEDULING ALGORITHM

A. Virtual Resource Mapping Mechanism

In the above vehicle-mounted communication sub-system, each train carriage has its own 2G, 3G and WiFi access point. In order to ensure QoS of multi-mode communication and convert date from different format into TD-LTE format conveniently, the design of resource buffer pool is based on the different communication modes and different service types for resource allocation. Every data packet will find the appropriate queue according to the data type. Before being transmitted to the Mobile Relay Gateway, data packets will enter into corresponding service queue of the buffer pool firstly. When packet enters into corresponding queue, the time is marked into the packet parameter for delay computation. The Virtual Resource Mapping Mechanism is designed in accordance with real-time requirement of different service type and let the high real-time data format transformation preferentially. The buffer pool form is shown in Fig.4.

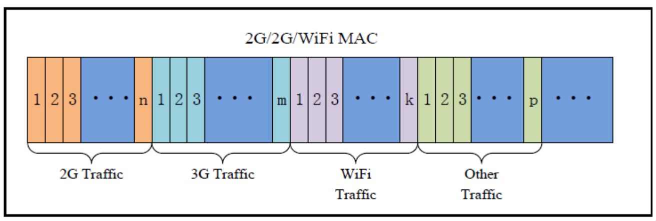

Fig.4.Buffer Pool for 2G/3G/WiFi Resource

Each queue header of the buffer pool updates the parameters periodically, including queue length, latency demand, SINR and packet loss rate, etc. If these parameters are updated, the Mobile Relay Gateway will update and save them into Virtual Resource Mapping Table, which is shown in Table I. In each Transmission Time Interval (TTI), the data packet will be mapped and preprocessed firstly according to different communication mode and different service type, and then Mobile Relay Gateway will allocate and schedule resource for the queue according to the Virtual Resource Mapping Table.

Table I. Virtual Resource Mapping Table

Service mode (2G/3G/WiFi)	Queue service type	queue Length	Latency	SINR	Packet loss rate	QCI

About the resource scheduling algorithm for the heterogeneous network system with multi communication modes coexisting, the main definitions include:

Definition 1: The QCI priority parameter named Q factor $\exp\left(\frac{1}{Q_{QCI}}\right)$ is defined as the new QCI level parameter. In order to improve the QCI priority weight in resource scheduling algorithm, exponential form is used here to make sure that Q factor is a decreasing and non-negative function. The QCI priority of the packet in the heterogeneous system is defined in Table II.

QCI is one of the most important QoS parameters in TD-LTE bearing. It representatives which service data the TD-LTE system should service and each service type only has one QCI. The priority is used to distinguish service type for the same UE and different UEs.

Table .II.QCI Priority In Heterogeneous Network System

QCI	Priority	Latency	Loss Rate	3G Traffic	2G Traffic	WiFi Traffic
1	2	100ms	10^{-2}	Conversation (Voice)	Voice	
2	4	150ms	10^{-3}	Stream		
3	3	50ms	10^{-3}	Conversation (Real-time Game)		
4	5	300ms	10^{-6}	Interactive		
5	1	100ms	10^{-6}	Conversation and IMS Signaling	Short Message	
6	7	100ms	10^{-3}	Interactive	GPRS	
7	6	300ms	10^{-6}	Interactive (E-mail and Internet Surfing)		Mobile Internet Service
8	8					
9	9					

Definition 2: The latency factor is defined that the current latency value of the data packet. It is changed dynamically during packet transmission process. This factor makes sure the data could be scheduled within latency requirement.

Definition 3: The scheduling function is shown as follows:

$$P_{i,k} = argmax_{i,k}\left\{-\log\left(\delta_{i,k,QCI}\right)\cdot\exp\left(\frac{1}{Q_{i,k,QCI}}\right)\cdot SNR_{i,k}\cdot\left(\frac{\lambda_{i,k}(t)}{\lambda_{i,k}}+\frac{Q_{i,k}(t)}{Q_{i,k}}\right)\right\}$$

$$1 \le i \le N \quad 1 \le k \le M \tag{1}$$

Where N is the number of service modes, i is the index of service modes, M is the number of queues which indicate the service type in mode i. k is the index of queue in mode. $\delta_{i,k}$ is the loss rate of packet. $Q_{i,k,QCI}$ is the QCI priority. $SINR_{i,k}$ is the SINR of data transmission within carriages. $\lambda_{i,k}(t)$ is the latency value at time t. $\lambda_{i,k}$ is the packet latency requirement. $Q_{i,k}(t)$ is the length of queue k in mode i at time t. $Q_{i,k}$ is the maximum queue length.

