A Dual-antenna Based Handover Scheme for GSM-R Network

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***Abstract*—In the GSM-R (GSM for Railways) mobility management technology, handover is the crucial factor to maintain high reliability and validity of mobile communication. However in high-speed movement scenario where shorter handover latency is required, the traditional handover scheme which has been adopted in the GSM network could no longer guarantee high quality performance and results in higher probability of handover failure as a consequence. In order to solve such problem, we propose an innovative handover scheme based on dual-antenna technology for GSM-R network. The proposed scheme modulates the frame structure of Traffic Channel (TCH) in order to send measurement report more quickly and adopts more complicated signaling procedure to achieve seamless handover. Simulation results show that interruption time in the proposed scheme is effectively reduced compared with the conventional handover scheme and call dropping rate is also acceptable when the train speed achieves 500km/h. Therefore the proposed dual-antenna handover scheme guarantees better service quality in high-speed scenario.**

I. INTRODUCTION

Recently, the development of high-speed railway has caught the attention of countries all over the world. GSM-R (GSM for Railways) network is specialized in mobile communication and it has been adopted by many countries to serve for different railway systems. Since the safety of passengers and commodities is definitely the key consideration in the operation and management of railway system, the validity of GSM-R network is extremely important. Due to several special aspects in railway system such as linear coverage along railway, the high-speed scenario, special geographic conditions including valleys and channels, there are more and more requirements for GSM-R network from its network design to the transport of wireless signal. As a consequence, the construction of GSM-R network will be a huge challenge in the future.

Handover is the key technology in the mobility management of GSM-R network and it keeps wireless communication between the Base Station (BS) and Mobile Station (MS) from dropping. The effectiveness of the handover process in GSM-R network is crucial for improving the overall system and therefore it has become a research hotspot in wireless communication.

Handover is triggered by measurement report in GSM-R network. After that procedures including channel detection, channel selection and execution are needed to complete the whole handover process. When the train speed is low(under 100km/h), latency incurred in each procedure of the handover process is not too severe to influence the continuity of wireless communication. However, when the train speed increases the handover latency obviously appears to become a problem and results in communication disconnection between the BS and the MS in the train.

To reduce the handover latency, several schemes have been proposed in related literatures. In order to realize low handoff latency without increasing overhead in wired channel, a handover scheme using positional information is proposed in [1]. Some other schemes are based on Mobile IP to minimize handover latency [3]-[6]. A resource reservation scheme for handoff using location-aided mobility prediction is proposed in [15] which performs better than the solely distance-based scheme. In [10,11] schemes focused on the reduction of the latency incurred in scanning, channel detection and execution procedures are proposed, However a fast handover algorithm in [7] achieves shorter handover delay based on the information within the measurement report about the position and the speed of MS. A fast handover scheme that reduces the re-authentication latency is proposed in [2] so that neighboring APs could be authenticated in advance. All of the previous work mentioned above can solve some specific problems and reduce handover latency. However these handover schemes maintain the characteristic of hard handover, which means that the communication during the handover process could be disconnected for some time even though it will not cause high drop rate.

In this paper we propose a novel handover scheme for GSM-R network based on dual-antenna. The two antennas are mounted in the front and rear of the train respectively. Technically the two antennas work independently, but based on our assumption that BS can identify and distinguish the front antenna and the rear antenna, the dual-antenna system can work together and complete the whole handover process according to our handover scheme. Additionally the dual-antenna handover scheme turns the handover process to be a soft handover or seamless handover, which means that the communication between BS and MS will no longer disconnect during the whole handover process and therefore guarantee better wireless communication service. To achieve that we adapt the frame structure of Traffic Channel (TCH) and get two kinds of logical channels with different functions. Our scheme may be more complicated in its handover signaling procedure, but simulation analysis shows that such scheme could efficiently reduce both the disconnection time during the handover process and the drop rate.

The remainder of this paper is organized as follows: Section II introduces conventional handover scheme in GSM-R network and analyze drawbacks of the scheme in high-speed scenario. Section III provides the details of the proposed scheme including basic assumptions and modulation, while Section IV presents the simulation and performance analysis of our handover scheme. Finally we conclude the paper in Section V.

II. CONVENTIONAL HANDOVER SCHEME

A. Conventional Handover Process

The conventional handover scheme in GSM-R network is basically the same as that in GSM network. In the conventional scheme handover is completed through the communication between a single antenna (MS) and BS.

