Handoff for Wireless Networks with Mobile Relay Stations

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***Abstract*- Wireless Relay networks have become very important technologies in the future wireless systems. Current research works mostly focus on scenarios where relay stations are either stationary or mobile with uniform velocity. However, in many applications, relay stations are mobile with irregular patterns. In particular, when mobile relay stations (MRSs) are deployed to complement the cellular systems, many issues such as handoff should be carefully investigated. In this paper, we focus on the handoff problem and propose a new handoff decision algorithm based on the relative velocities of user equipment (UE) to the serving access point (AP) and the target AP. We have show that the proposed handoff algorithm can significantly improve the handoff successful rate when the mobile relay station changes its moving patterns.**

***Keywords*: Handoff; Mobile relay stations; cellular systems.**

I. INTRODUCTION

A wireless cellular network is typically organized into geographical regions called cells [1]. Normally one cell is covered by one base station (BS) and a user equipment (UE) in the cell connects with the network to the BS directly. The communication continuity is guaranteed by handoff mechanism when the UE passes through different cells. With demand on high data rate, the traditional cellular network may not be able to provide the desired bandwidth when the UE and the BS are far apart (say, the UE is near the boundary of the cell). To provide high data rate connections between the UE and the BS, some relay station may be used to relay the data with potentially higher data rate. The envisioned applications of relaying stations in the traditional cellular systems lead to the multi-hop cellular networks [13]. Thus, the deployment of relay station (RS) becomes an important strategy in increasing data rate while preserving the coverage that cellular systems bring to us in the future wireless systems [8]. One type of RSs is the mobile relay stations (MRSs), which is installed on the high-capacity vehicle such as the high-speed rail systems (HSR). If such MRSs are integrated into cellular systems, UEs will have a new way to connect to the cellular systems, correspondingly we have to examine how this would impact the cellular system management. One of the important issues would be the mobility management. One natural question is how a UE should choose the BSs, including the MRSs, during the handoff process. This is the problem to be addressed in this paper.

As in the traditional wireless cellular networks, handoff management is extremely important in the wireless cellular networks with MRSs. Handoff schemes based on hysteresis margin and time-to-trigger are used in the GSM Standard [2], the PCS standard [3] and the LTE standard [4] to make more accurate handoff decision and avoid ping-pong effect. Unfortunately, it is not efficient to reduce the handoff failure rate when UEs are moving with high speed.

The effects of the terminals or UEs moving velocities on handoff performance have been studied in [5] [6]. It has been shown that early handoff for high moving UEs can decrease the call drop and delayed handoff for low moving UEs can avoid ping-pong effect. By predicting which cell is the target cell based on the direction and velocity of a UE, the target cell can prepare the handoff for the UE in advance [7]. However, this method is not effective in the wireless networks with MRSs, which cause dynamic topology changes and make it more difficult to predict the target cell for a UE for future handoff. The study in [9] offers a handoff algorithm which adapts the hysteresis margin with the UE velocity. This algorithm avoids both call drop for high moving UEs and unnecessary handoffs for low velocity UEs, respectively, but it is difficult to make appropriate adaptation. On the other hand, the studies in [5][6][7][9] are for the traditional cellular networks and assume UEs move in constant velocity. When MRSs are deployed, more complicated mobility model will be introduced into the networks. Here, handoffs are caused not only by the movement of a UE, but also by the movement of the MRS connected to the UE.

Lately, there are also some studies on the handoff issue in wireless networks with MRS [10] [11]. Although the proposed methods can improve the handoff performance of UEs moving with the MRS in constant velocity, they have not addressed the situation that the UEs have connected to the MRS but not moved with the MRS. When UEs are connected to an MRS which is moving away from them with high speed, the connected calls to the MRS can be easily dropped, which means that a group of UEs connected to the MRS will most likely drop their calls when the MRS changes its state from the static state to the moving state. In this paper, we focus on this scenario and propose a new handoff algorithm based on the UE relative velocities to the serving AP and the target AP to increase the handoff successful rate when the MRS changes its moving pattern.

The rest of this paper is organized as follows. In Section 2, we present the detail of the proposed relative velocity aided handoff algorithm (RVAH). Section 3 describes the system simulation models. The performance results are presented and discussed in Section 4. A concise conclusion in Section V summarizes the gain from the new proposed handoff method and future perspectives.

II. HANDOFF METHOD AIDED BY UE RELATIVE VELOCITY TO SERVING AP AND TARGET AP

A. What are the problems for UE handoff in the wireless network with MRSs?

Relay stations can be classified into fixed relay stations and mobile relay station (MRS) according to the moving state of a relay station. However, a MRS may not always move and may experience various kinds of moving patterns. For example, a MRS located on the high-speed vehicle may change its role from a fixed relay station (when it stops to pick up customers) to mobile relay station (when it is moving again). Such moving state changes for an MRS will occur frequently from stop to stop. Before presenting the proposed relative velocity aided handoff algorithm (RVAH), we first analyze the characteristics of the MRS movement at a railway station as shown in Figure 1.

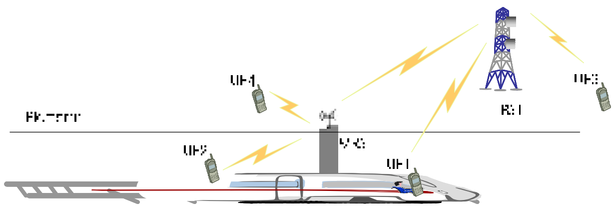

Figure 1. Typical Scenario

Firstly, the coverage areas of a BS and an MRS should include both the platform and the cars of the train in order to avoid call drop when a UE moves between the platform and the cars on the train.

Secondly, the system capacity can be improved if a static MRS on the train also provides services to the UEs on the platform. This means that the UEs on the platform can access either the BS near the platform or the MRS in the train currently stopping and picking up customers.

Thirdly, the user density in train stations is usually high and most of the users are static or moving with low velocity. So how to reduce the ping-pong effect in such scenario is important.

Fourthly, different from the traditional cellular networks, the instantaneous speed change of an MRS in such a scenario will very likely result in handoff failure for a large group of UEs. Thus, handoff should be made as quickly as possible when the MRS starts moving because the train will soon reach a very high speed especially for high speed rails.

Finally, normally there are more than one vehicles stopping at a train station or passing through a train station. So it is reasonable to assume that there are more than one MRS that can be accessed by a UE on the train platform. How a UE avoids accessing/connecting to a relay station passing by should be considered in order to reduce ping-pong effect.

Based on these observations, we propose a relative velocity aided handoff algorithm (RVAH), which utilizes the UE's relative velocities to the serving access point (AP) and the target AP to aid the handoff decision making, where the AP here refers to a base station, fixed relay station, or mobile relay station.

Considering the UE's relative velocities to all APs, including serving AP and the adjacent APs, if the relative velocities of UE to all possible accessing APs are lower than a threshold, the traditional handoff algorithms based on the hysteresis margin (HOM) and time-to-trigger (TTT) mechanisms will be used. Otherwise, the UE should avoid accessing/connecting to the AP with high relative velocity (higher than the threshold). The detailed RVAH is explained as follows.

B. Basic scheme for the relative velocity aided handoff method (RVAH)

1. In the scenario where an MRS frequently visits, such as a railway station, the network broadcasts to the UE that RAVH handoff method will be used. The broadcast message also carries some parameters which are needed in the handoff decision making process, including the relative velocity threshold V_0. The message can be broadcasted by the MRS or by the fixed AP in the scenario.
2. A UE will receive the broadcast message when it enters the area. Then, the UE will measure the adjacent APs including the serving AP. The UE measures parameters such as the RSS (Received Signal Strength) from a AP and the relative velocity to a AP. The UE will maintain the state of possible accessing APs according to the measurements.
3. The UE in the connected state should make the handoff decision based on the HOM and TTT mechanisms if it detects that its relative velocities to the serving AP and the target AP are all lower than the threshold V_0.
4. The UE in the connected state should initiate the handoff procedure immediately if it detects that the relative velocity to the serving AP becomes greater than the threshold V_0. Those accessible APs whose relative velocity is lower than the threshold V_0 should be chosen as the target AP.

C. Handoff trigger algorithm for RVAH

Let the logic variable E_d^l denote whether or not the RSS E_d at the target AP is strong enough to enable a UE to access. If the condition is satisfied, then let $E_d^l = 1$. Otherwise, $E_d^l = 0$.

Let the logic variable E_m^l denote whether or not the RSS E_d at the target AP comparing to the RSS E_s at the serving AP satisfies the condition: $E_d \geq E_s + H_0$, where H_0 is the handoff hysteresis margin. If the condition is satisfied, let $E_m^l = 1$. Otherwise, $E_m^l = 0$.

Let the logic variable T^l denote whether or not the condition $E_d \geq E_s + H_0$ is satisfied for longer than T_0 seconds, where T_0 is the threshold of time to trigger the handoff. If yes, $T^l = 1$. Otherwise, .

Let the logic variable V_s^l denote whether or not the UE's relative velocity to the serving AP is lower than the threshold V_0 . If the condition is satisfied, let $V_s^l = 1$. Otherwise, $V_s^l = 0$.

Let the logic variable V_d^l denote whether or not the UE's relative velocity to the target AP is lower than the threshold V_0 . If the condition is satisfied, let $V_d^l = 1$. Otherwise, $V_d^l = 0$.

According to the RVAH, a UE should initiate the handoff when it detects its relative velocity to serving AP is greater than the threshold V_0 , and try to choose the relatively static AP as the target AP, otherwise it should initiate the handoff when the condition $E_d \geq E_s + H_0$ is satisfied for T_0 seconds. So the five-variable Karnaugh map can be used to describe the handoff logic of RVAH as table I.

TABLE I
KAMAUGH MAP OF RAVH

$E_d^l E_m^l T^l$ \ $V_s^l V_d^l$	000	001	011	010	110	111	101	100
00	**0**	**X**	**X**	**X**	**0**	**1**	**X**	0
01	**0**	**X**	**X**	**X**	**1**	**1**	**X**	1
11	**0**	**X**	**X**	**X**	**0**	**1**	**X**	0
10	0	X	X	X	0	0	X	0

Note: 001, 011, 010 and 101 are not possible value of $E_d^l E_m^l T^l$. In order to avoid the ping-pong effect, the UE should better not initiate handoff when the condition $V_s^l V_d^l E_d^l E_m^l T^l = 10111$ is satisfied.

Let F_h denote the logic function for a handoff decision of RAVH, and $F_h = 1$ means that the UE should initiate handoff. So the handoff logic function of RAVH can be described as equation (1)

$$F_h = E_d^l E_m^l T^l (V_d^l + \overline{V_s^l}\,\overline{V_d^l}) + \overline{V_s^l}\, V_d^l E_d^l \tag{1}$$

The first term in the equation (1) is the extension of the HOM and TTT mechanisms which have been widely adopted by the existing cellular systems. So it is useful to reduce the ping-pong effect in the network with MRS. The second term in the equation (1) will help the UE to quickly initiate the handoff when its serving AP starts to move.

III. PERFORMANCE ANALYSIS

The handoff mechanism described in Section II is applicable to high-speed transportation systems, especially operable in stations of high-speed railway (HSR) systems. In this section, we will evaluate the performance of the RAVH method in details for the HSR scenario.

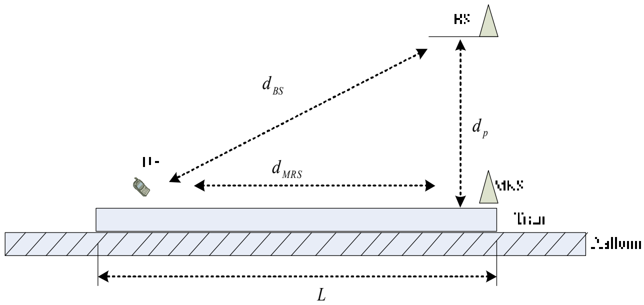

Figure 2. Network model

A. Mathematical model

Figure 2 shows the system model used for study of the performance of RAVH. Normally there are more than one MRS or fixed AP, such as BSs in the HSR station. For simplicity, we assume only one MRS and one BS are around.

It is assumed that the MRS is located in the front-end of the train. When the train stops, we assume the users are situated along the platform near the train uniformly along the distance $[0, L]$, where L denotes the length of the train. Let d_p represent the distance from BS to the platform, d_{mrs}^0 the initial distance from UE to MRS, d_{mrs} the distance from UE to MRS, and d_{bs} the distance from UE to BS. In order to simplify the analysis, the angle between UE and MRS is ignored here.

We assume the underlying channel model is an ideal AWGN channel. The signal strength received from BS R_{bs} and from MRS R_{mrs} by a UE can be expressed as

$$R_{bs} = K_{bs} - K_0 \log(d_{bs}) \tag{2}$$

$$R_{mrs} = K_{mrs} - K_0 \log(d_{mrs}) \tag{3}$$

where K_{bs} represents the gain of the transmission and reception antennas as well as the wavelength-dependent part of the channel model between UE and BS, K_{mrs} represents that between UE and MRS, and K_0 represents environment-specific attenuation characteristics [12].

B. Probability of successful handoff from MRS to BS

When the train sets off at an accelerating speed, the UEs will trigger the handoff according to the first or second term in equation (1). Let t_1 and t_2 represent the delay when the handoff is triggered by the first and second term in equation (1), respectively.