In the equation (1), the data packet priority $P_{i,k}$ of 2G/3G/WiFi resource allocation in the buffer pool is considered. It is used for calculating the priorities of all data packets in the 2G/3G/WiFi resource allocation in one TTI. When data packets reach the corresponding queues in 2G/3G/WiFi buffer pool, the Mobile Relay Gateway will check these queues, save corresponding parameters in the Virtual Resource Mapping Table and calculate the packet priority using equation (1). The packet which has larger $P_{i,k}$ value means it has higher priority. The Mobile Relay Gateway will select the high priority packet to convert into TD-LTE format packet and finish the first resource schedule.

In each TTI, the Mobile Relay Gateway updates the queue parameters periodically and saves the parameters into Virtual Resource Mapping Table. Then it calculates the weights $P_{i,k}$ of all packets in the buffer pool using equation (1). The Mobile Relay Gateway orders this weight and selects the packet from the highest weight to the lowest to convert into TD-LTE format using LTE Converting Block. If the latency of a packet exceeds the demand, the packet will be dropped. Then the Mobile Relay Gateway will inform the UE to retransmit the packet. The packet also will be dropped after three times of retransmission. In this way, different modes and different service data can be scheduled considering their QCI priority weight and latency requirement.

B. Railway Resource Grab Mechanism

LTE Converting Block of Mobile Relay Gateway acquires data from the buffer pool according to the virtual mapping table, and then put them into the TD-LTE transmission queue, which is classified by QCI priority in TD-LTE specification. The data in TD-LTE transmission queues will sort again according to different QoS needs. The service queue is shown in Fig.5.

Service Class properties	Service Class 1	……	Service Class 9
QCI Priority	High	⟶	Low

Fig.5.QCI priority for TD-LTE service

In the proposed mechanism, the railway signaling weight R is the key point and specially used for high-speed railway scenario, which is defined as $\frac{1}{I_0 - I_i(t)}$. In the expression of R, I_0 is a constant, whose value is 1, $I_i(t)$ is the flag indicating that whether it is railway signaling at time t. When $I_i(t)=0$, which indicates this service is not railway signaling, the value of railway signaling weight R is 1; when $I_i(t)=1$, which indicates this service is railway signaling, the R is positive infinite, it is indicates that the data has the highest priority to obtain resources for transmission.

So in the Railway Resource Grab Mechanism, the equation for TD-LTE resource scheduling algorithm is shown as follows:

$$i^* = \arg max_i \left\{ R \cdot \frac{\lambda_i(t)}{\lambda_i} \cdot \left[\exp\left(\frac{1}{Q_{i,QCI}}\right) + \exp\left(\frac{1}{Q_{i,coach}}\right) \right] \cdot H \right\} \quad (2)$$

Where R is the railway signaling factor, $\lambda_i(t)$ is the latency of data packet in queue at time t, λ_i is the latency requirement of packet, $Q_{i,QCI}$ is the QCI priority factor, $Q_{i,coach}$ is the coach priority in the train, H is the retransmission weight.

In equation (2), the TD-LTE packet priority i^* will be calculated and the railway signaling weight R is emphasized to fit the high-speed railway scene. When TD-LTE data packet enters into its queue, the Mobile Relay Gateway calculates priority i^*, the TD-LTE packet which has larger i^* will has higher probability to transmit. If the R is positive infinity, which means this packet is railway signaling and its priority value i^* is positive infinity, it will be allocated resource block promptly and transmitted in this TTI. If not, the packet priority value will be calculated using parameters in equation (2).