In the measurement procedure MS should keep sending measurement report to BS at a constant frequency. Then BS analyzes information within the received measurement report such as signal strength and determines whether handover should be triggered based on the handover criteria.

Different handover methods could be adopted in the conventional handover scheme, and we introduce three kinds of handover method [4]. They are summarized below:

The *Threshold* method initiates a handover when the average signal strength of the current BS is dropped below a given handover threshold Th_{HO}, and the signal strength of a neighboring BS is greater than that of the current BS. We denote $Lv(P)$ as the signal strength in the current BS and $Lv(N)$ as the signal strength in the neighboring BS, and the minimum signal strength for calling is designated as Th_{min}. Then the handover is triggered when the condition below holds:

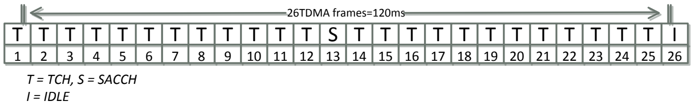
$$\begin{cases} Th_{min} < Lv(P) < Th_{HO} \\ Lv(P) < Lv(N) \end{cases} \tag{1}$$

The *Hysteresis* method initiates a handover only if the signal strength of a neighboring BS is higher by a given hysteresis margin to that of the current BS. Advantage of this method is that it prevents a so-called ping-pong effect, in which handovers occur back and forth between BSs, but still initiates unnecessary handoff when the current signal strength is sufficiently strong for communication. We denote Hm as the hysteresis margin. Then the handover is triggered when the condition below holds:

$$Lv(N) - Lv(P) = Hm \tag{2}$$

The *Threshold* with Hysteresis method combines the above two methods to initiate a handover when the signal strength of the current BS drops below the handover threshold THO, and the signal strength of a neighboring BS is higher by a given hysteresis margin to that of the current serving BS. Then the handover is triggered when the condition below holds:

$$\begin{cases} Lv(P) < Th_{HO} \\ Lv(N) - LV(P) = Hm \end{cases} \tag{3}$$



T	T	T	T	T	T	T	T	T	T	T	T	S	T	T	T	T	T	T	T	T	T	T	T	T	I
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26

T = TCH, S = SACCH
I = IDLE

Fig. 1. Frame Structure of TCH

After the measurement procedure, MS should execute the handover process, i.e. MS releases its current channel and connects to the activated channel in neighboring BS.

B. Latency Analysis

The conventional handover scheme performs well when the train speed is under $250km/h$. However in high-speed scenario where train speed reaches $500km/h$, it fails to guarantee normal service quality due to its inherent handover latency. To make it clear we briefly analyze latency incurred in each procedure of the handover process and we also need such analysis to build up the simulation model in section IV. We mainly focus on latency incurred in the measurement procedure and the execution procedure.

In the conventional handover scheme, latency incurred in the measurement procedure is given by:

$$T_m = \tau_m \times Hrequave \tag{4}$$

left τ_m denotes the time interval between two measurement reports are sent from MS to BS, and $Hrequave$ is usually 4 in GSM-R network. We can simply calculate τ_m according to the frame structure of TCH as shown in Fig. 1.

In the conventional handover scheme TCH is not only used to transmit encoded speech or data, but also used to transmit measurement report through Slow Associated Control Channel (SACCH) , and during the execution procedure Fast Associated Control Channel (FACCH) will be interpolated into TCH for necessary signaling. There is only one frame used for SACCH in TCH and the period of TCH is $120ms$, and we also know that it requires 4 SACCH to transmit a measurement report. Therefore we deduce that τ_m is $0.48s$ in the conventional handover scheme and T_m is about $2s$.

As for latency incurred in the execution procedure we can simply take it as a constant time and we denote it as T_e. According to measured data of K1205 Protocol Tester, T_e is $0.2s$ for handover between Base Transceiver Station (BTS), $0.532s$ for handover between Base Station Controller (BSC), and $1.358s$ for handover between Mobile Switching Center (MSC). Therefore the overall latency incurred in the single-antenna based handover process is given by:

$$T_h = T_m + T_e \tag{5}$$

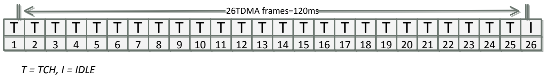


Fig. 2. Frame Structure of Full TCH

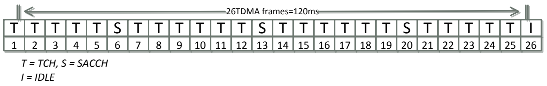


Fig. 3. Frame Structure of Hybrid TCH

When train speed goes beyond $300km/h$, signal strength along railway decreases so fast that the intrinsic handover latency appears to become unacceptable because signal strength could easily drop below the lowest level for communication during the handover process. As a consequence the conventional handover scheme cannot satisfy the demands of wireless communication in high-speed scenario.

