Signaling Cost Analysis for Handoff Decision Algorithms in Femtocell Networks

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***Abstract*—Femtocells are deployed to provide good indoor coverage and to offload data traffic from macrocell networks. Unnecessary handoffs (HOs), ping-pong effects, and cell utilization are important performance metrics for evaluating the quality of connections and data offloading in femtocell networks. Though significant research has been conducted on HO decision algorithms to reduce unnecessary HOs and ping-pong effects, only a few of these studies consider unnecessary HOs and cell utilization together. Moreover, all of the existing HO decision algorithms add extra signaling overhead to the HO procedure. Therefore, it is important to analyze the HO signaling cost of existing HO decision algorithms. In this paper, we propose an analytical model to study the HO signaling cost of different HOs in open-access femtocell networks. In addition, we propose HO decision algorithms that can reduce unnecessary HOs without increasing HO signaling costs and sacrificing cell utilization. Simulation results show significant performance improvement as compared to the existing HO decision algorithms. To the best of our knowledge, this is the first analytical model that can be applied to all existing HOs available in open-access femtocell networks.**

I. Introduction

Femtocells are introduced as a promising solution to improve indoor coverage and to offload data traffic from cellular networks (i.e., macrocells) [1]. Femtocells are low-powered, short-ranged, and low-cost indoor base stations (BSs), which are deployed and managed by users. Femtocells can offload traffic from cellular networks based on their access modes and the availability of user equipment (UE) within their coverage area. There are three access modes available in femtocell networks: closed, open, and hybrid. These modes form three types of handoffs (HOs): macro-to-femto, femto-to-macro, and femto-to-femto. Only a limited number of registered UEs can access the femtocell in closed-access mode. This access mode supports macro-to-femto and femto-to-macro HOs. Any UEs that are within the coverage area of an open-access femtocell can access it. Besides the two HOs available in closed-access, open-access mode also supports users in performing HOs from a femtocell to another femtocell (femto-to-femto). On the other hand, hybrid access mode supports all types of users and HOs.

HO plays an important role during data offloading in a femtocell-deployed macrocell network. Due to indoor and unplanned deployment of femtocells, unnecessary HOs 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, it is necessary to design an HO decision algorithm that can reduce unnecessary HOs and improve cell utilization at the same time. Most of the existing works propose HO decision algorithms that reduce unnecessary HOs and ping-pong effects [2]–[4]. A few of them have considered cell utilizations while designing an HO decision algorithm [5], [6]. All of these algorithms have used different parameters and techniques to design HO decision algorithms [2]. This practice adds extra HO signaling overhead at the core network and increases the HO signaling cost. Limited research has been conducted to analyze the HO signaling cost in femtocell networks [7], [8]. However, these works do not analyze the signaling cost of different types of HOs in open-access modes. Moreover, a comparison of the HO signaling cost for existing HO decision algorithms is necessary.

In this paper, we propose an analytical model to study the HO signaling cost of different HOs in open-access femtocell networks. In addition, we extend our work [6] to propose a target cell selection method and to propose HO decision algorithms that can reduce unnecessary HOs without increasing HO signaling costs and sacrificing the femtocell utilization. Finally, we compare the HO signaling cost of existing HO decision algorithms in femtocell networks.

The rest of the paper is organized as follows. Related work and contributions are introduced in Section II. In Section III, the proposed target cell selection method and HO decision algorithms are described. The analytical model for HO signaling costs are presented in Section IV. Performance evaluation is given in Section V, followed by the conclusions in Section VI.

II. Related Work and Contributions

A. Related Work

Though a number of papers on HO decision algorithms are available in the literature [2], only a few of the existing works consider the HO signaling cost in femtocell networks [7]–[9]. An architecture for LTE femtocell networks which introduces an intermediate node (HeNB GW) is presented in [7]. Two methods for mobility management are proposed in this paper. In the first method, the HeNB GW acts as a mobility anchor to control HOs among femtocells, and it works as a relay in the second method. An analytical model to evaluate and compare HO signaling costs of these two methods are described here. However, not all HO scenarios are considered. In [9], an HO decision algorithm based on users' speed and traffic types is discussed. The signaling procedure for both macro-to-femto

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and femto-to-macro HOs are also presented in this paper. A simple HO decision algorithm for the macro-to-femto HO scenario that considers users' speed is discussed in [8]. The HO signaling cost is also analyzed for this HO scenario, and the proposed algorithm is compared to a traditional HO decision algorithm. Both of the papers [7], [8] analyze the HO signaling cost for a simple general scenario. For example, a femto-to-femto HO scenario is considered in [7], and a macro-to-femto HO scenario is discussed in [8]. However, the rest of the HO scenarios in the open-access mode have not been considered.

B. Contributions

In this paper, we propose HO decision algorithms and an analytical model for the open-access femtocell networks. The contributions of this paper are summarized as:

- We extend our work [6] for open-access femtocell networks and propose a target cell selection algorithm, along with HO decision algorithms for macro-to-femto, femto-to-femto, and femto-to-macro HO scenarios.
- We propose an analytical model of the total HO signaling cost for all types of HOs in open-access femtocell networks.
- We analyze and compare the total HO signaling cost of different existing HO decision algorithms that are designed to reduce unnecessary HOs.
- We use a realistic simulation scenario to evaluate the performance of these existing algorithms in terms of total HO signaling cost and femtocell utilization.

III. Proposed HO Decision Algorithm

In this section, the proposed target cell selection method and HO decision algorithms are presented. The proposed algorithms work in two phases: initialization and utilization. The initialization phase is used to build a location-history database, and this database is used in the utilization phase to adapt the hysteresis margin (HM). The notations used in our algorithms are listed in Table I.

TABLE I
Notations Used in the Algorithms

$RSSI$	Received Signal Strength Indicator
$RSSI_m$	Received Signal Strength Indicator for the macrocell
$RSSI_{sf}$	Received Signal Strength Indicator for the serving femtocell
$RSSI_{tf}$	Received Signal Strength Indicator for the target femtocell
$RSSI_{min}$	Minimum received signal strength indicator for the macrocell
Th	Threshold for the femtocell
HM_{ad}	Adaptive hysteresis margin
MME	Mobility management entity
FGW	Femto gateway
MBS	Macro-base station
Th_{spd}	Threshold for users' speed
UE_{spd}	Users' speed

Despite the access policies, the requirements for a macro-to-femto and a femto-to-macro HO are the same for both closed-access and open-access femtocell networks. The proposed HO decision algorithms for these HOs are given in Algorithm 1 and Algorithm 2. We have modified the HO decision algorithms to make them applicable for open-access femtocell networks by considering the users' speed. The calculation of Th, $RSSI_{min}$, and HM_{ad} is shown in [6].

The most important issue during a femto-to-femto HO in open-access mode is how to select a proper target femtocell to perform an HO. We propose to use a location-history database that can store the ID of the target femtocell along with the location fingerprint. In the initialization phase, when the location-history database is built, each time a UE sends a measurement report to the serving BS, it determines the target cell based on the maximum $RSSI$ and forwards this information, along with the measurement report, to the MME/FGW. This forwarded message contains a list of neighboring cell IDs (with $RSSI > RSSI_{min}$), their corresponding $RSSI$s, and a target cell ID. The MME/FGW stores this information in the database until it is full. The database building and updating algorithm is shown in [6]. In the utilization phase, this database is used to adapt the HM and to select the target cell during a femto-to-femto HO scenario. In this manner, the serving BS can reduce the delay of selecting a target cell each time an HO request arrives. The proposed HO decision algorithm for a femto-to-femto HO scenario is shown in Algorithm 3.

Algorithm 1: Macro-to-femto HO decision algorithm

```
if UE_spd < Th_spd then
    if RSSI_tf > Th or RSSI_m < RSSI_min, and
    RSSI_tf > RSSI_m + HM_ad then
        HO to femtocell;
    else
        Stay in macrocell;
else
    Stay in macrocell;
End;
```

Algorithm 2: Femto-to-macro HO decision algorithm

```
if UE_spd > Th_spd then
    HO to macrocell;
else
    if RSSI_sf < Th or RSSI_m > RSSI_min, and
    RSSI_sf + HM_ad < RSSI_m then
        HO to macrocell;
    else
        Stay in the femtocell;
End;
```

Algorithm 3: Femto-to-femto HO decision algorithm

```
if UE_spd > Th_spd then
    HO to the macrocell;
else
    if RSSI_sf < Th or RSSI_tf > Th, and
    RSSI_sf + HM_ad < RSSI_tf then
        HO to the target femtocell;
    else
        Stay in the serving femtocell;
End;
```

IV. Analytical Model for The HO Signaling Cost

In open-access femtocell networks, a macro-to-femto HO happens when an active UE moves towards a femtocell boundary, and a femto-to-macro HO happens when an active UE moves out of the boundary. There are four events that occur in open-access femtocell networks, including these HOs. All of these events are shown in Fig. 1.

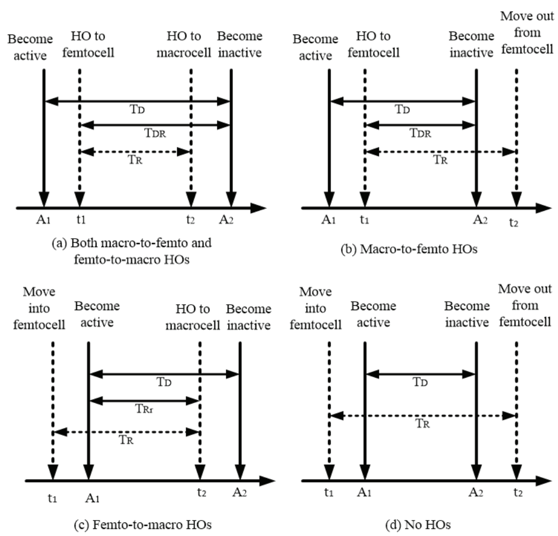


Fig. 1. Timming diagrams for mobility events in marco-femto HOs.

In the timing diagram (Fig. 1), we assume that a UE may become active at any moment (A_1), and the data session arrival rate (λ) is a Poisson process. On the other hand, A_2 is the moment when the data session ends. In addition, the moment when a UE enters the range of a femtocell is indicated by t_1, and the moment when it leaves the range of a femtocell is indicated by t_2. The first event shown in Fig. 1(a) represents that an active UE moves into a femtocell coverage area and moves out while it is still active. Both macro-to-femto and femto-to-macro HOs happen in this case. In the second event (Fig. 1(b)), an active UE moves into the femtocell coverage area, and the data session ends before it moves out of the area. A macro-to-femto HO happens in this case. During the third event (Fig. 1(c)), a UE becomes active within a femtocell coverage area and moves out of the area while still active. In this case, the UE performs a femto-to-macro HO. In the fourth event (Fig. 1(d)), since the UE becomes active, and the data session ends within the femtocell coverage area, no HOs happen. The probabilities of these events are P_{r1}, P_{r2}, and P_{r3}.

