Group Handover Scheme using Adjusted Delay for Multi-Access Networks

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Abstract—In this paper, we propose a group handover scheme in multi-access networks, which utilizes adjusted delay to prevent handover blockings caused by a group handover. In the group handover, a lot of users try to initiate a handover at the same time, which causes network congestion and increases the probability that the handover would be blocked. In our proposed scheme, to prevent these problems of a group handover, each user which participates in the group handover, optimally selects an access point (AP) based on the remaining resources of the AP, and each user initiates a handover after adjusted delay to prevent network congestion. To find an optimal AP selection strategy, we formulate an optimization problem whose objective is to minimize handover blocking probability, and derive an optimal solution by using the Karush-Kuhn-Tucker (KKT) condition. Through performance analysis and simulation results, we show that our proposed scheme can reduce handover blocking probability in a group handover compared to a conventional scheme and keep handover blocking probability to be less than the maximum allowable value of handover blocking probability.

I. INTRODUCTION

Recently, the amount of wireless communication usages in our daily lives increases rapidly, which brings forth many different wireless technologies. As a result, many different wireless systems such as UMTS, WiMAX and WLAN, coexist in the same area [1], and a wireless communication user selects an AP to use from many heterogeneous APs. The user selects the AP based on certain criteria, which can be the received signal strength (RSS) of the AP, distance to the AP [2], the amount of load of the AP [3], or some other factors. Given that wireless systems are shared by a lot of users, this AP selection becomes more important in the environment in which many different wireless systems coexist in the same area. If users are concentrated to a certain AP, all the resources that the AP has will be used and the AP cannot give wireless service to users. And hence, the utilization of wireless resources and the quality of service will be severely degraded.

An AP selection problem becomes more problematic if users move together. When users take the same vehicle such as a bus or a train, they will be close to each other and group handovers are likely to happen. If the number of users which participate in the group handover is large, the group handover will cause network congestion, because it may demand a lot of resources from APs. Especially, given that the channel of the users on the same vehicle will be similar, all the user are likely to select the same AP, and it will cause network congestion and cause handover to be blocked. This problem of the group handover becomes more severe in tactical wireless systems because users are likely to move in cluster [3], which increases the number of group handovers. And given that users in the tactical wireless systems will move faster compared to users in commercial wireless systems, which also increases the number of group handovers and the problem of the group handover becomes more troublesome.

The majority of previous works on a group handover consider the use of a mobile relay station [4] [5]. In [4], authors consider a group handover occurring at a train station. The authors propose a group handover scheme in which a mobile router deployed on a train helps the initiation of the group handover to minimize the latency of a group handover. In [5], authors use channel borrowing scheme in the group handover to minimize handover dropping probability when a mobile relay station exists. But in the real environment, the mobile relay station may not exist and therefore cannot be used in the group handover. So, it is important to consider the communication environment where the mobile relay station does not exist. This environment has been taken into account in [1]. In [1], the authors use random delay in the group handover to prevent network congestion and reduce the probability that the handover is blocked. However, the authors do not find optimal delay and the proposed scheme does not guarantee the handover blocking probability to be less than predefined value which is important in wireless systems [2].

In this paper, we propose a new group handover scheme in which each user in a group handover optimally selects the AP based on the remaining resources of an AP, and performs handover after adjusted delay. The delay in handover is determined by the maximum allowable value of handover blocking probability. Our proposed scheme guarantees the handover blocking probability to be less than the maximum allowable value of handover blocking probability, which has not been proposed previously.

II. PROBLEM STATEMENT AND ASSUMPTIONS

We propose a new group handover scheme which guarantees handover blocking probability to be less than the maximum allowable value of handover blocking probability. In this
paper, we assume heterogeneous wireless systems which are composed of many different wireless systems. And we assume that all the wireless systems are time slotted systems. To simplify analysis, we assume that all the APs are synchronized and each user can only initiate handover procedure at the beginning of each time slot. Moreover, we assume that each AP has the certain amount of resources and the amount of resources that AP \( k \) has is \( C_k \). In general, it changes over time because the number of users and the amount of resources that users demand change over time. However, for simplicity, we assume that \( C_k \) does not change during the procedure of a group handover. The case when \( C_k \) varies can be extended easily. Moreover, due to overcrowded users at an AP, the remaining resources of the AP can be exhausted at a certain time slot. In this case, we assume that the AP acquires \( C_k \) resources in the next time slot by using load balancing or channel borrowing scheme [5], so as to continuously give wireless services to users.

