Efficient Handoff Algorithm for Inbound Mobility in Hierarchical Macro/Femto Cell Networks

Jung-Min Moon, *Student Member, IEEE,* and Dong-Ho Cho, *Senior Member, IEEE*

***Abstract*—To improve indoor coverage and network capacity, the use of hierarchical macro/femto cell networks is regarded as the most promising approach. We present an efficient handoff algorithm to support the inbound mobility from macro cells to femto cells under the consideration of large asymmetry in the transmit power of the cells. Numerical analysis reveals that the proposed algorithm yields a higher probability that the user will be correctly assigned to the femto cell while maintaining the number of handoffs at the same level.**

***Index Terms*—Handoff algorithm, handoff criterion, cell selection, hierarchical macro/femto cell networks.**

I. INTRODUCTION

THE recent development of hierarchical macro/femto cell networks is a realistic way of providing better quality of service to indoor mobile users [1]. In these emerging networks, many low-power femto base stations (f-BSs) are implemented within the coverage of macro BSs (m-BSs) that typically use large transmit power for covering a wide geographic area. One challenge here is to support the successful inbound mobility that corresponds to the handoff from the m-BS to the f-BS. To achieve this purpose, we are interested in designing an efficient handoff algorithm to be used in the hierarchial macro/femto cell networks.

A variety of handoff algorithms based on received signal strength (RSS) with hysteresis and threshold have been studied [2]. The threshold sets a minimum RSS from a serving BS and the hysteresis adds a margin to the RSS from the serving BS over that from a target BS. Although their efficiency has been verified in many previous works, the performance in the hierarchical macro/femto cell networks was not evaluated.

Therefore, we propose a new RSS-based handoff algorithm that is suitable for the hierarchical macro/femto cell networks. The handoff scenario considered in this paper is the inbound mobility from the m-BS to the f-BS. The system model is presented in Section II and the proposed algorithm is analyzed in Section III. Numerical results are discussed in Section IV and conclusions are made in Section V.

II. SYSTEM MODEL AND PROBLEM DEFINITION

Let $s_m[k]$ and $s_f[k]$ denote the RSS from an m-BS and an f-BS at time k. Given that we assume that an MS moves in a straight line from the m-BS to the f-BS with constant velocity, the index k also yields the location of the MS. With the values of transmit power $P_{m,tx}$, $P_{f,tx}$ and path loss $PL_m[k]$, $PL_f[k]$, $s_m[k]$ and $s_f[k]$ can be expressed as follows:

$$\begin{aligned} s_m[k] &= P_{m,tx} - PL_m[k] - u_m[k] \\ s_f[k] &= P_{f,tx} - PL_f[k] - u_f[k] \end{aligned} \tag{1}$$

where $u_m[k]$ and $u_f[k]$ represent log-normal shadowing with mean zero and variance σ_m^2 and σ_f^2. We assume that $u_m[k]$ and $u_f[k]$ are independent of each other and have an exponential correlation function [3] with a correlation distance d_0.

To prevent the RSS from varying abruptly, the exponential window function $w[k] = (1/d_1)\exp(-kd_s/d_1)$, where d_s and d_1 represent the distance between two adjacent measurement locations and the window length, respectively, is applied to $s_m[k]$ and $s_f[k]$. This operation can be expressed as follows:

$$\bar{s}_m[k] = w[k] * s_m[k] \quad \text{and} \quad \bar{s}_f[k] = w[k] * s_f[k] \tag{2}$$

Then, the variance of the shadowing, in which the correlated shadowing and the window function are considered, becomes $\sigma_{mw}^2 = (d_0\sigma_m^2)/(d_0+d_1)$ and $\sigma_{fw}^2 = (d_0\sigma_f^2)/(d_0+d_1)$, and the correlation coefficient ρ_c between two RSS samples can be written as follows [4]:

$$\rho_c = \left\{d_0\exp(-d_s/d_0) - d_1\exp(-d_s/d_1)\right\}/(d_0-d_1) \tag{3}$$

Given these representations of the received signals, we now clarify the problem of a conventional handoff algorithm. The most general form is the RSS comparison using hysteresis and threshold [2]. If this criterion is used for inbound mobility, the criterion for handoff can be expressed as follows:

$$\bar{s}_m[k] < s_{m,th} \quad \text{and} \quad \bar{s}_f[k] > \bar{s}_m[k] + \Delta \tag{4}$$

where $s_{m,th}$ and Δ denote the minimum RSS level from the m-BS and the value of hysteresis, respectively.

