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Research Article

Probabilistic Path and Data Capacity Based Handover Decision for Hierarchical Macro- and Femtocell Networks

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Femtocells are considered a technology to improve performance of a network by increasing network coverage and communication capacity at a relatively low cost. However, if there are a lot of femtocells in a macrocell, the number of handovers greatly increases, and unnecessary handovers can occur from the mobile station temporarily passing through a femtocell. In this paper, we propose a method that probabilistically estimates the path in a femtocell and makes a handover decision based on the available data capacity of a mobile station on the estimated path. Simulation results show that the proposed method effectively reduces the number of unnecessary handovers while improving the data rate and capacity.

1. Introduction

Due to the emergence of various communication devices and the increase in related traffic, recent demand for mobile communications services has been increasing. A lot of research has been conducted into enhancing network capacity to meet this rapid increase in traffic. Femtocells are small base stations with a short transmission range, low transmission power, and low operational costs. By reducing the distance between the user and the base station, compared to the macrocell, a femtocell can increase spectrum efficiency and effectively eliminate the shadow area [1].

In order to use femtocell technology, however, a number of technical issues need to be resolved, such as interference among the cells, synchronization, handover, and the cell-selection method. In particular, the handover procedure between a macrocell and femtocells is closely related to network performance. Appropriate handover improves network performance, whereas thoughtless handover decreases network performance. If there are a lot of femtocells in a macrocell, unnecessary handovers can frequently occur from mobile stations temporarily passing through femtocells. Therefore, research on an appropriate and superior handover decision is needed for efficient usage of femtocell technology.

The traditional handover uses a threshold value to avoid a ping-pong effect, but it is not appropriate in a hierarchical network structure with a macrocell and multiple femtocells. So, several handover methods were studied. Chambers [2] proposed a handover decision method that predicts the path of the user in the femtocell and determines handover through a mobility rule extracted by analyzing the movement of users. However, a separate server and additional time are needed to extract the mobility rule, and it cannot be applied to general cases because actual movement may differ from the mobility rule. Cho and Kim [3] proposed a handover decision algorithm that makes the handover decision by considering several factors: three different speed sections of the mobile station, received signal strength (RSS), quality of service, and available bandwidth. However, the proposed method does not consider residence time in the femtocell, so frequent unnecessary handovers can occur. Chowdhury et al. [4] proposed a handover decision method that calculates residence time in a femtocell using global positioning system (GPS) coordinates and then makes the handover decision by comparing the amount of data that can be obtained by macrocell and femtocell residence time. However, the proposed method needs additional time to calculate residence

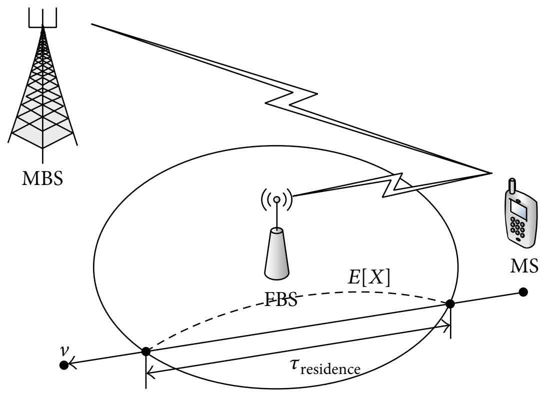


Figure 1: System model.

time and has the problem of high energy consumption and overhead.

To solve the aforementioned problems, a more common and simple handover method is needed to determine efficient handover. In this paper, we propose a method that probabilistically estimates the path in a femtocell and makes a handover decision by comparing the available data capacity that can be obtained in the estimated path. Without any complex and additional positioning device and direction estimation, we derive the probabilistic path and residence time of a mobile station. The proposed decision mechanism compares the available data capacity that the mobile station can obtain based on the received power of the signal and the available bandwidth for macrocell and femtocell.

The rest of this paper is organized as follows. In Section 2, the system model is presented. In Section 3, we estimate the path and residence time of a mobile station in a femtocell. In Section 4, we describe the proposed handover decision method from macrocell to femtocell by comparing the data capacity difference in accordance with handover cases. In Section 5, we evaluate the performance of the proposed handover method through simulation. Finally, in Section 6, we conclude this paper.

2. System Model

The system in this paper consists of a macrocell, a femtocell, and a mobile station (MS), as shown in Figure 1. The MS communicating with a macrocell is entering the femtocell area. At this time, the proposed method probabilistically estimates the MS's path and residence time in the femtocell and makes a handover decision by comparing the available data capacity depending on the handover along the estimated path.

To find the available data capacity depending on the handover, we estimate the *probabilistic path* of the MS in the femtocell. *Probabilistic path* is not the actual path of the MS; instead, the expected path probabilities of the MS are calculated by analyzing candidates for the actual path. In this paper, *probabilistic path* length $E[X]$ is defined as the expected distance from the current femtocell entrance point to any point of the femtocell's outgoing boundary, in which the probability density function (pdf) of the distance x (from any entrance point to an exit point) is used to estimate the expected distance, as in (1). The corresponding *residence time* of the MS is defined as the average time inside the femtocell when the average speed of the MS is v. Residence time is calculated with (2). Consider

$$E[X] = \int x f_X(x)\,dx, \tag{1}$$

$$\tau_{\text{residence}} = \frac{E[X]}{v}. \tag{2}$$

The handover decision is made by comparing the available data capacity depending on handover along the *probabilistic path*. In the case of handover to a femtobase station (FBS) from the macrobase station (MBS), the MS communicates with the FBS in the femtocell area. On the other hand, if the MS is not handed over to the FBS, the MS remains connected to the MBS regardless of the area. Consequently, the handover decision is a choice about which base station to communicate with in the femtocell.

