A Self-Adaptive Handoff Decision Algorithm for Densely Deployed Closed-Group Femtocell Networks

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***Abstract*—Due to the high traffic demand in cellular networks, femtocells are considered as one promising solution for providing cellular traffic offloading and better indoor coverage. However, coexistence of femtocells with macrocell networks introduces special challenges to mobility management. In particular, since indoor and unplanned deployment of femtocells usually suffers abrupt signal drop due to mutipath propagation, wall penetration loss, and shadowing, unnecessary handoffs and ping-pong effects may happen frequently, which severely degrades the quality of connections and user experience. On the other hand, offloading in femtocells requires a high cell utilization. Therefore, handoff decision algorithms should be carefully designed to trigger proper handoffs and fulfill the different requirements of macro-to-femto and femto-to-macro handoffs. In this paper, we propose a location history based adaptive handoff decision algorithm to address the special challenges of indoor and unplanned deployment of femtocells. Our proposed algorithm uses the neighboring cell list in dense femtocell networks to obtain the location of users. Based on the user location history, a new concept, handoff frequency of occurrence, is introduced to assist intelligent handoff decision-making. The hysteresis margin in our proposed handoff decision criteria can be adaptively adjusted to meet various handoff requirements. Simulation results show that our proposed location history based adaptive handoff decision algorithm can significantly improve the femtocell utilization and handoff failure rate. To the best of our knowledge, this is the first adaptive handoff decision algorithm that considers specific challenges of indoor deployment of femtocells.**

I. Introduction

The exponentially increased mobile data traffic is forcing cellular networks to offload their traffic to other networks [1]. Indoor small cell deployment is one of the most promising solutions to the seamless offloading of data from cellular networks. These low-powered, short-ranged, and low-cost indoor small cells are known as femtocells [2], [3]. The support of femtocells is a key feature of Long Term Evolution-Advanced (LTE-A) system [4]. The deployment scenario of femtocells in a LTE-A system is given in Fig. 1. Comparing with macrocells, femtocells have the characteristic of unplanned installation and management by users. The unplanned and indoor deployment of femtocells within the existing macrocell networks introduces a number of challenges. Spectrum allocation, interference management, and mobility management (MM) are the most important ones among them.

Handoff (HO) is an important operation to perform offloading in femtocell networks [5]. How and when an offload is performed, and how long a user equipment (UE) can offload, depend on the HO decision. There are two kinds of HO in closed-access femtocell networks: macro-to-femto and femto-to-macro. As only a limited number of subscribers, known as closed subscriber group (CSG), have the access in closed-group femtocells, they are more desirable as compared to other access modes: open and hybrid [6]. In addition, the CSG users want to be connected to femtocells as long as possible while staying within the coverage area because of low-cost. To meet this requirement, HO decision should work in a way that macro-to-femto HO is early enough to offload from a macrocell network, and femto-to-macro HO should wait to trigger a HO until the signal strength from a femtocell goes down. However, service failure may still happen if the HO-decision cannot adapt with the unplanned nature of femtocell networks. Due to the importance of HO decision in femtocell networks, in this paper, we address HO decision related issues for both macro-to-femto and femto-to-macro HO scenarios.

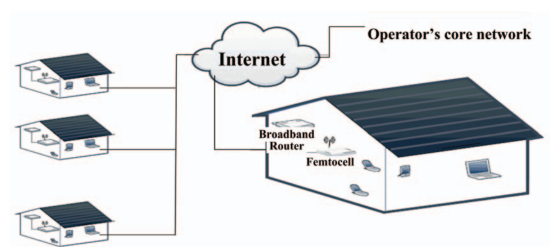

Fig. 1. Femtocell deployment scenario in an LTE-A system.

Though femtocells operate on the same frequency spectrum as macrocells, the dense yet unplanned and indoor deployment of femtocells within the overlaid macrocell networks makes the HO decision more difficult and different from macrocell networks. The first difficulty is the difference in the transmission power of a femto-base station (FBS). The transmission power of a FBS (usually 10-15dB) is much lower than that of a macro-base station (MBS) which is usually 45dB [7]. Because of this low transmission power, a femtocell might be undiscovered by a UE. This can happen because a UE has the natural tendency to connect to the highest received signal strength (RSS) and it receives higher RSS from a macrocell rather than a femtocell. There are two ways to solve this problem. One is to take an offset to compensate the power difference. This method is proposed in [8], [9] for HO decision-making from macrocells to femtocells. Another way is to set a proper threshold. In this paper, an optimization of the HO threshold is proposed.

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The second problem is related to co-channel interference. Because of indoor deployment of femtocells, they suffer higher path-loss due to multi-path propagation, wall penetration loss, and shadowing effects than other small cells [3]. As a result, an abrupt signal-to-interference-plus-noise-ratio (SINR) drop occurs at the boundary of femtocells. Due to this drop, the HO-decision algorithm for the femto-to-macro needs to be different from that of the macro-to-femto. We will explain the interference effect in femtocells in Section III and propose two different HO-decision algorithms by considering the difference between macro-to-femto and femto-to-macro HOs.

