Telecommun Syst (2013) 52:317–325
DOI 10.1007/s11235-011-9667-1

An efficient handoff algorithm based on received signal strength and wireless transmission loss in hierarchical cell networks

Peng Xu · Xuming Fang · Rong He · Zheng Xiang

Published online: 15 September 2011

Abstract Compared with the macrocell systems, the femtocell systems allow users to obtain broadband service with high data rate by using lower costs of transmit power, operation and capital expenditure. Traditional handoff algorithms used in macrocells cannot well satisfy the mobility of users efficiently in hierarchical macro/femto cell networks. In this paper based on the received signal strength (RSS) and wireless transmission loss, a new handoff algorithm in hierarchical cell networks called RWTL-HO is proposed, which considers the discrepancy in transmit power between macrocell and femtocell base stations. The simulation results show that compared with the conventional algorithm, the proposed algorithm improves the utilization of femtocells by doubling the number of handoffs; and in comparison with the handoff algorithm based on combining the RSSs from both macro and femto cell base stations, reduces half the number of redundant handoffs.

Keywords RSS · Wireless transmission loss · Hierarchical networks · Transmit power

P. Xu (✉) · X. Fang · R. He · Z. Xiang
Key Lab of Information Coding & Transmission, Southwest Jiaotong University, Mailbox 634#, Erhuanlu beiyiduan 111#, Chengdu, 610031, China
e-mail: pengxup@gmail.com

X. Fang
e-mail: xmfang@swjtu.edu.cn

R. He
e-mail: rhe@home.swjtu.edu.cn

Z. Xiang
e-mail: xz3_83@hotmail.com

1 Introduction

Increasing demand of mobile services with high data rate has resulted in the reduction of cell radius and increase in the number of handoffs. A new technology called femtocell emerged in 2006 is proposed to resolve the signal coverage of the indoor voice service and high-speed data service in the cellular mobile communications systems [1, 2]. The low-power base stations (BS) of femtocell systems are deployed in indoor environment by users. Typically, femtocells connect to Internet via a digital subscriber line (DSL) router or cable modem. Femtocells can not only offer benefits to the operators with low-cost operation and capital expenditure, but also bring the subscribers better voice service coverage and data service with higher rate [3, 4].

The recent proposed hierarchical macrocell/femtocell networks can provide better quality of service for both indoor and outdoor users [5]. In these networks many low power femtocell base stations (f-BSs) are implemented within the coverage of macro base stations (m-BS) which typically use large transmit power for covering a wide geographic area [6, 7]. To support satisfying mobility in hierarchical networks, an appropriate handoff scheme which considers the random deployment and mobility of femtocells is essential.

A variety of conventional handoff algorithms used in macrocells, based on received signal strength (RSS) with hysteresis and threshold, have been studied in [8], in which a handoff occurs when the RSS from the serving base station is not only smaller than the threshold but also larger than the sum of the RSS and the margin of target base station, where the threshold means the minimal RSS from the serving BS. Another handoff algorithm based on the estimation of location and moving speed of mobile station is proposed in [9]. Then the optimal moving speed is studied in [10], meanwhile a mobility management scheme for hybrid networks in which both wired network and wireless network exist is suggested. However, the aforementioned algorithms neither consider the base stations of femtocells nor the asymmetry in transmit power between macrocells and femtocells, resulting in the fact that these algorithms cannot be applied to hierarchical networks directly.

A hierarchical handoff algorithm which takes the users' moving speed into account is proposed in [1]. However the issue of power asymmetry cannot be well reflected and resolved only by adding a fixed value to the RSS from the base station of femtocell, because the difference of the RSSs from macrocell and femtocell base stations would be varying when femtocells are located in different positions. Another hierarchical handoff algorithm in which the combined RSSs from both macrocells and femtocells are used as a new handoff criterion is proposed in [11]. For convenience we refer to this algorithm as RSS-α-HO algorithm in this paper. Although the asymmetry in transmit power has been avoided, the system performance will decrease because of increasing computational burden for mobile stations, which is resulted from obtaining dynamic parameter α, and increasing the number of redundant handoffs that lack some certain quality of service (QoS) guarantees such as high interruption rate and low data rate caused by the RSS lower than predefined threshold.

In this paper an efficient handoff algorithm in the hierarchical macro/femto cell networks called RWTL-HO is proposed, which makes both of the RSS and wireless transmission loss as a new handoff criterion. The results of analysis and simulation represent that the proposed algorithm can improve the utilization of femtocells, and reduce the number of redundant handoffs. Besides, the RWTL-HO algorithm can be easily implemented with fewer amounts of calculation, and provide the guarantee of the handoff performance.

2 System model

Figure 1 shows the system topology used in this paper, in which femtocells are deployed randomly in a macrocell. Here f-BS is adopted to denote the base station of femtocell, and m-BS denotes the base station of macrocell. As the analysis of handoff is carried out in the whole system, the hierarchical environment is adopted here. The handoff of a mobile station may occur from a femtocell to a macrocell, which is easily dealt with by adopting the conventional algorithms, or from a macrocell to a femtocell, which will be concentrated and analyzed thoroughly in this paper.