The priority value i^* also consider User packet's QCI priority and latency needs in the TD-LTE transmission queues. Instead of being interrupted as in conventional schemes, the user who has higher QCI priority and latency requirement would calculate i^*. High value packet has opportunity to allocate the free resource block, which is not used for railway signaling packet, and communicate at the same TTI when railway signaling is transmitting. It can improve the user's experience in great extend. This mechanism guarantees information interaction using for normal operation in high-speed railway system and has high practical applicability.

In addition to latency requirement and QCI priority, some factors will also be considered in the TD-LTE packet priority value i^*, such as coach priority factor $Q_{i,coach}$. Because railway mobile station schedules the Mobile Relay Gateways according to the priority of gateways, so the coach priority factor is defined to indicate the priority level of each coach. The higher priority level has higher coach weight and data of user who is in the coach which has higher priority (e.g. first class coach) would be transmitted to ground eNB preferentially.

In each transmission time interval (TTI), the Mobile Relay Gateway will calculate the weight i^* of every data packet firstly using equation (2). Also here we consider the retransmission scenario and the procedure is the same with resource scheduling in 2G, 3G and WiFi resource. This algorithm guarantees routinely transmission in high-speed railway system and improves the data transmission efficiency. After the TD-LTE scheduling, the data will be transmitted to ground eNB.

IV. SIMULATION ANALYSIS AND DISCUSSION

A. Simulation scene description

For the convenience of analysis, this section makes some assumptions as follow:

There are four users with different service types, and each user generates one type of service data. Service types are randomly generated and include 3G voice traffic, 3G video traffic, 2G SMS traffic and WiFi Internet traffic. The railway signaling traffic is generated at 10 times interval compared with the other services. First packet generating block to is used to generate five service traffics. The traffic data of 2G/3G/WiFi is processed in first scheduling block which using Virtual Resource Mapping Mechanism to calculate their priority weights and the data packets are sorted in order of priority. After scheduling in first scheduling block, the data will be sent into LTE Converting Block which switching 2G/3G/WiFi data into TD-LTE format and some TD-LTE parameters are added into data structure here. Then the TD-LTE data is processed in second scheduling block which dispose the data considering railway signal flag, latency and QCI index. At last the scheduled data will be sent to ground system via LTE transmission block. UE transmits one data packet after each successfully accessing.

Here RR algorithm is taken as traditional algorithm in this simulation. The process is circulated in 10000, 40000, 160000 and 640000 times so that we can get the accurate simulation results.

B. Analysis of simulation results

Fig. 6 to Fig.9 show the plots of BER v/s E_b / N_0 ; where the modulation scheme used in TD-SCDMA is 8PSK and Spreading Factor(SF)=1.The red plot shows the ideal BER plot where as the blue plot is the BER plot obtained as the result of the simulation.

