Research on Multi-frequency Network Optimization Strategy for LTE-R System in High-Speed Railway Scenario

Li Ling[1], Wang Shuangyou[1], Zhao Hongwei[2], Hou Jiayi[3]
[1]School of Software, Handan College, Handan 056000, China;
[2]China Mobile Communications Group Hebei Co., Ltd. Handan Branch, Handan 056000, China;
[3]Department of Intelligent Manufacturing, Jinan Technician College, Handan 056000, China

Abstract: LTE-Railway (LTE-R) is a 4th-generation wireless communication technology that provides voice, data, and video services through LTE, optimized for the railway environment. The number of LTE-R users continues to rise, and traditional single F network coverage cannot meet the requirement of users. Moreover, the speed perception of high-speed rail users becomes worse. The optimization of LTE private network of high-speed rail is proposed through F+D dual-band network, layering between VOLTE and data service, public network user moving out, high-speed railway user migration back, downlink Doppler shift optimization, FDD blending networking and other aspects jointly. This method is meaningful for meeting the service growth of future high-speed railway user group and enhances the LTE network rate perception of high-speed railway users.

Keywords: LTE-R, High-Speed Railway; Multi-Band Network; FDD; Optimization

1. Introduction

High-speed rail LTE private network is mainly used to cover high-speed rail lines, and the target user group is high-speed rail passengers [1]. In the early stage of high-speed rail LTE private network construction, the high-speed rail has fewer trips and fewer 4G users, so the single F-band network can meet the needs of data service coverage and capacity [2]. However, with the rapid growth of 4G users and the increase in the number of people who choose high-speed rail travel, the problem of capacity limitation of single F network becomes more and more prominent, and the customer rate perception becomes worse.

2. Research Status of Development and Application of High-Speed Railway Private Network

As an important infrastructure of a country, railway plays an important role in the development of the national economy. High-speed railway is fast, efficient, environmentally friendly, safe and comfortable. It is crucial to accelerate the information-based and intelligent development of high-speed rail. The so-called high-speed railway (HSR) private network is a mobile communication network that provides dedicated wireless communication services for HSR operation management or HSR passenger groups, which is mainly deployed and applied around the special scenario of high-speed railway.

At present, 4G networks are still the main force in the field of wireless communication. In the 4G era, many scholars have deeply discussed and analyzed the wireless network communication coverage and application technology in the high-speed rail scenario. From the perspective of coverage, network optimization and mobility management of 4G high-speed rail private networks, the existing research discusses the coverage characteristics, network capacity and optimization of different service perception, the improvement of switching performance and the solution of Doppler frequency deviation problem of TDD-LTE and FDD-LTE networks in different modes [3, 4].

Aiming at the main problems encountered in the deployment of high-speed railway private network, Yan [5] analyzes the problems of millimeter wave communications in network coverage robustness, mobility support capability, link stability and management. LTE-R not only controls the transmission of train data, but is also expected to provide passenger services such as Internet access and high-quality mobile video broadcasting [6, 7, 8]. The increasing demand for high-speed railway wireless communications leads to significant attention on the study of radio resource management (RRM), [9] provides an overview on the key issues that arise in the RRM design for HSR wireless communications, including the communication systems, channel models and characteristics. Jointly considering the quality-of-service requirements and dynamic characteristics of HSR wireless communications, the resource management problem is formulated as a stochastic optimization problem in [10], which a cross-layer optimization framework is developed for facilitating the design and optimization of dynamic resource management. In order to better describe the non-stationary properties of such channels, the concept of active scatterer region as an improvement for geometry-based stochastic channel models for HSR is proposed [11]. For lower download speed and poor user perception brought by conventional single-band high-speed railway TD-LTE private network, a method of F1 + F2 dual-band networking for building TD-LTE high-speed railway private network was proposed by [12] to improved download speed and user perception, on which CA technology and an improved PF algorithm are also used. In response to the fast fading in LTE, [13] proposed an air interface technology against Doppler frequency shift. Besides, a mobile MPLS soft handover technology was proposed to address the LTE hard handover gap so as to achieve vehicle-wayside broadband communication under the environment of high-speed railway.