$s_m[k]$ and $s_f[k]$ represent the RSS from an m-BS and an f-BS at time instant k, respectively. Assume that an MS is moving in a straight line from the region covered by the m-BS to the region covered by the f-BS with a constant pedestrian speed.

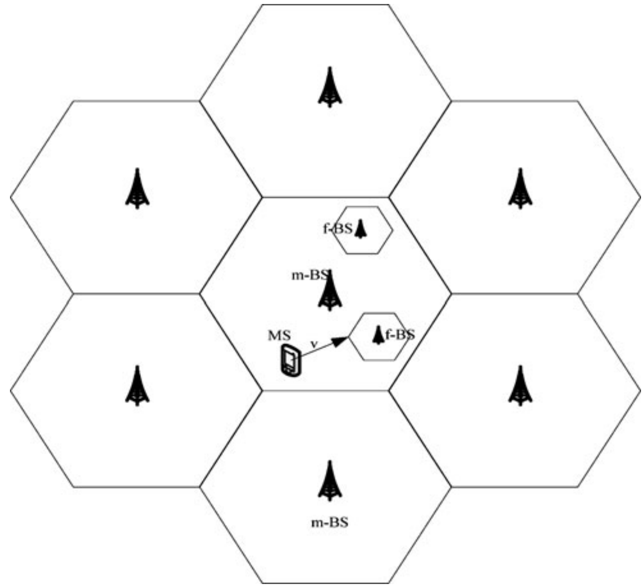

Fig. 1 System scenario

Given $T_{m,tx}$ and $T_{f,tx}$ are respective transmit power of an m-BS and an f-BS, $PL_m[k]$ and $PL_f[k]$ are respectively relevant to path losses from an MS to a BS, $s_m[k]$ and $s_f[k]$ can be expressed as:

$$s_m[k] = T_{m,tx} - PL_m[k] - u_m[k] \tag{1}$$

$$s_f[k] = T_{f,tx} - PL_f[k] - u_f[k] \tag{2}$$

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 with a correlation distance d_0 [12].

To prevent the RSSs from varying abruptly, the exponential window function is defined as $w[k] = (1/d_1)\exp(-kd_s/d_1)$, where d_s and d_1 represent the distances between two adjacent measurement locations and the window length, respectively. Then the window is applied to $s_m[k]$ and $s_f[k]$ as in [8], and can be expressed as:

$$\bar{s}_m[k] = w[k] * s_m[k] \tag{3}$$

$$\bar{s}_f[k] = w[k] * s_f[k] \tag{4}$$

Then the variances of the shadowing in which the corresponding shadowing and the window function are considered, become $\sigma_{mw}^2 = (d_0\sigma_m^2)/(d_0 + d_1)$ 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 in [11]:

$$\rho_c = \{d_0 \exp(-d_s/d_0) - d_1 \exp(-d_s/d_0)\}/(d_0 - d_1) \tag{5}$$

The conventional handoff algorithm generally used in most macrocells, in which the RSSs are compared along

Table 1 Pseudocodes of conventional algorithm

```
if s_m < s_m,th
  s_f > s_m + Δ then handoff to f-BS
else keep associated to m-BS
```

with hysteresis and threshold [8], can be expressed in formula as (6) and pseudo codes as Table 1:

$$\overline{s}_m(k) < s_{m,th} \,\&\, \overline{s}_f(k) > \overline{s}_m(k) + \Delta \tag{6}$$

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

Since there is a large difference between the transmit power of an m-BS (≈43 dBm) and an f-BS (≈10 dBm), when the MS is near the m-BS, the RSSs from both of the m-BS and the f-BS are not comparable in some regions, in which the RSS from the m-BS is always larger than that from the f-BS, where the RSSs from f-BSs with different transmit power equal the RSS from the m-BS is shown in Fig. 2. In this case it is difficult to satisfy the handoff criterion described by (6), which may cause undesired congestion of the m-BS and low usage of the f-BSs [11].

The RSS-α-HO algorithm proposed in [11] to settle this problem are represented as (7) and (8) in formulas which are sufficient conditions when handoffs happen, and as Table 2 in pseudo codes:

$$\overline{s}_f(k) > s_{f,th} \,\&\, (\overline{s}_f(k) + \alpha\overline{s}_m(k)) > \overline{s}_m(k) + \Delta \tag{7}$$

Table 2 Pseudocodes of RSS-α-HO algorithm

```
if s_f > s_f,th
  if s_f + α · s_m > s_m + Δ then handoff to f-BS
  else keep associated to m-BS
else s_f < s_f,th
  if s_f > s_m + Δ then handoff to f-BS
  else keep associated to m-BS
```

or

$$\overline{s}_f(k) < s_{f,th} \,\&\, \overline{s}_f(k) > \overline{s}_m(k) + \Delta \tag{8}$$

where $\alpha \in [0, 1]$ denotes a combination factor that reflects large asymmetry in the transmit power of cells, and $s_{f,th}$ denotes a threshold that is the minimum RSS level from the f-BS for keeping normal communication not interrupted. However from the users' point of view, a certain level of QoS will not be guaranteed if the threshold of RSS is not achieved. That is, the condition of (8) will increase some redundant handoff, which means the service may not be supported well even if handoff occurred. Meanwhile along with the location change of MSs and f-BSs, attaining the value of α will increase the amount of calculation for MSs.

