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A Trade-off Between Unnecessary Handover and Handover Failure for Heterogeneous Networks

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***Abstract*—With fast growing traffic, high-density small cells (SC) deployment is envisioned in 5G network under the macrocell (MC) coverage area. This will improve the capacity and the cellular coverage, however, it will also introduce unnecessary handovers (UHO) and handover failures (HOF) due to user mobility and, in turn, degrades the user's quality of service (QoS). This paper aims to reduce the UHOs in a SC heterogeneous networks (HetNets) and to maintain the HOF to an acceptable level specified by the operator. Time metric is used to find a trade-off between UHO and HOF. In order to reduce the target SC list for handover, the estimated time of stay is used to avoid long neighbour list. Interference from different base stations is taken into account through the use of signal to interference plus noise ratio (SINR) metric. Simulations are performed to evaluate the performance of the proposed method. Results show that the proposed method outperformed the competitive methods presented in the literature with a lower level of UHOs and HOFs.**

I. Introduction

Data traffic demand has tremendously increased due to the ever-increasing number of mobile user equipments (UE). Significant growth in network capacity and coverage is required to cope with this demand. Adding more MC sites would significantly increase network operations cost due to the equipments installation and maintenance costs. A promising solution is the use of SCs [1]. There are various types of SCs including picocell, micro cell, and femtocell. With more deployment of SCs, the architecture of the future network is anticipated as heterogeneous.

Despite their huge benefits in providing network coverage in the gaps, that could not be covered by MCs, and their promising capacity enhancements, dense SC deployment is expected to introduce a very high number of handovers (HO) and HOFs in future wireless networks which in turn would degrade the end users' QoS due to the high-speed users, which visit the SC for a very short time. When the UE performs the HO to a SC and within a short time it performs another HO to the source cell or different SC this is known as UHO. On the other hand, when a UE initiates a HO to a SC but the SINR from both the source and target cell drops below a predefined threshold during the HO execution a failure in the cell switching happens and this is known as HOF.

Many works have been accomplished in the literature to address this problem in heterogeneous networks. Vast majority of HO algorithms use the received signal strength (RSS) metric for HO decision [2] which is not efficient in HetNets.

Authors in [3] proposed a method to reduce UHO in HetNet with hybrid access femtocells. The HO decision is taken by utilising the reference signal received power (RSRP) measurements and available bandwidth. However, the neglecting of using the HO margin (HM) during RSRP comparison is expected to introduce many UHOs due to channel variation. Also, they utilized a fixed time threshold metric to control the HO to femtocell (e.g 10 and 30 sec) which is not practical in HetNets with SC. In [4], an RSS and path loss based HO method was proposed. The scenario used in this work consists of a single MC and a single femtocell and a window function is applied to the RSRP of both femtocell and MC. A Ping-Pong HO is expected to occur in this scenario because the path loss of a cell may fluctuate due to the rapid variations of the network. Authors in [5] proposed a call admission control (CAC) mechanism and resource management method to minimize the probability of UHOs in WiMAX femtocell network. Metrics used to design the CAC include RSS, UE speed, time required for UE to maintain minimum RSS for service continuity, and duration that UE spends in cell coverage area. Three levels of UE speed are considered low, medium, and high. High speed UE will not be permitted to HO to femtocell. Medium speed UE will only be permitted to continue HO procedures if the traffic is real time traffic. Low speed UE continues the HO procedures by checking signal level. The evaluation of this method takes into account the number of HOs in the network. Authors in [6] proposed a single-MC single-femtocell scenario for femtocell HO when its RSRP is offset greater than that of the MC and the UE velocity drops below a predefined threshold. Compared to the conventional methods, this method has minimized the probability of UHO for high-speed UEs. However, no justification for choosing the speed threshold was given in this work. Both of the previously mentioned works in [5] and [6] did not take into account the HOF. A HO decision method that uses an adaptive hysteresis margin which is adjusted periodically according to user movement was presented in [7]. However, the use of these HO metrics have increased the signalling overhead in the network which may cause a degradation in the end users' QoS.

When the UE spends very short time in the SC after performing the HO, this will result in high number of UHOs and even HOF if the quality of the signal from the serving and target cells dropped simultaneously before the completion of the HO process. However, most of the existing works focus on minimizing the UHO in the femtocell networks and they did not account for the phenomena of the short time of stay and the HOF. In this work, we propose a HO method which accounts for the avoidance of short time of stay in SCs and hence reducing the UHO and HOF in SC HetNets. We used different metrics for HO including RSRP with HM, UE's time of stay (ToS), a time threshold, signal to interference plus noise ratio (SINR), and the capacity of the target HO SC.

The rest of this paper is organised as follows. Section II describes the system model. