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A Novel Handover Decision-Making Algorithm for HetNets

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Abstract—This paper aims to improve the handover performance in heterogeneous networks (HetNets). Since achieving high data rates, low signaling loads, and a better coverage area are highly dependent on the number of handovers, reducing the number of unnecessary handovers is crucial for both mobile users and the whole network. In this paper, a new decision-making algorithm, based on traffic and propagation metrics, is proposed for HetNets that can reduce the number of unnecessary handovers in comparison with the traditional handover algorithms, especially when the femtocell assignment probability is relatively high. We further analyze the handover probability for the proposed scheme which is in a close agreement with simulation results. Simulation results show that a higher assignment probability is achieved for the femtocell base station in the proposed scheme. We also show that the proposed scheme reduces the number of unnecessary handovers compared to the conventional RSS- α algorithm.

Index Terms—HetNet, handover, femtocell, RSS.

I. INTRODUCTION

Heterogeneity is one of the main properties of emerging next generation wireless networks. Recent trends in wireless communications indicate that wide area cellular networks can offer high speed and reliable multimedia services to mobile and fixed end users. In this regard, various access technologies can be incorporated with each other in order to achieve a high performance. In heterogeneous networks (HetNets), a variety of low power base stations (BS), such as micro, pico, and femto BS that can work in overlay with a macrocell BS [1]. In fact in HetNets, we encounter with a multi-tier network that provides high quality services. In order to benefit such positive points, some challenges must be alleviated at the beginning. The most challenging issue in HetNets is a seamless handover (HO) between various base stations from different network tiers. Handover (Handoff) management maintains active connections for roaming mobile terminals as they change their point of attachment to the network [2], [3]. Handover management techniques in HetNets include intra technology handover, referred to as the horizontal HO, and inter technology handover, referred to as the vertical HO, which mainly aim to apply an appropriate handover initialization strategy. These techniques were shown that can improve the resource utilization and user quality of service (QoS) in HetNets.

Conventional handover techniques are developed based on

the comparison between the received signal strength (RSS) of the current and candidate access points [4]. However, in two-tier HetNets with femtocells, due to the limitations of femtocells, handover decision-making algorithms usually utilize several input parameters in addition to RSS, in order to maximize the decision efficiency. Some existing handover techniques combine network loading with RSS. Many other research works applied fuzzy logic in handover decision-making process, because of its inherent strength in providing solutions to imprecision problems [5]. In [6], a handover decision-making strategy which uses principles of fuzzy logic to reduce the number of unnecessary handovers in homogeneous cellular systems was implemented. Also [7] utilizes speed and traffic load to decide the RSS hysteresis values, by using an adaptive fuzzy based vertical handover algorithm. Moreover, [8] provides a multi-criteria decision-making algorithm based on the fuzzy theory for multiple access network selection. Another techniques, such as location awareness, were also shown to help to reduce unnecessary handovers in femtocells [9].

Due to asymmetric power of macro and femto BSs in HetNets, some modifications must be done on RSS algorithms which have been mainly proposed for homogeneous networks, to be effectively used in HetNets. Authors in [10] proposed a new RSS based HO algorithm, referred to as RSS- α , for a handover scenario where a user moves from a macrocell to a femtocell. The main idea behind the RSS- α algorithm is to find the optimum combination factor that merges the values of RSS from a serving macro BS and the target femto BS to derive a reasonable handover criterion. In RSS- α , a significant improvement in the assignment probability of the femtocell has been achieved. Since the user's location with respect to the femtocell constantly changes, attaining the combination factor will increase the calculation complexity. To solve this problem, a new algorithm, called RWTL-HO, was proposed in [11] that improves the femtocell utilization and reduces the redundant HO compared to the RSS- α algorithm.