To overcome the drawbacks of both conventional and RSS-α-HO algorithms, and derive a reasonable handoff criterion, a new RSS and wireless transmission loss-based handoff algorithm is proposed. The wireless transmission losses from an MS ($W_{c,MS}$) to a BS and from a BS ($W_{c,BS}$)

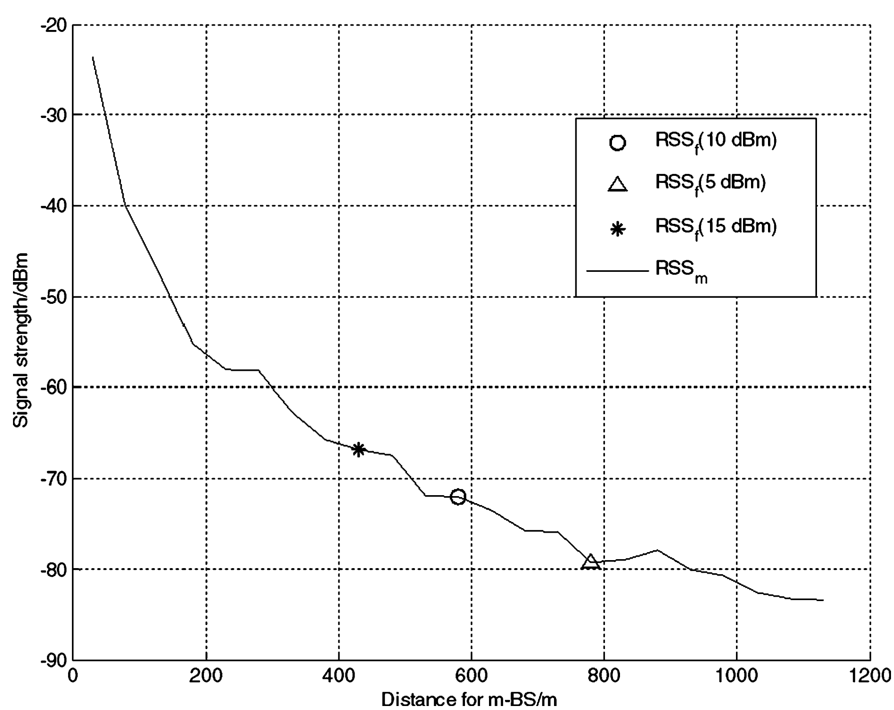

Fig. 2 Decay of RSSs versus distance

Table 3 Pseudocodes of the proposed algorithm

if $s_f > s_{f,th}$	
if $s_f > s_m + \Delta$ then handoff to f-BS	{area (a)}
else	
if $W_{c,m} > W_{c,f,}$ then handoff to f-BS	{area (b)}
else then keep associated to m-BS	{area (c)}
else then keep associated to m-BS	{area(d)}

to the relevant MS can be calculated respectively as follow:

$$W_{c,MS} = T_{t,MS} - R_{r,BS} \tag{9}$$

$$W_{c,BS} = T_{t,BS} - R_{r,MS} \tag{10}$$

where $T_{t,MS}$ and $T_{t,BS}$ separately represent transmit power of the MS and the BS. $R_{r,BS}$ and $R_{r,MS}$ denote the correlative receive power at the BS and at the MS respectively, which are the same as corresponding received signal strength. Then $W_{c,MS}$ and $W_{c,BS}$ can be almost considered as the same in very short time because of symmetry. The relevant wireless transmission losses $W_{c,m}$ and $W_{c,f}$ can be described as (11) in macro network and as (12) in femto network, respectively.

$$W_{c,m} = T_{t,mBS} - R^m_{r,MS} \tag{11}$$

$$W_{c,f} = T_{t,fBS} - R^f_{r,MS} \tag{12}$$

where $T_{t,mBS}$ and $T_{t,fBS}$ separately denote transmit power of the m-BS and the f-BS. Here $R^f_{r,MS}$ and $R^m_{r,MS}$ denote the received powers of the MS from different base stations. Then relying on (1) and (2) in addition to (11) and (12), relevant wireless transmission losses can be represented as:

$$W_{c,m}[k] = T_{t,mBS}[k] - R^m_{r,MS}[k] = PL_m[k] + u_{mw}[k] \tag{13}$$

$$W_{c,f}[k] = T_{t,fBS}[k] - R^f_{r,MS}[k] = PL_f[k] + u_{fw}[k] \tag{14}$$

3 RWTL-HO algorithm and performance analysis

For an easy analysis of the handoff process, a scenario is set as one macrocell with one randomly deployed femtocell, in which only the mobility of the MS with pedestrian speed from a macrocell to a femtocell is considered.

