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Research on Mobile Communication on High Speed Railway in China

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Abstract

This paper mainly focuses on the mobile communication system that has been or will be used in China's railway at present or in the future. This paper first introduces the second generation mobile communication system GSM-R, which is widely used in China's railway, and studies the two kinds of signal fading encountered by the system, and gives the corresponding solutions. After that, the paper analyzes the LTE-R railway dispatching mobile communication system which will be widely used, compares it with GSM system to show its advantages, and also gives the common problems and solutions with GSM system. Then, this paper analyzes the most popular 5G mobile communication system and introduces its application scenarios in high-speed railway. Finally, the paper summarizes the above contents and puts forward the possible problems in the application of 5g network.

Keywords

Handoff; Doppler Spread; Multipath Effect; Anti-interference; OFDM; GSM-R; LTE-R; 5G.

1. Introduction

At present, the construction of high-speed railway has ushered in the spring of vigorous development in China. The development of high-speed railway makes people reach their destination faster, but the waiting time of several hours on high-speed railway needs to be fully utilized in today's fast food era. People need mobile communication to deal with company affairs, play games and listen to online music. Therefore, mobile communication technology must keep up with the development of high-speed railway. At the same time, not only the customers, but also the dispatching and communication between trains need mobile communication technology. There are many high-speed trains with high speed and great kinetic energy. If the speed and train distance are not well controlled, great accidents will occur. Therefore, high-speed railway also needs faster and better wireless mobile communication technology to realize the dispatching and communication between trains. Next, from the perspective of customer mobile communication and train dispatching mobile communication, this paper will explore the mobile communication on high-speed railway and the existing problems, as well as the corresponding solutions.

2. The demand of Railway Communication:

(1) The network structure, hardware equipment, software algorithm and other aspects of wireless mobile communication must meet the requirements when the train speed reaches 300 km / h to 500 km / h.

(2) The wireless mobile communication system should be able to realize the wireless train control mode, that is, the signal and train control mode based on communication. It needs to be able to carry out a large number of two-way information transmission between the high-speed train and the ground,

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that is, high-speed full duplex communication. The amount of communication information is large, and the communication rate is fast. However, the bandwidth of wireless communication / wired communication line is limited. If the limited bandwidth wants to achieve high-speed transmission, it needs to start from the modulation mode, base number and other aspects.

(3) The wireless base station should be a chain structure, and the wireless communication system must have the function of fast handoff. This problem is very easy to understand. In the process of rapid train traffic, the address position changes rapidly. If it does not have the function of fast handover, the system on the train can not receive in time, so the communication quality must not be guaranteed; In addition, the wireless communication system must be able to adapt to different terrain environment.

(4) Good anti-interference performance is required; Because there are many kinds of buildings or obstacles in the process of train running, if the signal can not have a good penetration ability, it is bound to affect the transmission of communication; In addition, the choice of frequency band is also a very important factor, such as 2.4G WiFi band. There are a variety of communication means in this band, such as Bluetooth, ZigBee, etc., which may interfere with each other.

(5) Good confidentiality and reliable confidentiality measures should be taken;

(6) Good compatibility and fault tolerance are required while ensuring the quality;

(7) Make full use of spectrum resources.

3. The introduction of current railway communication system in China

Standard: GSM phase 2 +;

Form:

NSS (network switching subsystem)

GPRS (General Packet Radio Service)

BSS (base station subsystem)

Fas (fixed user access switching system)

OMC (operation and maintenance subsystem)

In (intelligent network system)

Terminal subsystem

Working frequency band: GSM-R works in 900MHz frequency band, uplink 885-889MHz (transmitted by vehicle mobile station and received by base station), downlink 930-934MHz (transmitted by base station and received by vehicle mobile station), and duplex transceiver interval is 45MHz;

The channels are divided according to the interval of 200KHz. There are 21 carrier frequencies in total. The channel number ranges from 999-1019. The low-end 999 and high-end 1019 are used as isolation protection with China Mobile. In fact, there are only 19 available channels (The GSM used by China Mobile is 900MHz; China Unicom CDMA still adopts 900MHz. Although the two communication modes have gradually withdrawn from the stage, it also shows that there are user communication problems in the process of using GSM-R system, that is, user communication may interfere with GSM-R communication.)