III. DUAL-ANTENNA BASED HANDOVER SCHEME

In the conventional handover scheme, the single antenna (MS) should transmit both of the measurement report and encoded speech or data according to the frame structure of TCH and we believe that this is the key reason of the latency incurred in the measurement procedure and cause the disconnection during the handover process. Therefore we adapt the frame structure of TCH to distinguish the transmission of measurement report and encoded speech or data. Furthermore we allocate these two transmissions to the two antennas so that technically the two antennas perform different functions. Based on our basic assumption and the detail in the proposed handover scheme, the two functional antennas could complete seamless handover process collaborately.

A. *TCH Modulation*

To fully take the advantage of dual-antenna system, we modulate the frame structure of the original TCH and get two kinds of functional TCH.

The first kind of TCH is only in charge of the transmission of encoded speech or data. We can simply replace SACCH in the 13th frame with TCH and we call it Full TCH as shown in Fig. 2.

The second kind of TCH performs almost the same as the original TCH except that the number of SACCH in it is increased and therefore the measurement report is sent more quickly. We call it Hybrid TCH as shown in Fig. 3.

Since there are more antennas and different kinds of TCH in our system, the handover process is inevitable more complex than the conventional process. The two antennas will switch between Full TCH and Hybrid TCH during handover.

B. *Proposed Scheme*

First of all, we assume that in our handover scheme the International Mobile Subscriber Identification Number (IMSI) of the front antenna and the rear antenna should be related. After they have access to GSM-R network, Visitor Location Register (VLR) could identify the two antennas and guarantee that the dual-antenna system collaborate with BS and complete the whole handover process. The dual-antenna system model [12]-[14] is shown in Fig. 4.

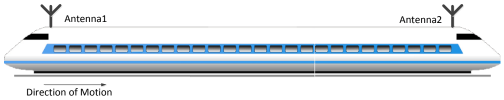


Fig. 4. Dual-antenna System

We denote the front antenna as A_1, and the rear antenna A_2. During each handover process we denote the current and the next BS as BS_1 and BS_2, respectively. The detailed dual-antenna handover scheme is as follows:

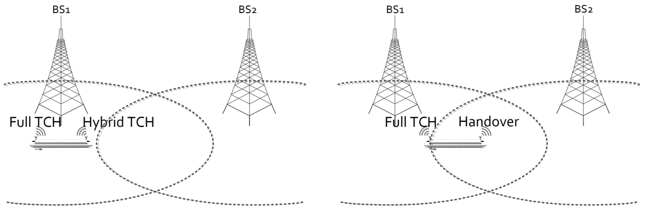
(1) At first, the train is within the coverage area of BS_1 as shown in Fig. 5 (a). A_1 connects to Hybrid TCH for transmitting measurement report while A_2 connects to Full TCH for transmitting encoded speech or data.

(2) When the train proceeds to the overlapped area of BS_1 and BS_2 as shown in Fig. 5 (b), handover should be triggered by the measurement report transmitted by A_1, and therefore A_1 executes its handover process which is similar to the conventional handover process. However the difference is that A_1 should activate two Full TCHs and one Hybrid TCH in BS_2 to prepare for the following handover process. After that A_1 connects to Full TCH in BS_2 while A_2 still keeps communication with BS_1.

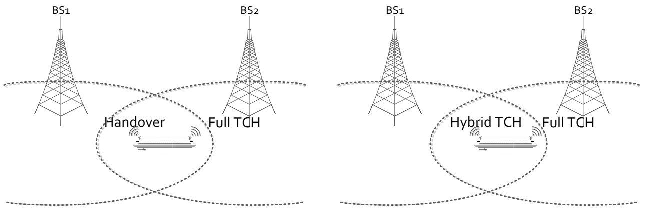
(3) After A_1 finishes its handover, BS_1 releases the corresponding channel and then triggers the handover process of A_2 automatically. A_2 directly connects to Hybrid TCH in BS_2 because A_1 has already activated channels in BS_2. Meanwhile A_1 connects to Full TCH in BS_2 so that it can take charge of the communication with BS. The process is shown in Fig. 5 (c).