3.1 RWTL-HO

The RWTL-HO algorithms can be described in pseudo codes as Table 3.

The proposed algorithm described in Table 3 can avoid the asymmetry of transmit powers, and be applied to hierarchical network immediately. Here (a) represents that an f-BS is far away from the m-BS, and MS will handoff to femtocell if the condition is satisfied. (b) and (c) denote the f-BS is deployed close to m-BS, and the RSSs are incomparable because of large asymmetry. To avoid the foregoing case, wireless transmission loss is considered. By comparing wireless transmission loss of an MS in different cell networks, the MS will choose one cell with the lowest wireless transmission loss. (d) means that the MS is almost not in the coverage of the f-BS. From the aforementioned analysis, where an MS may be located can be expressed with a two-dimensional vector of RSS and wireless transmission loss in Fig. 3. Figure 3 (a) shows the case when $s_m + \Delta > s_{f,th}$, and Fig. 3 (b) presents contrary case when $s_m + \Delta < s_{f,th}$.

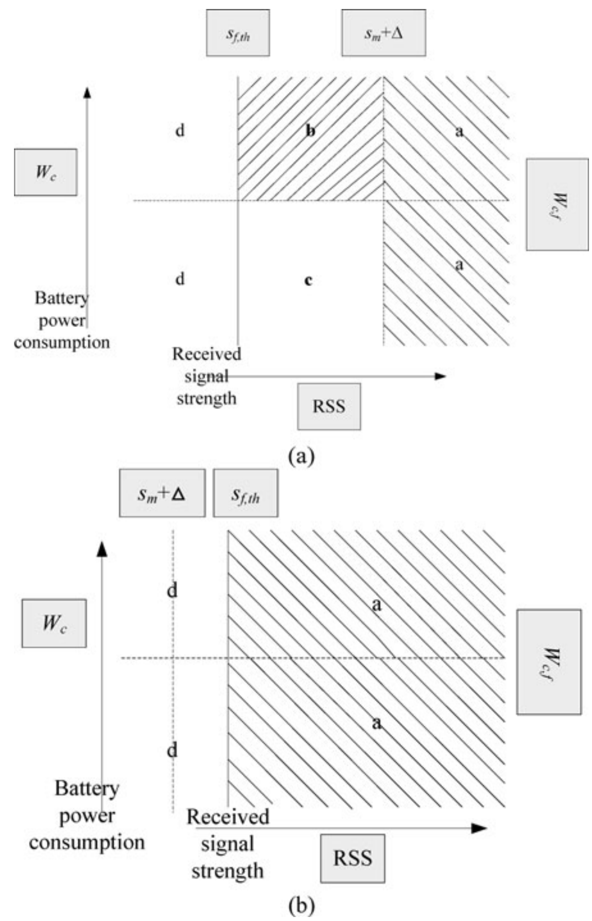

Fig. 3 Location of MS with two dimension vector

In addition, the amounts of calculation for both RSS-α-HO and RWTL-HO algorithms can be roughly evaluated. To obtain the key parameter α of the RSS-α-HO algorithm as described in [11], not only the location information of the f-BS such as femto cell boundary and marginal distance, but the probability that both events assigned to the m-BS and $s_f > s_{f,th}$ occur simultaneously, are required. However compared with the RWTL-HO algorithm, mentioned above are almost additional amounts of calculation which will increase calculation burden of an MS. And the more numbers of femtocells deployed, the more amounts of calculation needed. From another point of view, that will decrease standby time of an MS's battery.

3.2 Performance analysis of proposed algorithm

As stated in the previous study [11, 13], related assignment probabilities are analyzed in depth to investigate the suitability of the proposed algorithm. The probabilities that an MS will be assigned to an m-BS and an f-BS at k, denoted by $P_m[k]$ and $P_f[k]$ respectively, and the probability that a handoff occurs at k, denoted by $P_{ho}[k]$ can be expressed as follows [14]:

$$P_m[k] = P_m[k-1](1 - P_{f|m}[k]) + P_f[k-1]P_{m|f}[k] \quad (15)$$

$$P_f[k] = P_m[k-1]P_{f|m}[k] + P_f[k-1](1 - P_{m|f}[k]) \quad (16)$$

$$P_{ho}[k] = P_m[k-1]P_{f|m}[k] + P_f[k-1]P_{m|f}[k] \quad (17)$$

where $P_{f|m}[k]$ represents the probability of the handoff from an m-BS to the f-BS at k, and vice versa for $P_{m|f}[k]$.