Besides the existing research efforts, there are still some challenges and open research issues on RRM design for HSR private network [5]. The network coverage in the HSR scene has its special characteristics, such as fast moving speed of HSR vehicles, strong compartment closure, complex terrain, and strong randomness of traffic changes. Higher wireless carrier frequency band, greater propagation path loss, penetration loss and more obvious Doppler effect bring greater challenges to the planning, design and optimization of HSR private network.

According to the change of the maximum number of users of RRC connection in the community along a section of Beijing-Guangzhou high-speed Railway from January to June 2016, the growth rate of high-speed rail users is about 6%, and the maximum number of users of RRC connection in the community has reached about 400 in June 2016, which has seriously affected customer perception [14]. Therefore, from the perspective of improving customer rate perception, this paper proposes the strategy of optimizing TDD F+D dual-band network and superimposing FDD network for fusion network.

3. Optimization of F+D Dual-Band Network of High-Speed Railway

In the early stage of high-speed rail 4G network construction, there are relatively few 4G users, the single F-band upgrade is relatively fast, the deployment is convenient, the initial investment cost is low, and the coverage advantage of F-band can be well played to ensure the continuous coverage of high-speed rail lines [15]. However, with the increase of high-speed rail users, the single F-band network can no longer meet the growing needs of users. Therefore, F+D dual-band networking [16] is proposed to solve the capacity problem of high-speed rail. The new D-band has a wide spectrum and strong scalability, and the subsequent expansion only requires software upgrade, which is relatively convenient, which can meet the long-term growth demand of the number of users, and greatly diverts the users of F-band, so as to achieve a balanced service and improve the throughput rate of high-speed rail users. The main optimization measures of dual-band network are described below.

3.1 Parameter Strategy Optimization

3.1.1 The Adjacent Area Configuration Strategy

The adjacent area configuration in the shape of ladder is adopted for the purpose of improving the perception of 4G users of high-speed rail, simplifying the relationship between adjacent areas of high-speed rail, and improving the measurement accuracy and reliability of adjacent areas, as shown in Figure 1.

(a) Intra-cell: The bidirectional adjacent relationship is added to cells F and D to enable the load balancing switch.

(b) Inter-cell: The bidirectional adjacent relationship is added to cell F to enable overlay-based A3 switching.

(c) Inter-cell: The bidirectional adjacent relationship is added to cell D to enable overlay-based A3 switching.
(d) Inter-cell: F and D cells do not add adjacent relations to each other.
(e) High-speed rail station: The bidirectional adjacent relationship is added between the public waiting room network and private F+D network to ensure the uniqueness of the entrance.

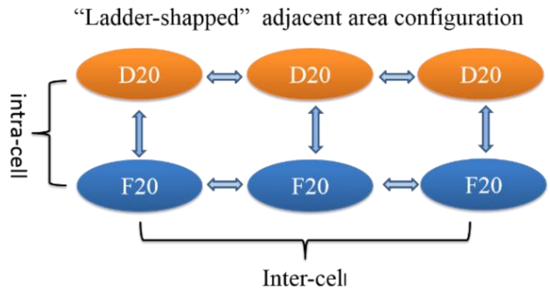

Figure 1. Schematic Diagram of the Neighborhood Configuration Strategy

3.1.2 Parameter Strategy

Through qualitative research, the types of handover events of inter-city and intra-city private network connection are determined, and the parameters of handover and load balancing are scientifically calibrated through the quantitative analysis of massive test data [17] and network management data. As shown in Figure 2.

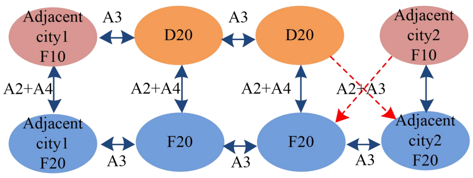

Figure 2. Neighborhood Switching Strategy

(a) Intra-cell: F and D cells adopt A4 switching based on coverage of different frequency.
(b) Inter-cell: F and F cells, D and D cells adopt A3 switching based on coverage of the same frequency.
(c) Intra-provincial localities: F and F cells, D and D cells adopt A3 switching based on coverage of the same frequency.
(d) Inter-provincial localities: F and D cells adopt A3 switching based on coverage of different frequency.

3.2 Application of New Network Features

3.2.1 High-speed User Migration Back

High-speed rail users switch quickly on the public network. The high-speed and low-speed users on the public network are distinguished based on the switching frequency, so that the high-speed users are redirected back to the private network, thus improving the user experience of the high-speed railway private network. See Figure 3 for details.