In this paper, data capacity indicates the total amount of transmitted data during a certain time. Meanwhile, data rate is the amount of transmitted data per unit of time, which can be computed with bandwidth (W) and received power ($P_r(\cdot)$), which is a function of transmitted power (P_t) and distance (d) between the transmitter and receiver. Since the distance between the MS and the base station is a function of time on the *probabilistic path*, the data rate can be converted with

$$R(P_r(d, P_t), W) \longrightarrow R(P_r(t), W). \tag{3}$$

The available data capacity can be obtained by integrating the data rate during a certain time, as shown in the following:

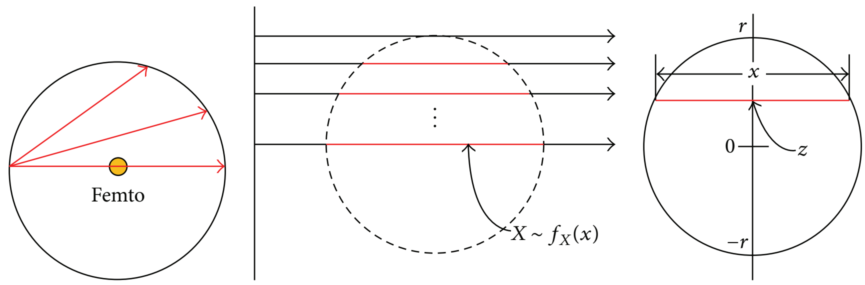
$$C = \int R(P_r(t), W)\,dt. \tag{4}$$

We obtained the data capacities by integrating data rates depending on the handover. As seen in (5), if the data capacity with handover is larger than the data capacity without handover, the MS will accept handover from the MBS to the FBS to obtain a higher data capacity. On the other hand, if the data capacity without handover is larger than the data capacity with handover, the MS remains connected to the MBS to prevent an unnecessary handover:

$$\text{Handover Decision} = \begin{cases} \text{Handover} & C_{\text{HO}} > C_{\text{Non-HO}} \\ \text{Keep the connection} & C_{\text{HO}} < C_{\text{Non-HO}}. \end{cases} \tag{5}$$

3. Estimation of Probabilistic Path and Residence Time in the Femtocell

In this section, we define *probabilistic path* and *residence time* of the MS when the MS enters a femtocell area. We assume that the MS moves in a straight line with a certain average speed inside a relatively small femtocell area. Except for the



(a) Possible paths (b) Equivalent paths (c) cdf calculation

FIGURE 2: Probabilistic path model.

average moving speed and femtocell radius, in our system model, additional information such as location, direction, and/or angulation is not required. As shown in Figure 2(a), when an MS meets a femtocell boundary, it will pass through the femtocell following one of an infinite number of paths. If we only consider the path length of the MS, then the paths can be represented in parallel lines as equivalent paths, as seen in Figure 2(b). The distance of each path is defined as random variable X with probability density function $f_X(x)$.

The *probabilistic path* of the MS is defined as the expected value of random variable X. The cumulative distribution function (cdf) of random variable X is defined as the probability of event $\{X \le x\}$. To derive the cdf, we use the femtocell scenario seen in Figure 2(c). In Figure 2(c), the origin of the vertical line indicates the FBS; r is the radius of femtocell coverage; z is the intersection point of the path of the MS and the vertical line. The cdf of X can be calculated with

$$\begin{aligned}\Pr\{X \le x\} &= \frac{1}{2r} \times 2(r-z), \quad \text{where } 0 < z < r, \\ &= \frac{1}{r}\left(r - \sqrt{r^2 - \left(\frac{x}{2}\right)^2}\right) \\ &= 1 - \sqrt{1 - \frac{1}{4}\left(\frac{x}{r}\right)^2} = F_X(x).\end{aligned} \tag{6}$$

Since the pdf is defined as a derivative of a cdf, the pdf of random variable X can be calculated as follows:

$$\begin{aligned}\frac{dF_X(x)}{dx} &= \frac{d}{dx}\left(1 - \sqrt{1 - \frac{1}{4}\left(\frac{x}{r}\right)^2}\right) \\ &= \frac{x}{4r\sqrt{r^2 - (1/4)x^2}} = f_X(x), \\ &\qquad \text{where } 0 < x < 2r.\end{aligned} \tag{7}$$

The *probabilistic path* of Figure 3, defined as an expected path length of an MS, can be calculated with

$$\begin{aligned}E[X] &= \int_0^{2r} x f_X(x)\,dx = \int_0^{2r} \frac{x^2}{4r\sqrt{r^2 - (1/4)x^2}}dx \\ &= \frac{\pi r}{2}.\end{aligned} \tag{8}$$

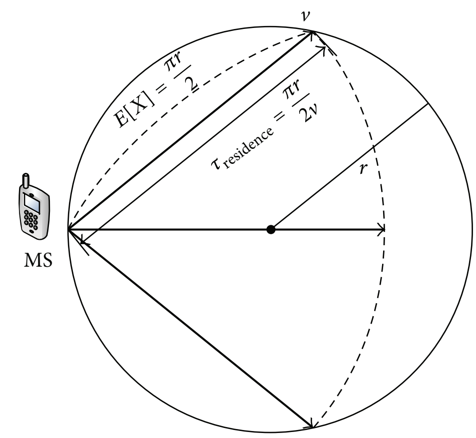


FIGURE 3: Probabilistic path and residence time.