Besides these four events, the open-access mode has five additional mobility events that can cause different HO scenarios. These five events are shown in Fig. 2. In the timing diagram, the event in Fig. 2(a) represents an active UE that moves into a femtocell coverage area from a macrocell and then moves into another femtocell coverage area. Both macro-to-femto and femto-to-femto HOs happen in this case. The event in Fig. 2(b) represents an active UE that moves between femtocells while it is still active, and a femto-to-femto HO happens in this case. An active femtocell UE performs an HO to another femtocell when it moves into the next femtocell area and to a macrocell when it moves out of femtocells (Fig. 2(c)). Femto-to-femto and femto-to-macro HOs happen in this case. The next event (Fig. 2(d)) represents an active femtocell UE that moves into the coverage area of another femtocell, and the data session ends while within the area. Therefore, only a femto-to-femto HO happens in this case. On the other hand, a UE becomes active within a femtocell coverage area, and then it performs an HO to a femtocell (Fig. 2(e)). If the probabilities of these events are P_{r4}, P_{r5}, P_{r6}, P_{r7}, and P_{r8}, then we can calculate probabilities of all three types of HOs in open access femtocell networks as:

$$P^{open}_{macro-to-femto} = P_{r1} + P_{r2} + P_{r4}, \quad (1)$$

$$P^{open}_{femto-to-macro} = P_{r1} + P_{r3} + P_{r6}, \quad (2)$$

and

$$P^{open}_{femto-to-femto} = P_{r4} + P_{r5} + P_{r6} + P_{r7} + P_{r8}. \quad (3)$$

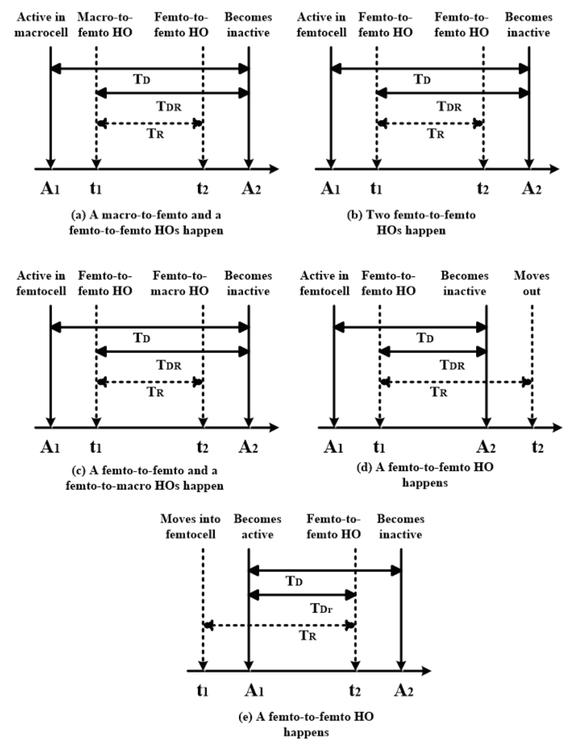


Fig. 2. Timming diagrams for mobility events in femto-femto HOs.

Since both the session duration (T_D) and the duration that a UE stays within a femtocell coverage area (T_R) are exponentially distributed, we can calculate the probabilities of events in Fig. 2 the same way as the events in Fig. 1. Therefore, we can infer $P_{r4} = P_{r5} = P_{r6} = P_{r1}$, $P_{r7} = P_{r2}$, and $P_{r8} = P_{r3}$. Using these values in (1), (2), and (3), we obtain

$$P^{open}_{macro-to-femto} = 2P_{r1} + P_{r2}, \quad (4)$$

$$P^{open}_{femto-to-macro} = 2P_{r1} + P_{r3}, \quad (5)$$

and

$$P^{open}_{femto-to-femto} = 3P_{r1} + P_{r2} + P_{r3}. \quad (6)$$

In the timing diagrams, T_D and T_R are independent random variables. T_D denotes the session duration which is exponentially distributed with mean $1/\eta$, and the probability density function of this session duration is $f_{TD}(t) = \eta e^{-\eta t}$. Similarly, T_R is the duration of a UE being within the coverage area of a femtocell which is exponentially distributed with mean $1/\mu$, and the probability density function of this duration of stay is $f_{TR}(t) = \mu e^{-\mu t}$. T_{DR} and T_{Rr} in the timing diagram follow the memoryless property of the residence times, T_D and T_R, respectively. In addition, the probability density function of T_{DR} is f_{DR} (which is exponentially distributed with mean $1/\eta$) and the probability density function of T_{Rr} is f_{Rr} (which is exponentially distributed with mean $1/\mu$). Now, we can calculate P_{r1}, P_{r2}, and P_{r3} as:

