An optimal wireless handover approach of high speed train on CPS

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Abstract- This paper focuses on the optimization of the brand wireless handover approach of the high speed train cyber physical system. It can improve the performance of handover. The simulation results show the handover approach can reduce the frequency of handover greatly. It can reduce the handover dropping probability and outage probability to support the safety of the high speed railway communication.

Keywords—cyber physics system, railway communication, wireless handover

I. INTRODUCTION

Cyber-Physic System (CPS) is a new complex system that is integrations of computation and physical process with many networks and technologies[1]. Railway Cyber Physical System (RCPS) is a new approach which combining the physical railway world and the cyber railway world. Such systems will grow significantly in the near future as the current railway traffic system requires a lot of change of existing technologies. The systems include set of wireless sensors, embedded computing devices and central computing and memory resource. The synthetic decision of the cyber world will control these devices and give information to the train with a set of command and control statements. RCPS are commonly used in railway traffic related applications. In remote railway traffic monitoring system, these are small wireless sensors that connect trains, stops, passengers, railways, bridges, identifications of tunnel, and surrounding information, etc [2, 3]. In high speed train the frequent switch and drop off has been becoming the main problem. In this paper, Mobile frequency and Overlay double-antenna handover scheme is proposed and we proposed processing framework for RCPS. In section II, we design a framework of the RCPS .In section III, the optimal switch approach of the communication has been proposed. The description and analysis has been given in this part. The future is proposed in section IV. The conclusion is given in part V.

II. FRAMEWORK OF RAILWAY CYBER PHYSICS SYSTEM

In this part, the paper will describe the RCPS framework of our design of future RCPS.

The new feature to be deal with in railway traffic design:

1. Mobility
2. Variability of outside surroundings
3. High speed
4. Safety

With the alterations for various railway monitor systems, there is a strong requirement for wireless sensors and embedded devices with efficient and robust communication and control. The term Railway Cyber Physical systems refers to systems that have combination of wireless sensors, embedded devices, communication channel for data and control to transfer, central computing and storage nodes. Erecting robust and effective RCPS requires new design, verification and evaluation techniques due to larger size and more variety of data. The challenges for completion such kind of systems include model formulation development, smart alarms, user fitted design and infrastructure for railway traffic information integration and processing.

We proposed the system with 4 parts including the sensing unit, communication unit, data processing unit and report generating unit.

For the sensor unit, it can be divided to 2 parts.

A. *on-train wireless sensors*

It mainly collects the velocity of the train, the pressure of the wet temperature, the identification of the train, etc. In this part we mainly get the information of the environment inside and the runtime state of the train to monitor whether it is running in normal way.

In addition to the part which clings to the system state, we also propose the new services of the RCPS for the customer use such as the healthy monitor system for somebody he is not good in health. It can detect the blood pressure, the pulse rate, blood sugar and other healthy parameters. In one hand we should

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provide the devices in every train carriage, the information should be transferred to the center node of the train to give the help timely to the customers especially for someone who need immerse health care; In the other hand the system will provide the convenient mechanics for other body healthy wireless devices to access the health network of the train. Telemedicine system is developing more wildly. But in the traffic system such as long travel railway, it will be a specially and necessary component of the telemedicine system in the future. The network media will add more method such as blue tooth and infrared ray for near inside communication.

For the good transfer, the RFID technique will be used to response the situation of the goods for the safety of the traffic.

B. off-train wireless sensors

It is used to detect the railway, stop, tunnel, bridge and other surrounding information. If there are something seriously wrong with that, the forecast-alarm mechanism must make an emergent response to the related trains and devices. The information should be recorded regularly if no emergent situation happens and used for statistics algorithm to intelligent forecast danger degree.

