Femtocell Selection Scheme for Reducing Unnecessary Handover and Enhancing Down-Link QoS in Cognitive Femtocell Networks

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Abstract: Femtocell networks have been proposed for indoor communications as the extension of cellular networks for enhancing coverage performance. Because femtocells have small coverage radius, typically from 15 to 30 meters, a femtocell user (FU) walking at low speed can still make several femtocell-to-femtocell handovers during its connection. When performing a femtocell-to-femtocell handover, femtocell selection used to select the target handover femtocell has to be able not only to reduce unnecessary handovers and but also to support FU's quality of service (QoS). In the paper, we propose a femtocell selection scheme for femtocell-to-femtocell handover, named Mobility Prediction and Capacity Estimation based scheme (MPCE-based scheme), which has the advantages of the mobility prediction and femtocell's available capacity estimation methods. Performance results obtained by computer simulation show that the proposed MPCE-based scheme can reduce unnecessary femtocell-to-femtocell handovers, maintain low data delay and improve the throughput of femtocell users.

Keywords: *Cognitive radio, femtocell selection, femtocell handover, Quality of Service (QoS).*

I. Introduction

The evolution of wireless communications technologies and mobile devices brought up many advantages to mobile users. It leads to the unimaginable growth of the number of mobile users and the amount of data delivered in mobile networks [1]. To fulfill the requirements, cognitive radio and femtocell are considered as the key technologies which are expected to build cognitive femtocell networks for the future 5th generation (5G) mobile communications [2–4].

Although femtocell networks are mainly deployed for indoor communications in small areas, a femtocell user (FU) might still have to perform several femtocell-to-femtocell handovers during its connection lifetime because femtocells have small coverage radius and high density [5, 6]. Femtocell selection is an important function of femtocell-to-femtocell handover which has to find an accurate target femtocell. An efficient femtocell selection scheme should be able to reduce the number of unnecessary handovers and avoid overloading femtocells. We can find a number of femtocell selection methods in literature such as [7–10] which commonly use mobility prediction or signal strength for selecting a target femtocell. However, to our best knowledge, the problems of unnecessary handovers and FU's QoS support are still open challenging research issues.

In this paper, we first discuss a generic system model of cognitive cellular femtocell networks. We then describe briefly the operation of three femtocell selection schemes of interest. The first one is conventional and based on Received Signal Strength (RSS), hence denoted here as *RSS-based scheme*. The second one is designed based on mobility prediction, hence denoted as *Prediction-based scheme*. The third one is designed based on downlink capacity estimation, hence denoted as *Sensing-based scheme*. The latter two schemes have been introduced before in our previous paper [11]. Extended from this work, we propose in this paper a fourth scheme, which is based on both Mobility Prediction and Capacity Estimation (MPCE), hence denoted as *MPCE-based scheme*. This scheme takes the advantages of mobility prediction and femtocell's available capacity estimation methods. Its performance is evaluated and compared to those of the other three schemes.

The paper is organized as follows. The system model is described in Section II. The conventional RSS-based, Prediction-based, Sensing-based and MPCE-based femto-

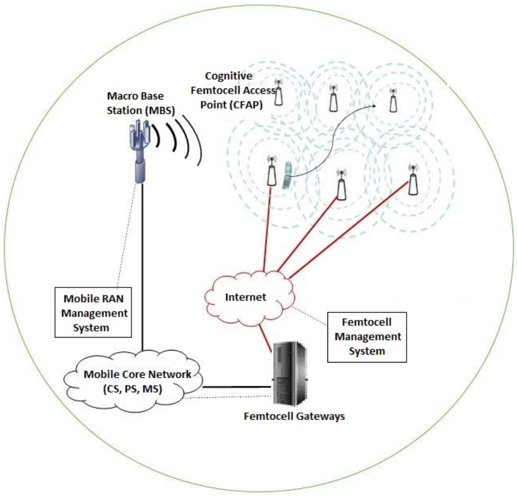

Figure 1. Cognitive femtocell network model.

cell selection schemes are presented in Section III. Simulation model and parameters are described in Section IV. Performance evaluation and comparison are presented and discussed in Section V. Conclusions are given in Section VI.