To facilitate the analysis, some transforms are made as:

$$s[k] = \bar{s}_f[k] - \bar{s}_m[k] \quad (18)$$

$$W_c[k] = W_{c,f}[k] - W_{c,m}[k] = PL_f[k] + u_f[k] - PL_m[k] - u_m[k] \quad (19)$$

where $s[k]$ denotes the difference of the signal strengths with mean $u_{fw} - u_{mw}$, variance $\sigma_{mw}^2 + \sigma_{fw}^2 = d_0(\sigma_m^2 + \sigma_f^2)/(d_0 + d_1)$. $W_c[k]$ denotes the difference of wireless transmission loss with mean $u_m - u_f$ and variance $\sigma_m^2 + \sigma_f^2$, because of independence.

To obtain the handoff probability from a macrocell to a femtocell, $P_{f|m}[k]$, the joint probability density function (PDF) of $s[k]$ in (18) and $W_c[k]$ in (19) can firstly be defined as $g_{k-1}(s, W_c)$ shown in (20), where γ is the correlation coefficient between the random variables $s[k]$ and $W_c[k]$ [13, 15–17].

$$\begin{aligned} g_{k-1}(s, W_c) = &\frac{1}{2\pi\sqrt{(\sigma_{mw}^2 + \sigma_{fw}^2)(\sigma_m^2 + \sigma_f^2)(1-\gamma^2)}} \\ &\times \exp\left\{-\frac{1}{2(1-\gamma^2)}\left[\frac{(s - (u_{fw}[k-1] - u_{mw}[k-1]))^2}{(\sigma_{mw}^2 + \sigma_{fw}^2)} - 2\gamma\right.\right. \\ &\times \frac{(s - (u_{fw}[k-1] - u_{mw}[k-1])) \times (W_c - (u_m[k-1] - u_f[k-1]))}{\sqrt{(\sigma_{mw}^2 + \sigma_{fw}^2)(\sigma_m^2 + \sigma_f^2)}} \\ &\left.\left. + \frac{(W_c - (u_m[k-1] - u_f[k-1]))^2}{(\sigma_m^2 + \sigma_f^2)}\right]\right\} \end{aligned} \quad (20)$$

Then the handoff probability, $P_{f|m}[k]$, can be described as:

$$\begin{aligned} P_{f|m}[k] &= \frac{\Pr\{F[k] \text{ and } M[k-1]\}}{P_m[k-1]} \\ &= \frac{1}{P_m[k-1]}\iint_{c\cup d} g_{k-1}(s, W_c)H_{k|k-1}\, ds\, dW_c \end{aligned} \quad (21)$$

where $H_{k|k-1}$ represents the probability that MS will be assigned to the f-BS at k when the RSS at $k-1$ is given. The probability can be obtained by integrating the joint conditional PDF $h_{k|k-1}(s, W_c)$ over the region $a \cup b$ marked in Fig. 3 [11], which can be expressed as:

$$H_{k|k-1} = \iint_{a\cup b} h_{k|k-1}(s, W_c)\, ds\, dW_c \quad (22)$$

where $h_{k|k-1}(s, W_c)$ has the same form as in (20), but the mean and variance should be changed in accordance with the correlation between two RSS samples at k and $k-1$. Equations (23)–(26) show the conditional mean, $u_{sc}[k]$ and $u_{W_cc}[k]$, and the conditional variance, σ_{sc}^2 and $\sigma_{W_cc}^2$, which are used in $h_{k|k-1}(s, W_c)$:

$$u_{sc}[k] = u_{fw}[k] - u_{mw}[k] + \rho_c(s - (u_{fw}[k-1] - u_{mw}[k-1])) \quad (23)$$

$$u_{W_cc}[k] = u_m[k] - u_f[k] + \rho_c(W_c - (u_m[k-1] - u_f[k-1])) \quad (24)$$

Table 4 Parameters setting

Parameter	Value
Macro cell radius	1.2 km
Femto cell radius	30 m
Femto transmit power	10 dBm
Macro transmit power	45 dBm
$s_{f,th}$	−72 dBm
$s_{m,th}$	−108 dBm
Δ	0/3 dBm
Path loss model	PL_{macro}, PL_{femto}

$$\sigma_{sc}^2 = (\sigma_{mw}^2 + \sigma_{fw}^2)(1-\rho_c^2) \tag{25}$$

$$\sigma_{W_c c}^2 = (\sigma_m^2 + \sigma_f^2)(1-\rho_c^2) \tag{26}$$

where ρ denotes the correlation coefficient between two samples at k and $k-1$ of random variables $s[k]$ and $W_c[k]$.