In this paper, we also assume that each user who participates in a handover, demands the certain amount of resources. For simplicity, we normalize the amount of demanded resources to one, which means that when the handover occurs, each user demands unit resource from an AP. And we also define that a handover blocking occurs when the number of users that access an AP exceeds the amount of resources that the AP has [2]. For example, when the amount of resources of AP \( k \) is \( C_k \) and \( M \) users try to access to the AP \( k \) at the same time, a handover blocking occurs if \( C_k < M \) and \( M - C_k \) users are blocked in the handover. In this paper, we let \( P_{\text{HO,block}} \) be the probability that the handover is blocked.

As we have stated in the previous section, a network congestion problem occurring in a group handover is significant and should be solved. Given that the network congestion is related to the \( P_{\text{HO,block}} \) of the group handover, it is important to maintain \( P_{\text{HO,block}} \) to be less than maximum allowable level, \( P_{\text{HO,block,threshold}} \), for the stability of wireless systems. To this end, we give adjusted delay to the procedure of a handover that each user takes, likewise in [1], so that the handover attempt of each user can be distributed in multiple time slots and only some of users initiate handover at the same time slot. The number of users that attempt the handover at the same time slot is determined to maintain \( P_{\text{HO,block}} \) to be less than \( P_{\text{HO,block,threshold}} \) at each time slot. And users select an AP based on the resources that each AP has, to minimize \( P_{\text{HO,block}} \).

### III. Proposed Scheme

Now, we will explain the procedure of our proposed group handover scheme. First, in our proposed scheme, each user recognizes that handover criterion is met. Each user in a group handover will be close to each other and hence they will experience similar channel condition. Therefore, we assume that the handover criterion of the users is satisfied at the same time, and the users will inform a current AP that they will initiate a handover to other APs. Then, the current AP can know how many users are in group handover procedure and notifies this information to users who participate in the group handover procedure, so that the users can know how many users are participating in the group handover. In this paper, we let \( M_{\text{total}} \) be the number of users participating in the group handover. This value also can be known by using existing neighbor discovery schemes [6].

After that, each user determines whether to initiate a handover at this time slot or not based on the amount of resources that neighboring APs have, and \( M_{\text{total}} \). We let the number of neighboring APs be \( K \) and we assume that users can know the amount of resources that neighboring AP \( k \) has, \( C_k \), from advertising messages which are broadcasted by the AP. In this paper, we neglect the difference of channel between users, because, as stated above, given that users in the group handover will be close to each other, their long term channel conditions will be similar [7]. Of course, short term channel condition can be different due to the short correlation distance [7] of multipath fading. However, each user will select an AP based on the long term channel condition and not based on the short term channel condition, because the short term channel condition changes fast. Given that we neglect the difference of channel, users which participate in group handover are indistinguishable.

Given that it is more desirable to make the latency of handover to be small as possible [4], the number of used slots for a group handover should be minimized while satisfying \( P_{\text{HO,block}} \leq P_{\text{HO,block,threshold}} \) when \( M_{\text{total}} \) users are in the procedure of a group handover. This problem can be formulated as follows:

\[
\text{Minimize } \quad N_{\text{HO,slot}} \\
\text{Subject to } \quad P_{\text{HO,block}} \leq P_{\text{HO,block,threshold}} \quad (1)
\]

where \( N_{\text{HO,slot}} \) is the number of used slots for the group handover.

To solve eq.(1), minimum achievable \( P_{\text{HO,block}} \) when \( M \) users initiate a handover at the same time slot, should be found. Let \( P_{\text{sel}} \) be the probability that an user selects AP \( k \) and \( P_{\text{sel}} = [P_{\text{sel}}^1, \ldots, P_{\text{sel}}^K] \). \( P_{\text{sel}} \) needs to satisfy the constraints \( \sum_{k=1}^K P_{\text{sel}}^k = 1 \) and \( P_{\text{sel}} \geq 0 \).

Since we assume that users are indistinguishable, \( P_{\text{sel}} \) which makes \( P_{\text{HO,block}} \) as small as possible, will be the same for all the users. In our proposed scheme, a user which chooses an AP \( k \), encounters handover blocking with the probability \( max(1-\frac{C_k}{M},0) \) when other \( i \) users select the same AP. This event occurs with the probability \( \frac{(M-1)!}{(i)! \cdot (M-1-i)!} \cdot \left( \prod_{k=1}^K P_{\text{sel}}^k \right)^{i+1} \cdot (1 - P_{\text{sel}})^{M-i-1} \). Therefore, by multiplying this probability with \( \frac{i^C_k}{i} \) and summing it over all the \( K \) APs and all \( i \geq C_k \), \( P_{\text{HO,block}} \) can be obtained as follows: [8]:

\[
P_{\text{HO,block}} = \sum_{k=1}^K \sum_{i=C_k}^{M-1} \frac{(i+1-C_k)!(M-1)!}{(i+1)!(M-1-i)!} \times \left( \prod_{k=1}^K P_{\text{sel}}^k \right)^{i+1} \cdot (1 - P_{\text{sel}})^{M-i-1} \quad (2)
\]