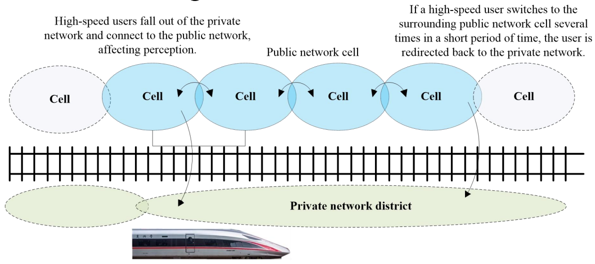

Figure 3. Schematic of the High-Speed User Migration Characteristics

3.2.2 Low-speed User Migration Out

In high-speed railway private network, UE moving speed is identified based on Doppler frequency shift. For high-speed users in the private network, they need to reside in the private network; For low-speed users in the private network, they need to switch back to the public network to reduce the load on the private network [18]. See Figure 4 for details.

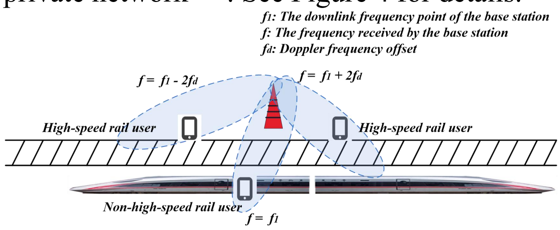

Figure 4. Schematic of the Low-Speed User Emigration Feature

3.2.3 Downward Correction Characteristics

When sending data, the base station pre-corrects the downlink data according to the uplink Doppler frequency offset received by each physical cell [19], thereby reducing the frequency offset of users in the edge area and improving the downlink rate of such users. The Doppler frequency shift [20] is calculated as follows:

$$f_d = \frac{f}{c} \times v \times cos\theta$$

Where,
v——Speed of vehicle,
c——Speed of Light,
f——Operating frequency.

The relation between Doppler frequency offset and terminal distance is shown in Figure 5.

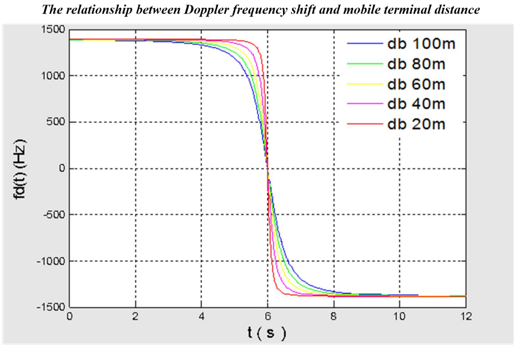

Figure 5. Relation between Doppler Frequency Offset and Terminal Distance

When the high-speed rail user is in the center position of the pole, the terminal will track the positive and negative frequency offset from the two sectors of the device at the same time, resulting in error correction and affecting the terminal downlink speed.

At present, some manufacturers have further improved the downlink pre-correction algorithm, in order to solve the problem of positive and negative frequency offset between adjacent poles in the cell, and do not do downlink pre-correction in the switch zone area between adjacent cells. The overlap and overlaying of small station spacing scenes are serious, which causes the problem of unexpected effect of downlink pre-correction in the switching zone. According to the characteristics of the small station spacing scene, the downlink pre-correction algorithm is optimized to ensure the stable and normal switching index.

3.2.4 Uplink Spatial Division Multiplexing

The uplink spatial division multiplexing function in high-speed rail scenarios mainly adopts the mode of spatial multiplexing [21], see in Fig.6. Users that meet the isolation requirements use the same upstream time-frequency resources. This improves the cell uplink throughput and user uplink perception rate in high-load scenarios.

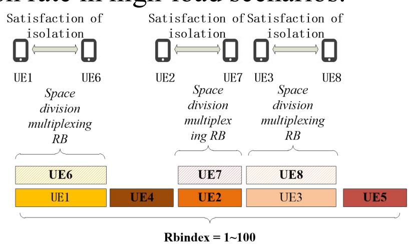

Figure 6. Schematic diagram of uplink space division multiplexing

3.2.5 Power Control and Switching Optimization

Aiming at the characteristics of high-speed railway scene, such as fast moving speed, large signal fluctuation, and low reference degree of historical demodulation information, the power control policy should refer to the current signal as much as possible, reduce the influence of historical information, raise the UE transmit power, raise the selection level, maintain a moderate initial block error rate level, and obtain the uplink actual spectrum power and uplink perception rate.

