Adaptive Hysteresis Using Mobility Correlation for Fast Handover

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***Abstract*— The value of hysteresis has a significant effect on the handover performance measured in terms of the handover initiation delay and the number of handovers. To determine the hysteresis value effectively, a mobility correlation among users is utilized. In this letter, a grouping algorithm and an adaptive hysteresis algorithm based on the mobility correlation are proposed. It is shown that the proposed algorithms are very efficient in reducing both the handover initiation delay and the number of handovers.**

***Index Terms*— Fast handover, handover initiation delay, unnecessary handovers, hysteresis, mobility correlation.**

I. Introduction

An extensive amount of research has been conducted on hysteresis values as they have a significant effect on handover performances. A user performs a handover if the signal-to-interference-and-noise-ratio (SINR) from an adjacent base station (BS) exceeds that from the serving BS by the hysteresis value. Though hysteresis was introduced to avoid unnecessary handovers, it causes a delay in the initiation of handovers. Therefore, instead of performing handovers for users when they reach the midpoint location with respect to the serving BS and target BS, handovers are performed at points further away from the serving BS. In this letter, the handover initiation delay represents the delay in the initiation of handovers due to hysteresis. The distance from the serving BS at the time when a user performs a handover is used as a measure of the handover initiation delay.

The larger the hysteresis value, the smaller the number of handovers, however there is a longer handover initiation delay. On the other hand, the smaller the hysteresis value, the shorter the handover initiation delay but the larger the number of handovers [1]. Handover initiation delays lead to an increase in the call dropping probability, especially in the case of highly mobile users. They also produce an increase in inter-cell interference. Moreover, frequent handovers cause an increase in signaling overhead and in the network load. Therefore, the determination of the hysteresis value is very important in terms of system performance.

To determine the hysteresis value effectively, user information such as the signal strength [2], location [3], and velocity [4] has been considered in various studies. However, an instance of users moving together has not been considered although in actuality there are many such cases, e.g., passengers traveling in a car or on a train, in which the locations of users are statistically correlated as mentioned in [5]. As the number of subscribers has increased rapidly in the recent years, situations in which users use wireless communication devices while moving together in a car or on a train are now commonplace. When users moving together perform handovers, the handover performance of each user can be improved if the information of other users who move together is considered.

In this letter, we first propose a grouping algorithm to group users based on the mobility correlation, and then propose an adaptive hysteresis algorithm to adjust the hysteresis value by using the concept of grouping. Finally, simulation results are obtained when the proposed algorithms are adopted.

II. Grouping Algorithm

A grouping algorithm that does not require the exact location of users is proposed. The proposed grouping algorithm consists of two steps. Users are grouped using the history of the serving BS in Step 1, and then re-grouped using variations of SINRs from the serving BS and adjacent BSs in Step 2.

A. Step 1) Serving BS Based Grouping

If users travel through the same BSs at the same points in time, it can be assumed that they move together and that their mobility patterns are correlated. Hence, the history of the serving BS is utilized in order to group users moving together into the same group. If $B_i(t)$ is the serving BS to which user i belongs at time t, the relational distance between user i and j at time t is then defined as follows:

$$D_{i,j}(t) = \begin{cases} 0 & \text{if } B_i(t) = B_j(t) \\ 1 & \text{if } B_i(t) \text{ is adjacent to } B_j(t) \\ \infty & \text{otherwise.}^1 \end{cases} \quad (1)$$

To calculate the mobility correlation between two users, the concept of a time slot is employed. Each BS preserves the histories of the serving BSs which were sampled at the start of each time slot for all users who belong to that BS. The correlation factor between user i and j at time t, $C_{i,j}(t)$, is defined as follows:

$$C_{i,j}(t) = \frac{1}{N_B} \sum_{k=0}^{N_B-1} D_{i,j}(t - k \cdot T_B) \quad (2)$$

where T_B is the length of the time slot, and N_B is the number of time slots reflecting how much past information is considered. $C_{i,j}(t)$ indicates the average relational distance between user i and j over time duration $N_B \cdot T_B$; therefore, the value of $C_{i,j}(t)$ goes to zero as the mobility patterns of users are strongly correlated. Using (2), the users whose $C_{i,j}(t)$ is less than a predefined threshold (th_c) are grouped into the same group. This is a temporal group and will be re-grouped in Step 2.