$$P_{r1} = P(A_1 < t_1 < A_1 + T_D) \cdot P(T_{DR} > T_R), \quad (7)$$

$$P_{r2} = P(A_1 < t_1 < A_1 + T_D) \cdot P(T_{DR} \leq T_D), \quad (8)$$

and

$$P_{r3} = P(t_1 < A_1 < t_1 + T_R) \cdot P(T_D \geq T_{Rr}). \quad (9)$$

Here, (7) ensures that the session starts before the UE enters the femtocell coverage area, and the UE leaves the area before the session ends. Similarly, (8) indicates that the session starts before the UE enters the femtocell coverage area and ends before it leaves the area. (9) ensures that a session starts after the UE enters the femtocell coverage area and ends after it leaves the area. Using the Laplace transform, we have

$$P_{r1} = \int_0^\infty \int_t^\infty \lambda t e^{-\lambda t} f_{TD}(y) dy dt \cdot (1 - \int_0^\infty \int_t^\infty \mu e^{-\mu x} f_{DR}(t) dx dt), \quad (10)$$

$$P_{r2} = \int_0^\infty \int_t^\infty \lambda t e^{-\lambda t} f_{TD}(x) dx dt \cdot (1 - \int_0^\infty \int_t^\infty \eta e^{-\eta t} f_{DR}(y) dy dt), \quad (11)$$

and

$$P_{r3} = \int_0^\infty \lambda t e^{-\lambda t} f_{Rr}(t) dt \cdot \int_0^\infty \int_t^\infty \eta e^{-\eta y} f_{Rr}(t) dy dt. \quad (12)$$

After solving (10), (11), and (12), we can find the probability of the three events as:

$$P_{r1} = \frac{\lambda \mu}{(\lambda + \eta)^2 (\mu + \eta)}, \quad (13)$$

$$P_{r2} = \frac{\lambda \eta}{(\lambda + \eta)^2 (\mu + \eta)}, \quad (14)$$

and

$$P_{r3} = \frac{\lambda \mu^2}{(\lambda + \eta)^2 (\mu + \eta)}. \quad (15)$$

Finally, these three probabilities can be calculated from (13), (14), and (15). Then, the total HO signaling cost of macro-to-femto, femto-to-macro, and femto-to-femto HOs in open-access femtocell networks are

$$C^{open}_{macro-femto} = P^{open}_{macro-femto} \cdot (\sum T^i_j + \sum P_i), \quad (16)$$

$$C^{open}_{femto-macro} = P^{open}_{femto-macro} \cdot (\sum T^i_j + \sum P_i), \quad (17)$$

and

$$C^{open}_{femto-femto} = P^{open}_{femto-femto} \cdot (\sum T^i_j + \sum P_i). \quad (18)$$

Here, T^i_j is the delivering cost of an HO message between node i and j, P_i is the processing cost of a message at node i, and the terms in the brackets are the signaling cost of a successful HO. The macro-to-femto and the femto-to-macro HO signaling procedures are given in [6]. By analyzing the HO signaling procedure, we get $\sum T^i_j$ and $\sum P_i$ for a macro-to-femto HO as:

$$\sum (T^i_j)_{macro-femto} = 3T^{MBS}_{UE} + 6T^{FBS}_{FGW} + 5T^{MME}_{FGW} + 5T^{MME}_{MBS}, \quad (19)$$

$$\sum (P_i)_{macro-femto} = P_{UE} + P_{FBS} + P_{FGW} + 2P_{MME}. \quad (20)$$

Similarly, we get $\sum T^i_j$ and $\sum P_i$ for a femto-to-macro HO as:

$$\sum (T^i_j)_{femto-macro} = 3T^{FBS}_{UE} + 5T^{FBS}_{FGW} + 3T^{MME}_{FGW} + 5T^{MME}_{MBS}, \quad (21)$$

$$\sum (P_i)_{femto-macro} = P_{UE} + P_{FBS} + 2P_{FGW} + P_{MME}. \quad (22)$$

In addition, we present the HO signaling procedure for a femto-to-femto HO in Fig. 3. Now, we get $\sum T^i_j$ and $\sum P_i$ for a femto-to-femto HO as:

$$\sum (T^i_j)_{femto-femto} = 3T^{FBS}_{UE} + 10T^{FBS}_{FGW} + 2T^{MME}_{FGW}, \quad (23)$$

$$\sum (P_i)_{femto-femto} = P_{UE} + P_{FBS} + 2P_{FGW} + P_{MME}. \quad (24)$$

Notations for different costs and their values are given in Table II [7], [8], [10]–[12].

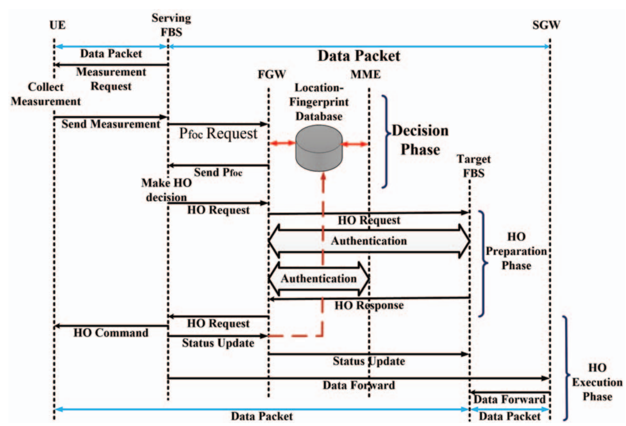


Fig. 3. Femto-to-femto HO signaling procedures for the proposed HO decision algorithm.

V. Performance Evaluation

In this section, we evaluate the performance of the proposed HO decision algorithm in terms of the total HO signaling cost, the rate of unnecessary HOs, and femtocell utilization for open-access femtocell networks. The rate of unnecessary HOs represents the probability that a UE temporarily hands over to the target cell and hands over back to the serving cell. On the other hand, the femtocell utilization represents the probability that a UE stays connected to the femtocell while within the coverage. Furthermore, we compare our proposed algorithm with five existing algorithms: 1) RSS TH: HO decisions based on an RSSI-based threshold; 2) RSS TH HM: HO decisions based on both an RSSI-based threshold and a fixed HM; 3) RSS ADHM: HM adapts based on the formula from [13], which is $HM = max\{HM_{max} \cdot (1 - 10^{\frac{d}{R}})^4; 0\}$. Here, R is the radius of the femtocell, and d is the distance between the femto-base station (FBS) and a UE; 4) SINR ADHM: adaptive HM is calculated from $HM = max\{HM_{max} \cdot (1 - 10^{\frac{SINR_{act} - SINR_{min}}{SINR_{min} - SINR_{max}}})^4; 0\}$ [3]; 5) RSS Speed: thresholds for both the users' speed and $RSSI$ are used to make HO decisions; 6) Proposed: location-history database is used to adapt HM based on the indoor location of a UE [6]; and 7) Proposed Speed: threshold for users' speed and adaptive HM based on the location-history database are used.