The delay t_1 consists of two parts t_{11} and t_{12}, where t_{11} is introduced by the hysteresis margin h dB when the condition of $R_{bs} - R_{mrs} = h$ is met, and it is given by

$$t_{11} = \sqrt{\frac{2d_{bs}e^{\frac{(K_{bs}-K_{mrs}-h)}{K_0}} - 2d^o_{mrs}}{a}} \tag{4}$$

t_{12} is caused by the TTT (Time to Trigger). Usually h and t_{12} are configured as system parameters. Since t_{12} is equal to T_0, t_1 is given by

$$t_1 = t_{12} + t_{11} = T_0 + \sqrt{\frac{2d_{bs}e^{\frac{(K_{bs}-K_{mrs}-h)}{K_0}} - 2d^o_{mrs}}{a}} \tag{5}$$

Suppose the train starts up at constant accelerating speed a (m/s), the handoff delay t_2 triggered by the second term in equation (1) is given by:

$$t_2 = \frac{V_0}{a} \tag{6}$$

For a train station scenario, it is reasonable that V_0 is given based on the maximal walking speed of people.

The handoff performance of UEs situated on the platform but connected to the MRS is analyzed as follows.

If the UE is still connected to the MRS when the MRS starts up, the UE will initiate the handoff. Let P_{os} denote the successful handoff probability in HOM and TTT handoff method. Let R_t denote the minimum received signal strength required to access an AP and $R_{mrs}(t)$ is the UE's received signal strength from MRS at time t. So P_{os} is given by

$$P_{os} = P(R_{mrs}(t_1) \geq R_t) \tag{7}$$

Depending on the correlated handoff thresholds, there are two cases. Let P^1_{ns} and P^2_{ns} represent the handoff success probability of RAVH for the case $t_1 \leq t_2$ and for the case $t_1 > t_2$, respectively. They are given by

$$P^1_{ns} = P(R_{mrs}(t_1) \geq R_t), \quad t_1 \leq t_2 \tag{8}$$

$$P^2_{ns} = P(R_{mrs}(t_2) \geq R_t), \quad t_1 > t_2 \tag{9}$$

Substituting (3) (5) (6) into (8) (9), we have

$$P^1_{ns} = \begin{cases} 1 - \frac{Y_0}{L}, & 0 \leq Y_0 < L \\ 0, & \text{otherwise} \end{cases} \tag{10}$$

where

$$Y_0 = d_{bs}e^{\frac{K_{bs}-K_{mrs}-h}{K_0}} - \frac{1}{2a}\left[\frac{2e^{\frac{K_{mrs}-R_t}{K_0}} - aT_0^2 - 2d_{bs}e^{\frac{K_{bs}-K_{mrs}-h}{K_0}}}{2T_0}\right]^2$$

$$P^2_{ns} = \begin{cases} \frac{1}{L}\left[e^{\frac{K_{mrs}-R_t}{K_0}} - \frac{V_0^2}{2a}\right], & 0 \leq e^{\frac{K_{mrs}-R_t}{K_0}} - \frac{V_0^2}{2a} < L \\ 100\%, & \text{otherwise} \end{cases} \tag{11}$$

C. The impact of threshold of relative velocity V_0 on handoff performance

From the equation (11) we can draw the following conclusion. If the threshold V_0 is small enough as limited by (12),

$$V_0 \leq \sqrt{2a\left[e^{\frac{K_{mrs}-R_t}{K_0}} - L\right]} \tag{12}$$

the handoff success rate of RVAH for the UE situated on the platform and connected to the MRS can be achieved almost 100% when the MRS starts up at high accelerating speed.

Let ΔP_{ns} denote the performance improved by RVAH compared to HOM and TTT handoff method. From(7) (8) (9) , it is given by

$$\Delta P_{ns} = \begin{cases} 0, & t_1 \leq t_2 \\ P(R_{mrs}(t_2) \geq R_t) - P(R_{mrs}(t_1) \geq R_t), & t_1 > t_2 \end{cases} \tag{13}$$

From the equation (13) we can draw the following conclusion. If $t_1 \leq t_2$, the RVAH method does not result in any performance improvement. In other words, only if V_0 is limited by inequality (14),

$$V_0 < aT_0 + \sqrt{2a\left(d_{bs}e^{\frac{K_{bs}-K_{mrs}-h}{K_0}} - d^0_{mrs}\right)} \tag{14}$$

the RVAH method shows gain.