Switching optimization: When the high-speed railway passes through the switching belt, the interference of the switching belt is suppressed by limiting the switching source cell and the up-down sub-frame scheduling, thus to alleviate the problem of multiple reconstruction times caused by the switching failure and the wireless link failure.

3.2.6 Speed Recognition Scheduling

In the high-speed cell, the Doppler shift of UE upstream signals is measured per second and the user movement speed is estimated to distinguish high-speed users from low-speed users. The priority scheduling function of high-speed users is realized by increasing the priority of Non-GBR initial transmission scheduling for high-speed users and decreasing the priority of Non-GBR initial transmission scheduling for low-speed users.

3.3 Precise RF Optimization

Overlapping coverage band: Reasonable overlapping coverage is the basis for service continuity. If the overlapping coverage band is too small, the switchover fails, and if the overlapping coverage band is too large, interference and Ping-Pong switchover will be increased. Therefore, reasonable overlapping coverage optimization is particularly important in RF optimization.

Theoretical calculation: Overlap distance = 2 × (Switching hysteresis corresponding distance + Switching measuring distance (128ms) + Switch execution time (100ms)), in high-speed railway scenarios, you are advised to properly set overlapping overlay belts based on the distance between stations.

Antenna incidence Angle: Different incidence angles correspond to different penetration losses. Actual tests show that as the incidence Angle becomes smaller, the penetration losses continue to increase. Therefore, a reasonable antenna feeder azimuth is the basis for ensuring good coverage. In the optimization process, the antenna should be covered as close as possible to reduce signal attenuation. In high-speed railway scenarios, it is recommended to set the antenna incidence Angle reasonably based on the station spacing and station gauge.

3.4 VOLTE Voice Optimization

3.4.1 VOLTE User Priority Access

Reserve certain resources to preferentially connect VOLTE users when cell access specifications are limited, ensuring voice service experience in crowded scenarios.

The base station reserves a certain number of user resources. When the number of access users in the cell is limited, the base station judges the users within the reserved number. If the QCII carrier is established after a few seconds of access, the user is judged as a voice user, and the access is maintained, then a data user (optional) can be excluded; otherwise the user is determined as a data user to be released [22].

3.4.2 IBLER Target Value of SINR Correction Algorithm for Voice Users

As the high-speed railway private network is dedicated to the private network, the base stations are distributed on both sides of the railway, and the station spacing has strict planning requirements, so the users are close to the base stations, and there are many near-point users. The SINR correction algorithm IBLER target value represents the SINR correction algorithm IBLER target value for the dynamic scheduling of voice users in the non-TTI Bundling state. The larger the parameter setting, the larger the SINR adjustment, and the larger the MCS selected. If the uplink IBLER target value is set to a smaller value, the uplink MCS of VOLTE users will select a smaller mode, the channel quality of near-point voice users will be better, and the VOLTE uplink packet loss rate will be lower (voice quality is better). The channel quality of medium and remote voice users is relatively poor, and the uplink RLC segment of packets increases, and the VOLTE uplink packet loss rate increases (voice quality decreases); Vice versa will have the opposite effect. In view of the fact that high-speed railway users are close to the base station (the distance between the station track is 75~150 meters, and the distance between the channel is 100~450 meters), and the channel quality is good, it is beneficial to improve the speech quality to reduce the value.

3.4.3 CCE Uplink and Downlink Ratio Optimization

High-speed rail scenarios have fast user movement speed, high signal penetration loss, and unstable signal. Semi-static scheduling and DRX are not suitable for high-speed rail scenarios, and high-speed rail scenarios have high burst instantaneous traffic, so different requirements are put forward for CCE scheduling.

Individual scenarios exist phenomenon of packet loss: The analysis shows that the uplink CCE congestion of the 3/8 sub-frame causes the uplink scheduling delay, resulting in packet loss. In TDD ratio 2, the protocol only supports the uplink scheduling indication of the 3/8 sub-frame, and the uplink control channel is more restricted than the downstream control channel. Therefore, change the ratio of upstream and downstream CCE resources to 10 to 1 to increase the proportion of upstream CCE resources. After the adjustment, the success rate of upstream CCE allocation was increased from 89% to 97%.