Then $h_{k|k-1}(s, W_c)$ can be represented as (27). By integrating $g_{k-1}(s, W_c)H_{k|k-1}$ over the region $c \cup d$, $P_{f|m}[k]$ can be calculated. $P_{m|f}[k]$ can also be calculated in the same way. Then $P_m[k]$, $P_f[k]$ and $P_{ho}[k]$ can be obtained from (15), (16) and (17) respectively.

$$\begin{aligned} &h_{k|k-1}(s, W_c)\\ &= \frac{1}{2\pi\sigma_{sc}\sigma_{W_c c}\sqrt{1-\rho^2}} \exp\left\{-\frac{1}{2(1-\rho^2)}\right.\\ &\quad \times \left[\frac{(s-(u_{sc}[k-1]))^2}{\sigma_{sc}^2} - 2\rho\right.\\ &\quad \times \frac{(s-(u_{sc}[k-1])) \times (W_c - (u_{W_c c}[k-1]))}{\sigma_{sc}\sigma_{W_c c}}\\ &\quad \left.\left. + \frac{(W_c - u_{W_c c}[k-1])^2}{\sigma_{W_c c}^2}\right]\right\} \end{aligned} \tag{27}$$

4 Simulation results

In order to evaluate the proposed algorithm, the simulation is divided into two parts. Firstly the assignment probability described in the section on performance analysis will be validated. Then the numbers of handoffs in different cases are discussed under some assumptions. For the purpose of comparison, we use the same parameters as in [11]. The filter period is $d_0 = 20$ m, the correlation distance is $d_1 = 30$ m, and the sampling distance is $d_s = 1$ m. The other parameters are listed as in Table 4.

PL_{macro} and PL_{femto} in Table 4 are represented as in [18, 19]:

$$PL_{macro} = 128.1 + 37.6\log_{10} d \tag{28}$$

where d is the distance from the macrocell to the MS in meters.

$$\begin{aligned} PL_{femto} = {} & \max(15.3 + 37.6\log_{10} d, 37 + 20\log_{10} d)\\ & + qW + L_{ow} \end{aligned} \tag{29}$$

where d denotes the distance between the femtocell and the MS in meters, W is the wall partition loss set to be 5 dB, L_{ow} is the outdoor penetration loss set to be 10 dB with probability 0.8 and 2 dB with probability 0.2 respectively, q is the number of walls between the MS and the femtocell.

Figure 4 shows the relation of the assignment probability that the MS will handoff to an f-BS for conventional, RWTL-HO and RSS-α-HO algorithms, when the distance from the MS to the m-BS is continuously changing. Firstly from Fig. 4, the curve of conventional algorithm which accords with the RSS-α-HO algorithm when α is zero can be acquired. When α equals one, the curve of RSS-α-HO in [11] is also obtained as shown in Fig. 4. The assignment probability of the RWTL-HO algorithm along with different parameters shifts among the two curves. In addition as shown in Fig. 4, the conventional algorithm cannot improve the usage of femtocells because of the low assignment probability. The RSS-α-HO algorithm works only when α is not equal to zero, and it is not very efficient due to large amounts of calculation by attaining α and redundant handoffs which can not satisfy a certain QoS requirement. From Fig. 4, the RWTL-HO algorithm can properly operate by having a high assignment probability which means high utilization of femtocells compared with the conventional algorithm and a low assignment probability which means lessened redundant handoffs compared with the RSS-α-HO algorithm.

Figure 5 shows the numbers of handoffs for both of RSS-α-HO and RWTL-HO algorithms vary with the change of the relevant distance from the f-BS to the m-BS, when an MS is located at the edge of the femtocell. And comparative results do not involve the conventional algorithm, because handoffs practically impossibly occur in the same region for the conventional algorithm as shown in Fig. 2. From Fig. 5, we can see that when the distance is small enough, such as less than 150 m, the numbers of handoffs for both algorithms are very small because very large RSS from the m-BS does not lead to handoff. When the distance is more than 150 m but less than 350 m, the numbers of handoffs for both algorithms are the same. It means the RWTL-HO algorithm achieves the same performance as RSS-α-HO algorithm does in this region. When the distance is more than 350 m, the numbers of handoffs increase at least 100% for both algorithms, because the fluctuated RSSs from both the f-BS and the m-BS are fair comparable. Moreover compared with the RSS-α-HO algorithm, the proposed algorithm reduces half the number of redundant handoffs.

Although only one femtocell in a macrocell is taken into account, it is not sufficient in the foregoing two cases.