The unplanned and unstable nature of neighboring femtocells introduces a third challenge. As femtocells are fully operated by users and the network operator does not have any control on this, the number and position of neighboring femtocells may vary randomly. This nature of neighboring femtocells will create an uneven interference effect on the boundary of femtocells from time to time. As a result, it is difficult to use the same HO-decision algorithm when the environment changes occasionally, because this may cause a large number of unnecessary HOs and even service failures. Therefore, using an adaptive hysteresis margin (HM) is a good way to solve this problem [10].

The use of an adaptive HM can reduce the number of unnecessary HOs and ping-pong effects of users. An indoor user follows a specific mobility pattern and moves back and forth frequently in some boundary areas without actually moving out of the cell (e.g., the corner of a room) and in other boundary areas where the user actually moves out of the cell (e.g., a door). This is the fourth obstacle when designing the HO-decision algorithm. Using the same HM may lead to unnecessary HOs and ping-pong effects in the former areas.

In this paper, we propose a self-adaptive HO-decision algorithm to address the unique issues of both maro-to-femto and femto-to-macro HOs. The HM of our algorithm is able to adapt not only with the deployment environment, but also with the mobility pattern of the user. The proposed algorithm is intelligent enough to set the HM to a proper value based on the history of previous HOs. We propose to keep a database containing the location fingerprinting of a user who has requested HOs before. The location fingerprinting is taken from the measurements of the neighboring femtocells. The goal of this self-adaptive HO-decision algorithm is to reduce the rate of unnecessary HOs and service failure, and at the same time, increase the cell utilization.

The rest of the paper is organized as follows. Related works are explained in Section II. In Section III, research motivation and contributions of this paper are discussed. In Section IV, our location-fingerprint based self-adaptive HO-decision algorithm is described. In Section V, simulation results are given, followed by the conclusions in Section VI.

II. Related Work

The problems addressed by existing research on HOs in femtocell networks include transmission power difference between MBS and FBS [8], [9], [11], [12], frequent and unnecessary HOs [13]–[23], selecting the target cell for HOs [16], [22]–[24], HO failure rate [14], [25], interference [12], [14], [26], energy saving strategy [27], [28], HO delay/cost minimization [14], [29], and ping-pong effects [30]–[32]. The power difference between FBS and MBS during an inbound (macro-to-femto) HO is considered in [8], [9], [11], [12]. In [8] and [9], a combination factor is proposed to compensate the power asymmetry in a way that the UE will be correctly assigned to a femtocell while maintaining the number of HOs at the same level. A window function is also proposed to prevent the RSS from varying abruptly. However, the abrupt signal drop cannot be ignored in real indoor scenarios. It is claimed in [11] that only considering this combination factor may increase the rate of unnecessary HOs. Therefore, another parameter, transmission loss, is proposed in [11] for HO decision-making. A cost-effective HO-decision algorithm is proposed in [12] considering the power discrepancy which will be discussed later.

Most of the existing works on HO decision in femtocell networks are focused on minimizing the unnecessary HO rate due to the dense femtocell deployment and small cell radius [13]–[23]. A mobility prediction method to predict the mobility pattern of a user, which is used to select the proper cell to HO, is proposed in [13], [22], [23]. The mobility prediction is based on the current mobility-history of a user. Different parameters, such as user's velocity, RSS, and traffic type are considered for HO decision-making in [14]–[16]. In addition, call admission control (CAC) is used in [17] and [19] for HO decision-making. A waiting time with a SINR threshold is proposed in [18] to avoid unnecessary HOs. Adaptive techniques to eliminate unnecessary HOs in femtocell networks are considered in [20], [21]. An adaptive HM is proposed based on the distance between a UE and a BS to avoid unnecessary HOs in [20]. The efficiency of two HO elimination techniques, i.e., windowing and HO delay timer are investigated in [21]. Both techniques are modified for femtocells based on the distance between a UE and the serving BS. In conclusion, existing works on eliminating unnecessary HOs consider user's speed, traffic type, waiting time, mobility pattern prediction, and distance-based adaptive HM for HO decision-making.

Another problem of making a HO-decision in densely deployed open-access femtocell networks is how to select the target cell properly. Large number of femtocells may create a long neighboring cell list and selecting a wrong target cell may cause unnecessary HOs. To overcome this problem, mobility-prediction is used to select a proper target cell [24] or to make an effective neighboring cell list [16], [22]–[24]. [24] considers that knowing the current position can help us know where a UE is going, which can later help to select the target cell. As described previously, [16] tries to avoid the long neighboring cell list problem in order to eliminate unnecessary HOs by considering user's speed and traffic type. A mobility-history database is proposed in [22], [23] which contains a list of target cells where users are recently handed over.

A few works have addressed the interference problem during a HO. Intracell HO (IHO) is considered in [12], [14], [26] to avoid the cross-tier interference. A cost-function based on the available bandwidth of the target cell is proposed in [14] to provide better QoS to users by reducing interference.