[1] In this case, it can be assumed that the mobility patterns of two users are not correlated because the users are far away at the same point in time.

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B. Step 2) SINR Based Re-grouping

Even if two users are grouped into the same group in Step 1, they may show different mobility patterns in the current cell. Thus, a more precise grouping algorithm is necessary to reflect mobility patterns in the current cell. To accomplish this, variations of the SINRs of users are utilized to re-group them in Step 2. If the mobility patterns of two users are correlated, their path-loss components from a BS, the serving BS or an adjacent BS, are similar. Due to the effects of fast fading and slow fading, however, the SINRs of users whose mobility patterns are correlated may be quite different. To eliminate these fading effects, SINR should be averaged for some duration. The average SINR from BS n to user i at time t is defined as follows:

$$A_{i,n}(t) = \frac{1}{T_{avg}} \sum_{k=0}^{T_{avg}-1} S_{i,n}(t - k \cdot T) \quad (3)$$

where T is the frame length, T_{avg} is the averaging duration, and $S_{i,n}(t)$ is the instantaneous SINR from BS n to user i at time t. Averaging SINR is commonly used in handover decision for eliminating fast fading effect. In this algorithm, however, T_{avg} is set to a larger value than that used in handover decision for eliminating the effects of both fast fading and slow fading.

For each group previously made in Step 1, the users are re-grouped based on the variations of the SINRs. If the SINR only from the serving BS is considered, a user who moves from the center of the cell to the right and a user who moves from the center of the cell to the left are grouped into the same group despite the fact that the mobility patterns of the two users are not correlated. Therefore, the SINRs from adjacent BSs as well as from the serving BS should be considered. To this end, for user i and j, we define the set of BSs to be considered at time t, $N_{i,j}(t)$, as follows:

$$N_{i,j}(t) = (B_i(t) \cup Adj(B_i(t)) \cap (B_j(t) \cup Adj(B_j(t))) \quad (4)$$

where $Adj(n)$ is the set of adjacent BSs of BS n. The grouping factor between user i and j at time t, $G_{i,j}(t)$, is then defined as follows:

$$G_{i,j}(t) = \frac{\sum_{n \in N_{i,j}(t)} \sum_{k=0}^{N_S-1} |A_{i,n}(t - k \cdot T_S) - A_{j,n}(t - k \cdot T_S)|}{N_S \cdot |N_{i,j}(t)|} \quad (5)$$

where T_S is the length of the time slot, N_S is the number of time slots, and $|N_{i,j}(t)|$ is the cardinality of the set $N_{i,j}(t)$. Similar to $C_{i,j}(t)$, the value of $G_{i,j}(t)$ goes to zero as the mobility patterns of users are strongly correlated. For each group previously made in Step 1, the users whose $G_{i,j}(t)$ is less than a predefined threshold (th_g) are re-grouped.

III. Adaptive Hysteresis Algorithm

In this section, an adaptive hysteresis algorithm that adjusts the hysteresis value is proposed. Users can perform faster handovers and avoid unnecessary handovers effectively with the help of the proposed algorithm. Details of the algorithm, which is run in each group, are as follows:

TABLE I
SIMULATION ENVIRONMENTS

Items	Description
Frame length	5 ms
Channel model	ITU-R Vehicular B [6]
Fast fading	Jakes model [7]
Slow fading	Log-normal distribution with standard deviation of 8.9 dB
Distance between BSs	1000 m
T_{avg} for handover decision	1 s
T_{avg} for grouping	3 s
Simulation time	600 s
T_B, T_S	10 s, 1 s
N_B, N_S	10, 10
th_c, th_g	0.2, 2
T_H	3 s
P_H	20 %