Since there is large difference in the transmit power of the m-BS (≈ 46 dBm) and the f-BS (≈ 20 dBm) [1], the criterion for handoff in (4) is difficult to satisfy. Especially when the f-BS is located in the inner region of the macro cell, the m-BS easily has the first priority as a target BS for handoff, although the RSS from the f-BS is high enough. It may cause undesired congestion in the m-BS and low utilization in the f-BS.

III. PROPOSED SCHEME AND PERFORMANCE ANALYSIS

A. Overall Description of Proposed Algorithm

To overcome the above mentioned drawback of a conventional algorithm and derive a reasonable criterion for handoff, we propose a new RSS-based handoff algorithm. The main idea is to combine the RSSs from both a serving m-BS and a target f-BS through following process:

$$s_{pro}^{\alpha}[k] = \bar{s}_f[k] + \alpha\bar{s}_m[k] \tag{5}$$

Manuscript received April 8, 2009. The associate editor coordinating the review of this letter and approving it for publication was H. Yomo.

The authors are with the Department of Electrical Engineering, Korea Advanced Institute of Science and Technology (KAIST), 335 Gwahangno, Yuseong-gu, Daejeon 305-701, Republic of Korea (e-mail: jmmoon@comis.kaist.ac.kr).

Digital Object Identifier 10.1109/LCOMM.2009.090823

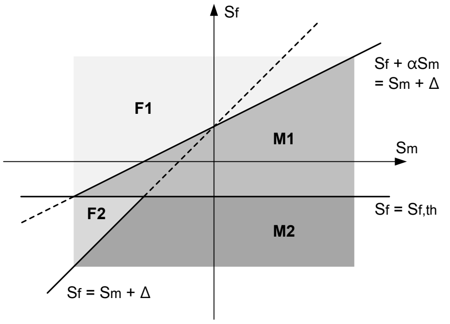

Fig. 1. Handoff criterion for proposed algorithm.

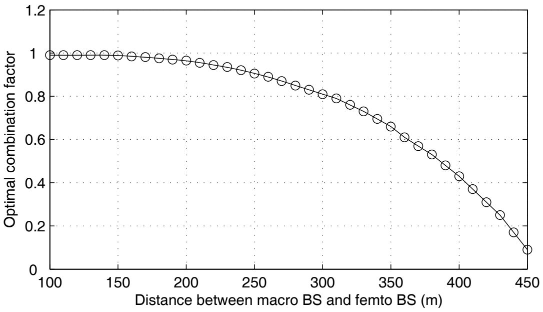

Fig. 2. Optimal combination factor vs. distance of macro-femto BS.

where $\alpha \in [0, 1]$ denotes a combination factor that reflects large asymmetry in the transmit power of the cells. Thus, a proposed criterion for handoff can be written as follows:

• Criterion for Handoff in Proposed Algorithm

---

if $\bar{s}_f[k] > s_{f,th}$ **and** $s^{\alpha}_{pro}[k] > \bar{s}_m[k] + \Delta$ (F1)
or if $\bar{s}_f[k] < s_{f,th}$ **and** $\bar{s}_f[k] > \bar{s}_m[k] + \Delta$ (F2)
then connect to femto BS

---

if $\bar{s}_f[k] > s_{f,th}$ **and** $s^{\alpha}_{pro}[k] < \bar{s}_m[k] + \Delta$ (M1)
or if $\bar{s}_f[k] < s_{f,th}$ **and** $\bar{s}_f[k] < \bar{s}_m[k] + \Delta$ (M2)
then connect to macro BS

The procedure just described has several remarkable properties. First, the combination process in (5) may be interpreted as the generation of an adaptive offset that is determined by the RSS from the m-BS and the combination factor, so that a more reasonable comparison can be performed. In addition, the combination process is applied when the RSS from the f-BS exceeds a threshold $s_{f,th}$. By carefully controlling the threshold, it is possible to choose a better connection with the m-BS or the f-BS to guarantee a certain level of QoS during handoff. Note that the hysteresis Δ is still needed to avoid the unnecessary trials of handoff and each condition is marked by F1, F2, M1 and M2 in Fig. 1.