Along with these main issues, some other issues are also addressed, such as to avoid the HO failure rate which is one of the biggest challenges for designing a HO-decision algorithm [14], [25], to minimize the HO cost [14], [29], and to provide cost-effective service to users [33]. An intelligent HO management is proposed in [27] for energy efficient green femtocell networks and [28] works on reducing power transmission at the UE side by adapting the HM suitably with respect to the SINR from the target cell and the standard LTE measurements.

The location-based HO-decision algorithm for different small cell networks is discussed in [22], [23], [31], [32], [34], [35]. As described earlier, [22] and [23] keep the mobility-history of users to predict the target cell in small cell networks. Here, location is used to set the target cell and to minimize the HO delay. User's mobility and location are also used to provide better service during a HO. Geographical fingerprint for HOs are considered in [36], [37], where location-fingerprint is obtained using artificial neural networks. This fingerprint is used to select the target cell and neither a GPS nor a sensor is used.

Based on the discussion above, we observe that the following issues in femtocell networks are not addressed for HO-decision algorithms:

- Indoor environment
- Abrupt signal drop and high interference at cell boundary
- Indoor ping-pong effects
- Ad-hoc nature of neighboring femtocells

III. Research Motivation and Contributions

A. Research Motivation

The above issues, not addressed in existing works, are the motivation for our work. How and why these issues can affect HO decision in femtocell networks are investigated in this section.

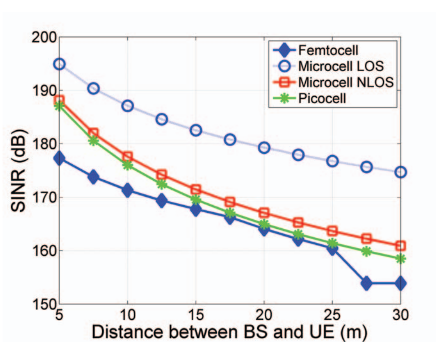


Fig. 2. The comparison of SINR of different small cells.

Femtocells suffer from higher interference than other small cells due to the indoor deployment. Simulation results on the SINR with respect to the distance between a UE and the BS of different small cells are shown in Fig. 2. We use the ITU-R P.1238-7 path-loss model in our simulation [38]. The indoor deployment is indicated as NLOS (non-line-of-sight) and outdoor deployment is indicated as LOS (line-of-sight) here. From the figure, it is observed that a femtocell suffers from higher interference than others because of the low transmission power and indoor deployment. Hence, it has an abrupt signal drop at the cell boundary. How this abrupt signal drop and high interference affect the HO decision-making is explained in Fig. 3.

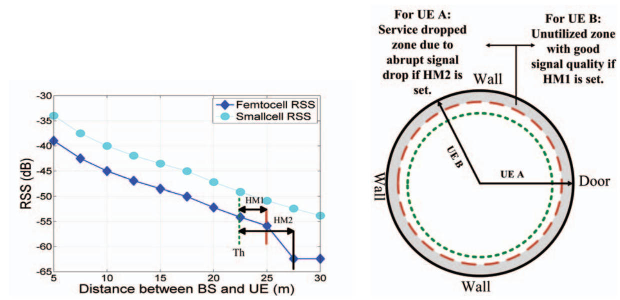


Fig. 3. Effect of abrupt signal drop at the cell boundary in HO decision making.

In the left side of Fig. 3, the comparison of the femtocell RSS between indoor and outdoor deployment (which is indicated as smallcell RSS) is shown. In the right side of Fig. 3, the scenario of selecting different HM is given. From the figure we observe that, a HO should initiate early (at threshold shown by the green dotted-line) because of the RSS drop at the cell boundary. Now, as UE A moves towards the door, the HM (HM1 in the figure) should be selected in a way that the service of UE A does not fail. On the other hand, this HM causes an unnecessary HO for UE B who will stay inside the femtocell, which also leads to poor utilization of femtocells. In this case, setting a high HM ($HM2 > HM1$) is required to overcome this problem. However, this is not acceptable for UE A. To solve this conflicting issue, we need to design a self-adaptive HO-decision algorithm.

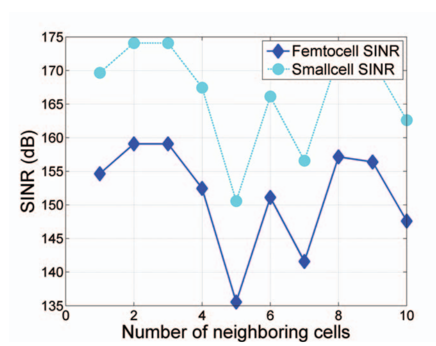


Fig. 4. The effect of ad-hoc nature of neighboring femtocells on SINR at the boundary of the home femtocell.

The changeable characteristics of both the home femtocell and the neighboring femtocells make this situation more complicated. Fig. 4 presents the SINR at the home femtocell boundary with different number of neighboring femtocells. We observe that the SINR changes randomly and unpredictably, which can increase the ping-pong effects for indoor femtocell users. This issue needs to be addressed in order to provide seamless mobility support between femtocells and macrocells and to ensure a better user experience.