However in above mentioned algorithms, the traffic condition of femtocells were not considered in the handover decision making process. In this paper, a new decision-making algorithm, based on traffic and propagation metrics, is proposed for HetNets that can reduce the number of unnecessary handovers in comparison with the traditional handover algo-

gorithms, especially when the femtocell assignment probability is relatively high. More specifically, in the proposed scheme, we combines the RSS value as the propagation metric and the service time as the traffic metric in the handover decision making process. We further analyze the handover probability for the proposed scheme which is in a close agreement with simulation results. Simulation results show that a higher assignment probability is achieved for the femtocell base station in the proposed scheme. We also show that the proposed scheme reduces the number of unnecessary handovers compared to the conventional RSS- α algorithm.

The rest of the paper is organized as follows. The system model is presented in Section II. The proposed handover decision-making algorithm is represented in Section III. A closed-form expression for conditional probability is also derived in section III. Simulation results are shown in Section IV. Finally, Section V concludes the paper.

II. SYSTEM MODEL

Fig. 1 shows the system model under consideration for a HetNet, consisting of one macrocell and one femtocell base station (BS). It is assumed that a user with a constant velocity, V , is moving towards the femtocell BS. Let T_m and T_f denote the transmit power of the macrocell and femtocell BSs, respectively, in dB. We use the path loss model to represent the received power at the mobile terminal as follows:

$$P_m[n] = T_m - PL_m + u_m \quad (1)$$

$$P_f[n] = T_f - PL_f + u_f, \quad (2)$$

where n is the time index, $P_m[n]$ and $P_f[n]$ are the received power in dB at the mobile terminal from the macrocell and femtocell base stations, respectively, PL_m and PL_f are the path loss in the macrocell and femtocell, respectively, which can be calculated as follows:

$$PL_m = 28 + 35 \log_{10}(d_1) \text{ dB} \quad (3)$$

$$PL_f = 38.5 + 20 \log_{10}(d_2) \text{ dB}, \quad (4)$$

where d_1 and d_2 are the distances of the mobile user to the macrocell and femtocell base stations, respectively, and the wall partition loss is also assume to be 10 dB. The shadowing of macrocell and femtocell, denoted respectively by u_m and u_f , are modeled by mutually independent zero-mean log-normal distributions with variances σ_m^2 dB and σ_f^2 dB, respectively.

Due to abrupt changed of the received signal strength from macrocell and femtocell BSs, we use the average received signal powers from macrocell and femtocell BSs to track the signal power changes at the mobile terminal. Let $\bar{P}_m[n]$ and $\bar{P}_f[n]$ denote the average received power at the mobile terminal from the macrocell and femtocell BSs, respectively.

Fig. 1. System model for two-tier HetNet and channel model for femtocell

As shown in [12], they can be found as follows:

$$\bar{P}_m[n] = \frac{1}{W_{av}} \sum_{i=0}^{W_{av}-1} P_m[n-i] \quad (5)$$

$$\bar{P}_f[n] = \frac{1}{W_{av}} \sum_{i=0}^{W_{av}-1} p_f[n-i], \quad (6)$$

where W_{av} is the window size defined as follows:

$$W_{av} = \max \left\{ 10, \left\lfloor \frac{D_{av}}{VT_s} \right\rfloor \right\}, \quad (7)$$

T_s and D_{av} denote RSS sampling interval and averaging distance, respectively [12], and $\lfloor \cdot \rfloor$ is the floor operation.

The rate of change in the received signal strength from the macrocell BS can then be calculated as follows:

$$R_m[n] = \frac{S_1[n] - S_2[n]}{W_s T_s}, \quad (8)$$

where W_s is the slope estimator window size which is given by:

$$W_{av} = 2 \times \max \left\{ 50, \left\lfloor \frac{D_s}{VT_s} \right\rfloor \right\}, \quad (9)$$

and D_s is the slope distance window [12]. $S_1[n]$ and $S_2[n]$ can also be expressed as follows:

$$S_1[n] = \frac{2}{W_s} \sum_{i=0}^{\frac{W_s}{2}-1} \bar{P}_m[n - W_s + 1 + i] \quad (10)$$

$$S_2[n] = \frac{2}{W_s} \sum_{i=\frac{W_s}{2}}^{W_s-1} \bar{P}_m[n - W_s + 1 + i]. \quad (11)$$