We can simplify eq.(2) by using the definition of an incomplete beta function. Let \( B(a, b) \) be the beta function and
$B(P^\text{sel}_k, a, b)$ be the incomplete beta function as follows [10]:

$$B(a, b) = \int_0^1 t^{a-1} \cdot (1 - t)^{b-1} \, dt$$

$$B(P^\text{sel}_k; a, b) = \int_0^{P^\text{sel}_k} t^{a-1} \cdot (1 - t)^{b-1} \, dt$$

Then, $B(a, b)$ and $B(P^\text{sel}_k; a, b)$ are related as follows [10]:

$$\frac{B(P^\text{sel}_k, a, b)}{B(a, b)} = \sum_{j=0}^{a+b-1} \frac{a+b-1)!}{j!(a+b-1-j)!} (P^\text{sel}_k)^j \times (1 - P^\text{sel}_k)^{a+b-1-j}$$

By using the eq.(4), the eq.(2) can be written as follows:

$$P_{\text{HO,block}} = \sum_{k=1}^{K} P^\text{sel}_k \cdot \frac{B(P^\text{sel}_k, C_k - M - C_k)}{B(C_k, M - C_k)} - \sum_{i=0}^{M-1} \frac{C_k \cdot (1-i)}{\prod (M-i)} \times ((P^\text{sel}_k)^{i+1} \cdot (1 - P^\text{sel}_k)^{M-i-1})$$

Then, we can formulate the following optimization program whose objective is to find $P^\text{sel}_k$ which minimizes $P_{\text{HO,block}}$ when $M$ users initiate a handover at the same time slot as follows:

$$\begin{align*}
\text{Minimize} & \quad \sum_{k=1}^{K} P^\text{sel}_k = 1 \\
\text{Subject to} & \quad P^\text{sel}_k \geq 0
\end{align*}$$

If the objective function of an optimization problem is a convex function and a constraint set is a convex set, the optimization problem is a convex optimization problem. In the convex optimization problem, the KKT condition can be used to find an optimal solution [9]. Given that the constraints in the optimization problem in eq.(6) are linear, the problem in eq.(6) becomes a convex optimization problem, if the objective function is a convex function. To check the convexity of the objective function, we find the Hessian of the objective function which is $P_{\text{HO,block}}$, and check whether the Hessian is positive semi-definite (PSD) or not. If the Hessian is PSD, then $P_{\text{HO,block}}$ is a convex function and the optimization problem becomes a convex optimization problem whose solution can be found by using the KKT condition. To this end, we derive the Hessian which can be represented as a diagonal matrix and $k$-th diagonal term is $\frac{\partial^2 P_{\text{HO,block}}}{\partial P^\text{sel}_k^2}$. Therefore, to show that the Hessian is PSD, it is sufficient to show that $\frac{\partial^2 P_{\text{HO,block}}}{\partial P^\text{sel}_k^2} \geq 0$ for all $k$.

To find $\frac{\partial^2 P_{\text{HO,block}}}{\partial P^\text{sel}_k^2}$, we first derive $\frac{\partial P_{\text{HO,block}}}{\partial P^\text{sel}_k}$ which is shown in eq.(7). Given that $\frac{\partial B(P^\text{sel}_k, a, b)}{\partial P^\text{sel}_k} = (P^\text{sel}_k)^{a-1} \cdot (1 - P^\text{sel}_k)^{b-1}$, $B(x, y) = \frac{\Gamma(x) \Gamma(y)}{\Gamma(x+y)}$ and $\Gamma(n + 1) = n \cdot \Gamma(n)$ when $n$ is a natural number [8] [10], the eq.(7) can be simplified to eq.(8). Then, $\frac{\partial P_{\text{HO,block}}}{\partial P^\text{sel}_k}$ can be derived from the eq.(8) as follows:

$$\frac{\partial^2 P_{\text{HO,block}}}{\partial P^\text{sel}_k^2} = \frac{\partial B(P^\text{sel}_k, C_k - M - C_k)}{B(C_k, M - C_k)} \geq 0$$