3.4.4 Precise Optimization of eSRVCC Scenarios based on Station Spacing

The triggering process of eSRVCC [23]is mainly divided into three steps: The measurement of different systems is started (A2), the measurement report of B2 is triggered, and the network side sends the switching execution command, as shown in Figure 7.

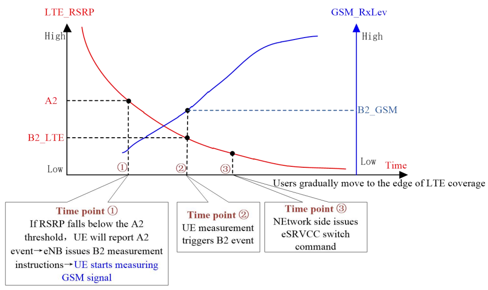

Figure 7. eSRVCC Trigger Process

Since the HSR user is moving at a high speed, the RSRP value received by the user may have rapidly decayed during the execution of the above three actions. The actual switching level has been reduced compared with the B2 switching trigger level, so a certain threshold advance should be considered when setting the eSRVCC threshold to resist the adverse effects caused by signal attenuation.

Take the switching threshold of eSRVCC as -117dBm (as shown in Figure 8), backtrack a switching delay (the experience value is 900ms), take the speed of 260km/h as an example, the distance of 900ms is 60 meters, and the switching threshold can be set to -115dBm when the signal attenuation of high-speed rail is equivalent to about 2dB in the fast decay scenario. Then backward measurement synchronization delay (including GSM signal measurement (theoretical value of 400ms), GSM cell synchronization (empirical value of 100ms) and local signal measurement time lag (128ms)), in the high-speed fast decay scenario equivalent to 1.8dB channel attenuation, then the start threshold can be set to -113dBm. Considering that the theoretical calculation is not ideal, under the actual signal fluctuation, it may be necessary to reserve time for the signal to reach the threshold, and a certain threshold value needs to be reserved, so the starting threshold is higher than -113dBm.

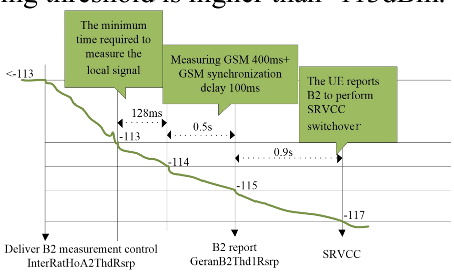

Figure 8. eSRVCC Switchover

3.4.5 Voice Priority Scheduling Policy

For lines with higher traffic load, it is recommended to schedule voice first. The scheduling priority sequence is: Control Signaling > BSR and SR Scheduling for VoIP services > SR Scheduling for Data services > BSR scheduling for data services. In scenarios where mixed data and voice services are overloaded, voice services can be scheduled preferentially to ensure voice quality.

4. FDD Overlay Networking Strategy for High-speed Rail

With reference to the experience of constructing advanced lines in high-speed rail private networks (such as the Beijing-Shanghai high-speed railway), in order to further ensure the coverage and capacity of high-speed rail, multi-standard and multi-frequency networking of high-speed rail has become the current trend. According to the current situation of mobile network, the DCS1800 is de-frequencized at 10MHz, which can be used for FDD planning. Using 1.8GHz for FDD construction can further improve the coverage and uplink awareness compared to the current 1.9 and 2.6GHz TDD networking.

4.1 Advantages of High-speed Rail FDD Networking

4.1.1 Distance of Coverage

In the case of meeting the continuous coverage requirements of sub-services, FDD uses the 1.8GHz band for LTE networking, covering a distance of about 700 meters. The network coverage distance of 2.6GHz band is about 470 meters. 1.8 GHz frequency band range of about 2.6 GHz frequency band of 1.5 times.

4.1.2 Penetration Loss

High-speed railway cars are fully enclosed and have high penetration loss. For the same high-speed rail model, due to the lower frequency band, the 1.8GHz band of FDD has less penetration loss than the 2.6GHz band of TDD, and the signal coverage inside the car is better, so the coverage level inside the car can be about 8dB better than that in the 2.6GHz band.