The most important step in the proposed algorithm is to determine a proper value for the combination factor. If it is unnecessarily high, the criterion for handoff is always satisfied, even when the RSS from the f-BS is low. If it is unnecessarily low, the proposed algorithm converges to the conventional algorithm. A method for determining an optimal value for the combination factor is suggested as follows:

$$\alpha^* = \arg \max_{\alpha \in [0,1]} \frac{P_f[k_0 + k_1] - P_f[k_0 - k_1]}{2k_1}$$
$$\text{subject to } P^c_m[k_0] = \Pr\{M(k_0) \text{ and } \bar{s}_f[k_0] > s_{f,th}\} < \epsilon \quad (6)$$

where $P_m[k]$ and $P_f[k]$ denote the probability that an MS will be assigned to the m-BS and the f-BS at k, and $M(k)$ and $F(k)$ indicate the corresponding events, respectively. In addition, k_0 and k_1 represent the indexes corresponding to the femto cell boundary and the marginal distance, which are used to measure how fast the handoff is performed. Thus, (6) yields the optimal combination factor that supports fast handoff, or generates only small delay, around the boundary under the constraint of $\Pr\{M(k_0) \text{ and } \bar{s}_f[k_0] > s_{f,th})\} < \epsilon$. Because the combination process is triggered when the RSS from the f-BS exceeds the threshold $s_{f,th}$, it is reasonable to bound the probability that both events $M(k_0)$ and $\bar{s}_f[k_0] > s_{f,th}$ will occur simultaneously for high utilization of the femto cell. However, the comparison between the RSSs is still required, even after the combination process has been triggered, so that a better connection for handoff may be chosen.

B. Performance Analysis of Proposed Algorithm

As stated in the previous study [4], the probability that an MS will be assigned to an m-BS and an f-BS at k, $P_m[k]$ and $P_f[k]$, and the probability that handoff will occur at k, $P_{ho}[k]$, can be expressed as follows:

$$\begin{aligned} P_m[k] &= P_m[k-1](1 - P_{f|m}[k]) + P_f[k-1]P_{m|f}[k] \\ P_f[k] &= P_m[k-1]P_{f|m}[k] + P_f[k-1](1 - P_{m|f}[k]) \\ P_{ho}[k] &= P_m[k-1]P_{f|m}[k] + P_f[k-1]P_{m|f}[k] \end{aligned} \quad (7)$$

where $P_{f|m}[k]$ represents the probability that the handoff from the m-BS to the f-BS will occur at k, and vice versa for $P_{m|f}[k]$. Then, $P_{f|m}[k]$ can be calculated as follows:

$$\begin{aligned} P_{f|m}[k] &= \frac{\Pr\{F(k) \text{ and } M(k-1)\}}{P_m[k-1]} \\ &= \frac{1}{P_m[k-1]} \iint_{M1 \cup M2} g_{k-1}(x, y) H_{k|k-1} \mathrm{d}x\mathrm{d}y \end{aligned} \quad (8)$$

where $g_{k-1}(x, y)$ denotes the joint probability density function (PDF) of $\bar{s}_m[k]$ and $\bar{s}_f[k]$. As explained in (1), the RSSs from the cells are normally distributed and independent of each other. Thus, $g_{k-1}(x, y)$ can be written as follows:

$$g_{k-1}(x, y) = \frac{\exp\left\{-\frac{(x-\mu_{mw}[k-1])^2}{2\sigma^2_{mw}} - \frac{(y-\mu_{fw}[k-1])^2}{2\sigma^2_{fw}}\right\}}{2\pi\sigma_{mw}\sigma_{fw}} \quad (9)$$