Modulation and demodulation mode:

Multiplexing: TDMA time division multiplexing with 8 slots; Each TDMA frame contains 8 time slots, and the whole frame length is 4.615ms; Each frame length contains 156 bits, the slot frame length is 577 microseconds, and each bit takes about 3.7 microseconds.

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4. Influencing Factors and Solutions of Railway Dispatch Communication Quality

4.1 Overview

In fact, whether it is the customer communication system or the railway communication system, the factors that affect the communication between the high-speed railway and the surrounding trains are no different from three aspects: fading, interference, site switching.

4.2 The Signal fading

4.2.1 Large scale fading

(1) Large scale fading. Path loss and shadow fading are the main fading factors affecting communication quality;

Shadow fading: due to the terrain (such as mountains, hills, tall buildings and other buildings) shielding, that is, the absorption, reflection, diffraction and other processes of these obstacles on the signal, the radio wave may form a shadow of several hundred meters long. With the driving of the vehicle, the shadow fading of the radio wave will occur, Due to the shelter of the building, the signal strength received by the receiver on the car is also getting lower and lower, and even the signal isolation will be produced when it is serious. For the receiver receiving radio waves on the train, it seems to gradually enter the "shadow" (actually the shadow area of radio waves).

The way to solve shadow fading: mainly by increasing the density of the site or increasing the source power to solve.

Path loss: This is relatively easy to understand. It is the phenomenon that our signal is gradually lost with the transmission. It is mainly determined by the diffusion of transmission power and the propagation characteristics of our channel at that time. In the Internet of things, we have learned that the channel condition in free propagation space (wireless propagation) is changeable and complex, so the loss of path can also be regarded as the influencing factor of signal propagation.

The solution to this kind of problem is usually relatively simple in theory: 1; 2. Improve the gain and height of the antenna; 3. Increase the density of the site;

4.2.2 Small scale fading

Small scale fading is influenced by multipath effect and Doppler shift;

Multipath effect: the most basic principle is that due to different signal transmission paths, the time of the channel arriving at the receiver is different, the amplitude and phase of the signal arriving at the receiver will change, and the phenomenon of signal fading is caused by the superposition of different signals at the receiver. In serious cases, it may also lead to frequency selective fading.

There are many ways to solve problems;

(1) OFDM technology. Its principle is the same as its name. Orthogonal frequency division multiplexing divides the frequency domain into several sub frequency domains and sends data in parallel. The data stream changes from serial to parallel. The symbol rate and bandwidth are greatly reduced, and the impact of multipath effect can be reduced. Lte-r, which is still in the stage of experiment and standard formulation, adopts this technology;

(2) Diversity receiving technology: this process is to treat the signals with different amplitude and phase received by the receiver as uncorrelated signals, receive and process them separately, and then summarize and combine the processed signals to obtain the highest signal energy. There are two main diversity methods, macro diversity and micro diversity. Macro diversity mainly solves the problem of slow fading, while differential diversity (time diversity and space diversity) mainly solves the problem of fast fading.

(3) In theory, it is very simple, but it is difficult to realize: improve the measurement accuracy of the receiver;

Next is another important issue that affects the quality of mobile communication on high-speed rail.

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The basic principle is shown in the figure below:

Due to the relative motion between the receiver and the transmitter, the received signal frequency is different from the transmitted frequency, resulting in offset.