(4) A_2 can complete the whole handover process extremely quickly because it does not need measurement and triggering procedure, and its channel is also pre-activated by A_1. Considering that A_2 may not receive enough power to communicate with BS when it finishes handover, so it starts to send measurement report to BS so that BS could determine whether its signal strength is adequate for communication. That is to say measurement report transmitted by A_2 will trigger another *handover* process.

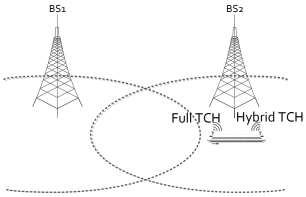
(5) The so called *handover* is not actually the same concept as its original definition. It is just a process that both of the antennas switch their current TCH to the initial status. Recall that A_1 activates an additional Full TCH during its handover. So A_2 directly connects to the additional Full TCH and release Hybrid TCH. A_1 follows A_2 and connects to the released Hybrid TCH. Then A_2 is in charge of transmitting encoded speech or data again while A_1 transmits measurement report. Finally the dual-antenna system completes a whole period of



(a) Handover Process-1 (b) Handover Process-2



(c) Handover Process-3 (d) Handover Process-4



(e) Handover Process-5

Fig. 5. Handover Process

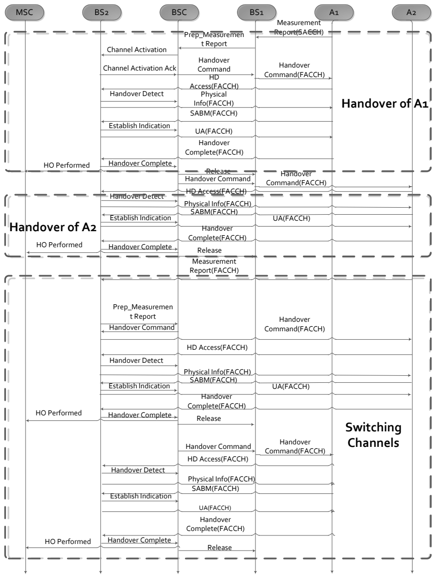


Fig. 6. Signaling Procedure of The Proposed Scheme

handover as shown in Fig. 5 (e).

The signaling procedure is shown as Fig. 6.

C. Insight Analysis of The Proposed Scheme

Even though the dual-antenna handover scheme is much more complicated than the conventional scheme, we can clearly see its main advantages by analyzing some of its substantial characteristic and crucial process.

(1) Consider the handover of A_1. Since measurement report is sent more quickly, latency incurred in measurement procedure is effectively reduced by at least 50%. After handover A_1 could be directly used for transmitting encoded speech and data.

(2) Consider the handover of A_2. The handover is completed very quickly within 1 second.

(3) According to the length of the train $(200m)$ and the train speed $(350km/h)$, A_2 starts handover 2 seconds later than A_1. Combined with (1) and (2), we can deduce that at any time during the handover process at least one antenna can be used to transmit encoded speech or data and therefore achieve seamless handover.

(4) There are two kinds of measurement report within the proposed scheme. The first kind is sent by A_1 which is used for BS to determine whether to trigger the handover of A_1. The second kind is sent by A_2 which is used for BS to determine whether the power level received by A_2 is adequate for communication. The basic assumption in our scheme could guarantee that BS identify and distinguish these two kinds of measurement report.

To sum up, we can see that the main differences between the proposed scheme and the conventional one are: After the modulation of TCH, measurement report is sent more quickly; Dual-antenna system collaborates with BS to complete handover and eventually achieves seamless handover.

IV. SIMULATION AND PERFORMANCE ANALYSIS

To evaluate the performance of the proposed handover scheme, we first build up simulation model of the proposed scheme considering propagation model, shadowing effect and determine specific parameters during the simulation. Then we simulates both of the conventional scheme and the proposed scheme adopting the three handover methods respectively. At last we analyze simulation results.