In addition, $H_{k|k-1}$ denotes the probability that the MS will be assigned to the f-BS at k when the RSS at $k-1$ is given as the condition. This probability can be obtained by integrating the conditional joint PDF $h_{k|k-1}(x, y)$ over the region $F1 \cup F2$ marked in Fig. 1.

$$H_{k|k-1} = \iint_{F1 \cup F2} h_{k|k-1}(x, y) \mathrm{d}x\mathrm{d}y \quad (10)$$

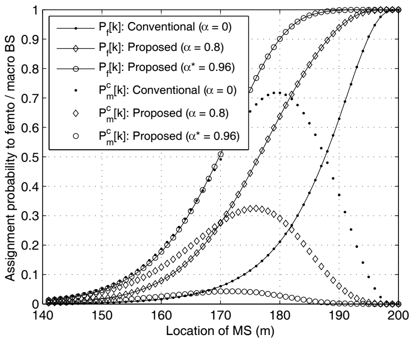

Fig. 3. Assignment probability to femto BS ($P_f[k]$) and macro BS ($P_m^c[k]$) vs. location of MS.

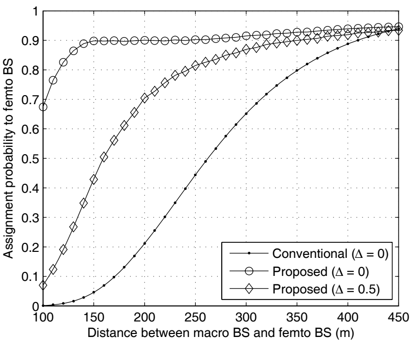

Fig. 4. Assignment probability to femto BS vs. distance between macro BS and femto BS.

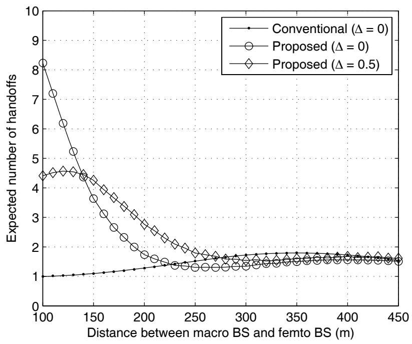

Fig. 5. Expected number of handoffs vs. distance between macro BS and femto BS.

where $h_{k|k-1}(x,y)$ has the same form as (9), but the mean and variance should be changed in accordance with the correlation between two RSS samples at k and $k-1$. The followings show the conditional mean, $\mu_{mc}[k]$ and $\mu_{fc}[k]$, and the conditional variance, σ_{mc}^2 and σ_{mf}^2, which are used in $h_{k|k-1}(x,y)$.

$$\begin{aligned} \mu_{mc}[k] &= \mu_{mw}[k] + \rho_c(x - \mu_{mw}[k-1]) \\ \mu_{fc}[k] &= \mu_{fw}[k] + \rho_c(y - \mu_{fw}[k-1]) \\ \sigma_{mc}^2 &= \sigma_{mw}^2(1-\rho_c^2) \quad \text{and} \quad \sigma_{fc}^2 = \sigma_{fw}^2(1-\rho_c^2) \end{aligned} \tag{11}$$

By integrating $g_{k-1}(x,y)H_{k|k-1}$ over the region $M1 \cup M2$, $P_{f|m}[k]$ can be calculated. Using the same way, $P_{m|f}[k]$ can also be calculated. So, $P_m[k]$, $P_f[k]$ and $P_{ho}[k]$ can be obtained, as expressed in (7). In addition, the total number of handoffs N_{ho} can be obtained by $N_{ho} = \sum_k P_{ho}[k]$.