When the average speed of the MS is v, the residence time of the MS on the *probabilistic path* of Figure 3 is represented by

$$\tau_{\text{residence}} = \frac{E[X]}{v} = \frac{\pi r}{2v}. \tag{9}$$

In this section, we have probabilistically estimated the path of an MS in a femtocell before we make an actual handover decision. In fact, the *probabilistic path* may differ from the actual path. However, as the number of MSs passing through the femtocell increases, an ensemble average of the actual paths becomes more similar to the *probabilistic path*. Therefore, probabilistically estimating the path of MS can be a proper and reliable approach.

4. Handover Decision on the Probabilistic Path

4.1. Data Rate from the Femtocell. When an MS moves on the *probabilistic path*, the available data rate of the MS from the FBS depends on the distance between the MS and the FBS. Figure 4 shows the MS passing through the femtocell on the *probabilistic path*. Point O is the FBS location, and M is the midpoint of the *probabilistic path*; d represents the distance between the FBS and the MS. Δt is the elapsed time after the MS enters the femtocell, $v\Delta t$ is the moving distance of the MS

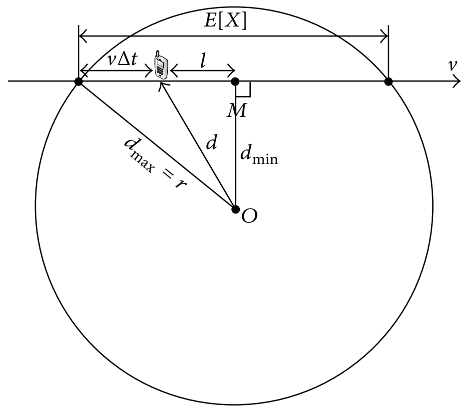


FIGURE 4: Analysis of the probabilistic path in the femtocell.

in the femtocell, and l is the distance between the MS and the point M.

The maximum and minimum values of the distance between the FBS and the MS are $d_{\max}$ and $d_{\min}$. $d_{\max}$ and $d_{\min}$ are determined with the following:

$$d_{\max} = r, \tag{10}$$

$$d_{\min} = \sqrt{r^2 - \left(\frac{E[X]}{2}\right)^2} = r\sqrt{1 - \left(\frac{\pi}{4}\right)^2}. \tag{11}$$

When an MS is in a femtocell, the distance between the MS and point M, which is denoted by l, can be computed as follows:

$$l = \left|\frac{E[X]}{2} - v\Delta t\right| = \left|\frac{\pi r}{4} - v\Delta t\right|. \tag{12}$$

When the radius of the femtocell and the average speed of the MS are given, the probabilistic distance d^* between the FBS and the MS on the *probabilistic path* is derived with (13) and (14) according to the elapsed time. Consider

$$d^{*2} = d_{\min}^2 + l^2 = \left(r^2 - \left(\frac{\pi r}{4}\right)^2\right) + \left(\left|\frac{\pi r}{4} - v\Delta t\right|\right)^2, \tag{13}$$

$$d^* = \left(v^2\Delta t^2 - \frac{\pi r}{2} v\Delta t + r^2\right)^{1/2}. \tag{14}$$

The receiving power in the Friis path loss model is formulated with

$$P_r = \frac{G_t G_r \lambda^2}{(4\pi)^2}\left(\frac{1}{d}\right)^{\beta} P_t = K\left(\frac{1}{d}\right)^{\beta} P_t, \tag{15}$$

where P_r and P_t represent receiving power and transmitting power, respectively; G_t and G_r are transmit antenna gain and receive antenna gain, respectively; λ is the wavelength; β is the path loss exponent.

If we replace distance d between the transmitter and receiver in (15) with the probabilistic distance d^* from (14), then we have the following equation:

$$P_r^* = K\left(v^2\Delta t^2 - \frac{\pi r}{2} v\Delta t + r^2\right)^{-\beta/2} P_t. \tag{16}$$

The data rate R in the additive white Gaussian noise channel is given in

$$R = W\log_2\left(1 + \frac{P_r}{N_0 W}\right), \tag{17}$$

where W is the bandwidth and N_0 is the noise power spectral density.

Using (16), we can derive the probabilistic data rate R^* at time Δt with

$$\begin{aligned} R^* &= W\log_2\left(1 + K\left(v^2\Delta t^2 - \frac{\pi r}{2} v\Delta t + r^2\right)^{-\beta/2}\frac{P_t}{N_0 W}\right). \end{aligned} \tag{18}$$

Therefore, we can estimate the probabilistic data rate that the MS can obtain from the FBS as a function of the elapsed time on the *probabilistic path* in the femtocell.