4.1.3 Doppler Bias

The faster the train runs, the larger the Doppler frequency offset, as shown in table 1. The running speed of high-speed rail trains generally reaches 350km/h [24], and the Doppler effect is obvious. Compared with the 1.9/2.6GHz band of TDD, the 1.8GHz band of FDD has a smaller Doppler frequency offset, especially compared with the 2.6GHz band, the uplink frequency offset is about 70% of the 2.6GHz.

Table 1. Relation Between Speed and Frequency Deviation of High Speed Railway

Uplink maximum Doppler frequency bias			
Speed/(km/h)	1800MHz/MHz	1900MHz/MHz	2600MHz/MHz
200	667	703	963
250	833	880	1204
300	1000	1055	1444
350	1167	1231	1685
450	1500	1583	2167

4.1.4 Uplink Perception

FDD provides a better uplink rate experience than TDD. Because of the difference between FDD and TDD standards, under the same bandwidth of 20MHz, the uplink rate of FDD is about 5Mbit/s higher than that of TDD with the configuration of up and down sub-frame of 2:2, and about 15Mbit/s higher than that of TDD with the configuration of up and down sub-frame of 1:3.

4.1.5 Public Network Interference

High-speed rail FDD uses the 1.8GHz frequency band for networking. Because its radio frequency resource is the 1.8GHz frequency band of the original GSM, the 1.8GHz stations along the GSM line need to be de-frequented during use to ensure the purity of wireless resources. The 1.8GHz frequency band occupied by GSM within 3km along the high-speed rail will be gradually removed, and the 1.8GHz frequency band of high-speed rail FDD will be less and less interfered by the public network in the later stage.

4.2 Collaborative Optimization of FDD and TDD for High-speed Rail

In the case of the joint networking of FDD and TDD, the optimization is mainly carried out in the following four aspects.

4.2.1 Coverage Optimization

4.2.1.1 RSRP Optimization

According to the test results, it is recommended that the RSRP measured by the terminal be kept above -95dBm, so as to ensure better coverage performance. In order to achieve this purpose, the signal strength needs to be guaranteed through the following aspects.

(a) Frequency Selection: When covering high-speed rail, it is recommended that customers use low-band coverage as much as possible, and it is necessary to avoid the 2.6GHz band directly using macro network coverage to cover high-speed rail.

(b) Site Selection: The "zigzag" layout station on both sides, the distance between the base station and the rail should be moderate, it is recommended to be 75 to 150 meters, to ensure that there is a direct beam path between the base station and the terminal, which can provide better RSRP and demodulation performance.

(c) Height of Station: The station height should be as high as possible to provide good coverage, but reasonable control should also be carried out according to the station spacing to avoid serious problems of over-zone coverage.

(d) Gain of Antenna: It is recommended to select a 33° narrow-beam high-gain antenna to provide conditions for obtaining high RSRP.

(e) Angle of Azimuth: The azimuth Angle needs to be hit along the direction of the rail, to ensure that the signal Angle of incidence is greater than 10°.

(f) Down-dip Angle: The down-dip angle is set reasonably according to the height of the station to ensure that the direction of the antenna main lobe can cover the height of the carriage.

(g) Transmitting Power: Select the RRU model according to the actual situation (after the model is determined, the total power of LTE is determined) and pilot power to prepare for providing high RSRP.

(h) Building Occlusion: Try to avoid areas covered by high-speed rail that are blocked by buildings or forests.

When optimizing RSRP, it is recommended to make reference to the above influencing factors and optimize in the direction conducive to the coverage of high-speed rail.

4.2.1.2 SINR Optimization

SINR is the key factor to ensure throughput performance. In the actual optimization, it is recommended to provide as high SINR as possible. Possible means are suggested below.

(a) Chain Coverage: HSR cells use chain-type coverage, where the cells are far apart and the interference ratio is low.

(b) Reduce the interference of the large network on the high-speed rail network: At the LTE station near the railway, RF parameters should be set reasonably to avoid overlapping with the high-speed railway cell coverage area to reduce interference.

(c) Optimize RF parameters of high-speed rail network: The uplink interference of HSR is relatively small. SINR can be optimized by optimizing RF parameters such as station height, azimuth Angle and down-dip Angle.