In the transfer unit, the internet, wireless GSM-R/3G/4G/WiMax and satellite communication such as BDS are comprehensively used to connect all the sensors and The basic idea of mobile frequency scheme is that CCS(Central Control System) predicates the next RAU(Remote Antenna Unit) the train would arrive and exchange wireless carrier frequency along the rail ,according to real-time capture of the train's location(provided by GPS on train) .As shown in Figure 4-1,the length of high-speed train's body is 200 m. At the moment t1, wireless frequency sent by RAU1, RAU2 and RAU3 is respectively f1, f2 and f1.However, RAUs'frequency would change according to location of train. At the moment t2, wireless frequency sent by RAU1, RAU2 and RAU3 now is respectively f2, f1 and f2.Therefore, wireless frequency of receiver-sender antennas in this scheme is permanent, while wireless frequency of RAUs along the rail alters according to motion of the train. So it is concluded that when the train moves within the cell coverage of the same CCS, the handover could be avoided with the idea of mobile frequency. When the train moves to the range of other CSSs, handover is still needed. If a CSS controls many RAUs and covers a long distance of rail, frequent handover in traditional scheme would be greatly improved [11]. However, controlling over many RAU increases the costs. According to the existing research results that one CSS controls over three RAUs, this paper assumes that every RAU's coverage is the same as the coverage of radius of LTE, 1.5km.

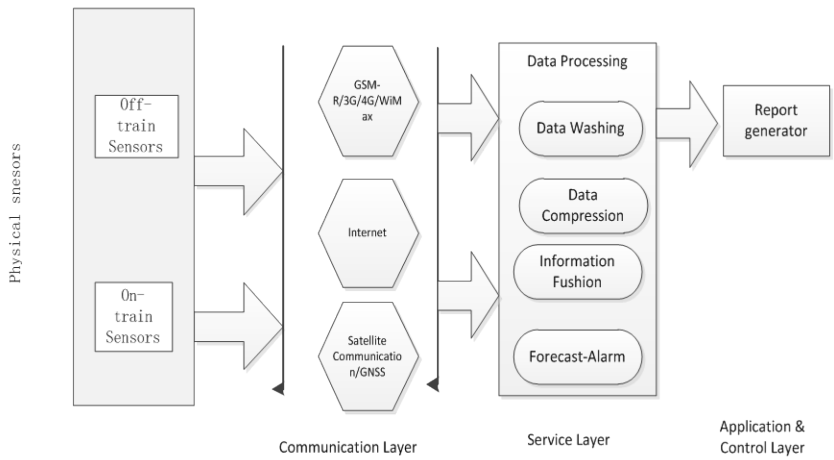

Fig.1 Platform for Cyber Physics system

devices. It is the mainly the most important part of the Cyber physical system. Reliable data transfer is very important for RCPS especially in the uncontrolled outside surroundings.

For the data processing, we should use the high performance computing devices to response to the result in real time. In the cloud computing networks, we utilize cloud computing, fuzzy recognition, data mining and semantic analyze technique, etc. to carry on information fusion and deep analyze to realize the environment of the physical surrounding of railway and intelligent decision control.

In Fig.1 the platform of RCPS is given.

III. An optimal handover approach in wireless broadband communications on high speed train

This Section will explore the application of CPS on high-speed train taking the example of the reliability of high-speed wireless broadband communication and solve the problems such as frequent handover and high rate of call drop in the high-speed wireless communication by providing a Mobile frequency and Overlay double-antenna handover scheme. The scheme is presented below.

A. Mobile Frequency Handover Scheme

To make full use of the characteristic that logic cell coverage in distributed antenna communication system is bigger than that of traditional cell, this paper comes up with mobile frequency scheme to decrease the handover .It is shown in Fig.2. The basic idea of mobile frequency scheme is that CCS(Central Control System) predicates the next RAU(Remote Antenna Unit) the train would arrive and exchange wireless carrier frequency along the rail ,according to real-time capture of the train's location(provided by GPS on train) .As shown in Figure 4-1,the length of high-speed train's body is 200 m. At the moment t1, wireless frequency sent by RAU1, RAU2 and RAU3 is respectively f1, f2 and f1.However, RAUs' frequency would change according to location of train. At the moment t2, wireless frequency sent by RAU1, RAU2 and RAU3 now is respectively f2, f1 and f2.Therefore, wireless frequency of receiver-sender antennas in this scheme is permanent, while