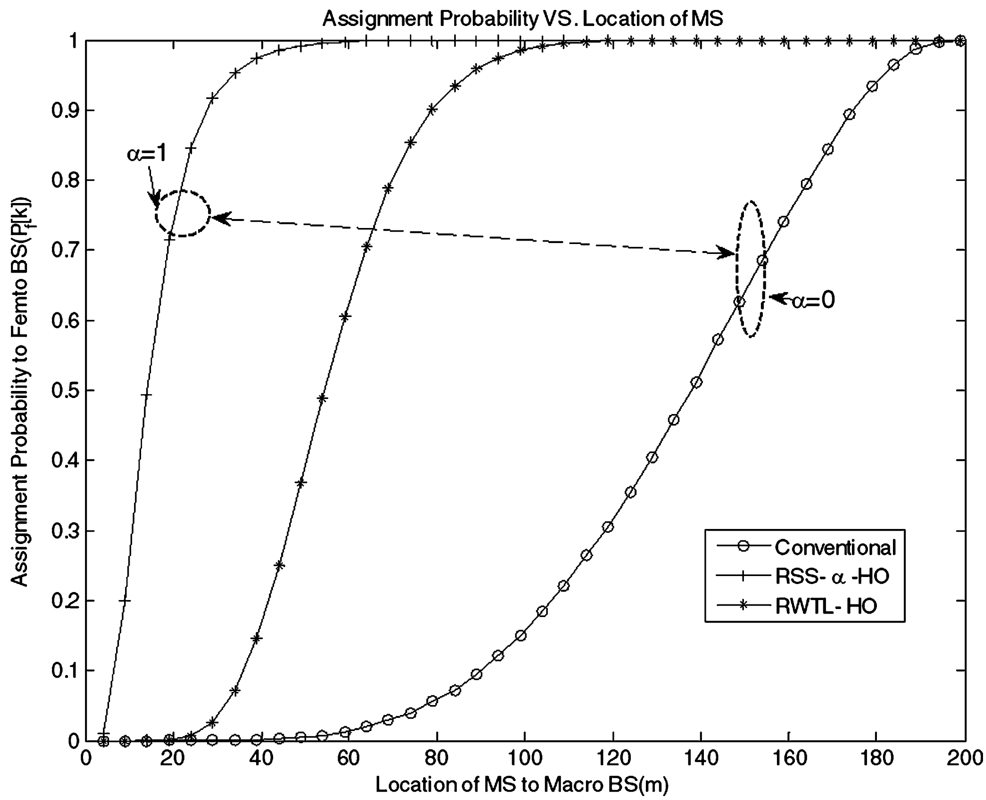

Fig. 4 Assignment probability to femto base station vs. location of mobile station

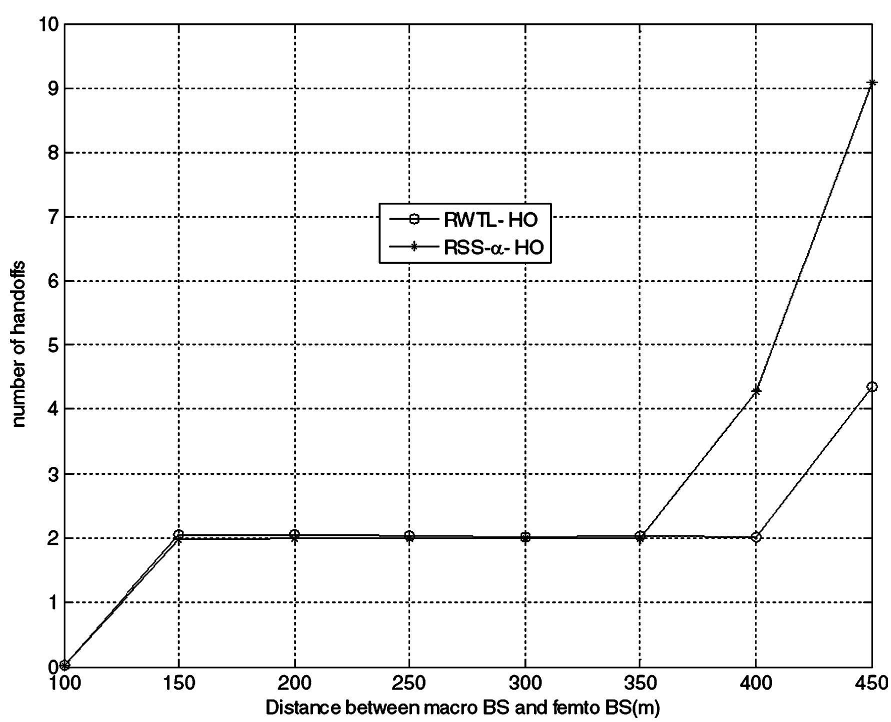

Fig. 5 Handoff numbers comparing with RSS-α-HO algorithm

To evaluate entirely the proposed algorithm, especially with different hysteresis values, we assume that one MS with low mobility goes through the macrocell in a straight line, in which numerous femtocells are randomly deployed. The comparative results for conventional, RSS-α-HO and RWTL-HO algorithms are represented as Fig. 6. With the increase in the number of femtocells, the numbers of handoffs increase accordingly for both hysteresis values because clearly for three algorithms, the chances of handoff become strong at this moment. Likewise for three algorithms, the