Besides all of these challenges, different HO scenarios in femtocell networks have different criteria and purposes. They are:

- Macro-to-femto HO: To offload traffic from macrocell networks in order to avoid network congestion.
- Femto-to-macro HO: To provide seamless mobility management and better QoS while the indoor signal is poor and the macrocell network is not congested.

To the best of our knowledge, all of these issues cannot be addressed by existing works. The offset-based HO-decision algorithms [8], [9], [11] can meet the requirement of macro-to-femto HOs. However, they can increase the number of unnecessary HOs for users. For example, in Fig. 5, all the UEs will be handed over to the femtocell, which is not necessary.

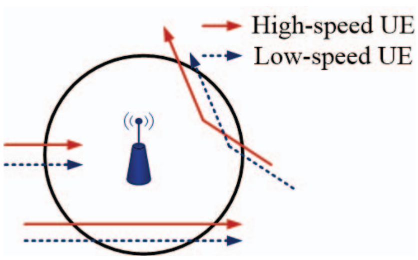


Fig. 5. Inbound mobility in femtocell networks.

A number of existing works in the literature propose to eliminate these redundant unnecessary macro-to-femto HOs. Speed-based HO algorithms and cost-function based HO algorithms [14]–[16] can eliminate unnecessary HOs of high-speed users, which may also prevent the HO of closed-group users with high-speed. As a result, offloading cannot be performed. Moreover, these algorithms are based on some parameters (e.g., speed, traffic types, and available bandwidth) which are not practical for a UE to obtain or calculate. On the other hand, the femto-to-macro HO scenario is different in that indoor users are usually in low speed and they suffer high interference at the cell boundary (which implies a high HO failure rate). The necessity of a HO is different for different users based on their locations (which is explained in Fig. 3). As a result, the offset-based, speed-based, and cost-function based algorithms cannot be applied to femto-to-macro HO scenarios. Existing HO failure rate elimination algorithms [14], [25] use the same parameters (speed, traffic type, etc.). They also cannot be directly applied to femto-to-macro HO scenarios. Therefore, more advanced HO decision algorithms are necessary to meet these requirements. Existing adaptive HM-based algorithms are either based on distance [10] or signal strength [20]. However, it is possible that users at the same distance to the BS or with the same received signal strength may need different HO decisions (as stated in Fig. 3). Considering all these issues, we propose a self-adaptive HO-decision algorithm for both macro-to-femto and femto-to-macro HO scenarios based on the location-fingerprint of UE's HO history. Existing works related to location-fingerprint for HO decisions [36], [37] use geographical fingerprint (i.e., latitude and longitude) to predict the target cell. However, the target cell is always the same for closed-group femtocell networks except that knowing the exact location is hard for indoor users. Additionally, since we need to find out only the HO areas, it is not necessary to know the exact location of a UE. As a result, we use location-fingerprint from the neighboring cell list and their RSS to find out the HO area.

B. Contributions

In this paper, we propose a self-adaptive HO decision algorithm based on location-fingerprint in order to provide seamless HOs between macrocells and femtocells. The contributions of this paper are summarized as follows:

- Considering the indoor deployment, we propose HO-decision algorithms for both macro-to-femto and femto-to-macro HO scenarios to meet offloading requirements and to provide seamless mobility.
- We propose a self-adaptive HM to adapt to the ad-hoc nature of femtocells and the locations of the UE. Each time a HO is requested, a new HM is calculated from a database entry based on the location-fingerprint of the requested HO.
- We propose a location-fingerprint database to assist HO decision-making. The database contains the information, i.e., location-fingerprint of previous successful HOs. No unrealistic data or measurement method is required to build the database, as it contains the information of neighboring cell IDs and their received signal strength indicator (RSSI). Both parameters are accessible for a UE during the HO measurement. To adjust with the ad-hoc nature of both home and neighboring femtocells, we propose to update the database each time a successful HO happens.
- A realistic simulation scenario is used to evaluate the performance of the proposed algorithm. We analyze the proposed algorithm in terms of the rate of unnecessary HOs, HO failure rate, and femtocell utilization, and compare them with other existing works.

IV. The Proposed Self-Adaptive HO Decision Algorithm

In this section, the proposed self-adaptive HO decision algorithm for both macro-to-femto and femto-to-macro HOs is introduced. The proposed algorithm works in two phases: 1) initialization phase and 2) utilization phase. In the initialization phase, a HO between a femtocell and a macrocell is triggered using the LTE-A system-based HO criteria, and a database is built in this phase. The database contains the location-fingerprint of UEs that are successfully handed over to their target cells. The database is used in the utilization phase to adapt the HM for different UEs. During this phase, the database is updated with new information to handle the ad-hoc nature of femtocells. The notations used in our algorithm are listed in Table I.