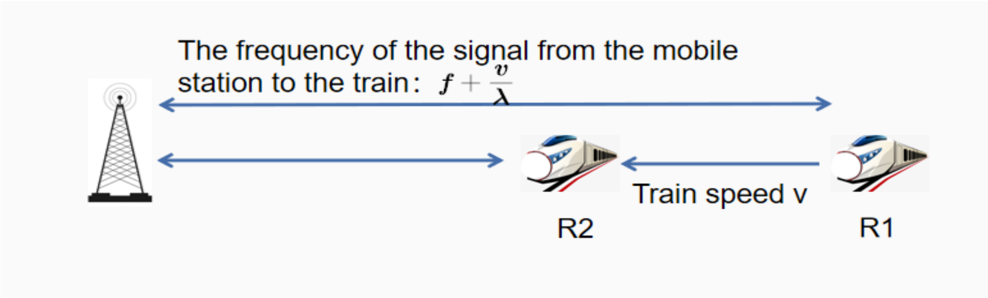

Figure 1. Demonstration of train approaching base station (Along a straight line)

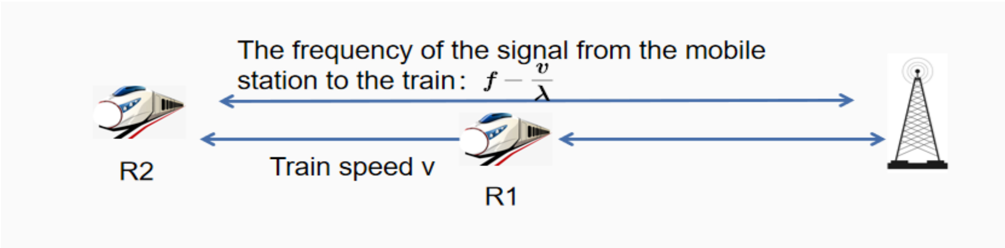

Figure 2. Demonstration of train far away from base station (Along a straight line)

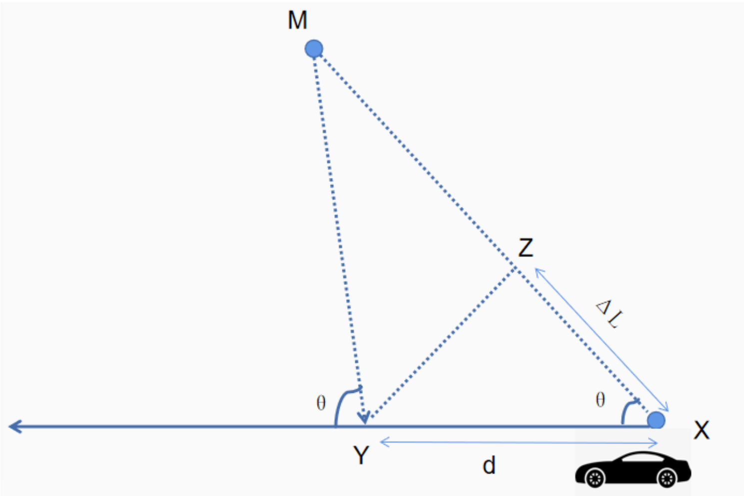

Figure 3. Demonstration of Doppler general situation

First, we need to set a few parameters(Figure 3):

V: Moving speed of mobile station(m/s);

Θ: Angle between incident wave and moving direction of mobile station;

d: Movement distance;

Assuming that the source M is far away from the mobile station, that is, in a short distance d, it can be assumed that the angles Θ at X and Y are the same. From this we can deduce MY = MZ.

The path difference of electromagnetic wave caused by moving is as follows:

$$MX-MY=MX-MZ=\Delta L;$$

$$\Delta L=d\cos\theta=v\Delta t\cos\theta;$$

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Because of the path difference, the phase difference also occurs,the calculation method of phase difference is as follows:

$$\Delta\phi = \frac{2\pi\Delta L}{\lambda} = \frac{2\pi v \Delta t}{\lambda}\cos\theta$$

The phase difference corresponds to the change of frequency:

$$f_d = \frac{1}{2\pi}\frac{\Delta\phi}{\Delta t} = \frac{v}{\lambda}\cos\theta$$

The maximum Doppler shift is: $f_m = \frac{v}{\lambda}$;

When the mobile station moves in the direction of incident wave, the Doppler shift is positive.