II. System Model

The generic system model of cognitive femtocell networks is illustrated in Figure 1 which was first introduced in [12]. In this model, Femtocell Management System (FMS) and Mobile RAN Management System (MRMS) have periodical information exchanges to support mobility management and radio resource management. When a femtocell user (FU) moves from one femtocell zone to another or between a femtocell zone to and a MBS zone, the FU needs support of connection handover. We carry out research of femtocell-to-femtocell handover in practical scenarios that Cognitive Femtocell Access Points (CFAPs) are deployed with a high density (high building residential areas, shopping centers, airports, railway stations, etc.).

Assume that the downlink channel uses dynamic time division multiplexing, *i.e.*, FUs can be assigned variable downlink time slots according to the data amount to be sent from the serving CFAP. CFAPs have cognitive functionalities including spectrum sensing, which allow them to be able to measure and sense the downlink transmission occupancy of CFAPs nearby [13]. By sensing the occupancy of downlink channel of neighbor CFAPs, a CFAP can analyze the estimated available capacity of the neighbor CFAPs. The information can be considered as a useful criterion when a serving CFAP wants to choose a target CFAP for FU's handover. A FU needs a handover when the handover condition is triggered, that is,

$$10 \log_{10} \frac{X_{\mathrm{CFAP}(i)}(t)}{X_{\mathrm{servingCFAP}}(t)} \geq \text{handover threshold}, \quad (1)$$

where CFAP(i) is a neighbor CFAP of the serving CFAP, $X_{\mathrm{CFAP}(i)}(t)$ and $X_{\mathrm{servingCFAP}}(t)$ are the pilot signal strength sent from a neighbor CFAP(i) and the serving CFAP measured at a FU at the time t, respectively.

III. Femtocell Selection Schemes

In this section, we first describe the operation of three other femtocell selection schemes including the conventional RSS-based scheme, Prediction-based scheme and Sensing-based scheme. We analyze disadvantages of these schemes and then present the proposed MPCE-based scheme which can eliminate existing problems of other schemes.

1. RSS-based Scheme

The RSS-based femtocell selection scheme uses the strength of the received signal as the criterion for the serving CFAP to select the target CFAP for FU's handover. When a FU has an active connection, it periodically sends a report of RSS measurements of neighbor CFAPs to its serving CFAP.

When the handover condition in (1) is triggered, according to the measurement report of the FU, the serving CFAP will select the target CFAP which satisfies this condition and has the highest RSS among the neighbor CFAPs. That is,

$$X_{\mathrm{targetCFAP}}(t) = \max\{X_{\mathrm{CFAP}(i)}(t) \mid \mathrm{CFAP}(i) \in \text{neighbor CFAPs}, X_{\mathrm{CFAP}(i)}(t) \text{ satisfies (1)}\}. \quad (2)$$

By selecting the target femtocell which has the strongest RSS, the RSS-based scheme can provide the high quality wireless link to the FU. However, this scheme does not guarantee whether the target femtocell has available capacity or not. It is not able to reduce the unnecessary handovers which happen when the FU has a short residing time in the target femtocell.

2. Prediction-based Scheme

When a FU moves into the overlapping areas of CFAPs, the variation of RSS can cause unnecessary handovers which will increase the signaling overhead and reduce the system performance. A handover prediction for femtocell wireless networks has been proposed in [10], which relies on the distance-based prediction and computationally expensive algorithm in order to optimize the selection of target femtocells. In our previous research [11], we proposed the Prediction-based scheme that aims to avoid ineffective handovers while consuming low computing load.

This scheme applies the exponential smoothing theory for predicting demand [14] to combine the relation of the RSS information collected in the past with the current RSS information in order to reduce the variation of the received RSS value and predict the mobility trend of the FU. The scheme operates as follows. The FU measures the RSSs of neighbor CFAPs and reports to its serving CFAP periodically. Using the RSS information report, the serving CFAP will estimate the *average relative RSS* value $\overline{X}(t)$ of a neighbor CFAP as

$$\overline{X}(t) = \alpha X(t) + (1 - \alpha)\overline{X}(t - 1), \tag{3}$$

and the average mobility trend as

$$\overline{b}(t) = \alpha(\overline{X}(t) - \overline{X}(t - 1)) + (1 - \alpha)\overline{b}(t - 1), \tag{4}$$

where $X(t)$ represents the actual RSS value at time t, $\overline{X}(t)$ is the estimated average relative RSS values at time t, $\overline{b}(t)$ is the average mobility trend which is used to evaluate and predict how the relative RSS value will vary, and α is the weighted value to evaluate how the current values and past values affect the average relative value. The higher value of $\overline{b}(t)$ corresponding to a CFAP, the higher the probability that a mobile FU will come across. By calculating and considering different values of α, we observed that the most suitable value of α should be in the middle of the range from 0 to 1. We select $\alpha = 0.5$ for the performance evaluation later.