A. Simulation Model

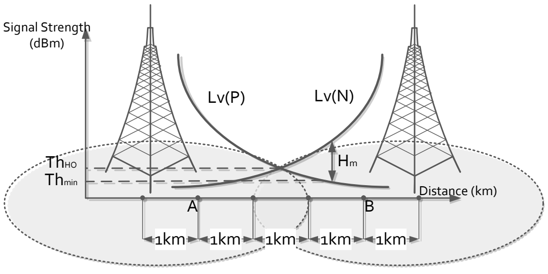
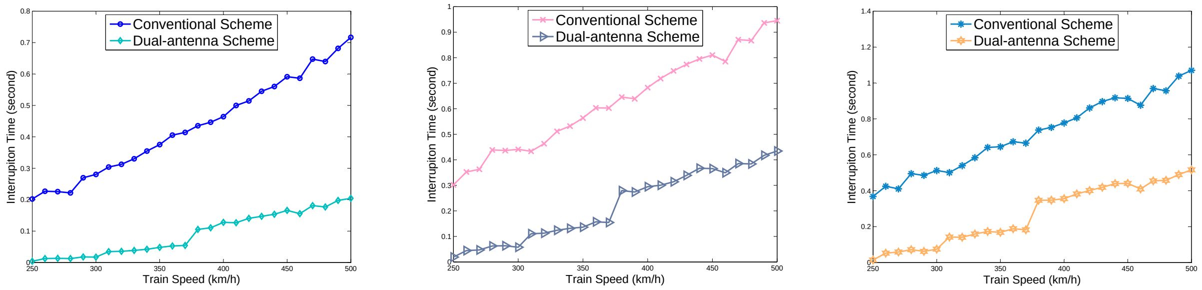


Fig. 7. Handover Scenario

According to the wireless channel model [8] in GSM-R network we build up the simulation model for the proposed scheme and simulates the handover process when the train moves from point A to point B in Fig. 7. When conducting

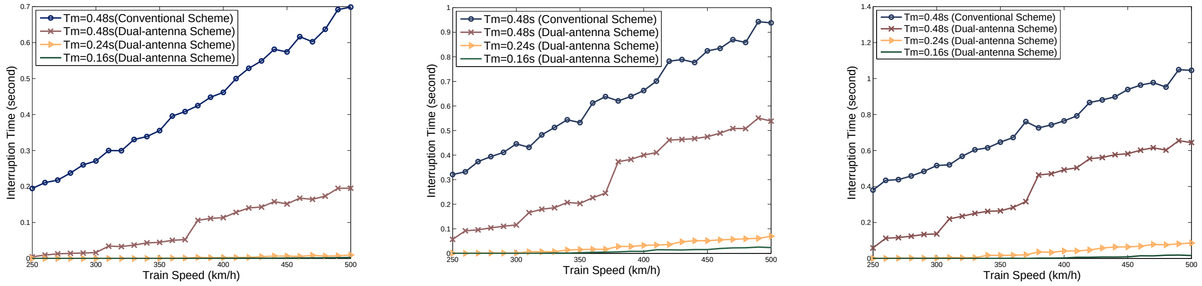


(a) Threshold Method

(b) Hysteresis Method

(c) Threshold+Hysteresis Method

Fig. 8. Interruption Time When Different Handover Method Is Adopted



(a) Threshold Method

(b) Hysteresis Method

(c) Threshold+Hysteresis Method

Fig. 9. Interruption Time of Different τ_m

the simulation we generate signal strengths at each point along the path from A to B. For a realistic view, the simulation follows the Hata Model for path loss calculation and we also add shadowing effect into consideration [9]. Therefore signal strengths along the path are given by:

$$\begin{aligned} L(d) &= K1 + K2 \log_{10} d + \varepsilon \\ &= -75 - 35 \times \log_{10} d + \varepsilon \end{aligned} \tag{6}$$

where d denotes the distance between MS and the serving BS, and ϵ denotes the Gaussian-distributed random variable that $\epsilon \sim N(0, 8dB)$ representing shadowing effect.

It is also necessary to elaborate the calculation of latency incurred in the handover process of A_1 and A_2 since the overall handover latency results from each handover process of A_1 and A_2(we ignore the latency within the third handover process where antennas switch TCH according to the scheme).