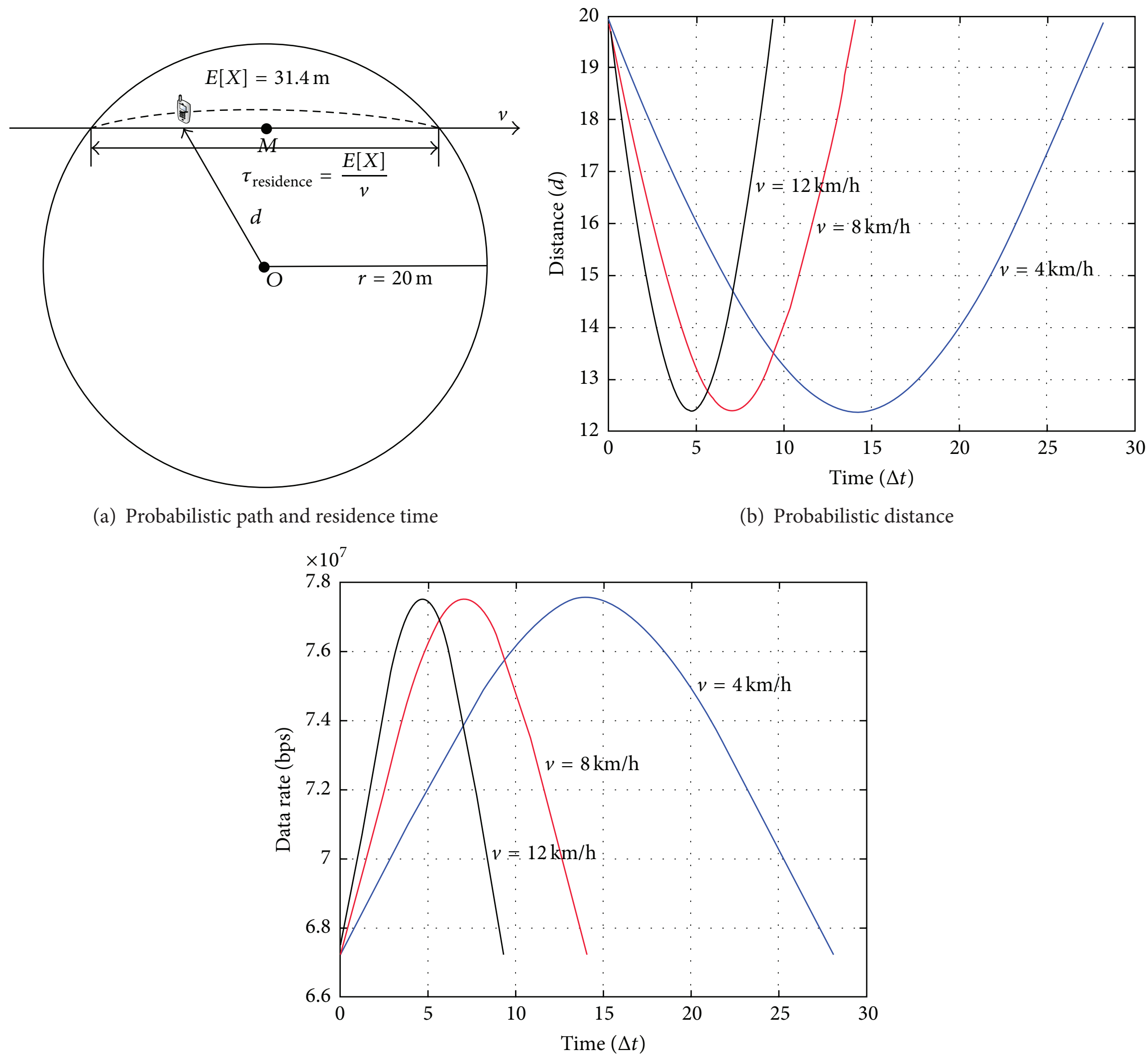
Figure 5 shows an example scenario. A femtocell of radius 20 m results in a 31.4 m *probabilistic path* from (8) and $\tau_{\text{residence}}$ *residence time* at a v MS moving speed from (9), as seen in Figure 5(a). Each different MS's moving speed results in differentiated probabilistic data rates and residence time, in the case of femtocell handover as seen in Figures 5(b) and 5(c).

We can derive the probabilistic distance between the FBS and the MS according to the elapsed time from (14), which is shown in Figure 5(b). When the moving speed of the MS is 4 km/h upon entering the femtocell ($\Delta t = 0$) and leaving the femtocell ($\Delta t = 28.27$), the distance between the FBS and the MS is the longest, at 20 m. When passing the midpoint of the *probabilistic path* ($\Delta t = 14.135$), the distance between the FBS and the MS is the shortest, at 12.38 m. The probabilistic data rate according to time is derived from (18). As shown in Figure 5(c), the probabilistic data rate is the smallest when entering and leaving the femtocell and is the largest when passing the midpoint of the *probabilistic path*.

4.2. Comparing the Available Data Capacity and Handover Decision. In this section, we propose a handover decision method based on the available data capacities that an MS can obtain when the MS passes a femtocell boundary. An MS estimates possible data capacities from the MBS and the FBS during its *residence time*. The available data capacity is defined as a sum of the data amount during the MS's *residence time*.

Figure 6 shows the change in probabilistic data rate depending on handover. Figure 6(a) represents the probabilistic data rate when the MS undergoes handover to the FBS and is passing by on the *probabilistic path*. Figure 6(b) shows the case where the MS does not undergo handover and is continuously connected to the MBS.

In this paper, we assume that the probabilistic data rate of the MS is constant if the MS retains the connection with the MBS when it is in the femtocell area. In fact, an MS can enter



(a) Probabilistic path and residence time

(b) Probabilistic distance

(c) Probabilistic data rate

FIGURE 5: Example scenario.