The parameter $R_f[n]$ can be similarly defined for the received signal from the femtocell BS. Using the above equations, we can estimate the time duration, D_m and D_f , where the signal strengths from the macrocell and femtocell BSs are above their threshold values, γ_m and γ_f , respectively, as follows:

$$D_m[n] = \frac{\bar{P}_m[n] - \gamma_m}{R_m[n]} \quad (12)$$

$$D_f[n] = \frac{\bar{P}_f[n] - \gamma_f}{R_f[n]} \quad (13)$$

As shown in Fig.1, a mobile terminal randomly selects one of the N available channels of the femtocell. It is assumed that the channel holding time, t_h of the mobile terminal is previously known by the BS. It is clear that during this time, the signal strength of the femtocell BS must be above its threshold value to support the quality of a proper call.

III. THE PROPOSED HANDOVER DECISION-MAKING ALGORITHM

In this section, we present the proposed handover decision-making algorithm for HetNets based on the network traffic and received signal strength, to reduce the number of unnecessary handovers and effectively increase the assignment probability of the femtocell BS. We then analyze the proposed scheme and find the probability of the femtocell assignment probability.

A. The Proposed Algorithm

Benefiting from parameters D_m and D_f , we can introduce a new decision-making algorithm in which not only the propagation condition such as the average signal strength, but also the traffic metric such as the expected service time of mobile terminals, play significant roles on triggering the handover process.

The proposed handover decision-making process is summarized in Table I. In the proposed scheme, when the average received signal power from the macrocell BS, $\overline{P_m}[n]$ is below the threshold value, γ_m , and the average received signal power from the femtocell BS, $\overline{P_f}[n]$ is larger than $\overline{P_m}[n]$, by a constant factor Δ , referred to as the hysteresis margin, the mobile terminal will be connected to the femtocell BS. Moreover, when D_f is larger than the holding time, t_h , the mobile terminal will be connected to the femtocell BS.

It is important to note that simultaneous changes of RSS in conventional handover techniques is replaced by the average signal strength in our proposed algorithm. The main reason is to increase the chance of handover to the femtocell BS while maintaining the number of unnecessary handovers as low as possible. For this aim, the second condition in the proposed scheme (Table I) is used to compare the rate changes of the signal strength to the average service time. During this time, if the average signal power of the macrocell BS falls below the threshold value and the average signal power of the femtocell BS goes higher than that, the handover can be triggered. In addition to decreasing the unnecessary number of handovers, the risk of handover failure and blocking probability will be reduced in the proposed scheme. This is due to the fact that in the proposed scheme, the channel condition of the femtocell is checked before performing the handover.

B. Performance Analysis

In this section, we calculate the probability of handover from the macrocell BS to the femtocell BS, denoted by $p(f|m)$. We focus on the second condition in the proposed scheme, as the first condition were previously analyzed in the

TABLE I
THE PROPOSED ALGORITHM

If $\overline{P_m}[n] < \gamma_m \wedge \overline{P_f}[n] > \overline{P_m}[n] + \Delta$
Connect to the femtocell BS
Else if $D_m < t_h \wedge D_f > t_h$
Connect to the femtocell BS
End

RSS algorithm in [12]. According to the proposed scheme in Table I, $p(f|m)$ can be represented as follows:

$$p(f|m) = p\left(\frac{\overline{P_m}[n] - \gamma_m}{R_m[n]} < t_h \mid \frac{\overline{P_f}[n] - \gamma_f}{R_f[n]} > t_h\right), \quad (14)$$

which can be rewritten as follows:

$$p(f|m) = pr(\overline{P_m}[n] - R_m[n]t_h < \gamma_m \mid \overline{P_f}[n] - R_f[n]t_h > \gamma_f).$$