Since the handover of A_1 is triggered by measurement report transmitted through Hybrid TCH, its latency is given by:

$$T_h = 4 \times \tau_m + 1.358 \tag{7}$$

$$\tau_m = 0.48/n \tag{8}$$

where n denotes the number of SACCH in Hybrid TCH.

Handover latency of A_2 is a constant time and we set it as $0.441s$ according to measured data.

Important parameters in the simulation model are summarized in Table I.

TABLE I
PARAMETERS IN SIMULATION MODEL

Radius of BS	$3km$
Th_{drop}	$-92dBm$
Th_{min}	$-90dBm$
Th_{max}	$-75dBm$
Th_{HO}	$-89dBm$
K_1	-75
K_2	-35

B. Simulation Results and Performance Analysis

We simulate the handover process of a train for 1000 times, and each time the speed of the train ranges from $250km/h$ to $500km/h$. Signal strengths at each point along the path has been determined by the simulation model and therefore handover of A_1 and A_2 could be triggered and performed according to the handover methods adopted. After each simulation we calculate two important indexes, interruption time and call dropping rate, to evaluate the performance of the proposed scheme.

In our simulation we define interruption time as the disconnection time between MS and BS. In conventional handover scheme interruption time could not be eliminated and therefore cause the call quality to deteriorate in high-speed scenario, and call dropping rate is also very high in this situation. However we can see from the results of our simulation that the proposed scheme could effectively reduce interruption time and guarantee a much better call quality. Simulation results

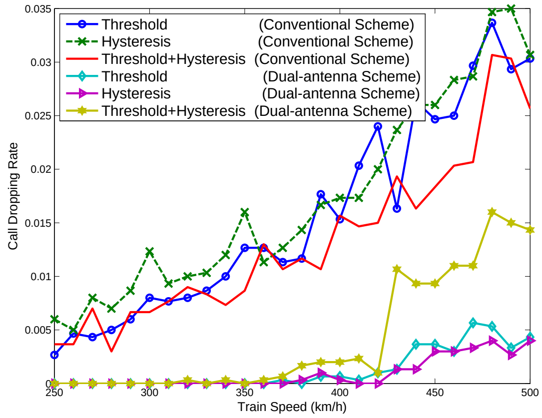


Fig. 10. Call Dropping Rate When Different Handover Scheme Is Adopted

about interruption time are shown in Fig. 8 and three kinds of handover methods are adopted in the simulation respectively.

According to the simulation results, no matter what kind of handover method is adopted, interruption time is dramatically reduced by over 50% in our proposed handover scheme.

Recall that we discuss the relation between τ_m and handover latency in simulation model which means that τ_m in our proposed scheme may have an impact on interruption time. Therefore we also needs to determine a suitable τ_m in order to achieve better performance. We choose τ_m to be $0.48s$, $0.24s$ and $0.16s$ by adjusting the number of SACCH in Hybrid TCH and simulation results are shown in Fig 9. When τ_m are reduced from $0.48s$ to $0.24s$ interruption time has a huge decrease. But when τ_m are reduced to $0.16s$ interruption time just decreases slightly while the overall burden of wireless channel may be increased due to the high frequency of measurement report. In our scheme we choose $0.24s$ as the suitable τ_m, i.e. there are two SACCHs in Hybrid TCH.

We should also evaluate the dropping probability because it is an index directly related to service quality. According to specification in GSM network call dropping rate should be within 1% when the system is normally working. We set τ_m as $0.24s$ and simulates the three handover methods.

Simulation results in Fig. 10 show that when the train speed is beyond $300km/h$, call dropping rate obviously exceeds 1% if the conventional scheme is adopted. However in the proposed scheme call dropping rate remains within 1% even train speed reaches $450km/h$.

To sum up, simulation results show that compared with the conventional scheme, the proposed dual-antenna handover scheme could effectively reduce interruption time and guarantee lower call dropping rate, therefore provides better service quality. We also determine the suitable τ_m to help the system achieve better performance.

V. CONCLUSION

In this paper, we have proposed a novel handover scheme based on dual-antenna system for GSM-R network. Different from the conventional scheme we use two functional TCH so that the dual-antenna system could collaborate and achieve seamless handover. Through simulation and performance analysis we prove that the proposed handover scheme is effective in high-speed scenario since it can reduce interruption time by more than 50% and keep call dropping rate within 1% when train speed reaches $500km/h$. Therefore the proposed dual-antenna handover scheme guarantees better service quality in GSM-R network.

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