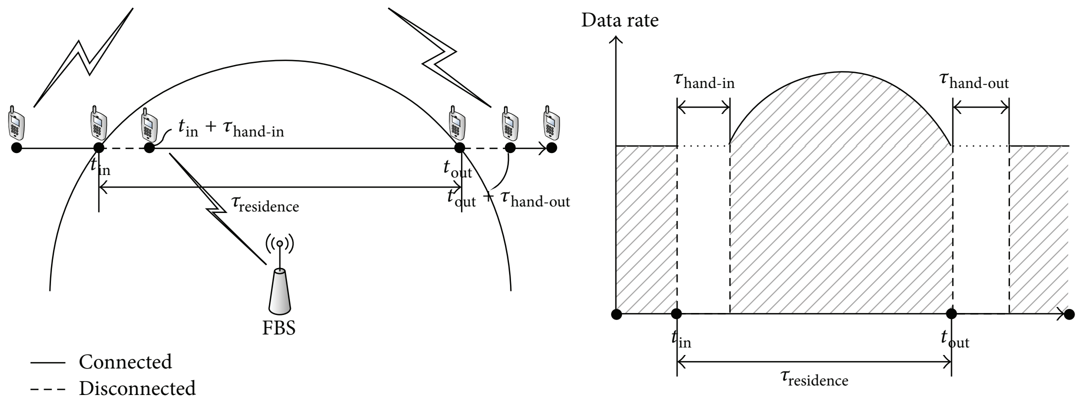
an FBS area from directions where the MS is getting either further from or closer to the MBS so that, in a probabilistic manner, the average rate is almost unchanged, as seen in Figure 7.

A femtocell system is assumed to use a hard handover because of limited frequency resources, in which the MS first disconnects from an MBS and then initiates a handover procedure with the target FBS so that handover in the femtocell system accompanies the handover delay from disconnecting and connecting with the base stations. Therefore, the MS cannot communicate with any base station when it enters and leaves the femtocell. The delay occurring during handover from the MBS to the FBS (hand-in) is expressed as $\tau_{\text{hand-in}}$, and the delay occurring during handover from the FBS to the MBS (hand-out) is expressed as $\tau_{\text{hand-out}}$. In Figure 6, t_{in} and t_{out} represent FBS disconnect time and MBS reconnect time, respectively.

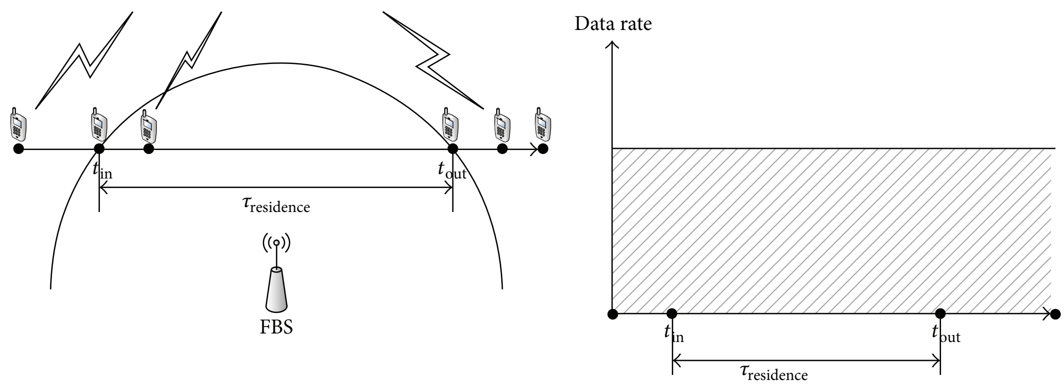
We make a handover decision comparing the available data capacity during the time duration from t_{in} to $t_{\text{out}} + \tau_{\text{hand-out}}$. The available data capacities can be obtained from

$$\begin{aligned} C_{\text{HO}} &= \int R_{\text{HO}}(t)\,dt, \\ C_{\text{Non-HO}} &= \int R_{\text{Non-HO}}(t)\,dt, \end{aligned} \tag{19}$$

where $R_{\text{HO}}(t)$ and $R_{\text{Non-HO}}(t)$ indicate the probabilistic data rates with femtocell handover and without handover, respectively. By comparing both available data capacities, we undergo femtocell handover only when the available data capacity from the FBS is greater than that from the MBS. Using the proposed probabilistic estimation method, we can reduce unnecessary handovers, and the MS also obtains more data capacity on average.



(a) Femtocell handover



(b) Macrocell connection (no handover)

Figure 6: Data rate depending on handover.