When the handover condition of (1) is triggered, with $X(t)$ corresponding to the average relative RSS value at time t, the serving CFAP generates a set A of CFAPs whose estimated average relative RSS values satisfy this condition. That is,

$$A = \{\text{CFAP}_i \mid i \geq 1,\ \overline{X_i}(t) \text{ satisfy (1)}\}. \tag{5}$$

The serving CFAP selects the target CFAP in A that has the highest average mobility trend, by

$$\overline{b}_{\text{targetCFAP}}(t) = \max\{\overline{b}_{\text{CFAP}(i)}(t) \mid \text{CFAP}(i) \in A\}. \tag{6}$$

3. Sensing-based Scheme

The Prediction-based scheme was designed to reduce unnecessary handovers but it does not consider the QoS provision of FUs. The target CFAP should have available channel capacity for provisioning QoS to arriving FUs. As the downlink channel deploys dynamic time division multiplexing, if the channel has more free time slots, it can provide lower packet delay and higher throughput to arriving FUs. This inspiration led us to propose the Sensing-based scheme in [11], which was designed based on the assumption that a CFAP can use its cognitive functionality to sense free time slots of the channel of neighbor CFAPs in order to estimate the available channel capacity for arriving FUs. A serving CFAP will evaluate the idle level of neighbor CFAPs during every sensing cycle period of one second. The idle level is called as Free Time Ratio (FTR), which is defined as the ratio of the amount of free-time in a sensing cycle over a sensing cycle time. The amount of free-time of a neighbor CFAP during a sensing cycle is defined as the total time that its downlink channel is free, that is,

$$\text{FTR} = \frac{\text{Free-time in one sensing cycle}}{\text{Sensing cycle period}}. \tag{7}$$

When the handover condition of (1) is triggered, with $X(t)$ corresponding to the RSS value at time i, the serving CFAP generates and maintains a set B of target CFAPs whose RSS values satisfy this condition. That is,

$$B = \{\text{CFAP}_i \mid i \geq 1,\ X_{\text{CFAP}(i)}(t) \text{ satisfy (1)}\}. \tag{8}$$

The serving CFAP selects the target CFAP in B that has the highest FTR, by

$$\text{FTR}_{\text{targetCFAP}} = \max\{\text{FTR}_{\text{CFAP}(i)} \mid \text{CFAP}(i) \in B\}. \tag{9}$$

4. MPCE-based Scheme

In the Prediction-based scheme, we were concerned about how to reduce the unnecessary handover frequency, while in the Sensing-based scheme, we focused on selecting the target CFAP which has high available channel capacity. Naturally, it is of our interest to develop a more efficient femtocell selection scheme that can take into account of the advantages of both mentioned femtocell selection schemes, that is, reducing unnecessary handover frequency and enhancing QoS metric in terms of packet delay and throughput. In particular, we propose in this section the MPCE-based femtocell selection scheme which combines the effectiveness of Prediction-based and Sensing-based schemes. When performing the MPCE-based scheme, the serving CFAP uses the mobility prediction technique as described in the Prediction-based scheme to create a set of tentative target CFAPs from neighbor CFAPs. The serving CFAP uses the cognitive functionality to calculate the FTR of the neighbor CFAPs.

When the handover condition of (1) is triggered, with $\overline{X}(t)$ corresponding to the average relative RSS value at time t, the serving CFAP creates a set C of CFAPs whose estimated average RSS values satisfy this condition. That is,

$$C = \{\text{CFAP}_i \mid i \geq 1, \overline{X_i}(t) \text{ satisfy (1)}\}. \tag{10}$$

The serving CFAP selects the CFAP in C that has the highest FTR, by

$$\text{FTR}_{\text{targetCFAP}} = \max\{\text{FTR}_{\text{CFAP}(i)} \mid \text{CFAP}(i) \in C\}. \tag{11}$$

