Optimization of Adaptive Handover Algorithm Based on Distributed Antenna in LTE-R

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Abstract. In the high-speed railway, the traditional handover algorithm uses a fixed handover hysteresis threshold, which will result in a lower success rate of the train when the train is traveling at a high speed, and cannot meet the wireless communication needs of the passenger. According to the distribution of antennas in the high-speed railway and the analysis of the handover process and measurement parameters, an adaptive handoff algorithm based on distributed antenna is proposed. For the deployment of antennas in high-speed railways, a distributed approach is adopted, and the RAUs with the best quality are selected to maintain the connection. In the process of switching, the hysteresis threshold value of switching is dynamically adjusted at different positions according to different speeds, and the success rate, interruption probability and average value of switching are simulated and compared. Simulation results show that in the case of distributed antenna deployment, handover threshold is dynamically adjusted according to different speeds to reduce the interruption probability of handover, and the success rate of handover is significantly improved, but the average number of handover will increase correspondingly, which can meet the requirements of passengers for wireless communication system in high-speed railway.

1. Introduction

With the rapid development of high-speed railways in China, passengers are increasingly demanding mobile communication requirements and enjoying good voice and broadband data services. The current GSM-R railway communication can no longer meet the development direction of the future railway two-way, real-time, large-capacity, especially the user's call experience is significantly different. UMTS (Universal Mobile Telecom System) Long Term Evolution (LTE) is a new generation of broadband developed by the 3rd Generation Partnership Project (3GPP) team to meet the needs of users for further improvements in wireless broadband speed. The wireless mobile communication standard, the International Union of Railways (UIC), has clearly stated that railway-specific wireless communications will be directly transitioned from GSM-R to 4G LTE-R [1-6].

Distributed antenna system is applied to railway system to enhance coverage, improve user SNR, and improve wireless communication system performance. Distributed antenna system is a multi-antenna system with a wider range of applications and stronger adaptability, which can better play its role in railway system. [7]. In the scenario of frequent handover of high-speed railways, the speed will lead to a rapid change of path loss. At this time, it is unreasonable to use the same RSRP and RSRQ handover decision delay tolerance for mobile terminals of different speeds. When the train speed is fast, it takes a short time to pass through the overlapping area, so it needs to switch the threshold value of the situation and the time. When the speed is low, it takes a long time to pass through the overlapping area,
so the hysteresis tolerance needs to be increased to avoid ping-pong switching caused by premature switching. Therefore, based on the speed characteristics, the adaptive algorithm is used to dynamically adjust the RSRP and RSRQ hysteresis tolerances to optimize the value of the hysteresis tolerance.

2. Handover Planning
In the high-speed scene, effective switching model planning for train switching can make the train switch faster and more efficiently, reducing the probability of failure. The planning of the switching area in this paper is shown in Figure 1:

![Figure 1. Handover model](image1)

![Figure 2. Coordinate system model](image2)

When the UE traverses the coverage areas of the two CCSs, after receiving the measurement report sent from the radio station, the CCS selects a neighboring RAU with the best received signal quality from the pre-stored neighbor cell list to maintain the connection. The handover request message is sent from the serving CCS to the target CCS. After the target CCS performs access admission control on the user information carried in the handover request message, the handover request confirmation message is sent to the serving CCS. The serving CCS then sends a handover command message to the UE. After receiving the handover command message, it begins to establish an underlying connection with the target RAU on the new wireless channel. The coordinate system model of the switching process is shown in Figure 2:

The distance between the two RAUs is 2km, the base station is 0.5km away from the rails, and the coverage of the two cells is 0.8km - 1.2km, so the sampling starts from 0.5km, the sampling ends at 1.5km, and the switch starts at 0.8km. From the starting point, the horizontal coordinate of the program simulation is [0.8, 1.5].

Table 1 shows the reference variables and reference values in the handover model:

| Simulation parameter          | symbol | Value       |
|------------------------------|--------|-------------|
| Base station power           | $P_{eNB}$ | 44dBm      |
| Base station antenna height  | $H$    | 30m         |
| Train speed                  | $V$    | 120/350km/h | 2km        |
| Base station spacing         | $D$    | 2km         |
| Overlap area length          | $D_1$  | 0.4km       |

3. ADAPTIVE HANDOVER ALGORITHM BASED ON DISTRIBUTED ANTENNA
In high-speed rail scenarios, periodic measurement reports cannot be triggered in time due to poor signal quality. In order to avoid this, consider using the position information of the train as a condition for triggering measurement reporting [9]. According to the characteristics of the high-speed railway scene, the following vehicle trajectory is fixed, the direction can be predicted, and the like, when the train travels to the specific position of the base station covering the overlapping area, as the trigger condition for the first reporting. If the base station is deployed in the center of the coverage area of the base station to enhance the signal, the trigger position is selected according to:

$$10 \log_{10}(R_{(x1)}) - 10 \log_{10}(R_{(x2)}) = H$$ (1)
Where $R_{1\text{,}x}$ is the signal quality of the target base station at the point $x$, $R_{\text{1\text{,}a}}$ is the signal quality of the serving base station at the point $x$, and $H$ is the hysteresis threshold.