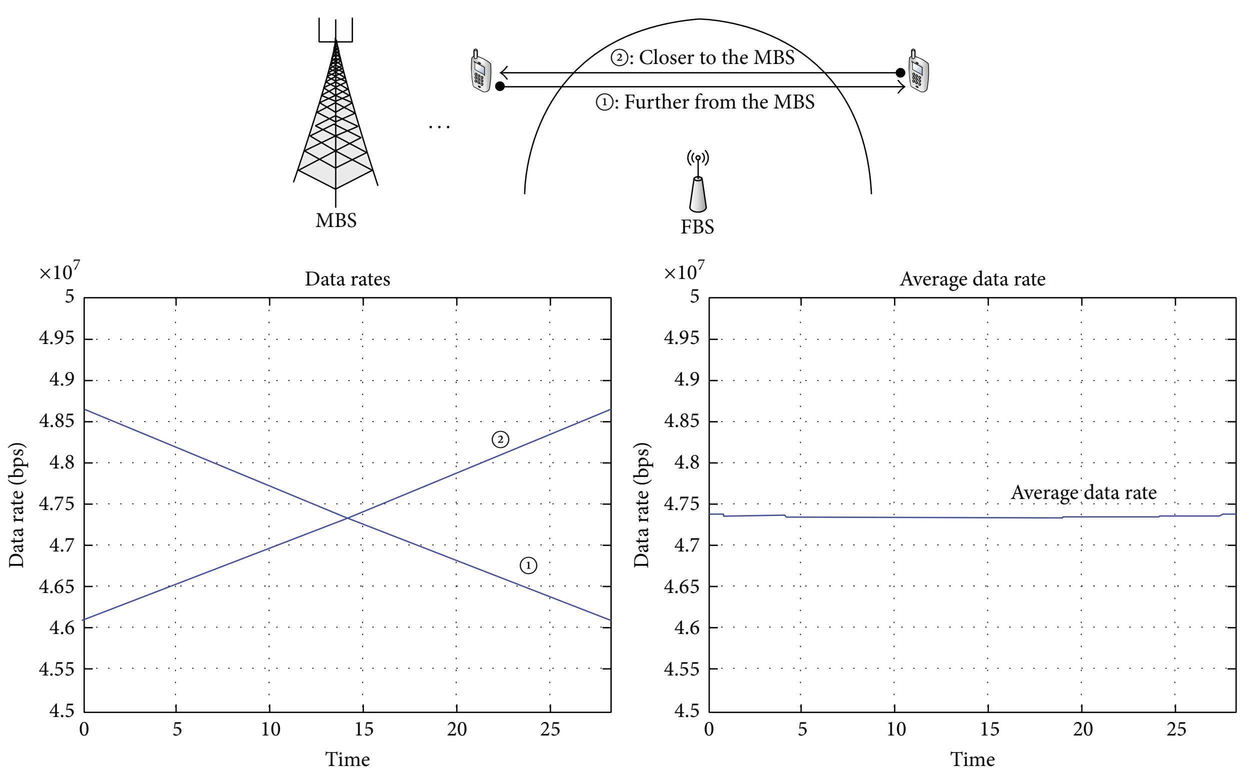


Figure 7: Probabilistic data rate from MBS.