Let us define z_1 and z_2 as follows:

$$z_1 = \overline{P_m}[n] - R_m[n]t_h \quad (15)$$

$$z_2 = \overline{P_f}[n] - R_f[n]t_h. \quad (16)$$

It is then easy to show that z_1 and z_2 are mutually independent normal random variables with means μ_{z_1} and μ_{z_2} and variances $\sigma_{z_1}^2$ and $\sigma_{z_2}^2$, respectively (See Appendix for the proof). Therefore, (14) can be rewritten as follows:

$$p(f|m) = \frac{pr(z_1 < \gamma_m, z_2 > \gamma_f)}{pr(z_2 > \gamma_f)} \quad (17)$$

Since z_1 and z_2 are independent random variables with normal distributions, we can rewrite the conditional probability function as follows:

$$p(f|m) = \frac{\int_{-\infty}^{\gamma_m} \int_{\gamma_f}^{\infty} f_z(z_1, z_2) dz_1 dz_2}{Q\left(\frac{\gamma_f - \mu_{z_2}}{\sigma_{z_2}}\right)}, \quad (18)$$

where $Q(x) = \frac{1}{\sqrt{2\pi}} \int_x^{\infty} e^{-y^2/2} dy$.

In a similar way, the first constraint in the proposed algorithm can be formulated as follows:

$$p(f|m) = 1 - Q\left(\frac{\gamma_m - \mu_{z_1}}{\sigma_{z_1}}\right) + Q\left(\frac{\overline{P_m}[n] + \Delta - \mu_{z_2}}{\sigma_{z_2}}\right). \quad (19)$$

IV. SIMULATION RESULTS

In this section, we evaluate the proposed scheme in terms of the handover assignment probability to the femtocell BS and the number of unnecessary handovers. We also compare our proposed algorithm with the conventional RSS- α scheme. We list all parameters used in our simulations in Table II for quick reference. It is assumed that a single user with a constant velocity is moving from the macro BS to femtocell. To examine the heterogeneity property of HetNets, the transmit power of macrocell and femtocell BSs are considered to be 43

TABLE II
PARAMETERS FOR PERFORMANCE ALGORITHM

$T_m = 43$ dBm	Transmit power of macro BS
$T_f = 21.5$ dBm	Transmit power of femto BS
$\sigma_m = 8$ dB	Shadowing standard deviations of macrocell signals
$\sigma_f = 6$ dB	Shadowing standard deviations of femtocell signals
$\gamma_m = -90$ dBm	Threshold of RSS from macro BS
$\Delta = 3$ dBm	Hysteresis margin
$W=10$ dB	Wall loss
$T_s = 0.7$ s	RSS sampling interval

Fig. 2. Received signal strength from macro and femto BSs in the MS.

dBm and 21.5 dBm, respectively. Also the coverage area of macrocell and femtocell BS is assumed to be 1 km and 30 m, respectively. Other parameters such as the shadowing variance and RSS threshold are listed in Table II.

Fig. 2 shows the received signal strength from macrocell and femtocell BSs at the mobile station versus the location of the user, when the user is moving towards the femtocell BS with a constant velocity. In general, the RSS from femtocell BS is increasing with the location of the mobile user, but due to shadowing in some locations the RSS value for the macrocell BS might be larger than that of femtocell BS. This may cause many unnecessary handovers in conventional handover decision-making techniques. However in our proposed algorithm, we consider a variable length window size and make an appropriate decision for handover in such situations.

Fig. 3 shows the handover probability to the femtocell BS versus the location of the mobile user. As can be seen in this figure, the handover probability increases when the mobile user is getting closer to the femtocell BS. The simulation results are also in a close agreement with the analysis in Section III. Moreover, as can be seen in this figure, the handover probability to the femtocell BS in the proposed scheme is much larger than that in the RSS- α algorithm. For example, for the handover probability of 0.6, the mobile terminal must be 700 m away from the macrocell BS in the proposed scheme, while it must be at least 870 m away from the macrocell BS in RSS- α .