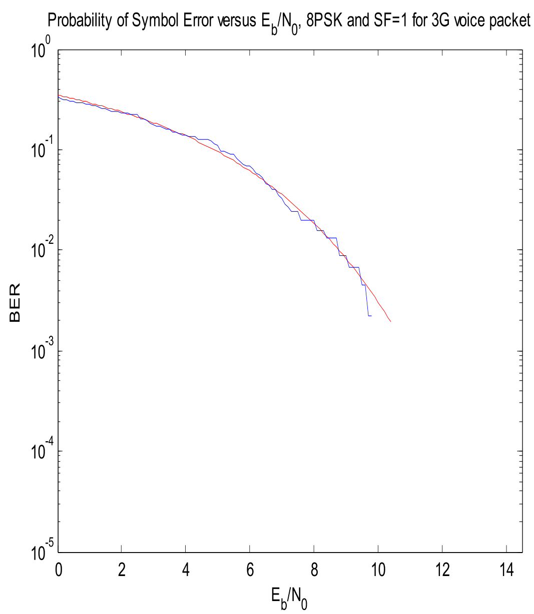

Fig.6 BER vs SNR of 3G voice traffic

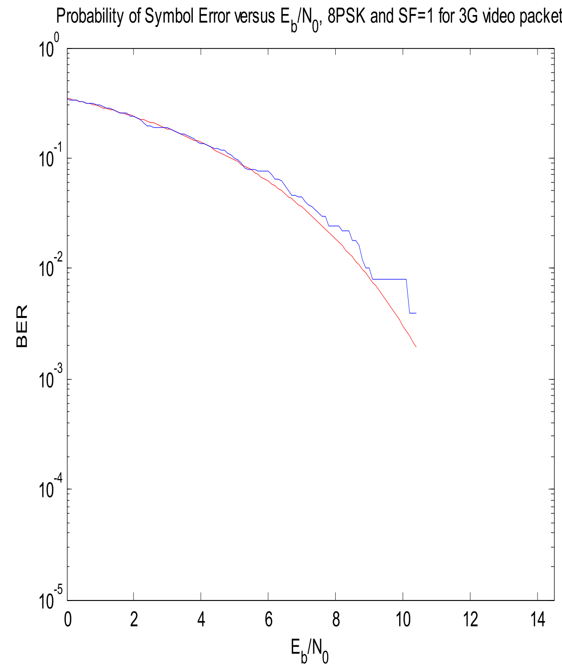

Fig.7 BER vs SNR of 3G video traffic

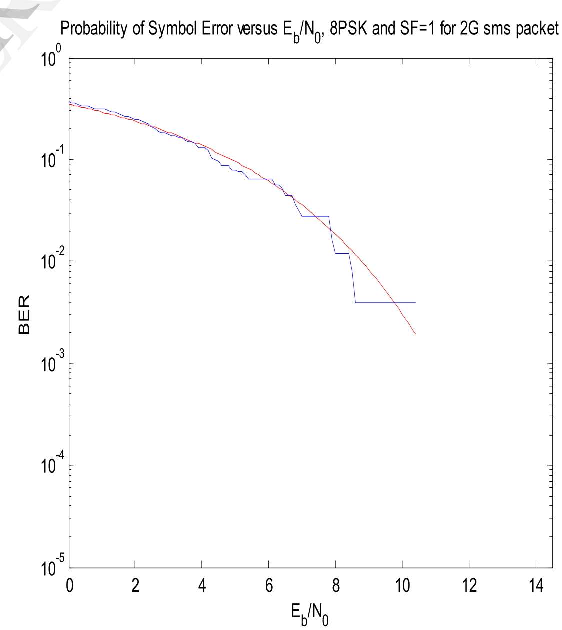

Fig.8 BER vs SNR of 2G SMS traffic

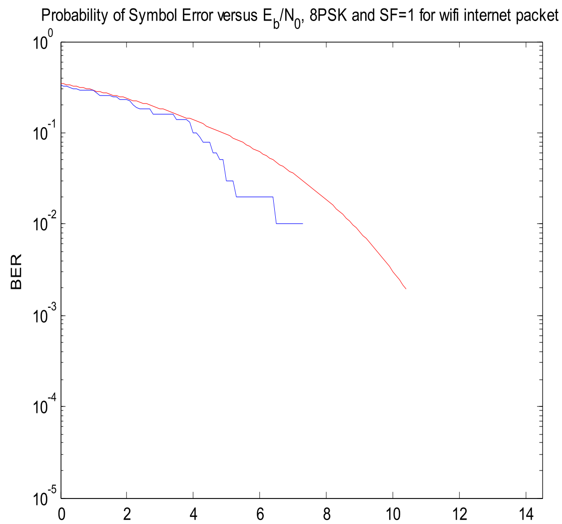

Fig.9 BER vs SNR of WiFi Internet traffic

The simulation results of system throughput are shown in Fig.10, where the red line represent for the throughput using traditional method based on RR algorithm, while the blue line shows the throughput after using the QoS-guaranteed resource scheduling algorithm. It can be seen from the simulation results that the proposed algorithm contributes better to ensure the system throughput and improve network performance.

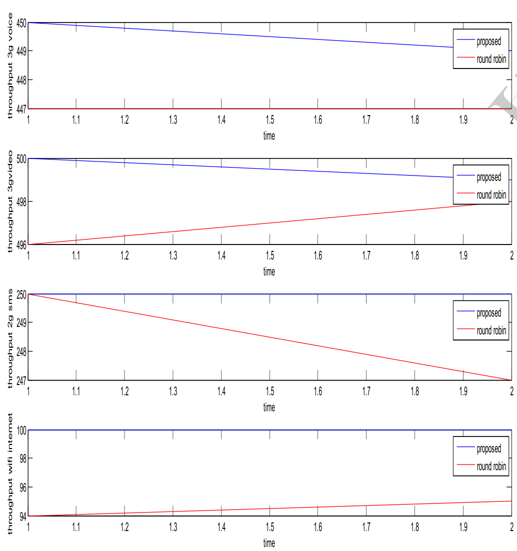

Fig.10.Performance comparisons with respect to throughput of four services.