IV. NUMERICAL RESULTS AND DISCUSSIONS

In order to evaluate the performance of a proposed algorithm, we use the same path loss and shadowing model, as represented in [1], and set the transmit power $P_{m,tx} = 43$ dBm for an m-BS and $P_{f,tx} = 21.5$ dBm for an f-BS. In addition, we set the filter period to $d_0 = 20$ m, the correlation distance to $d_1 = 30$ m, and the sampling distance to $d_s = 1$ m. The combination process is triggered when the RSS from the f-BS exceeds $s_{f,th} = -72$ dBm. Also, the femto cell boundary $k_0 = 30$ m, the marginal distance $k_1 = 10$ m, and the constraint $\epsilon = 0.05$ imposed on $P_m^c[k_0]$ in (6) were used.

We first observe an optimal combination factor that satisfies (6) for different positions of the f-BS, as shown in Fig. 2. When the m-BS and the f-BS are close to each other, less than 200 m apart, its value has nearly 1. Therefore, we can notice that the combination process is actively utilized, in particular, when the f-BS is located in the inner region of the macro cell or the RSS from the m-BS is strong.

Fig. 3 illustrates the cell assignment probabilities $P_f[k]$ and $P_m^c[k]$ that are used in (6). These probabilities are obtained in the situation where the f-BS is located 200 m away from the m-BS. When a conventional algorithm is used, $P_f[k]$ is below 0.1 and $P_m^c[k]$ is about 0.5 at the femto cell boundary $k = 170$. This means that a conventional criterion for handoff is hardly satisfied, because of the large RSS from the m-BS. However, when the proposed algorithm is used with the optimal combination factor $\alpha^* = 0.96$, $P_f[k]$ is about 0.5 and $P_m^c[k]$ is below 0.1 at the boundary. Such improvement can be obtained by the combination process that generates an adaptive offset according to the RSS from the m-BS and the combination factor. Thus, the proposed algorithm can support both successful and quick handoff from the m-BS to the f-BS.

Fig. 4 and Fig. 5 show the assignment probability $P_f[k]$ measured at 10 m inside from its boundary and the number of handoffs as a function of the distance between the m-BS and the f-BS, respectively. When the f-BS is located close to the m-BS, the proposed algorithm yields a much higher value for $P_f[k]$ than the conventional algorithm. However, the number of handoffs is also increased. Thus, there clearly exists a trade-off between the number of handoffs and the probability that the MS will be assigned to the f-BS. In order to reduce the number of handoffs, we suggest using an adaptive hysteresis, which is denoted by Δ, according to the RSS from the m-BS. For example, $\Delta = 0.5$ can be applied when the distance is smaller than 140 m. Then, the number of handoffs can be effectively reduced while keeping the gain in the probability that the MS will be assigned to the f-BS.

V. CONCLUSIONS AND FURTHER WORKS

We have proposed a new RSS-based handoff algorithm that is suitable for the hierarchical macro/femto cell networks with respect to providing successful handoff from an m-BS to an f-BS. The proposed algorithm reflects large asymmetry in the transmit power of the cells and its performance is analyzed by using the statistical properties of RSSs.

As further works, we will study an enhanced combination process by jointly considering both the signal quality and the number of handoffs. To this end, the optimization problem in (6) need to be updated with rigorous investigation of the trade-off among the signal quality, the number of handoffs and the corresponding handoff interruption time.

REFERENCES

[1] H. Claussen, "Performance of macro- and co-channel femtocells in a hierarchical cell structure," in *Proc. IEEE International Symposium on Personal, Indoor and Mobile Radio Communications 2007*, pp. 1–5, Sept. 2007.

[2] M. Halgamuge *et al.*, "Signal-based evaluation of handoff algorithms," *IEEE Commun. Lett.*, vol. 9, no. 9, pp. 790–792, Sept. 2005.

[3] M. Gudmundson, "Correlation model for shadow fading in mobile radio systems," *Electron. Lett.*, vol. 27, no. 23, pp. 2145–2146, Nov. 1991.

[4] K. Itoh *et al.*, "Performance of handoff algorithm based on distance and RSSI measurements," *IEEE Trans. Veh. Technol.*, vol. 51, no. 6, pp. 1460–1468, Nov. 2002.