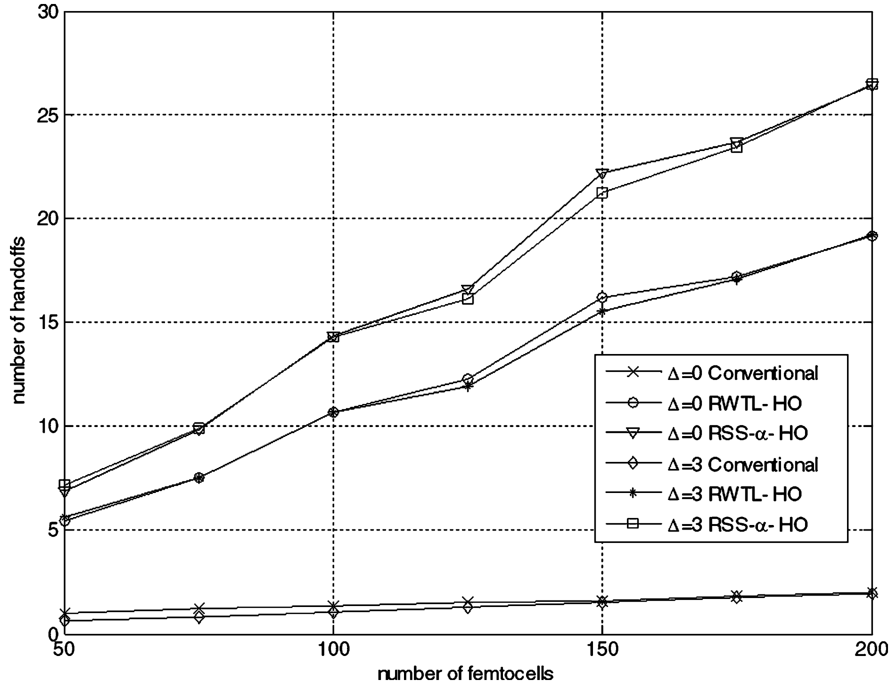

Fig. 6 Handoff numbers with different Δ in three algorithms

better performance of the high hysteresis value than the low value is also attained. The number of handoffs for conventional algorithm is nearly unchanged because asymmetry transmit power and randomly deployed femtocells may not result in handoff. On the contrary, the numbers of handoffs for both RWTL-HO and RSS-α-HO algorithms which settle the issue of asymmetry power have been augmented largely. Apparently the performance of the RSS-α-HO algorithm, under the same condition, is similar to that of the RWTL-HO algorithm on the whole, except for the larger number of handoffs.

Furthermore, both Fig. 5 and Fig. 6 show the consistent trend similar to that in Fig. 4, which further proves the feasibility and efficiency of the proposed algorithm.

5 Conclusions

In this paper, a RSS and wireless transmission loss-based handoff (RWTL-HO) algorithm is proposed to settle the mobility issue which means with large asymmetry transmit power, how a handoff occurs from an m-BS to an f-BS in hierarchical macro/femto cell networks. By comparing with the conventional and RSS-α-HO algorithms, the RWTL-HO algorithm improves the utilization of femtocells according to the increase in the number of handoffs and cuts down the number of redundant handoffs.

In addition the RWTL-HO algorithm is easy to implement in real systems, as only software is needed to be added into MSs. When lots of femtocells are irregularly deployed, the proposed algorithm can also be carried out rapidly due to its low computation.

Acknowledgements The work of author is supported partially by NSFC under the Grant 60772085, 61032002 and the central universities basic scientific research special fund under the Grant SWJTU 09ZT14.

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Peng Xu received the B.E. and M.E. degrees, respectively in 2004 and 2007, from Southwest Jiaotong University, Chengdu, China. Now he is a Ph.D. candidate majoring in communication & information systems in Southwest Jiaotong University. And his research interests include location technology, radio resource management of macro/femtocell hierarchical networks, wireless mesh network.

Xuming Fang received the B.E., M.E. and Ph.D. degrees, respectively in 1984, 1989 and 1999 in Southwest Jiaotong University, Chengdu, China. Now he is currently a Chair of IEEE VT of Chengdu Chapter. And he held visiting positions with Technical University at Berlin, Berlin, Germany, in 1998 and 1999, and with the University of Texas at Dallas, Richardson, in 2000 and 2001. He has more than 160 high-quality papers in journals and conference publications. He has authored or coauthored five books or textbooks. His research interests include mobile ad hoc, wireless mesh and multi-hop relay networks, scheduling admission control, power control, cognitive radio.

Rong He received the B.E. and M.E. degrees in 1997 and 2002 from Southwest Jiaotong University, Chengdu, China. She is a Ph.D. candidate in Computer application technology of Southwest Jiaotong University. Her research interests include wireless mesh network, access control, flow control, radio resource management for broadband wireless access networks.

Zheng Xiang received B.S. degree in communication engineering from Southwest Jiaotong University in 2005, and currently he is a Ph.D. candidate majoring in communication and information systems in Southwest Jiaotong University. His research interests include wireless routing, wireless handoff, wireless resource allocation and game theory.