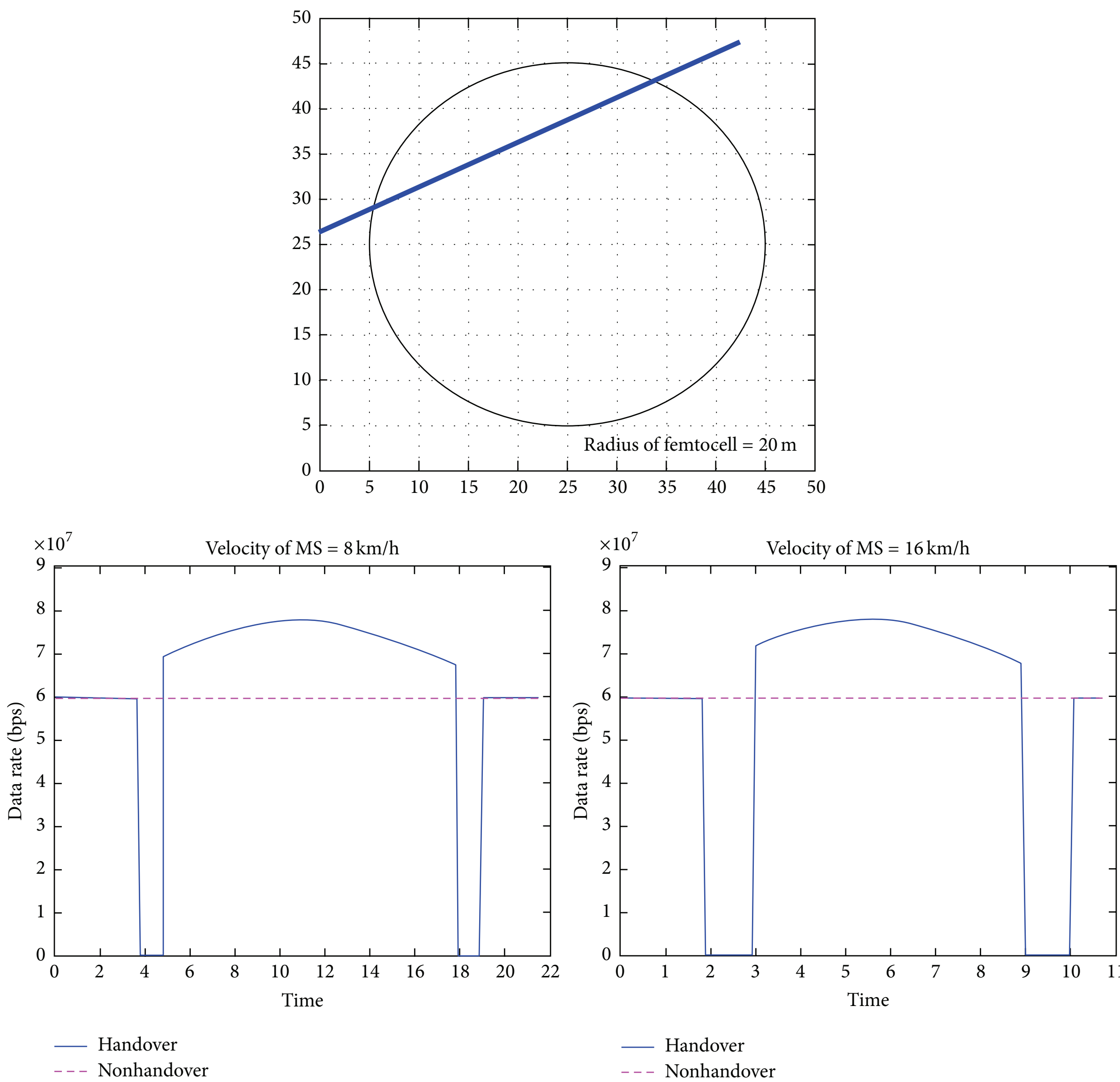


Figure 8: Handover decision scenario.

The following example scenario (Figure 8) shows the handover decision according to the speed of the MS. When the MS moves on the *probabilistic path*, the probabilistic data rate depends on the speed of the MS. In this scenario, the moving speeds of the MS are 8 km/h and 16 km/h, and the times the MS takes passing through the femtocell are 15.2 seconds and 8.1 seconds, respectively.

The available data capacity at a speed of 8 km/h is 967 Mbits from the FBS and 901 Mbits from the MBS. Therefore, the MS will undergo handover from the MBS to the FBS to obtain more data capacity. On the other hand, the available data capacity at a speed of 16 km/h is 445 Mbits from the FBS and 478 Mbits from the MBS, so, in this case, the MS will not undergo handover. The proposed method makes a proper handover decision considering not only the speed of the MS, but also a variety of network environments, such as transmission power of each base station, the radius of the cell, and available bandwidth.

5. Performance Evaluation

5.1. Simulation Environments. In this paper, we propose a new method that makes a handover decision by evaluating data capacity on the *probabilistic path*.

Figure 9 shows an example of a simulation environment. The femtocell is located in macrocell coverage, and the MS is located close to the femtocell. The *probabilistic path* of the MS is $E[X]$ derived from (8). The actual path of the MS is obtained from any θ ($-90^\circ \sim 90^\circ$). In this simulation, the MS enters the femtocell area at a random angle θ, and the simulation results in this section were derived through 100,000 trials. It should be noted that the handover decision is performed based on available data capacity, but all performance results including handover decision success probability and data capacity gain in this section are from random MS movement trials. In particular, considering the moving speed of a regular person (2~12 km/h), performance of the

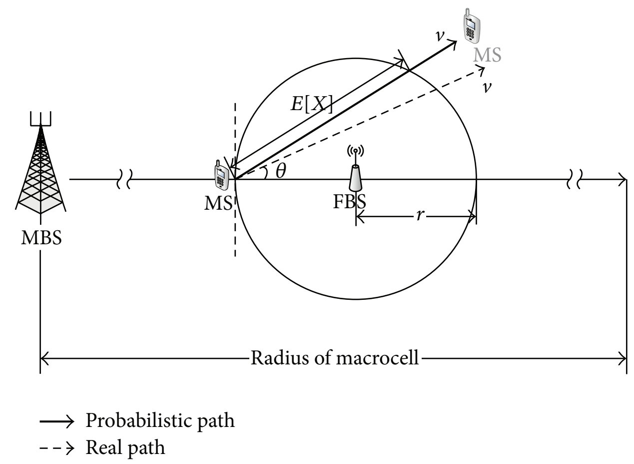


Figure 9: Simulation environment.

Table 1: Simulation parameters.

Parameter	Value
Radius of macrocell	500 m
Transmission power of MBS/FBS	1.5 W/10 mW
Frequency	1.8 GHz
Bandwidth	5 MHz
Path loss exponent	3
Noise power spectral density	−174 dBm
$\tau_{\text{hand-in}}/\tau_{\text{hand-out}}$	1 s
Speed of the MS	2, 4, 6, 8, 10, 12 km/h

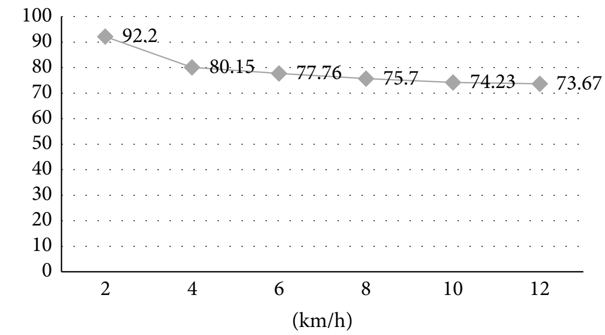


Figure 10: Success probability of the handover decision.

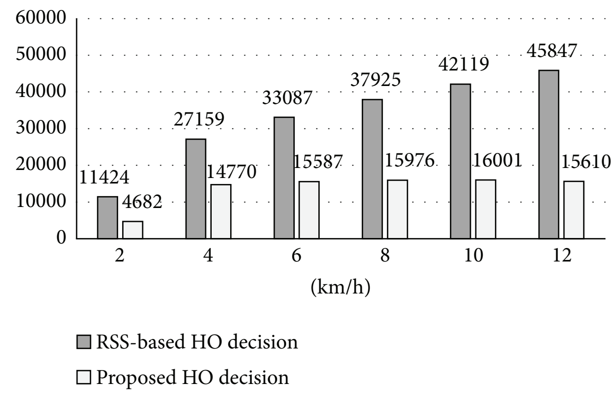


Figure 11: Number of unnecessary handovers.

proposed method was investigated in detail. Parameters used in the simulation are given in Table 1.