3.1 Handover measurements

The handover includes three phases: handover measurement, handover decision, and handover execution.

In the handover measurement phase, the high-speed train needs to perform layer three filtering on the received signal before the handover departure judgment. Layer three filtering can effectively reduce ping-pong switching. The performance of layer three filtering is:

$$F_n = (1-\gamma)F_{n-1} + \gamma M_t, \gamma = T_m/T_u \quad (2)$$

Where $F_n$ is the calculation result of this filtering: $F_{n-1}$ is the filtered measurement result reported by the previous measurement period; $M_t$ is the layer-filtered measurement value (point B); $\gamma$ is the layer three filter factor, $T_m$ is the layer-one filter period, and $T_u$ is the d-layer three-Filter period[1].

The UE performs related measurement according to the measurement configuration message sent by the CCS, and reports the measurement result to the CCS. This paper chooses the open channel model (Hata model) as:

$$L_{\text{bs}} = 69.5 + 26.16 \times \log_{10}(f) - 13.82 \times \log_{10}(h_{\text{b}}} - 2[\log_{10}(f/28)]^2 - 5.4 + X_d \quad (3)$$

Where $d$ is the same frequency interference: $X_d = \sqrt{(d+10)^2+(h_{\text{b}})^2}/10^\gamma$, Where $d$ is the location where the handover occurs, $d \times v \times t \times n$, a function of speed, $t$ is the switching time, and $n$ is the number of handovers. Normally, $n=2$ is considered, that is, the handover is successful twice.

The handover parameters discussed in this paper are based on RSRP and RSRQ. RSRP refers to a mobile terminal receiving received power from a base station. The larger the RSRP value, the higher the signal strength. RSRQ means that the mobile terminal receives the pilot signal reception quality from the base station, and its expression is as follows:

$$\text{RSRQ} = N \frac{\text{RSRP}}{\text{RSSI}}$$

Where $a$ is $N$ coefficient introduced during the measurement process to compensate for the difference in RSRP and RSSI bandwidth[3]. The RSSI is specifically the average of the measured sizes of all received carrier frequencies in the entire network bandwidth. In the conventional handover decision using RSRP, the trigger condition of the handover is that the received target base station signal power is higher than the serving base station by a fixed hysteresis threshold. Since the value of the received signal power is determined by the base station transmit power, path loss, and shadow fading, and the base station transmit power is generally equal, the received signals from the destination base station and the serving base station are respectively: the signal quality of the train receiving the service base station:

$$P_{(j,a)} = P_{\text{b},\text{NB}} - PL_{(j,a)} - A_{(j,a,\text{d})} \quad (3)$$

the signal quality of the train receiving the destination base station:

$$P_{(j,x)} = P_{\text{b},\text{NB}} - PL_{(j,x)} - A_{(j,x,\text{d})} \quad (4)$$

3.2 Handover trigger probability

During the handover decision phase, the CCS evaluates according to the measurement result reported by the UE, and determines whether to trigger the handover. Switch trigger decision conditions:

$$P_t = P_{t|\text{a}} = P_{\text{x}} = P_{\text{y}} = H \quad (5)$$

Where $P_{t|\text{a}}$ is the signal quality of the target base station at point $x$, $P_{t|\text{a}}$ is the signal quality of the serving base station at point $x$, $H$ is the hysteresis threshold, and is related to the position of the train, $A$ represents the shadow fading obeying the normal distribution, f-means is 0 and the variance is $\sigma$.

The condition for triggering the handover is that $\text{RSRP}$ received by the in-vehicle relay from the target cell is higher than $\text{RSRP}$ received by the current serving cell by a hysteresis H (dB).