TABLE I
NOTATIONS USED IN THE ALGORITHMS

$RSSI_m$	Received Signal Strength Indicator for macrocell
$RSSI_f$	Received Signal Strength Indicator for femtocell
$RSSI_{min}$	Minimum received signal strength indicator for macrocell
Th	Threshold for femtocell
HM_{max}	Optimized value of hysteresis margin
MME	Mobility management entity
FGW	Femto gateway
PCI	Physical cell identity
$RSSI_{fail}$	Minimum received signal strength indicator for femtocells

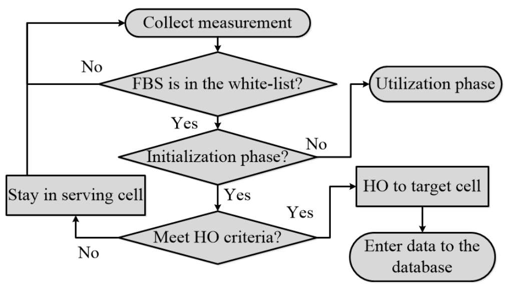


Fig. 6. Flow chart for the initialization phase.

Algorithm 1: Macro-to-femto HO-decision algorithm

if $RSSI_f > Th$ **or** $RSSI_m < RSSI_{min}$, **and** $RSSI_f > RSSI_m + HM_{max}$ **then**
  HO to femtocell;
else
  Stay in macrocell;
End;

Algorithm 2: Femto-to-macro HO-decision algorithm

if $RSSI_f < Th$ **or** $RSSI_m > RSSI_{min}$, **and** $RSSI_f + HM_{max} < Th$ **then**
  HO to macrocell;
else
  Stay in femtocell;
End;

A. Initialization Phase

The initialization phase is activated at the time when a new FBS is plugged in. The flow chart for this phase is given in Fig. 6. The initialization phase is used to build up the location-fingerprint database. In this phase, all HOs are performed based on a fixed HM and the measurement report of UEs. In LTE-A, the Radio Resource Control (RCC) protocol manages the events that a UE reports its HO measurement to the serving BS [39]. The measurement includes UE's ID, CSG ID, and available cell IDs (i.e., PCIs) along with their RSSIs. The PCI is not a unique ID for FBS (totally 504 PCIs from 0-503 are available for the LTE-A system). However, we assume that there will be a good distribution of offered PCIs within the coverage area of a macrocell. As shown in the flow chart, this measurement is used to check whether the UE is a registered-user for the closed-access femtocell. The HO process continues for the closed-group users and the HO decision. Whether the algorithm is in the initialization phase or not is determined from the database. An empty database indicates that the algorithm is in the initialization phase and the serving cell makes the HO decision based on the measurement report. The proposed HO algorithms for a macro-to-femto HO and a femto-to-macro HO are given in Algorithm 1 and Algorithm 2, respectively.

The selection of the Th and HM_{max} is explained later in the paper. After a successful HO, the location-fingerprint is entered in the database. We use both the neighboring cell IDs and their RSSIs as the location-fingerprint of UEs. The database has a specific length and the initialization phase ends as soon as the database is full.

B. Utilization Phase

When the database is full, it will be used for determining the adaptive HM in the utilization phase. Each time a user requests a HO, it sends location-fingerprint with its measurement report. After getting this report, MME (or FGW for femtocell) checks the database to find matches. Suppose the number of similar entries is N_d and the size of the database is d_s. Then the frequency of occurrence (P_{foc}) can be found as

$$P_{foc} = \frac{N_d}{d_s}. \quad (1)$$

P_{foc} is used for calculating the adaptive HM (HM_{ad}). A high value of P_{foc} indicates a frequent HO zone. As the frequent HO zones need a lower HM, P_{foc} and HM_{ad} are inversely proportional to each other. Hence, the relationship between them is $HM_{ad} \propto \frac{1}{P_{foc}}$ or $HM_{ad} \propto (1 - P_{foc})$ in dB. Given HM_{max}, the HM_{ad} is

$$HM_{ad} = (1 - P_{foc}) * HM_{max}. \quad (2)$$

After calculating the value of the adaptive HM, the serving BS checks the HO decision criteria. The proposed macro-to-femto and femto-to-macro HO criteria are given in Algorithm 3 and Algorithm 4, respectively. The HO is successful if the HO-decision criteria are met and the database is updated. The steps of the utilization phase are shown in Fig. 7.

Algorithm 3: Macro-to-femto HO-decision algorithm

if $RSSI_f > Th$ **or** $RSSI_m < RSSI_{min}$, **and** $RSSI_f > RSSI_m + HM_{ad}$ **then**
  HO to femtocell;
else
  Stay in macrocell;
End;

Algorithm 4: Femto-to-macro HO-decision algorithm

if $RSSI_f < Th$ **or** $RSSI_m > RSSI_{min}$, **and** $RSSI_f + HM_{ad} < Th$ **then**
  HO to macrocell;
else
  Stay in femtocell;
End;

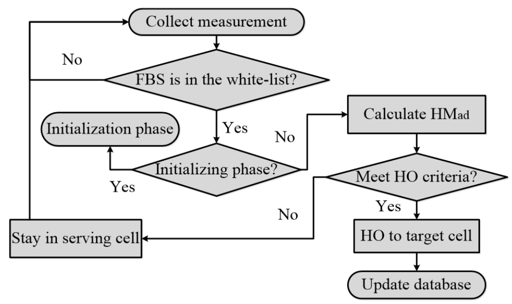


Fig. 7. Flow chart for the utilization phase.