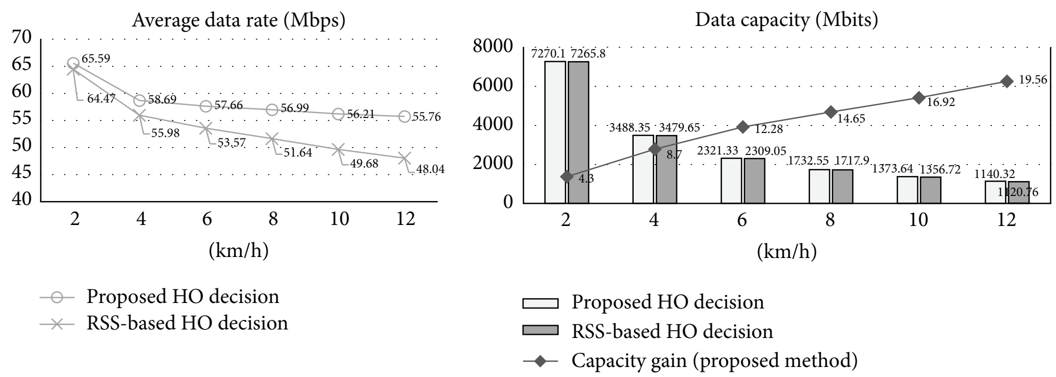
5.2. Simulation Results. In this section, we evaluate the success probability of the handover decision, the number of unnecessary handovers, and average data rate and data capacity after the handovers. We compare the performance with the RSS-based handover mechanism, in which femtocell handover is performed when the received signal strength from the FBS is greater than that of the MBS.

Figure 10 shows the success probability of the proposed handover method in accordance with the speed of the MS. After the handover decision based on the proposed manner, if the actual data capacity from the FBS is greater than that of the MBS (i.e., without handover), then we can say that the handover to the FBS is successful. Therefore, the success probability of the handover decision indicates how the proposed method makes the proper handover decision. As we can see in Figure 10, the proposed method shows 73.6%~92.2% successful handover decisions at MS speeds of 12 km/h~2 km/h.

Figure 11 shows the number of unnecessary handovers occurring under the proposed and the RSS-based handover methods. An unnecessary handover is where, although the MS performs a handover with a handover decision, the actual handover is not advantageous in terms of data capacity gain. This simulation was carried out when the MS passed through the femtocell 100,000 times, and all unnecessary handovers were counted under both methods. As a result, we know that the proposed handover method significantly reduces the number of unnecessary handovers. Specifically, when the moving speed of the MS is 12 km/h, unnecessary handovers occurred 45,847 times (45.8%) under the RSS-based handover method. By contrast, there were 15,610 unnecessary handovers (15.6%) under the proposed handover method.

Finally, Figure 12 shows the average data rate and data capacity obtained under the proposed and RSS-based handover methods. The average data rate is the average data rate during which MS stays in the femtocell area. The proposed handover method shows a higher data rate at all MS moving speeds. In particular, when the moving speed of the MS is 12 km/h, the average data rate of the RSS-based handover method is 48.04 Mbps, whereas the average data rate under the proposed handover method is 55.76 Mbps. The average data rate improves by about 16.07% under the proposed method. Figure 12(a) shows that the average data rate under both methods increases as the MS moving speed decreases. As the speed of the MS slows, its *residence time* in the femtocell increases, so that the disconnect time for handover is not dominant, and the average data rate increases. Also, as the speed of the MS increases, the number of unnecessary handovers increases.

Figure 12(b) illustrates the data capacity comparison. Since the data capacity is a multiplication of data rate and time, naturally, the data capacity increases as the residence



(a) Comparison of data rate

(b) Comparison of data capacity

Figure 12: Comparison of data rate and data capacity.

time in the femtocell increases. As we can see, the proposed method provides better performance and can additionally obtain up to a 19.56 Mbit data capacity compared with the RSS-based handover method. The faster movement of an MS results in higher capacity gain under the proposed probabilistic handover method.

6. Conclusions

In this paper, we propose a method that probabilistically estimates the path of an MS in a femtocell and makes a handover decision using a probabilistic data capacity comparison. Without any location or direction information, when an MS approaches a femtocell, it computes the *probabilistic path* and expected *residence time*. Based on the proposed probabilistic data capacity gain estimation, a more accurate handover decision to an FBS is made. The actual handover is performed only when an expected data capacity gain due to the handover exists in the proposed probability model. Simulation results show that the proposed handover method effectively reduces the number of unnecessary handovers and improves network performance with a higher handover success probability. The actual obtained data capacity after handover is greater than that of the RSS-based method at different speeds. In particular, when the MS moving speed is relatively fast, the data rate and capacity gain from the proposed handover decision method are dominant.

Disclosure

Parts of this paper were presented at ICTC2014 conference [5].

Competing Interests

The authors declare that there are no competing interests regarding the publication of this paper.

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