When the mobile station moves away from the incident wave, the Doppler shift is negative.

In the multipath channel, the signal propagates in different directions. The angle between each multipath component and the incident wave is different, and the Doppler frequency shift is different. As a result, the Doppler spread of the received signal is caused, and the signal bandwidth is increased.

After understanding the formula and analyzing the corresponding pictures and principles, obvious problems can be found.

Because on the route of high-speed railway, GSM-R base station is laid along the rail. When the base station sends signals to the high-speed train, the high-speed railway keeps away from the base station because the wave source does not move. Because the relative speed between the train and the base station is constantly changing, the frequency offset of the signal is in the process of constant change, which makes the frequency shift of the signal constantly changing, The center frequency shift of the signal will inevitably affect the demodulation performance of coherent demodulation (with BPF) and greatly improve the bit error rate. And in this case, because of the fading caused by the change of frequency shift, even if the transmission power is increased, the reliability can not be effectively improved. The frequency shift of the downlink is constantly changing. When the train responds to the downlink information, it is considered that the wave source moves and the receiver does not move, and the frequency change is relatively more dramatic. Doppler shift is one of the most important factors in high-speed railway communication.

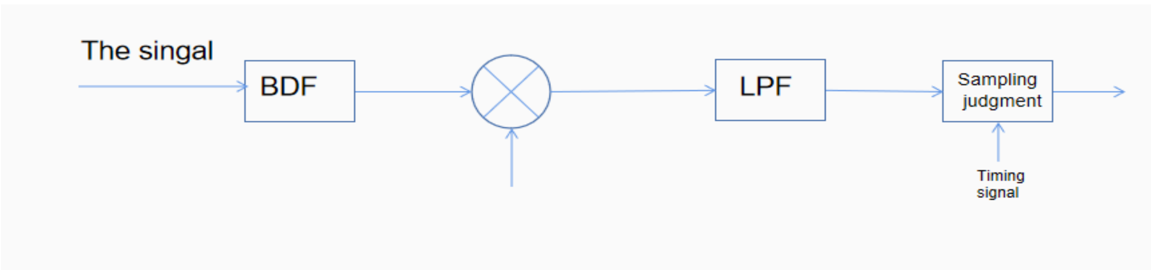

Figure 4. Schematic diagram of coherent demodulation principle

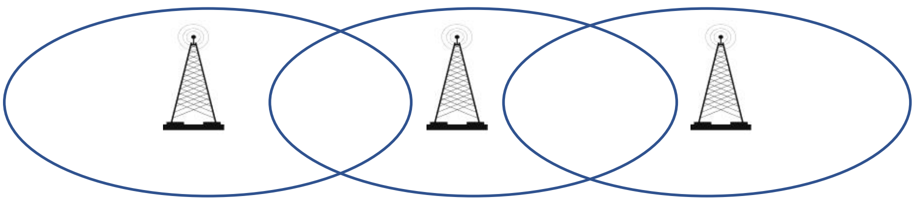

Figure 5. Coverage mode of base station single layer network

Solutions:

The following are Huawei's solutions to these problems:

Frequency offset preset and automatic correction: AFC algorithm.

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Basic principle: the algorithm adopts automatic frequency correction technology, which can quickly measure the frequency changes of base station and mobile station caused by Doppler frequency shift of high-speed mobile home, dynamically track and correct their frequency offset, make up for the signal loss caused by Doppler effect, and ensure the stability of wireless link connection.