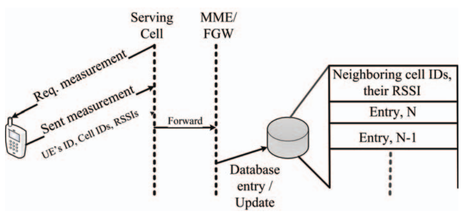


Fig. 8. Database building and updating.

C. Location-Fingerprint Database

One of the important purposes of our proposed HO decision algorithm is to get the location of the user during a HO, because a HO is necessary at a few particular locations for indoor users. However, localization of indoor users is difficult. A number of localization techniques are available in the literature for indoor localization [40]. Most of them require complex algorithms. In our design, we consider RF fingerprinting [41] instead of calculating the coordinates of the user location, because our HO-decision algorithm does not require the actual position of a user. Determining the HO zone is our main purpose of building the database. If a location-fingerprint, obtained from the neighboring cell list, is stored in the database each time a HO occurs, the serving BS can compare this list with the requested location-fingerprint, and can perform a quick HO triggering when necessary. The process of building the database is shown in Fig. 8.

Algorithm 5: Database building and update

```
if Data matches a previous entry within a time x from the same UE
then
    Delete both entries;
else
    if Database is full then
        Delete the oldest data and insert a new entry;
    else
        Insert the data;
End;
```

Each time a UE sends a measurement report to the serving BS, the serving BS determines the target BS and forwards the rest of the measurement to the MME/FGW. This forwarded message contains a list of neighboring cell IDs (with $RSSI > RSSI_{min}$) and their corresponding RSSIs. The MME/FGW stores this information in the database if the database is not full. This database is used in the utilization phase to calculate the adaptive values of the HM. To cope with the ad-hoc nature of femtocells, in the utilization phase, the database is updated in the FILO (first in last out) mode, i.e., the new location-fingerprint is entered and the oldest data is removed from the database if the database is full. The database building and updating algorithm is given in Algorithm 5.

D. Determining HO Parameters

The minimum received signal strength at the cell boundary of a macrocell and a femtocell is $RSSI_{min}$ and $RSSI_{fail}$, respectively. To find out these values, Okumura-Hata propagation model is used for macrocell networks and ITU-R P.1238-7 path-loss model is used for femtocell networks [38].

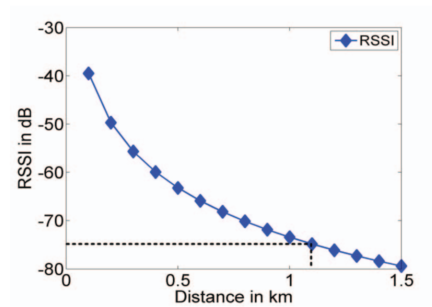


Fig. 9. Selecting $RSSI_{min}$ at the macrocell boundary.

We consider the radius of macrocells and femtocells in our simulation as 1.2km and 15m. Fig. 9 presents the RSSI values for different distances from the macro BS. The $RSSI_{min}$ is calculated as -75dB at the macrocell boundary as shown in the figure. Similarly, the calculated $RSSI_{fail}$ value is -50dB at the femtocell boundary which is shown in Fig. 10.

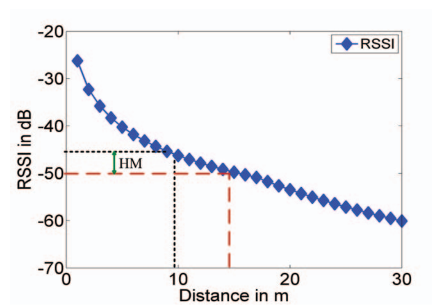
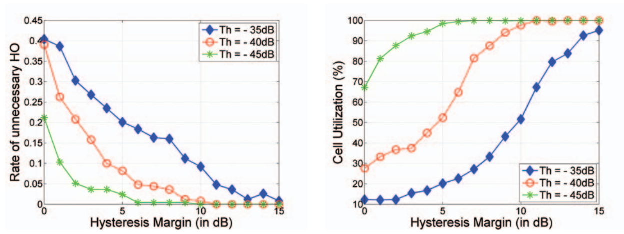


Fig. 10. Selecting $RSSI_{fail}$ and Th for a femtocell.

The value of HM_{max} and Th can be obtained using simulations. We consider two contrary performance metrics of femtocell networks: rate of unnecessary HOs and cell utilization. The simulation results are shown in Fig. 11 with respect to different values of Thresholds and HMs. From the figure, it is observed that when $HM = 5$dB and $Th = -45$dB, both metrics show better performance than others. Therefore, we set HM_{max} as 5dB. If the value of HM_{max} is 5dB in Fig. 10, we can also find that $Th = -45$dB. These values are used our simulation.

E. HO Signaling

Both the inbound and outbound signaling for self-adaptive HO decision in femtocell networks are given in Fig. 12 and Fig. 13.



(a) Rate of unnecessary HOs (b) Cell Utilization

Fig. 11. Rate of unnecessary HOs and cell utilization for different Th and HM.