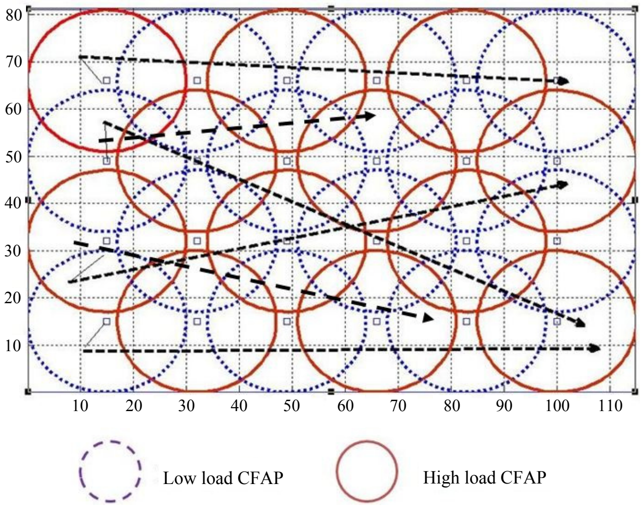

Figure 2. Simulation model.

TABLE I
SIMULATION PARAMETER

Parameters	Values
Indoor to indoor path loss model	ITU P.1238 [15]
Frequency	850 MHz [16]
External wall loss	10 dB [16]
Window loss	5 dB [16]
Speed of user	0.5 m/s
Indoor to indoor lognormal shadowing standard deviation	4 dB [16]
Downlink bandwidth	10 Mbps
Time slot duration	0.1 ms

TABLE II
SIMULATION SCENARIOS

Simulation scenario	Parameter	Load ratio (%) of background traffic
Scenario 1	Low-load CFAP	40
	High-load CFAP	80
Scenario 2	Low-load CFAP	60
	High-load CFAP	80

IV. SIMULATION MODEL AND PARAMETERS

The simulation model is shown in Figure 2. "Low-load" and "high-load" CFAPs have different load ratios of downlink data connections. Each CFAP has the coverage radius of 15 m and the antenna height is in range between 1 m and 5 m. In each CFAP coverage area, FUs are uniformly distributed and have the antenna height of 1.5 m. Considering the case in which CFAPs and FUs are indoor devices, standardized path-loss models and common simulation parameters are given in Table I.

Except left-edge CFAPs, other CFAPs generate background traffic according to their load ratio, which is the ratio of the total amount of generated downlink background data in a CFAP to the downlink bandwidth (see Table II). The left-edge CFAPs generate only mobile FUs every 50 s and create their downlink connections. Having been created, the mobile FUs will move to the right side in random directions. During their movement, handovers will occur. Each mobile FU has connection holding time following the exponential distribution with mean of 180 s. If a mobile FU reaches the right-edge or when its connection holding time expires, its number of handovers is updated. Two simulation scenarios and their parameters are shown in Table II.

V. PERFORMANCE COMPARISON

For performance comparison, we evaluate and compare the cumulative distribution function (CDF) of the number of handovers per connection, packet delay and FU's throughput. In general, the simulation results indicate that the proposed MPCE-based scheme has better performance and satisfies all requirements of low unnecessary handover, low packet delay and high user throughput. More detailed discussion about the performance is given below.

The simulation results observed in the first simulation scenario are shown in Figures 3, 4 and 5. Figure 3 shows that the Prediction-based scheme and the MPCE-based scheme were able to reduce the unnecessary handover frequency. The Prediction-based scheme is the most effective scheme in terms of providing low number of handovers because it gives the highest selection priority to the target CFAP where FUs can reside for long time. Because the MPCE-based scheme attempts to satisfy the unnecessary handovers, provides low packet delay and improves the throughput, it can offer better performance of handover number than the RSS-based and Sensing-based schemes. When we consider the ability to reduce the downlink packet delay, it can be seen in Figure 4 that the MPCE-based scheme outperformed other schemes. The Prediction-based scheme and RSS-based scheme cause high packet delay because they are not able to select the target CFAP which has available bandwidth. When using the Prediction-based scheme, if the target CFAP is a high-load CFAP, the Prediction-based scheme decides to handover FUs to a high-load CFAP. That will lead to an increase of packet delay when FUs transmit data after handover. Considering the throughput of mobile FUs, the performance results in Figure 5 show that the MPCE-based and Sensing-based schemes performed better than the two remain schemes. That means using MPCE-based and Sensing-based schemes can satisfy both low packet delay and high throughput.