1) Check whether the percentage of users who have performed handovers to the target BS in a group is greater than a predefined threshold (P_H). If this percentage is greater than P_H, this guarantees that the group is moving to the target BS; in this case, go to step 2). Otherwise, it cannot be confirmed that the group is moving to the target BS as the previously performed handovers in the group may have been unnecessary handovers; in this case, go to step 4).
2) Check whether a predefined time (T_H) is passed after the first handover in the group is performed. If T_H is passed, it can be assumed that the user who has not yet performed a handover is no longer moving together with other users in the group because handovers in a group are supposed to be performed at a similar point in time. Essentially, the user will be excluded from the group within a few seconds by the proposed grouping algorithm. If T_H is passed, go to step 4). Otherwise, go to step 3).
3) Apply the reduced hysteresis value (H_R) to the target BS for fast handover, and the increased hysteresis value (H_I) to the other BSs for avoiding unnecessary handovers. Wait one frame and return to step 1).
4) Apply the conventional hysteresis value (H_C) to all BSs. Wait one frame and return to step 1).

IV. Simulation Results

A simulation that considered the scenario of a moving bus was carried out in order to verify the effectiveness of the proposed grouping algorithm and adaptive hysteresis algorithm. The simulation environments are summarized in Table I. We assume that Step 1 and Step 2 of the proposed grouping algorithm are run at every T_B and T_S time, respectively. Initially, the number of users moving together on a bus is set to 20. Whenever the bus stops moving, N_{on} users get on and N_{off} users get off the bus. N_{on} and N_{off} are assumed to be uniformly distributed on $\{0, 1, 2, 3\}$. The velocity of the bus is chosen uniformly on $\{0, 30, 60, 90, 120\}$ km/h, and the moving direction is chosen from the uniform distribution on $[0, 2\pi)$. The velocity and moving direction remain unchanged for a period of time, which is uniformly distributed on $[3, 100]$ seconds, and then they are re-chosen. In addition, the velocity

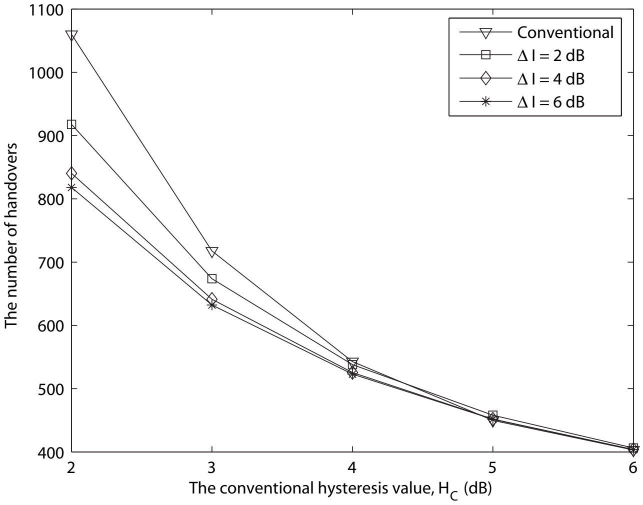

Fig. 1. The number of handovers.

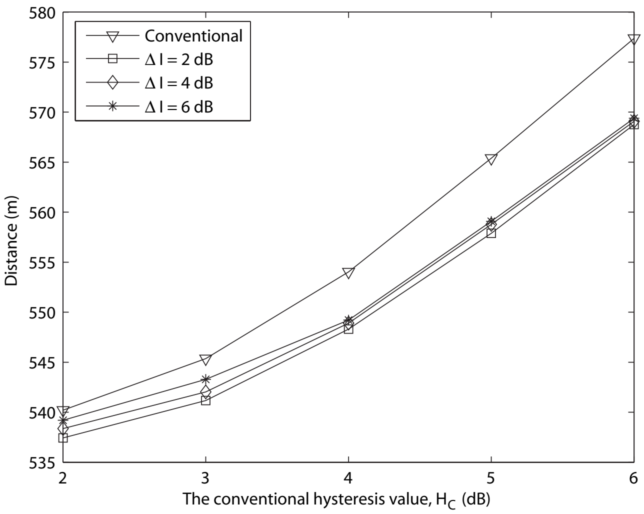

Fig. 2. The average distance from the serving BS at the time when handovers are performed.

and moving direction of each user who is not on the bus are chosen in the same way.