Fig. 4 shows the total number of handovers in both RSS- α

Fig. 3. Assignment probability to femtocells versus the location of MS.

Fig. 4. Total number of handovers versus the location of MS.

and the proposed algorithm versus the location of the mobile terminal. In the RSS- α , when the user is very close to the macrocell BS, the assignment probability is negligible and thus it requests many handovers that are usually unnecessary. But, in the proposed algorithm, the handover request starts when its chance to connect to the femtocell BS is increased to a certain value. This can be clearly seen in Fig. 4, where the number of total handover in the proposed scheme is significantly lower than that in the RSS- α algorithm. We further show the number of unnecessary handovers for both algorithms in Fig. 5. In the RSS- α algorithm, the number of unnecessary handovers reaches to 50 at distance 1000 m, that means about 33% of the total handovers are unnecessary. In contrast, in the proposed algorithm, the expected number of handovers is reduced to 10 at the same distance. In fact, in the proposed algorithm, the number of unnecessary handovers is only about 6.7% of total handovers, which shows a significant reduction in comparison with the conventional RSS- α algorithm.

Fig. 5. Number of unnecessary handovers versus the location of MS.

V. CONCLUSIONS

In this paper, a new handover decision-making algorithm was proposed for two-tier HetNets. In the proposed scheme, both the signal strength and the traffic metric such as the service time were taken into account in the handover decision-making process. The main design criteria was to improve the assignment probability to the femtocell BS, while minimizing the number of unnecessary handovers. Simulation results show that the proposed scheme achieve a higher assignment probability to the femtocell BS compared to that in the conventional RSS- α algorithm. Moreover, the number of unnecessary handovers was shown to be significantly reduced by the proposed scheme in comparison with RSS- α .

APPENDIX

Since u_m and u_f have log normal distributions, PL_m , PL_f , and transmit powers of macrocell and femtocell BSs are constant values, then $P_m[n]$ and $P_f[n]$ in (1) and (2) have normal distributions. Accordingly, $R_m[n]t_h$ and $R_f[n]t_h$ are constant values. Therefore, z_1 and z_2 in (15) and (16) are also have normal distributions with their mean given by:

$$\begin{aligned}\mu_{z_1}[n] &= \mu_{\overline{P_m}}[n] - t_h \mu_{R_m}[n], \\ \mu_{z_2}[n] &= \mu_{\overline{P_f}}[n] - t_h \mu_{R_f}[n],\end{aligned}$$

where,

$$\begin{aligned}\mu_{\overline{P_m}}[n] &= \mu_{P_m}[n] + \frac{1}{W_{av}} \sum_{i=0}^{W_{av}-1} 35 \log \left(1 - \frac{iVT_s}{d_1[n]} \right), \\ \mu_{\overline{P_f}}[n] &= \mu_{P_f}[n] + \frac{1}{W_{av}} \sum_{i=0}^{W_{av}-1} 20 \log \left(1 - \frac{iVT_s}{d_2[n]} \right), \\ \mu_{R_m}[n] &= \frac{\mathbb{E}S_1[n] - \mathbb{E}S_2[n]}{W_s T_s},\end{aligned}$$

The variance of z_1 can be found as follows:

$$\sigma_{z_1}^2[n] = \sigma_{\overline{P_m}}^2 + t_h^2 \sigma_{R_m}^2 + \frac{4t_h^2 \sigma_{P_m}^2 \sum_{i=0}^{W_{av}-1} (W_{av} - |h|)}{W_s^2 T_s W_{av}^2},$$

where

$$\begin{aligned}\sigma_{\overline{P_m}}^2[n] &= \frac{\sigma_m^2}{W_{av}} \\ \sigma_{R_m}^2[n] &= \frac{4\sigma_m^2}{W_s^2 T_s W_{av}} \left(W_{av} W_s \sum_{h=1}^{W_{av}-1} (W_{av} - |h|) (2W_s - 6|h|) \right).\end{aligned}$$

In a similar way $\sigma_{z_2}^2$ can be found.

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