In contrast to the Prediction-based scheme, the Sensing-based scheme can help the serving CFAP to avoid selecting

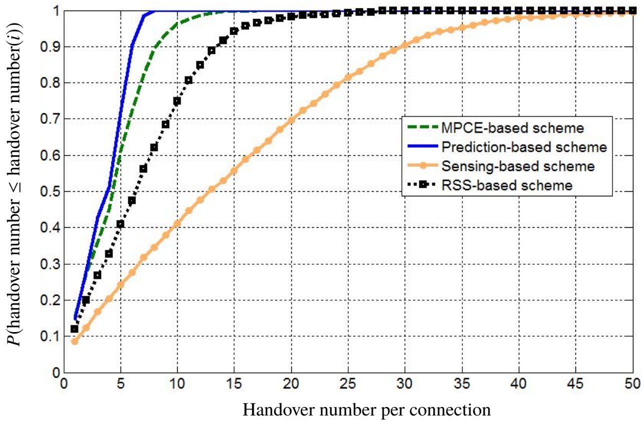

Figure 3. CDF of handover number per connection in Scenario 1.

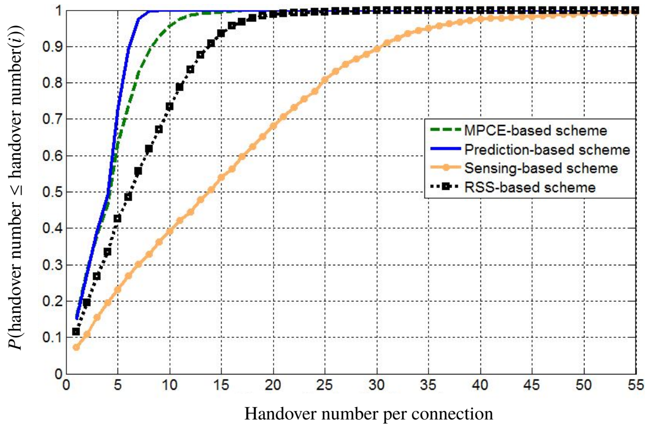

Figure 6. CDF of handover number per connection in Scenario 2.

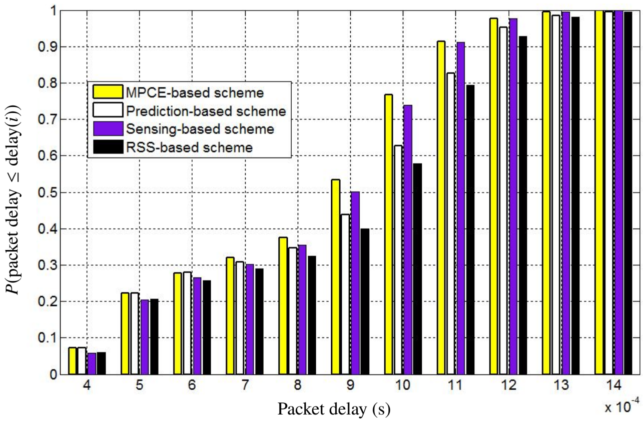

Figure 4. CDF of packet delay in Scenario 1.

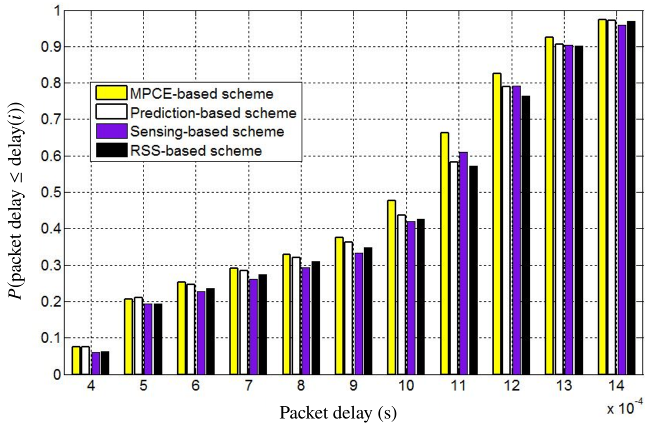

Figure 7. CDF of packet delay in Scenario 2.