(d) Reasonable PCI planning: PCI MOD 3 staggered to reduce interference between pilots.

(e) Weak covering: Avoid the phenomenon of poor SINR due to weak RSRP.

Through the above means, the performance impact caused by low SINR can be basically solved.

4.2.2 FDD and TDD Interoperation Strategy

Adjacent regions configuration: Public and private networks do not configure adjacent areas except for stations and boundaries.

Planning strategy: FDD serves as the capacity layer and preferentially absorbs user load. The priority of FDD frequency point is higher than that of TDD frequency point.

Coverage-based handover strategy [25]:

Intra-band coverage handoff is performed first, followed by inter-band coverage handoff.

MLB strategy: The 2600MHz and 1900MHz of the TDD private network and the 1800MHz of the FDD private network enable one-way user cross-frequency MLB.

4.2.3 Interoperability Parameters Implementation Scheme

Interoperability between systems: Because the support level of FDD terminals is lower than that of TDD terminals, the traffic absorption capacity of FDD terminals is limited when the terminals are configured with the same priority. Therefore, you are advised to configure a high priority for FDD. The ratio of the maximum number of users in the 10MHz FDD cell to the 20MHz TDD cell is 1:2, which can effectively absorb FDD traffic. The hetero-frequency switching and reselection strategies are shown in Table 2.

Table 2. The Hetero-Frequency Switching and Reselection Strategies

Switching recasting	Reselect priorities	Different frequency and different system measurement threshold	Hetero-frequency switching parameters		
TDD	5	3	A1-108	A2-113	A4-98
FDD	6	3	A1-108	A2-113	A4-98

Load balancing configuration is as follows:

(a) Daily configuration: The balancing priority of TDD cell-FDD cell is 7, the balancing priority of TDD cell-TDD cell is 5, and the load balancing threshold in connected/idle state is 50.

(b) Holiday configuration: The balancing priority of TDD cell-FDD cell is 7, the balancing priority of TDD cell-TDD cell is 5, and the load balancing threshold in connected/idle state is 100, which can prevent the FDD cell from being too busy due to too many users.

The load balancing threshold setting is shown in Table 3.

Table 3. The Load Balancing Threshold Setting

Load balancing	Allowed or not	Priority	Load balancing threshold	
			(Daily)	(Holiday)
F-FDD	Allowed	7	Connected/idle state 50	Connected/idle state 100
D-FDD	Allowed	7	Connected/idle state 50	Connected/idle state 100
F-D	Allowed	5	Connected/idle state 50	Connected/idle state 100
D-F	Not allowed			

4.2.4 Rule for Adding Adjacent Areas

(a) TDD adds the adjacent area of the FDD cell at the station entrance and exit, which is configured according to the adjacent area of the existing TDD plus TDD cell.

(b) TDD adds the adjacent area between the site cell and the FDD site cell using the A2+A4 switching policy.

(c) TDD adds the adjacent area between the station cell and the upstream and downstream stations of FDD, and uses the A2+A4 switching policy.

(d) FDD adds the adjacent area between the new residential area and all the frequency points of TDD on the site.

(e) FDD adds the adjacent area between the new cell and the upstream and downstream stations. The A2+A5 switching policy is used to configure the relationship.

(f) FDD adds the switching relationship between the new cell and the TDD cell at the station entrance and exit, which is configured using the A2+A5 switching policy.

5. Application Verification

In order to verify the effectiveness of the proposed method, an experiment was carried out on the covered section of regional private network in a certain city of Beijing-Guangzhou high-speed railway. The running mileage of this section is about 78 kilometers, which is continuously covered by 45 logical stations and 179 physical stations in a "zigzag" pattern, with an average physical station spacing of 435.75 meters and station gauge of 75-150 meters. At the beginning of 2018, in order to solve the capacity problem of the high-speed rail private network in this section, the superposition of the FDD high-speed rail private network was put into network operation, and the dual-mode networking of TDD+FDD was formed in this section. The TDD network includes F-band and D-band, and each logical station contains 3 logical cells after FDD is connected to the network, totaling 135 logical cells. In order to give full play to the network performance, the private network of this section adopts the switching parameter optimization mentioned above, the application of new network characteristics, fine radio frequency optimization, VOLTE special optimization, FDD and TDD interoperability optimization and load sharing optimization.