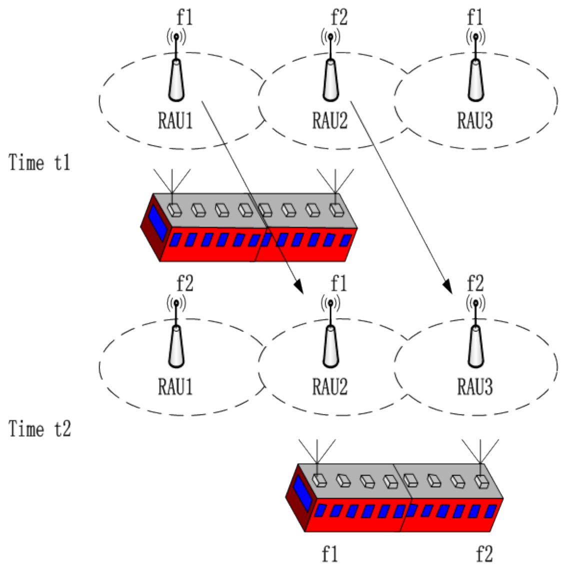

Fig.2 Mobile frequency scheme

wireless frequency of RAUs along the rail alters according to motion of the train. So it is concluded that when the train moves within the cell coverage of the same CCS, the handover could be avoided with the idea of mobile frequency. When the train moves to the range of other CSSs, handover is still needed. If a CSS controls many RAUs and covers a long distance of rail, frequent handover in traditional scheme would be greatly improved [12]. However, controlling over many RAU increases the costs. According to the existing research results that one CSS controls over three RAUs[13], this paper assumes that every RAU's coverage is the same as the coverage of radius of LTE 1.5km. Compared with standard LTE handover, after the implementation of mobile frequency scheme, network would operate differently after making the decision of handover because CSS keeps the same, only RAU changes. It also means that, every CSS is not permanently associated with some RAU; in addition, the number of CSS is smaller than that of RAU. And in the process of mobile frequency, antennas on the train and network have the same frequency, so new lower links are not built between RAUs and antennas on the train. The only needed thing is that the output port of CSS connects to the next RAU, which can be done by optimal handover. The delay of traditional handover is usually up to hundreds of milliseconds or several seconds. It is because when handover happens, synchronization with new base station and change of wireless channels is needed. The synchronization is time-consuming. The mobile frequency scheme which simplifies these operations is in the same logic cell. Although optimal handover consumes time to some extend when CSS handovers modulated frequency, it is only nanoseconds which can be ignored [14].

B. Overlay double-antenna handover scheme

Mobile frequency scheme which is introduced before can greatly reduce the numbers of the handover in the area covered by a CCS. But in the overlay area covered by different CCS, because of the different underlying parameter configuration in the different CCS, the train that is in this overlay area need to change the underlying connection (physical layer, data link layer and the network layer), hence the handover is inevitable. This paper propose an overlay double-antenna optimized handover scheme controlled by MRS to solve the problems such as high handover outage probability and big signaling overhead which exit in the train-ground broadband communication system for high speed railway.

In our scheme, as shown in Figure 3-3, both transmitting and receiving antennas are installed and placed in the front and back on the train. The antennas connect to the MRS through the optical fiber. When the train is located in the same coverage area of a CCS, radio signal received by the antennas mentioned above from RAU transmits to the MRS through the optical fiber, making selective merge at MRS, i.e. comparing the quality of the two signals, then select signal with the higher received signal strength as the received signal output. Meanwhile, each carriage is installed AP. The reception signal outputted by the MRS transmits to AP via optical fiber and finally transmits to user end (UE) through some standard means of communication (such as 2/3/4G, WLAN). When the train enters the overlapping coverage area of two adjacent CCS, it needs handover from the serving cell to target cell. When handover starts, the front antenna executes handover according to the standard LTE handover process, then the back antenna maintains link with service RAU. When the front antenna completes the handover, the back antenna executes handover to operating frequency of target RAU immediately. So a complete handover for distributed antenna system is completed, and during the handover process, the train remains radio link with RAU, no data transmission interruption occurring, so it greatly reduces the communication outage probability. However, if the front antenna's handover is failed, then the back antenna will execute the second handover. Because of twice handovers can be carried out in the overlapping coverage area, the adoption of this program can improve handover success probability. Secondly, in this scheme, two antennas executing the handoff instead of all the active UE on the train greatly reduces the signaling overhead and network load on the system. In addition, this paper also uses Bi-casting method, which means the same data is copied and sent to the service CCS and target CCS in advance, thus reducing the data forwarding delay.