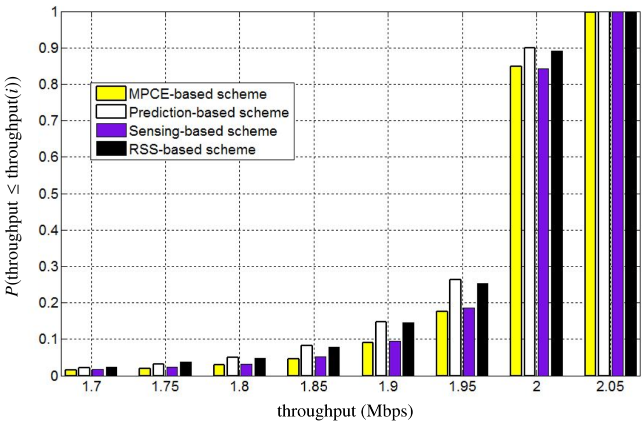

Figure 5. CDF of throughput in Scenario 1.

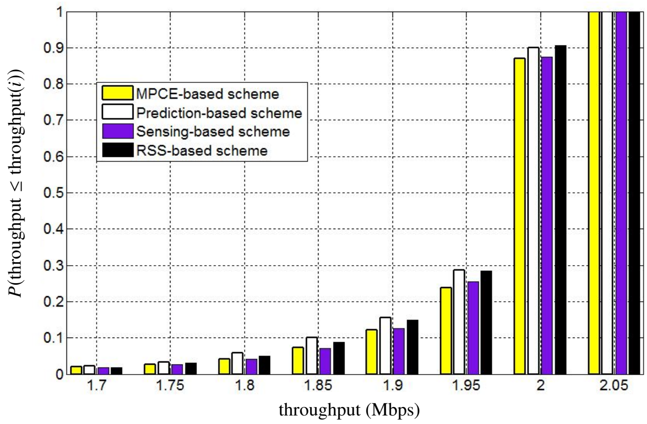

Figure 8. CDF of throughput in Scenario 2.

a high load CFAP as the target CFAP for FU. However, the variation of the RSS increases the handover number in the Sensing-based scheme. That increases the number of unnecessary handovers and, therefore, the Sensing-based scheme provides higher packet delay than the MPCE-based scheme, as shown in Figure 4.

In the second scenario, we reduce the difference in background traffic between high-load CFAPs and low-load CFAPs in order to evaluate the efficiency of the MPCE-based scheme when CFAPs have almost similar high traffic loads. The simulation results observed in Figure 6 shows that, in comparison with the performance shown in

Figure 3, these studied schemes provided similar performance in term of handover number. The reason is that the Prediction-based scheme and the RSS-based scheme only decide the femtocell selection according to the RSS value. Therefore, changing the background traffic load does not make any difference to these schemes. In case of the Sensing-based and the MPCE-based schemes, changes of the background traffic will cause only little changes to the performance in term of handover number because these schemes also use the RSS value when creating the list of tentative target CFAPs by using Equations (8) and (10), respectively.

Figure 7 shows that since the background traffic load of CFAPs was similarly high, the downlink packet delay of all four schemes increases. We observe that when CFAPs had nearly similar background traffic loads, the difference in performance of these femtocell selection schemes was reduced. However, we still can observe that the MPCE-based scheme provided lower packet delay than other schemes. The reason is that the MPCE-based scheme can help select and maintain a stable connection with the CFAP that has more available channel bandwidth. Performance results in Figure 8 show that the difference in throughput of all schemes was reduced. However, the MPCE-based scheme still can provide higher throughput comparing to others schemes. The performance results of the simulation for Scenario 2 are reasonable because, theoretically, when all femtocells have high traffic load, handover performance will be worse since there are less available radio resources for handover connections.

VI. Conclusions

In this paper, we have presented challenging research issues of femtocell-to-femtocell handover in a practical system model of cognitive femtocell networks where femtocells are deployed with a high density. Reducing unnecessary handovers and supporting QoS of femtocell users are most important requirements of the cognitive femtocell networks. In order to fulfill the challenging requirements, we proposed a new MPCE-based femtocell selection scheme, which aims to eliminate unnecessary handover and provide low packet delay and high throughput to mobile femtocell users. This scheme exploits advantages of mobility prediction and femtocell's available capacity estimation methods. We have compared the performance of the proposed MPCE-based scheme with other femtocell selection schemes in several scenarios where femtocells are densely deployed. The simulation results obtained by computer simulation verified that the proposed MPCE-based scheme can achieve better performance than the other three schemes did, providing a lower number of handover per connection, lower packet delay and higher femtocell user throughput. Future works include the investigation of other open research challenges such as mobility management for group mobility, femtocell-to-macrocell and macrocell-tofemtocell handover scenarios.

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