We consider the signaling procedure during a macro-to-femto HO as the inbound signaling. In this state, the MME checks the location-fingerprint database for similar entries after getting the measurement report from the UE through the serving BS. If the database is empty, the MME considers that the initialization phase is activated and makes a HO decision. The location-fingerprint is added to the database after the HO is succeeded. In the utilization phase, this database is used to calculate the HM as described previously and the database is updated with new location-fingerprint. The database is shared by the MME and FGW so that it can be used for both inbound and outbound mobility. In the outbound signaling, i.e., in a femto-to-macro HO, the signaling procedure is similar to the inbound signaling. However, the FGW makes the HO-decision instead of the MME. The outbound signaling is shown in Fig. 13.

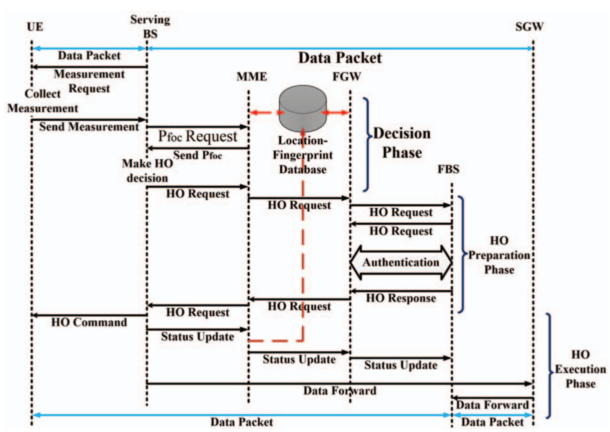


Fig. 12. Inbound signaling for self-adaptive HO-decision algorithm.

V. Performance Evaluation

In this section, we evaluate the performance of the proposed self-adaptive HO-decision algorithm. We use Net Logo 5.0.5 [42] to simulate our proposed algorithm in an indoor environment. We design a single-floored two-bedroom apartment with an FBS which has the capacity of supporting fifteen users surrounded by six neighboring FBSs in the coverage of a macro BS. We consider thirty users with a probability of 0.5 to enter and exit the apartment in a random manner. All users and FBSs are placed randomly and all users follow a modified version of the Random Waypoint mobility model. The mobility model is modified in a way that the users only use the door to get in/out of the apartment and none of them crosses the walls. For supporting the unplanned deployment of femtocells, we also consider the random placement of FBSs inside the apartment. The parameters used in our simulation are listed in Table II [38].

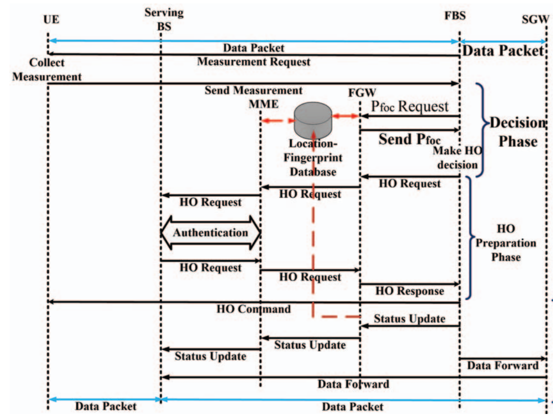


Fig. 13. Outbound signaling for self-adaptive HO-decision algorithm.

TABLE II
Simulation Parameters

Macrocell transmission power, P_m	45 dB
Radius of macrocell	1.2 km
Femtocell transmission power, P_f	10 dB
Radius of femtocell	15 m
Size of database, d_s	30
Users speed	5 km/hr
Threshold, Th	-45 dB
Wall penetration loss	5 dB
Outdoor penetration loss	2 dB - 10 dB
$RSSI_{min}$	-75 dB
$RSSI_{fail}$	-50 dB
HM_{max}	5 dB

In this paper, we mainly investigate the following three performance metrics: 1) *Rate of unnecessary HOs*: the probability that a UE temporarily hands over to the target cell and hands over back to the serving cell, 2) *HO failure rate*: the probability of a call/service-drop before a successful HO is triggered, and 3) *cell utilization*: the probability that a CSG UE stays connected to the femtocell while within the coverage area of it's home FBS. In addition, we compare our proposed self-adaptive algorithm with three other algorithms: 1) *fixed HM AL*: the HM does not adapt with the ad-hoc nature of femtocells; 2) *AL1*: the HM changes based on the formula from [10], which is $HM = max\{HM_{max} * (1 - 10^{\frac{d}{R}})^4; 0\}$. Here, R is the radius of the femtocell and d is the distance between the FBS and UE; and 3) *AL2*: the adaptive HM is calculated from $HM = max\{HM_{max} * (1 - 10^{\frac{SINR_{act} - SINR_{min}}{SINR_{min} - SINR_{max}}})^4; 0\}$ [20].

A. Rate of Unnecessary HOs

The rate of unnecessary HOs for the macro-to-femto HO, femto-to-macro HO, and both of them together are shown in Fig. 14, Fig. 15, and Fig. 16, respectively. Low rate of unnecessary HOs is desirable in order to provide better performance. The simulation result shows that the proposed algorithm has a lower unnecessary HO rate than other algorithms. As AL1 and AL2 change the HM based on the distance and SINR, respectively, and select the minimum value of the HM throughout the cell boundary, both algorithms show worse performance than others. Unlike the proposed algorithm, all the other three algorithms fail to adapt the HM based on the HO location area. As a result, the proposed algorithm eliminates more unnecessary HOs than others.