This scheme is based on MRS, i.e., installing MRS on the top of the train. MRS receives radio signal transmitted from the base station. Firstly, MRS carries out signal analysis, re-encodes and amplifies according to the radio channel characteristics; then the signal is forwarded to the train antenna; finally the radio signal is sent to the user terminal. This scheme forms a 'double layer' communication and avoids the penetration loss. In this scheme, MRS controls the front and back antennas on the train. The front and back antennas keep a distance in space, so they can receive the radio signal simultaneously from RAU along with rail, which forms spatial diversity. Signal is transmitted to the MRS through the optical fiber, performing selective merge at MRS, i.e. comparing the signal quality of the two antennas, choosing the signal with bigger RSS value as receiving signal output. This scheme improves SNR of the radio signal. Due to high requirements of handover performance reliability and seamless access for high speed mobility in high speed railway scenario, the traditional hard-handover strategy that breaks first and links later cannot meet this requirement, however the proposed overlay double-antenna handover scheme is equivalent to soft-handover, namely remaining link to the service cell and the target cell in the process of executing handover to ensure seamless data transfer. In this scheme, when the current antenna executes handover, the back antenna remains link to service cell, so in the process of handover communicate interruption will not occur. If the front antenna's handover failed, the back antenna initiate will execute the second handoff, which increases the handover success probability and greatly improves handover performance.

In general, the high speed railway track is on the plain or the viaduct. In this case, the transmission path between the train and RAU is the Line of sight（LOS）. It can be considered as the case that only has free-space loss. Because the Doppler effect and multipath effect has the same effect on the scheme proposed in this paper and LTE, the Doppler effect and Multipath effect on performance of the handover scheme is neglected in this paper. The scheme of this paper is mainly affected by path loss, large-scale fading and noise. Assume x is the distance between the front antenna and RAU_i^4 cover cell center，vehicle mounted antenna（including front antenna and end antenna）receiving the mean RSS from the RAU_i^4 or RRU_j^5 can be presented by the formula[15]

$$R(m,k) = P_t \times 10^{-PL(m,k)/10} \times 10^{\psi_m/10} \quad (1)$$

Among them, m presents RAU; k denote front antenna or end antenna; Pt present the sending power; PL（m，k）exploit the HATA COST231 transmit path loss of extended model ψ_m denote mean value 0，deviation is δ_m which is Gaussian random variable, that is shadow fading.

1．Handover probability

The time for Switch across cell is required if and only if at least in TTT. It is measured that the RSS of RAU is continuously bigger than the aim Udb. It can be presented by

$$10 \cdot \log_{10}(R(j,f)) - 10 \cdot \log_{10}(R(i,f)) \geq U \quad (2)$$

Based on the analysis, $P\{\psi_{sf} = \psi_j - \psi_i\} \sim N(0, 2\delta^2)$. Among them , $\sqrt{2}\delta$ present service RAU and the aim RAU at location x shadow fading joint probability distribution. So we can get the handover probability P_{HO} as:

$$\begin{aligned} P_{HO} &= P\{10 \cdot \log_{10}(R(j,f)) - 10 \cdot \log_{10}(R(i,f)) \geq U\} \quad (3) \\ &= P\{PL(i,f) - PL(j,f) + \psi_j - \psi_i \geq U\} \\ &= Q\left([U + PL(j,f) - PL(i,f)]/\sqrt{2}\delta\right) \end{aligned}$$

Q（*）present Q function.