$P_t$ is the probability that a handover occurs at time $t$. $P_{\text{b},\text{NB}}$ is the probability of switching from the serving cell to the target cell, $P_{\text{b},\text{C}}$ is the probability of switching from the target cell to the serving cell, and $P_{(t)}$ and $P_{(t)}$ respectively indicate the probability that the current cell is the serving cell and
the target cell. Then the probability of the current cell is:

\[ P_t(t) = P_t(t-1)(1-P_{30}(t)) + P_t(t-1)P_{30}(t), \]
\[ P_s(k) = P_s(k-1)P_{30}(k) + P_s(k-1)(1 - P_{42}(k)) \]  
(6)

Then the handover probability can be expressed by:

\[ P_h(t) = P_t(t-1)P_{30}(t) + P_t(t)P_{30}(t) \]  
(7)

The link interruption probability is that when the received signal strength of the current serving base station is less than the minimum threshold \( H \) of the guaranteed communication, the communication link is interrupted. The lower the probability of the link's outage, the better the switching performance of the system. Here we use \( P_o \) to indicate the outage probability of the handover, then the expression of \( P_o(t) \) is as follows: (better evaluation of the power allocation scheme in the distributed antenna system.)

\[ P_o(t) = Pr\{P_{i,x} < T\} + Pr\{P_{j,x} < T\} \]  
(8)

3.3 Handover success rate

After the train terminal is successfully triggered, it enters the handover execution phase. When the train passes the delay trigger, if the handover condition is still met, the handover is performed. During the handover execution, the average signal strength received by the target base station needs to be met, which is greater than the minimum strength threshold of the communication. The CCS controls the UE to handover to the target cell according to the decision result, and finally completes the handover by the UE. Execution rate during train switching:

\[ P_s(t) = \frac{1}{v_{t2}} \int_{x_1}^{x_2} P_{i,x}(F_{j,x}(x) > L)dx \]  
(9)

Where \( x_1 \) is the location at which the base station performs the handover command; \( t_2 \) is the time required to switch the execution process [1]. Switching success rate: Since the train may not be successfully switched during the switching process, it is necessary to perform two or even multiple switching to ensure the success of the handover. The probability of successful handover is subject to the binomial distribution. The probability that the train will switch successfully once is \( P_s(t) = P_{i,x}(t) \cdot P_s(t) \) (10). If one handover is not successful, a second handover is performed, and the success rate of the secondary handover is represented by \( P_{s2}(t) = (1 - P_{i,x}(t))P_{s2}(t) \cdot P_s(t) \) (11). Then the probability of the train switching from the serving cell to the destination base station is:

\[ P_s(t) = \sum (P_{i,x}(t) + P_{s2}(t)) \]  
(12)

4. Simulation Results

4.1 Handover success rate simulation

![Handover success rate comparison](image1)

Figure 3. Handover success rate comparison

![Interrupt probability comparison](image2)

Figure 4. Interrupt probability comparison

Figure 3 shows the switching success rate of the traditional scheme and the improved scheme when the train is in different positions. As shown in the figure, when the speed is 120km/h and 350km/h, the success rate of the improved algorithm is higher than that of the traditional scheme, and it reaches the
maximum at 1.2km, which is increased by 2.7 and 3.6 respectively. It is obvious. Because the base is in a different position from the train, the adaptive adjustment of the hysteresis tolerance makes the switching trigger more fast and accurate, so that it can be switched more quickly.

4.2 Interrupt probability simulation

Based on the difference in speed, the delay threshold of the relay is adjusted, and the probability of interruption of the handover between the train and the source base station is as shown in the figure above. Since the position of the train is different at the speed of the no-pass, the probability of interruption of the handover is also different. It can be seen from the above figure that when the speed is 120km/h and 350km/h, the probability of interruption of the improved scheme is reduced compared with the probability of interruption under the traditional scheme. At 1.2km, the probability of interruption is reduced from 0.7 to 0.1. For trains in high-speed environments, the increase in the probability of interruption will greatly reduce the call drop rate of users and increase the user's Qos experience.

5. Conclusion

According to the different speeds of trains in high-speed environment and different locations at the same time, an adaptive handoff algorithm based on distributed antennas is proposed. The deployment of the distributed antenna is used to establish a handover model, and the handover threshold is dynamically adjusted according to the speed. The values of RSRP and RSRQ under the traditional algorithm are compared, and the handover success rate, the interruption probability and the average handover number are compared. Algorithm verification and simulation. The simulation results show that the distributed adaptive handoff algorithm improves the success rate of handover and greatly reduces the interruption probability of handover, which ensures that the current wireless communication system Qos technology of China's railways has a handover rate greater than 99.5% required, but the average number of handovers has increased. Therefore, the adaptive algorithm optimization based on distributed antenna is more suitable for the choice of handover in high-speed scenarios, which provides the necessary technical support for the future application of LTE-R system in railway.

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