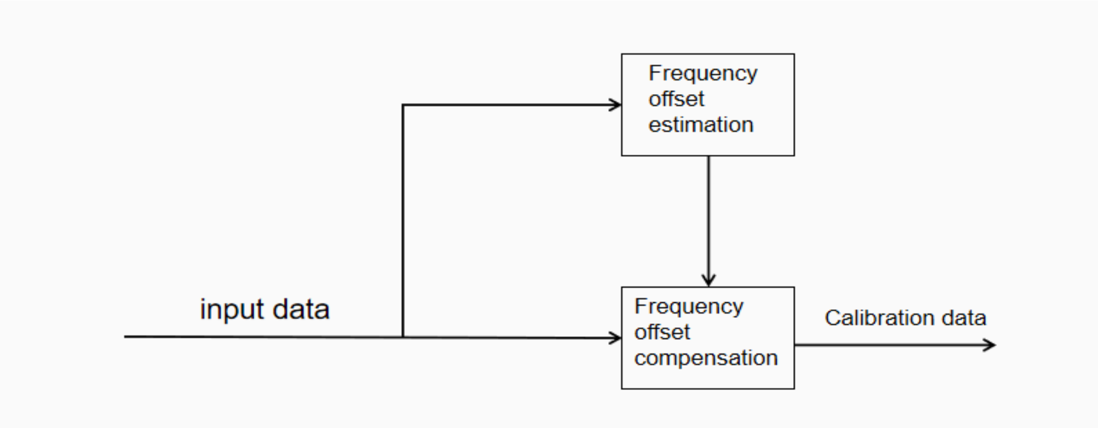

Figure 6. AFC algorithm schematic diagram

4.3 Communication interference

4.3.1 Overview

In the process of train running, interference is everywhere. From Gaussian white noise to civil signals in other frequency bands, such as CDMA system of China Unicom and GSM system of China Mobile, their working frequency is 900MHz, which will also cause great interference to signals. In addition, the electromagnetic field of maglev train and high-speed railway, and the power of high-speed railway itself will also affect the quality of communication as a kind of noise or interference. This paper mainly discusses two kinds of interference: CO frequency interference and adjacent frequency interference.

4.3.2 Co channel interference

Co channel interference: co channel interference is caused by frequency multiplexing, which means that two base stations with a certain distance in GSM-R system use the same frequency. Generally, the smaller the distance between cells in the same frequency, the greater the co frequency interference, and the greater the frequency utilization; On the contrary, the same frequency interference will be reduced, and the frequency utilization will also be reduced. For the same frequency interference, the frequency of the useful signal and the useless signal are the same. After frequency conversion and amplification in the receiver, they fall into the if passband, and the frequency range is $f_0 \pm \frac{B_r}{2}$. f is the frequency of the useful signal, B is the IF bandwidth of the receiver.

In this process, because the frequency of useful signal and interference signal is the same, so the processing is the same. The two will amplify and detect at the same time. If there is carrier frequency difference between the two signals, it will lead to beat interference. If the modulation amplitude of the two signals is different, distortion interference will occur. If there is a phase difference between the two signals, distortion interference will also occur. When the intensity of the interference signal is larger, the SNR of the receiver output is smaller. If the intensity of the interference signal is large enough, the receiver will be blocked. If the intensity of the interference signal is small enough, the sensitivity of the receiver will be reduced. If it is serious, the signal may be blocked.

The main reasons are the problems of planning or equipment parameter setting, such as the close distance between two cells in the same frequency, unreasonable antenna parameter setting and so on. The main solution is also from the planning problem.