The self-correlation function $R(\Delta x)$ can be described as the following function:

$$R(\Delta x) = e^{-\frac{|\Delta x|}{d_{cor}} \cdot \ln 2} \quad (4)$$

Assume $\Delta x = v \cdot zT$，from the above，at the position of shadow fading $x + \Delta x$，the mean is 0，the deviation is $(1 - R^2(\Delta x)) \cdot \delta^2$。So the switch probability can be presented as：

$$P_{HO} = Q\left(\frac{U + PL(j,f) - PL(i,f)}{\sqrt{2(1 - R^2(v \cdot zT))}\delta}\right) \quad (5)$$

Here v presents the speed of the train, T present the interval of one measurement report.

2．Handover interruption probability

In the proposed overlay double-antenna handover scheme, if the front antenna receiving signal RSS is little than the minimum signal strength of the normal communication Γ（dB），the front antenna handover fails. At this time the back antenna rises up the second handover. If the back antenna fails to handover also, it is defined as a handover probability in the scheme. Based on the analysis above，the interruption probability can be presented as:

$$P_{HO\_Out} = P_{out}^f \cdot \frac{1}{R + L - x_f} \int_{x_f}^{R+L} P_{out}^r dx. \quad (6)$$

P_{out}^f and P_{out}^r is the front antenna and the back antenna handover failure probability. P_{out}^r presents the position of the handover of the front antenna. R is the cell radius, L is the length of the train. P_{out}^f can be presented as：

$$P_{out}^{f} = P\{10\cdot\log_{10}^{R(j,f)} \le \Gamma \mid P_{HO}^{f}\}$$
$$= \frac{1}{P_{HO}}\int_{-\infty}^{\Upsilon} P\{\psi_i \le PL(i,f)-PL(j,f)+\psi_j-U \,|\, \psi_j=\psi\}\cdot P\{\psi_j=\psi\}d\psi$$
$$= \frac{1}{P_{HO}}\int_{-\infty}^{\Upsilon} \Phi\left(\frac{PL(i,f)-PL(j,f)+\psi-U}{\delta_i}\right)\cdot\frac{1}{\sqrt{2\pi}\delta_j}\cdot e^{-\frac{\psi^2}{2\delta_j^2}}d\psi \quad (7)$$

$\Upsilon=\Gamma-10\log_{10}P_t+PL(j,f)$。 For traditional LTE high speed way wireless communication handover, there is only one antenna for handover, so $P_{HO\_Out}=P_{out}^{f}$。

P_{out}^{r} can be presented as follows:

$$P_{out}^{r} = P\{10\log^{R(j,r)} \le \Gamma \mid P_{HO}^{r}\}$$
$$= \frac{1}{P_{HO}}\int_{-\infty}^{\mu} \Phi\left(\frac{PL(i,r)-PL(j,r)+\psi-U}{\delta_i}\right)\cdot\frac{1}{\sqrt{2\pi}\delta_j}\cdot e^{-\frac{\psi^2}{2\delta_j^2}}d\psi \quad (8)$$

$\mu=\Gamma-10\log_{10}P_t+PL(j,r)$。

3． communication interruption probability

Communication interruption probability is another metric to evaluate the handover performance. The communication interruption probability can be presented as the following:

$$P_{com\_fail} = \left(1-P_{out}^{f}\right)\cdot P_{link\_out}^{r} + P_{out}^{f} \quad (9)$$

$P_{link\_out}^{r}$ presents the communication interruption probability between the back antenna and RAU $P_{link\_out}^{r}$ can be presented as：

$$P_{link\_out}^{r} = \frac{1}{vt}\int_{x_f}^{x_f+vT} P\{R(i,r) \le \Gamma\}dx$$
$$= \frac{1}{vt}\int_{x_f}^{x_f+vT} P\{10\log_{10}P_t-PL(i,r)+\psi_i \le \Gamma\}dx$$
$$= \frac{1}{vt}\int_{x_f}^{x_f+vT} \Phi\left(\frac{\Gamma+PL(i,r)-10\log_{10}P_t}{\delta_i}\right)dx \quad (10)$$