Service packet loss ratio indicates service guaranteed transmission. The accumulated service packet loss ratio of the proposed and RR algorithm are illustrated in Fig.11 and Fig.12. It can be seen from the simulation results, for the other services, the proposed method has reduced packet loss ratio than the traditional algorithm for resoure allocation.

Fig.12 compares the performance of the proposed algorithm and traditional RR algorithm with respect to the accumulated packet loss rate. It can be seen from the simulation result that, for the railway signaling, this mechanism has reduced packet loss ratio; because this mechanism always put railway signaling as infinite priority, send out firstly and considers QoS of user as the same time.

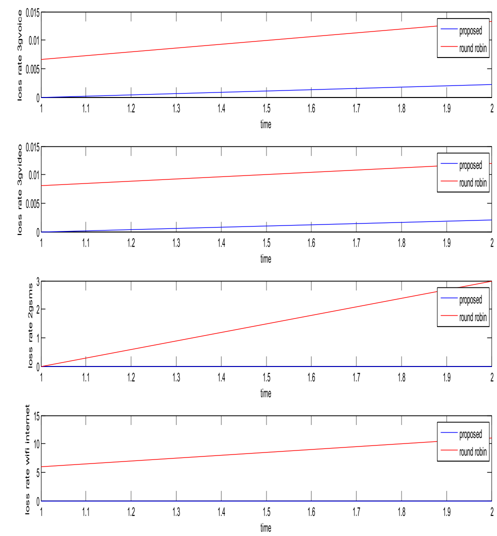

Fig.11.Performance comparisons with respect to accumulated packet loss ratio of four services

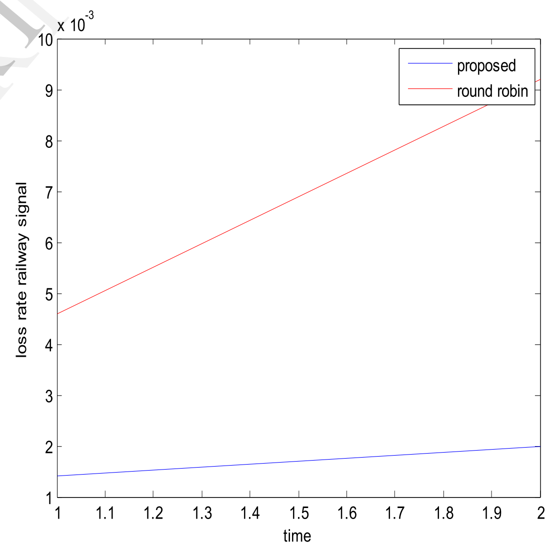

Fig12. Performance comparisons with respect to accumulated packet loss ratio of railway signaling.

V. CONCLUSIONS

In this work, a QoS-guaranteed resource scheduling algorithm is proposed for the heterogeneous convergence network with many communication modes coexisting in high-speed scenario. This algorithm uses Virtual Resource Mapping Mechanism which considers different priority level of businesses, SINR, QCI and latency in vehicle-mounted communication subsystem to guarantee the QoS. Meanwhile, railway signaling resource grab mechanism is realized in TD-LTE train-ground communication system. This algorithm can most adequately improve the user experience and transmission efficiency. The simulation results indicate that the proposed algorithm for resource allocation has better system throughput and lower packet loss ratio for each service. Thus this algorithm can be utilized to manage the resource very efficiently and reliably in a high-speed environment. More over this method also gives very high priority to the safety of the passengers by assigning infinite priority to the railway signals without deteriorating the user's communication experiences. The simulation results confirm that the proposed algorithm outperforms the traditional algorithms with respect to system throughput and accumulated packet loss rate.

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