IV. SIMULATION RESULTS

In this section, we provide some numerical evaluations to demonstrate the performance of the RVAH method. As described before, if a reasonable threshold is set, RVAH method results in performance improvement when the MRS starts up at high accelerating speed and no more ping-pong handoff when the MRS is stopped on the platform. The set of important simulation parameters are given in table 2.

TABLE 2
SIMULATION ASSUMPTIONS AND PARAMETERS

Parameter	Assumption
Access point layout	1 base station, 1 mobile relay station
Length of the train	200m
Distance from base station to the train	1000m
Carrier Frequency	2GHz
Path Loss	32.4+20logf(MHz)+20logd(km)dB
Shadowing Standard Deviation	6dB
hysteresis	4dB
Default Time To Trigger	400ms
Default accelerated velocity	0.5m/s
Default relative velocity threshold	2m/s

A. *Effect of acceleration on handoff failure rates*

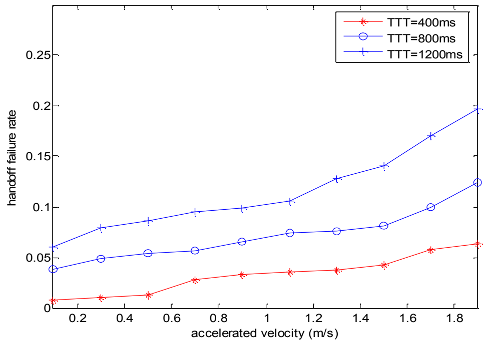

Figure 3. Effect of acceleration on handoff failure rates

Figure 3 shows how the handoff failure rate is affected by the accelerating speed a when the MRS changes its state from static to motion. Here only the HOM and TTT method has been simulated. It can be seen that the handoff failure rates increase with the accelerating speed. In particular, the handoff failure rates are deteriorated when TTT is increased. From equation (7) and (8), we can come to the conclusion that $P_{os} = P_{ns}^{1}$ in this simulation scenario and we can also see from the equation (10) that the handoff failure rate increases with the increment of the acceleration a.

B. *Performance of Ping-pong handoff*

Figure 4 shows the handoff rate when the users move slowly on the platform beside the train. It can be seen that the increment in TTT decreases the handoff rate for both RVAH method and HOM and TTT method. The performance of RVAH is slightly better than the HOM and TTT method when the value of TTT is small. But with the increment of TTT, the handoff rates of these two methods tend to be the same.

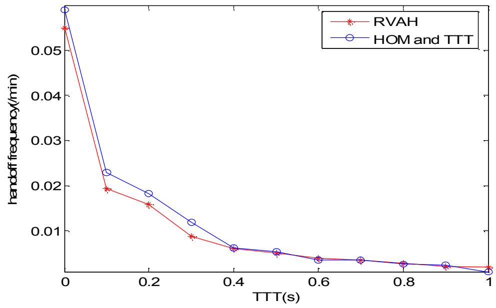

Figure 4. Ping-pong handoff rate

C. *Performance improvement with different V_0*

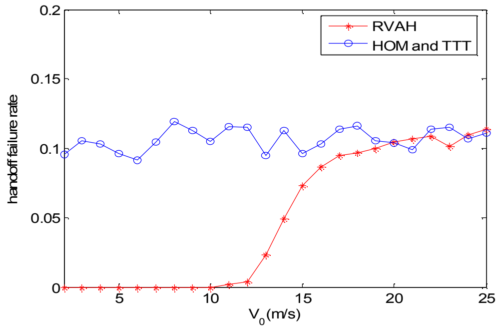

Figure 5. Effect of V_0 on handoff failure rate

Figure 5 shows how the handoff failure rates are affected by the relative velocity threshold V_0. Since the HOM and TTT method does not use the relative velocity to make handoff decision, its handoff failure rate does not change with the threshold V_0. In contrast, for the RVAH method, its handoff failure rate is almost zero when the value of threshold V_0 is less than 12m/s. With the increment of V_0, the handoff performance of the RVAH method begins to deteriorate. It can be seen from the Figure 5 that the handoff failure rate of RVAH will be consistent with the performance of the HOM and TTT method when the value of V_0 is higher than 20m/s. Such a performance can be explained by equations (11) (12) (13).

V. CONCLUSION

In this paper we have investigated the handoff problem in wireless networks with mobile relay stations. Based on the investigation, we propose a novel simple handoff mechanism RVAH and evaluate its handoff performance. We have shown that better handoff performance can be achieved by selecting the optimum threshold V_0 for relative velocity between mobile user equipment to the access points. We have also shown that our proposed RVAH mechanism does not have ping-pong.

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