The formula (9) can be represented as:

$$P_{com\_fail} = \left(1-P_{out}^{f}\right)\cdot\frac{1}{vt}\int_{x_f}^{x_f+vT} \Phi\left(\frac{\Gamma+PL(i,r)-10\log_{10}P_t}{\delta_i}\right)dx + P_{out}^{f} \quad (11)$$

In the traditional LTE wireless handover on the high speed train it is always 1, when the single antenna is on handover, the data link is interrupted.

C. Evaluation

To verify the handover performance, we carry on a contrast between the LTE scheme and our scheme. Assume one eNB cover radius of the standard LTE equals to the RAU coverage radius, according to the experienced value, one CCS controls 3 RAU cells. The simulation parameter is as follows:

Table 1 simulation parameter

parameters	value
RAU Radius	1.5km
RAU Tx Power	46dBm (40W)
Carrier Frenqency	2Ghz
Handover trigger hysteresis (μ)	3dB
Pass Loss Model	HATA COST 231extended model
RAU Height	32m
vehiclular MS Anntena Height	3m
Handover measurement parameter	RSS
The minimum received signal strength	-58dBm
Overlay area	400m
distance between RAU-to-RAU	2.4km
Distance between RAU-to-railway	50m
The standard deviation of the shadow fading (Ψ)	4dB
Shadow fading correlation distance	50m
Singnal Bandwidth	10MHz
Train length	200m
The time interval of measurement	200ms
The handover trigger time	100ms
The train speed	{90,180,360} km /h

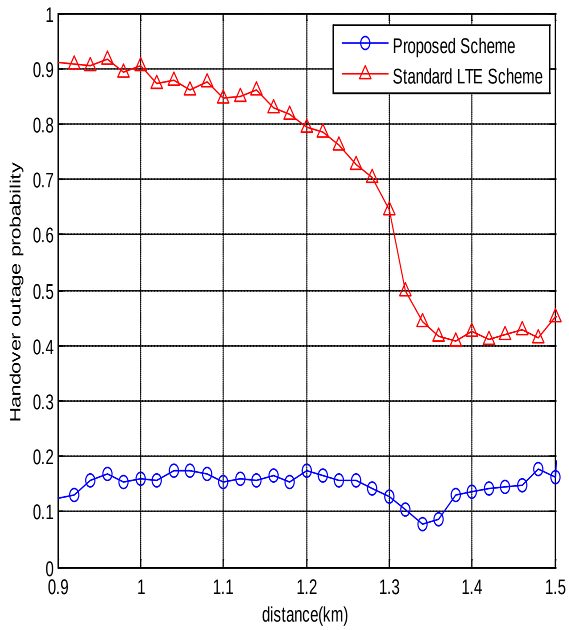

Fig.3 Handover interruption probability

Fig 3 presents the handover interruption probability with the position of the train, the speed of the train is 360km/h。The horizontal axis is the position of the train，the vertical axis presents the handover interruption probability. From the figure we can find，the handover interruption probability of our scheme is below 0.2 meanwhile it is above 0.4 in traditional LTE scheme.