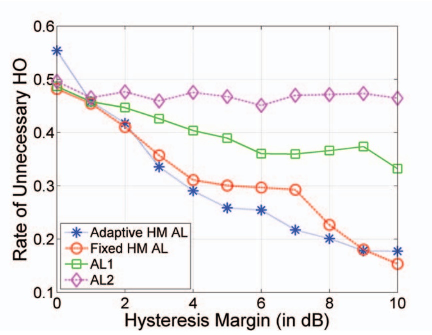


Fig. 14. Rate of unnecessary HOs for the macro-to-femto HO scenario.

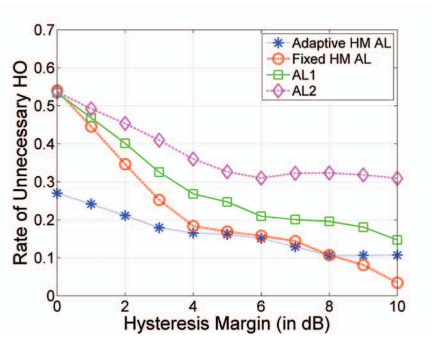


Fig. 15. Rate of unnecessary HOs for the femto-to-macro HO scenario.

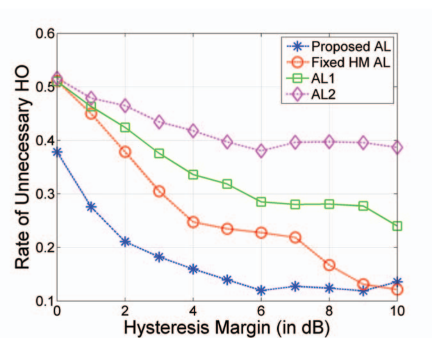


Fig. 16. Total rate of unnecessary HOs.

B. HO Failure Rate

The HO failure rate should be as minimum as possible. Since a high value of the HM can lead to a high value of the HO failure rate because of the abrupt signal drop, it is necessary to minimize the HM where a HO is necessary. Additionally, femtocells suffer high interference at the cell boundary, which may lead to a high service failure if HO-decision cannot adapt to the change of the environment. If the RSSI of the UE goes below $RSSI_{fail}$ and a HO does not happen, we consider this as a HO failure. The performance of the HO failure rate of our proposed self-adaptive algorithm as compared to the other three algorithms is given in Fig. 17. It is observed that the proposed algorithm outperforms the other algorithms in terms of lower HO failure rate.

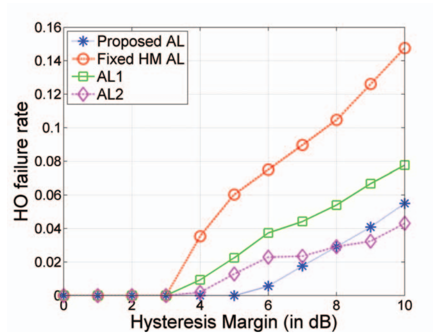


Fig. 17. HO failure rate.

C. Cell Utilization

As femtocells are deployed for offloading cellular traffic and to provide cost-effective service to the closed-group users, it is expected that whenever a UE is within the coverage area of its home FBS, it should be connected to the femtocell. However, traditional HO-decision algorithms do not consider this issue. As a result, their cell utilization is lower than the proposed algorithm. The simulation results of cell utilization are shown in Fig. 18.

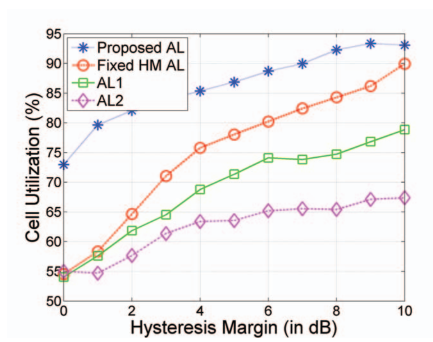


Fig. 18. Cell utilization.

VI. Conclusion

In this paper, a location-fingerprint based handoff decision algorithm is proposed to improve the handoff performance and to offload cellular data traffic in densely deployed heterogeneous networks with femtocells. In our algorithm, the hysteresis margin changes with the handoff priority based on the location of users. Therefore, a fast handoff can be triggered wherever necessary. Our algorithm can reduce the handoff failure rate and at the same time, provide better cell utilization to insure maximum data offloading. The performance of the proposed self-adaptive handoff-decision algorithm is analyzed in terms of unnecessary handoff rate, handoff failure rate, and cell utilization by considering the challenges of indoor deployment. Simulation results show significant improvement as compared to the existing handoff-decision algorithms in femtocell networks. It is observed that a proper selection of hysteresis margin and threshold can reduce unnecessary handoff rate and handoff failure rate without sacrificing cell utilization.

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