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4.3.3 Adjacent frequency interference

Adjacent frequency interference is the signal interference caused by using adjacent frequencies. Adjacent frequency interference is the signal interference caused by the use of adjacent frequencies. In GSM-R network, the adjacent frequency interference is often caused by unreasonable frequency planning. If the BCCH channel frequency or TCH channel frequency of the current cell is adjacent to the BCCH frequency or TCH frequency of the two adjacent cells of the current cell, then the adjacent frequency interference can be considered. If the frequency of the useful signal is f0 and the frequency of the interference signal is f, and the relationship between them is satisfied $\mathrm{f}=\mathrm{f}_0 \pm n\Delta f$, then the interference signal is called the useful signal n-order interference signal. In practical engineering, we usually only consider the 1st / 2nd order signal.

The causes are as follows:

(1) The main reason is that the accuracy of the receiver or transmitter can not meet the requirements. This problem can be solved by improving the performance of the filter.

(2) Planning problems or interference caused by other civil signal GSM / CDMA. Railway Administration and operators need to negotiate and plan reasonably.

5. Improved technology of GSM(LTE-R)

5.1 Overview

GSM-R belongs to narrowband communication technology, with narrow passband, low communication rate and large delay, which is easily affected by the environment. Under the background of people's increasingly strict requirements for communication quality and speed, GSM-R is difficult to meet the needs of users on trains, especially on high-speed trains. LTE (long term evolution) technology has gradually replaced GSM technology and become the mainstream communication technology on high-speed railway. Compared with GSM, LTE has the following technical advantages:

(1) LTE is a broadband communication technology, which can provide 100 Mbps downlink and 50 Mbps uplink peak rate in 20 MHz spectrum bandwidth; Compared with the narrowband communication technology of GSM, the uplink and downlink rate is much faster.

(2) MIMO technology is used to make the cell capacity larger and the system performance better without increasing the system bandwidth and transmission power.

(3) OFDM technology is adopted; It can support paired or unpaired spectrum, flexibly configure 1.25 MHz to 20MHz bandwidth, and resist ISI and ICI.LTE-R can perfectly overcome the problem of multipath fading in GSM system after applying this technology.

(4) The system delay is lower, the one-way transmission delay in the user plane is less than 5ms, the transition time of the control plane from sleep state to active state is less than 50ms, and the transition time from resident state to active state is less than 100ms.

(5) It can provide more than 100kbps access service for 350km / h high-speed mobile users.

Compared with GSM system, LTE has many advantages in technology, but some common problems still need to be solved.The technical problems encountered by LTE are analyzed below.

5.2 Main problems and solutions of LTE-R

5.2.1 Solution of penetration loss and Doppler effect by on board repeater

In the high-speed operation environment, lte-r system can use on-board repeater system, which can greatly improve the wireless signal coverage in the carriage in the high-speed operation environment. Vehicular repeater has powerful receiving function, which can deal with Doppler shift effect well. At the same time, it can also take into account the old terminal without frequency shift processing function, which has strong compatibility. The dynamic gain control function of vehicular repeater can automatically adjust the uplink / downlink gain of vehicular repeater according to the measurement

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of downlink signal. At the same time, the uplink gain is controlled with the downlink gain, so as to avoid excessive uplink noise when the gain is too large and reduce the receiving sensitivity of the base station system along the line; According to the moving characteristics of high-speed train, the uplink / downlink gain is adjusted quickly to make the wireless signal in the train relatively stable; Because the users of the car coverage system are all passengers in the car, the communication system of the high-speed mobile train is mainly limited in uplink, and the onboard repeater generally adopts the uplink power enhancement design.

5.2.2 Single cell multi RRU cascade technology to solve the problem of cell handover

From the coverage characteristics of LTE high-speed railway, in order to ensure reliable handover between cells, it is necessary to increase the coverage of cells and reduce the number of cell handover. In order to expand the coverage of the cell, the network coverage scheme of baseband pool + RRU (radio frequency remote unit) can be adopted. Multiple rrus can be networked and combined into a cell by using baseband merging technology. Rrus belonging to the same cell are deployed along the high-speed railway to reduce the handover frequency and improve the network performance,.In the downlink direction, the base station is equivalent to the same frequency diversity transmission of multiple stations, and the transmission signal of each RRU is the same. The mobile phone can get the receiving gain in the overlapping area of multiple rrus, which enhances the receiving effect of downlink signal.