From eq.(9), we can find that $\frac{\partial^2 P_{\text{HO,block}}}{\partial P^\text{sel}_k^2} \geq 0$ for all $k$. Thus, the objective function is a convex function and the problem in eq.(6) is the convex optimization problem. Therefore, by using the KKT condition, the solution of the problem can be found. Then, the optimal solution should satisfy the following KKT condition [9]:

$$0 = \frac{\partial L(P^\text{sel}_k, \lambda, \mu)}{\partial P^\text{sel}_k} = \frac{B(P^\text{sel}_k, C_k - M - C_k)}{B(C_k, M - C_k)} - \lambda - \mu_k$$

$$0 = \mu_k P^\text{sel}_k - \sum_{k=1}^{K} P^\text{sel}_k \leq P^\text{sel}_k$$

where $\mu_k \geq 0$ for all $k$ and $L(P^\text{sel}_k, \lambda, \mu)$ denotes the Lagrangian of the problem.

When $P^\text{sel}_k$ for certain $k$ is not zero, $\mu_k$ should be zero and $\frac{B(P^\text{sel}_k, C_k - M - C_k)}{B(C_k, M - C_k)} > 0$ when $P^\text{sel}_k$ is not zero and at least one of $P^\text{sel}_k$ be zero, $\lambda$ should be a positive value. If $P^\text{sel}_k = 0$ for certain $k$, $\frac{B(P^\text{sel}_k, C_k - M - C_k)}{B(C_k, M - C_k)}$ for the $k$ becomes zero, because $B(0; C_k, M - C_k) = 0$. It implies that $\mu_k$ for the $k$ should equal to $-\lambda$, because $\frac{B(P^\text{sel}_k, C_k - M - C_k)}{B(C_k, M - C_k)} - \lambda - \mu_k = -\lambda - \mu_k = 0$ as shown in eq.(10). However, this contradicts to the constraint that $\mu_k > 0$, because $\lambda > 0$ as shown above. Therefore, $P^\text{sel}_k > 0$ and $\mu_k = 0$ for every $k$. As a consequence, $P^\text{sel}_k$ which satisfies the KKT condition, can be found by using the following equation:

$$\lambda = \frac{B(P^\text{sel}_k, C_k - M - C_k)}{B(C_k, M - C_k)}$$

$$1 = P^\text{sel}_k$$

If all the APs have the same resources, $C_j = C_k$ for all $j$ and $k$. Therefore, $P^\text{sel}_k = \frac{1}{M}$ and users will select an AP with the same probability. In general, optimal $P^\text{sel}_k$ cannot be obtained in closed-form. Therefore, instead of finding an exact solution for the problem in eq.(11), we may find a heuristic solution. In our heuristic solution, we let $P^\text{sel}_k$ be proportional to $C_k$, which means that $P^\text{sel}_k = \alpha \cdot C_k$ by assuming that an AP which has large $C_k$ can accommodate the large amount of users. Then, by using a constraint, $\sum_{k=1}^{K} P^\text{sel}_k = 1$, we can derive heuristic $P^\text{sel}_k$ as follows:

$$P^\text{sel}_k = \frac{C_k}{\sum_{k=1}^{K} C_k}$$

By using eq.(11) or eq.(12) as selection probability that an AP is selected by users, we can obtain the minimum achievable $P_{\text{HO,block}}$ when the number of users in a group handover is $M$. Let $P^*_{\text{HO,block}}(M)$ be the minimum achievable $P_{\text{HO,block}}$ when the number of user is $M$. Then, the maximum number of users, $M^\text{sel}$, which initiate a handover simultaneously, while satisfying $P_{\text{HO,block,threshold}} \geq P^*_{\text{HO,block}}(M^\text{sel})$ can be found by solving the following problem:

$$\text{Maximize} \quad M^\text{sel}$$

Subject to $P_{\text{HO,block,threshold}} \geq P^*_{\text{HO,block}}(M^\text{sel})$

Given that $P^*_{\text{HO,block}}(M^\text{sel})$ is the non-decreasing function of $M^\text{sel}$, an optimal solution for the problem in eq.(13) can be found easily by increasing $M^\text{sel}$ one by one. Let $M^*$ be the
solution for the problem in eq.(13). Then, by allowing only $M^*$ users to contend in one slot for a handover, the number of needed slots for a group handover can be minimized while satisfying $P_{\text{HO-block,threshold}} \geq P_{\text{HO-block}}$. In summary, the solution for problem in eq.(1)