After the completion of networking and optimization, the network performance is compared and analyzed from two aspects. On the one hand, the KPI performance indicators of the high-speed railway private network management are analyzed through statistics, and on the other hand, the actual road test is analyzed. Among them, the performance indicators of network management KPI used in the analysis mainly include wireless connection rate, wireless drop rate, switching success rate, RRC establishment success rate, E-RAB establishment success rate and wireless connection rate. For the convenience of analysis and display, the overall network management performance index of the network is defined as XN= (radio connection rate + handover success rate + RRC establishment success rate +E-RAB establishment success rate + radio connection rate + 1-wireless drop rate) /6. With the completion of the preliminary optimization work, the network management performance indicators for a total of 10 days were counted, as shown in Figure 9.

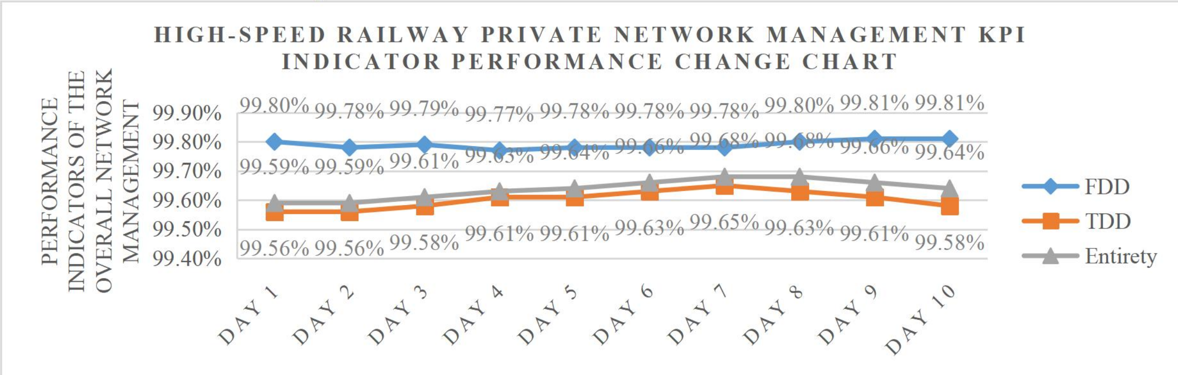

Figure 9. High-Speed Railway Private Network Management KPI Indicator Performance Change Chart

As can be seen from Figure 9, the overall network management performance indicators of each high-layer railway private network fluctuated but remained at a high level within 10 days. The network management index performance of FDD network is obviously better than that of TDD network due to mode advantages. However, with the completion of FDD network access and fusion network optimization, the overall network management index of high-speed railway private network is better than that of single-layer TDD network.

In order to analyze the customer perception after the optimization of the fusion network, the actual road test of the network is carried out, and the test results are shown in Table 4. The table shows that the optimized fusion network has better test indicators than before. Among them, the average download rate is about 1 times higher than before, the average upload rate is about 3 times higher than before, and the VOLTE voice quality is 45.33% higher than before, which is very obvious for improving the user experience and reducing the pressure on network capacity.

Table 4. Road Test Result

	Average RSRP	Average SINR	LTE comprehensive coverage	The proportion of SINR above 0	Average upload rate (Mbps)	LTE private network duration ratio	Average download rate (Mbps)	CSFB full success rate	The proportion of VOLTE MOS above 3.0
Before optimization	-82.11	12.92	97.66%	94.33%	2.11	100%	22.56	100%	67.86%
After optimization	-78.34	14.5	98.22%	96.28%	9.23	100%	43.98	100%	98.62%

6. Conclusion

In view of the limited capacity of high-speed rail LTE private network, this paper describes the inevitable evolution of high-speed rail from F single frequency network to multi-frequency network, and focuses on the research and demonstration of multi-frequency network mode and optimization strategy. On the one hand, the current F+D dual-frequency network parameter strategy, the application of new network features, detailed RF optimization, VOLTE voice optimization are analyzed and explained. On the other hand, the future high-speed rail TDD+FDD fusion network optimization strategy is prospected. Finally, the multi-standard and multi-band networking strategy is adopted to solve the problem of limited capacity and coverage, further improve the perception of high-speed rail users, and provide a good theoretical and practical basis for the subsequent construction and optimization of high-speed rail private networks.

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