In the uplink direction, the base station is equivalent to multi-channel reception. In the overlapping area covered by multiple rrus, the uplink signal of the mobile phone is received by the antennas of multiple rrus at the same time. After the received data is transmitted to the baseband pool through optical fiber, the baseband processing board realizes multi-channel combined diversity reception, which improves the uplink receiving sensitivity and anti-interference ability.

6. Application of 5g network in high speed railway

5g network communication technology, compared with 4G network, has obvious advantages, not only in the speed of transmission is quite fast, but also has strong compatibility, battery life has been significantly extended. This will make people's life more convenient. At present, many countries in the world have entered the research work of 5g network communication technology. With the deepening of the research on this problem, the transmission speed will be greatly improved in the future. 5g replacing 4G is an irresistible trend. In the future, 5g mobile network will be applied to railway mobile communication. The following analysis is made on several typical application scenarios of 5g network on high-speed railway.

6.1 Voice communication

5G network has Gbit/s user experience rate, which not only meets the traditional voice communication of traffic dispatch, but also provides video calling function. It can be used in many application scenarios such as station call, vehicle-to-ground communication, vehicle-to-vehicle communication, construction operation communication, emergency communication and so on.

6.2 Data Transfer

The 5G network can achieve end-to-end delay in milliseconds and support a mobile rate of more than 500 km/h, providing a stable and reliable high-bandwidth transmission channel for the next generation of download control systems.In addition, it can also provide real-time upload of video transmission of train operation, data transmission of train safety protection, and status monitoring data of locomotive equipment.

6.3 Internet of Things Applications

The 5G network allows you to quickly and easily deploy hundreds of millions of sensors to upload monitoring data in real time.Through the accumulation of various monitoring data, a large data analysis mode is established to better guide the field production and maintenance.

6.4 Emergency Communications Applications

When extreme natural disasters occur, traditional communication network infrastructure is often damaged, causing network congestion or paralysis.5G network can use personal terminals to set up a network using D2D technology, to ensure the smooth wireless communication between terminals, and to provide protection for rescue.

6.5 Failure/Trip Rescue Path

Automatic real-time Association of power supply SCADA system failure/tripping data, and automatic analysis of line class, kilometer mark, line class, tripping time, unit of operation, job content and other data, and real-time drawing of location reminder display on the map;

6.6 Natural Disaster Warning

Through efficient information analysis, combined with the relevant provisions of natural disaster emergency treatment, the first-time warning prompt, make full use of the high-speed and accurate transmission of system 5G information, to effectively improve the response capacity of high-speed natural disasters.

7. Conclusion

With the development of high-speed railway technology, it is inevitable that the speed of high-speed railway is getting faster and faster.This means faster speed, thicker cars and greater noise, as well as greater Doppler spread, greater penetration loss and more interference.Under the condition of guaranteeing the mobile communication rate demand of our users, we need to select and develop the mobile communication technology more suitable for high-speed railway, take into account the advantages and disadvantages of the technology we use, and adopt other methods to compensate.For example, although OFDM technology can resist ISI and ICI very well, the orthogonality of each carrier frequency of OFDM needs to be maintained and the peak average power ratio (PAPR) of OFDM needs to be suppressed.Whether in GSM system or LTE system, we can find that Doppler spread and crossover switching are unavoidable problems in railway mobile communication.5G mobile communication system uses high frequency band, large attenuation and limited coverage. Once applied in high-speed mobile communication system, it is unavoidable that frequent crossover switching problems will occur.In addition, the speed of high-speed rail will continue to rise, the car will become thicker, the Doppler spread will be greater, and the penetration loss will be greater. How to solve the new problem of 5G railway mobile communication in the future is our next research direction.

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