Algorithm 1 Procedure of proposed group handover scheme

\[ M_{\text{total}} = \text{total number of users which participate in group handover} \]

\[ M_{\text{remaining}} \leftarrow M_{\text{total}} \]

\[ \text{while } M_{\text{remaining}} \geq 0 \text{ do} \]

\[ \text{Each user determines whether to participate in handover or not with probability } \min(M_{\text{remaining}}, 1) \]

\[ \text{Calculate } P_{\text{sel}} \text{ using eq.(11) or eq.(12)} \]

\[ \text{Users which participate in handover select APs with probability } P_{\text{sel}} \]

\[ M_{\text{remaining}} \leftarrow (M_{\text{remaining}} - M^*) \]

end while

IV. PERFORMANCE EVALUATION

We now report on the performance of our proposed group handover scheme. We calculate $P_{\text{HO-block}}$ by varying the number of users and $P_{\text{HO-block,threshold}}$. We also calculate the number of used time slots for a group handover, $N_{\text{HO-slot}}$. In this simulation, we assume that each user can select one AP among three APs by assuming that three different wireless technology can be overlapped in the same area as in [11]. We first calculate $P_{\text{HO-block}}$ and $N_{\text{HO-slot}}$ when $C_k = 10$ for all the APs.

In the simulation results, a proposed optimal scheme denotes the case that each user selects an AP based on eq.(11), and a proposed heuristic scheme denotes the case that each user selects an AP based on eq.(12). And we also consider conventional handover schemes which do or do not utilize adjusted delay. Moreover, we assume that for conventional handover schemes, users can use the same AP selection probability for all the APs or they can use eq.(11) to decide AP selection probability. Simulation results are shown in Fig.1 and Fig.2.

As we can see from Fig.1, in the conventional scheme in which the number of time slots for a group handover
is fixed, $P_{\text{HO,block}}$ increases as the number of users increases. However, in our proposed scheme, $P_{\text{HO,block}} < P_{\text{HO,block,threshold}}$ even though the number of users in the group handover increases, because the number of time slots used for the group handover increases adaptively, according to the number of users to maintain $P_{\text{HO}}$ to be less than $P_{\text{HO,block,threshold}}$. We can see from Fig. 2 that the $N_{\text{HO,slot}}$ of our proposed scheme increases as the number of total users increases. And, we can also find that $N_{\text{HO,slot}}$ is smaller when $P_{\text{HO,block,threshold}} = 5\%$ compared to that the case when $P_{\text{HO,block,threshold}} = 2\%$. Therefore, in our proposed scheme, the latency of a group handover increases to reduce $P_{\text{HO,block}}$. And given that $C_k$ is the same for all the APs, $P_{sel}$ calculated from eq.(11) and eq.(12) are the same and there is no performance difference between the proposed optimal scheme and the proposed heuristic scheme.

Next, we calculate $P_{\text{HO,block}}$ and $N_{\text{HO,slot}}$ when the resources of each AP are different. In this simulation, we assume that $C_1 = 5$, $C_2 = 10$ and $C_3 = 20$. Simulation results are shown in Fig.3 and Fig.4. The tendency of $P_{\text{HO,block}}$ and $N_{\text{HO,slot}}$ in Fig.3 and Fig.4 is similar to that in Fig.1 and Fig.2. We can see that even when the amount of resources that each AP has is different, $P_{\text{HO,block}} < P_{\text{HO,block,threshold}}$. Given that the values of $P_{\text{sel}}$ calculated from eq.(11) and eq.(12) are different, the $P_{\text{HO,block}}$ and $N_{\text{HO,slot}}$ of a proposed optimal scheme and a proposed heuristic scheme are different. However, we can see that the $P_{\text{HO,block}}$ and $N_{\text{HO,slot}}$ of the proposed heuristic scheme are almost the same as those of the proposed optimal scheme, which means that our proposed heuristic scheme is as good as the proposed optimal scheme.

V. CONCLUSION

In this paper, we have proposed a group handover scheme. Our proposed group handover scheme uses optimized network selection and adjusted delay in a group handover to reduce handover blocking probability. In our proposed scheme, each user in a group handover optimally selects an AP based on the remaining resources of the AP and initiates a handover after adjusted delay. To find a network selection strategy which minimizes handover blocking probability, we formulate an optimization problem and solve the problem by using the KKT condition and the fact that the problem has a convex property. We have also proposed a heuristic scheme whose performance is similar to that of an optimal scheme. Through performance analysis and simulations, we have shown that our proposed scheme can reduce handover blocking probability and guarantee the handover blocking probability to be less than the maximum allowable value of handover blocking probability.

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