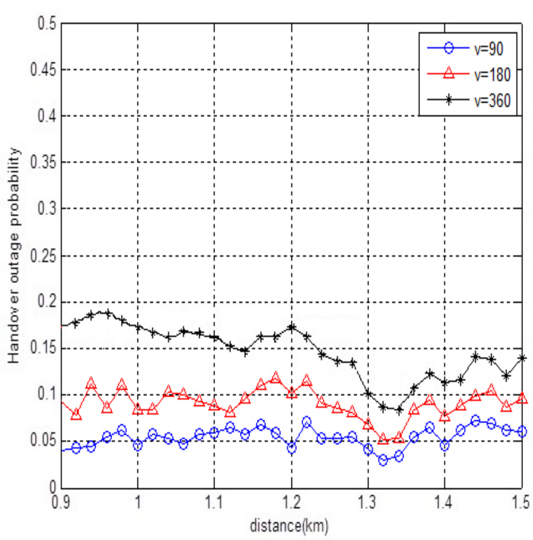

Fig.4 handover interruption probability under different rate

Fig.4 shows with the growth of the velocity, the interruption probability increases, because it is effected by the Doppler effect stronger. The quality of the signal is getting worse with the Doppler effect. With the rapid change of the cell, the transaction time decreases. So it is cline to interruption and leads to handover failure. The minimum handover interruption occurs at 1.33km. It can be concluded that at the appropriate position, the beginning of the handover can decrease the interruption probability.

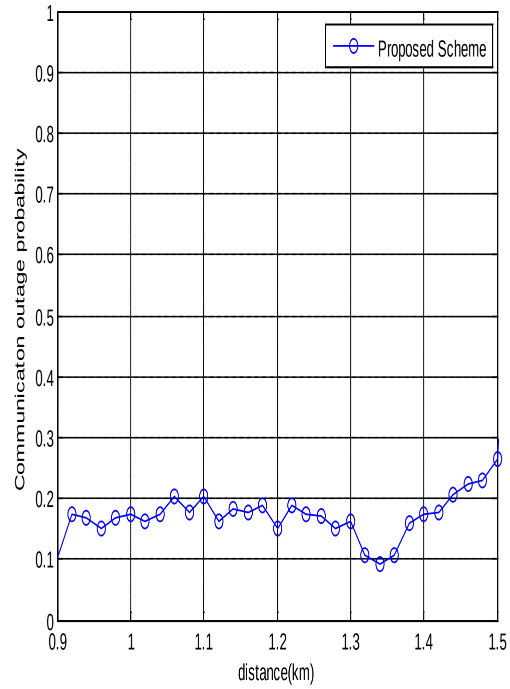

Fig. 5 communication interruption probability in the overlap of the cell

In Fig.5 the speed of the train is 360km/h. From the figure, to the edge of the cell, the probability increases. If we choose the reasonable engine to handover, the scheme in this paper can implement the seamless handover of high speed train.

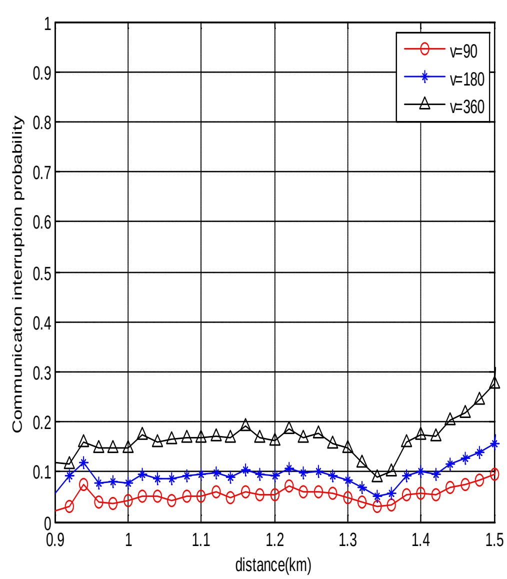

Fig.6 communication interruption probability under different speed

From Fig 6, it can be concluded that the speed of the train is a positive correlation with the communication interruption.

IV. FUTURE WORK

A. To be adaptive to the improvement of the speed of the train

*With the rapid increase of high-speed train, the velocity of the system brin*gs higher difficulty for the RCPS to collect the data in high speed accurately.

B. Efficient Larger Storage

More data should be stored in an instant of time. So it is necessary to improve the efficiency of memory system as well as enlarging the storage size.

C. High performance computing and communication

To deal with the situation according to the higher speed traffic, the RCPS should give the control and alarm information in time[6]. It is important to update the performance of the system to the new situations.

V. CONCLUSION

Cyber physics systems design for railway traffic need high performance communication. We give a framework of the RCPS and an optimal wireless handover approach on RCPS communication. It is beneficial to improve the performance and quality of communication in high speed railway system.

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