TABLE II
HO SIGNALING COST PARAMETERS

T_{UE}^{FBS}	Transmission cost between a UE and an FBS	2
T_{FBS}^{FGW}	Transmission cost between an FBS and an FGW	2
T_{FGW}^{MME}	Trnsmission cost between an FGW and an MME	4
T_{MBS}^{MME}	Transmission cost between an MBS and an MME	4
T_{UE}^{MBS}	Transmission cost between a UE and an MBS	2
P_{UE}	Processing time at UE	40
P_{FBS}	Processing cost at FBS	3
P_{FGW}	Processing cost at FGW	2
P_{MME}	Processing cost at MME	4

We use NetLogo 5.0.5 [14] to simulate the indoor environment for open-access femtocell networks. We design a single-floored two bedroom apartment with an FBS, which has the capacity to support ten users. The apartment is surrounded by six neighboring FBSs, and all these FBSs are within the coverage area of a macrocell. Thirty users and all FBSs are placed in a random manner. These users follow a modified version of the Random Waypoint mobility model, and they have a probability of 0.7 to enter and exit the apartment. The mobility model is modified in a way that the users use the door only to go in/out of the apartment, and none of them cross the walls. The Okumura-Hata propagation model is used for the macrocell network, and the ITU-R P.1238-7 indoor pathloss model [15] is used for the femtocell network. The parameters used in our simulation are listed in Table III [6], [16], [17]

TABLE III
SIMULATION PARAMETERS

Macrocell transmission power, P_m	45 dBm
Radius of macrocell	1.2 km
Femtocell transmission power, P_f	10 dBm
Radius of femtocell	15 m
Size of database, d_s	30
Users speed	0 to 10 km/hr
Threshold, Th	-45 dB
Wall penetration loss	5 dB
Outdoor penetration loss	2 dB - 10 dB
$RSSI_{min}$	-75 dB
Th_{spd}	5 km/hr
HM_{max}	5 dB

A. Total HO Signaling Cost

The performance of the total HO signaling cost for all types of HOs in open-access femtocell networks are given in Fig. 4. The signaling cost of an HO is determined by considering all transmission costs and processing costs during an HO. It is calculated for an exponential session duration (mean $1/\eta = 3$), a residence time (mean $1/\mu = 10$), and the session arrival rate λ (0.1 to 0.34). Then, the total HO signaling cost is calculated by multiplying the signaling cost of an HO by the rate of HOs, which also includes the rate of unnecessary HOs. From the figures, we can observe that the total HO signaling cost increases with the addition of HO decision criteria. We can also observe that using the users' speed reduces the total HO signaling cost by reducing unnecessary HOs of high speed users. The existing algorithms that adapt HMs have the highest total HO signaling cost. These existing algorithms adapt HMs either based on the distance between the BS and the UE or the SINR received at the UE side. As a result, the UE has to notify the serving BS frequently, which creates additional signaling cost. Moreover, these methods cannot eliminate the number of unnecessary HOs. On the other hand, we can observe that our proposed algorithms show better results in the open-access mode.

B. Rate of Unnecessary HOs

When a UE performs two consecutive HOs from a BS to another BS within a specific time limit, we consider it as an unnecessary HO. Then, the rate of unnecessary HOs is counted as the accumulated number of unnecessary HOs divided by the total number of HOs. The rate of unnecessary HOs in open-access femtocell networks are given in Fig. 5. The simulation results shows that the proposed algorithms has a lower unnecessary HO rate than the compared algorithms, which is desirable in order to provide better performance in femtocell networks. By observing results of both total HO signaling cost and rate of unnecessary HOs, we can infer that though the proposed HO decision algorithm without considering users' speed has almost the same HO signaling cost as the RSS-based algorithm, it eliminates more unnecessary HOs rate than all the compared algorithms.