In order to avoid unnecessary handovers effectively, H_I is set to the conventional hysteresis value plus an increment, $H_C+\Delta I$. On the other hand, for fast handover, H_R is set to 0 dB, which is the minimum hysteresis value. Though a small hysteresis value causes a greater number of unnecessary handovers, this number can be reduced effectively by the adaptive hysteresis algorithm. We also assume that the conventional algorithm always uses H_C as the hysteresis value.

There are many tunable parameters. The smaller are T_B and T_S, the more accurate grouping is possible, but complexity and overhead become higher. The larger are N_B and N_S, the more histories are reflected in grouping, but reaction to change of group members gets longer delayed. Accurate groups are formulated by setting th_c, th_g, and T_H to small values, and a large value of P_H makes target BS prediction more accurate. However, they may cause performance improvement to be reduced because the number of users to whom H_R and H_I are applied decreases. In addition, th_g and T_H should not be set to too small values because fading effects are not completely eliminated by (3). In this simulation, these tunable parameters are set experimentally as an example because it is difficult to find optimal parameters.

Figure 1 shows the number of handovers according to H_C. The number of handovers is reduced with the help of H_I though H_R was set to 0 dB. As the value of ΔI becomes larger, the number of handovers is further reduced as unnecessary handovers are avoided more effectively. The proposed algorithm achieves up to 23% improvement in terms of the number of handovers when H_C is 2 dB. However, the number of handovers is not further reduced compared to the conventional algorithm when H_C is greater than 4; in this case, unnecessary handovers are avoided effectively even if the proposed algorithm is not adopted.

Figure 2 shows the average distance from the serving BS at the time when handovers are performed according to H_C. In the proposed algorithm, the average distance is reduced in all cases with the help of H_R. The reason is that 80% of users in a group can perform handovers faster than the conventional algorithm because P_H is set to 20% in this simulation. The proposed algorithm achieves 7–15% improvement in terms of the handover initiation delay. [2] When H_C is greater than or equal to 4, the value of ΔI has little influence on the average distance. However, when H_C is less than 4, a group may perform unnecessary handovers; in this case, the larger value of ΔI causes a longer delay in handover initiation to the target BS for the members of the group, so improvement in the average distance is reduced as the value of ΔI increases.

V. Conclusion

A grouping algorithm and an adaptive hysteresis algorithm with the use of mobility correlation are proposed. Simulation results show that the proposed adaptive hysteresis algorithm reduces both the handover initiation delay and the number of handovers with proper selection of parameters.

References

[1] K. Itoh, S. Watanabe, J. Shih, and T. Sato, "Performance of handoff algorithm based on distance and RSSI measurements," *IEEE Trans. Veh. Technol.*, vol. 51, no. 6, pp. 1460–1468, 2002.

[2] M. Zonoozi, P. Dassanayake, and M. Faulkner, "Optimum hysteresis level, signal averaging time and handover delay," in *Proc. IEEE Vehicular Technology Conf. (VTC)*, vol. 1, 1997, pp. 310–313.

[3] S. Wang, A. Rajendran, and M. Wylie-Green, "Adaptive handoff method using location information," in *Proc. IEEE Personal, Indoor and Mobile Radio Communications*, vol. 1, 2001, pp. D43–D47.

[4] Y. Kim, K. Lee, and Y. Chin, "Analysis of multi-level threshold handoff algorithm," in *Proc. IEEE Globecom*, vol. 44, no. 1, 1996, pp. 1141–1145.

[5] R. Gau and C. Lin, "Location management of correlated mobile users in the UMTS," *IEEE Trans. Mobile Comput.*, vol. 4, no. 6, pp. 641–651, 2005.

[6] "Guidelines for evaluation of radio transmission technologies for IMT-2000," *ITU-R M.1225*, 1997.

[7] W. C. Jakes, Jr., *Microwave Mobile Communications*. Wiley, 1974.

[2]The midpoint location with respect to the serving BS and target BS is about 500m apart from the serving BS. When H_C is 4dB, handovers are performed at about 55m further points from the serving BS than the midpoint in the conventional algorithm while handovers are performed at about 47m further points in the proposed algorithm, which corresponds to 15% improvement.