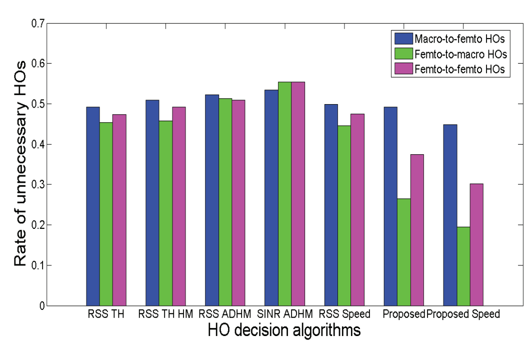
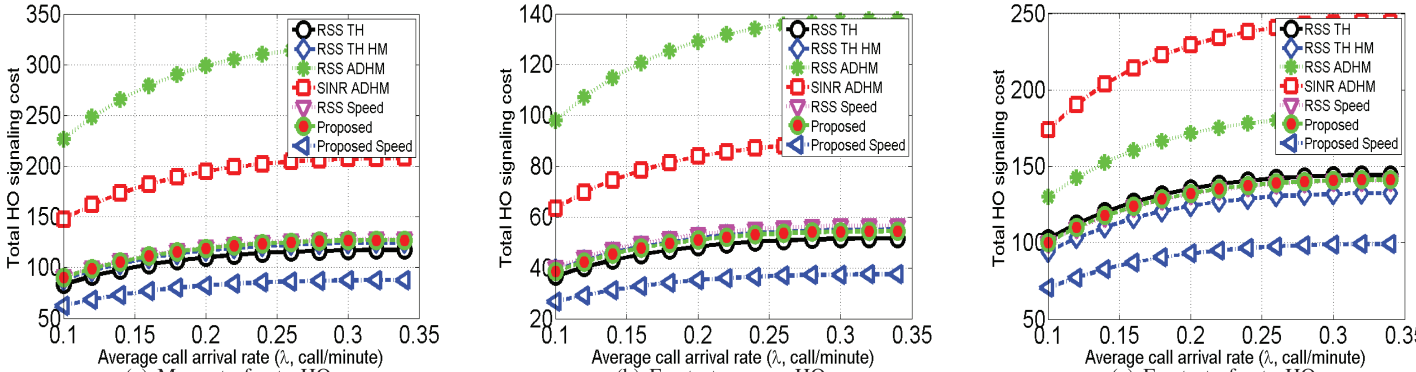


Fig. 5. Comparison of the rate of unnecessary HOs for open-access femtocell networks.



(a) Macro-to-femto HOs (b) Femto-to-macro HOs (c) Femto-to-femto HOs

Fig. 4. Comparison of the total HO signaling cost in open access femtocell networks.

C. Femtocell Utilization

Most of the time, a proper HO decision algorithm for reducing unnecessary HOs may also reduce the utilization of femtocells. On the other hand, a good femtocell utilization indicates a high traffic offload, and offloading is important for femtocell networks. Therefore, we simulate the femtocell utilization for open-access mode. These results, as shown in Fig. 6, represents good femtocell utilization for our proposed algorithms.

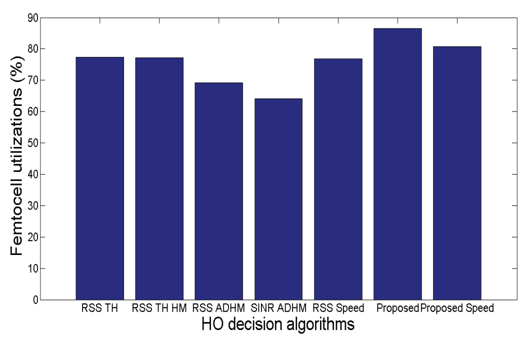


Fig. 6. Femtocell utilization for different HO decision algorithms for open-access femtocell networks.

VI. Conclusion

In this paper, we proposed an analytical model to evaluate the handoff signaling cost of macro-to-femto, femto-to-femto, and femto-to-macro handoffs in open-access femtocell networks. In addition, we also proposed a target cell selection method and handoff decision algorithms for open-access femtocell networks. The proposed algorithms are compared to five existing handoff decision algorithms with respect to the total handoff signaling costs and femtocell utilizations. Simulation results show that our proposed algorithms can significantly reduce the total handoff signaling costs without sacrificing femtocell utilization as compared to the existing algorithms.

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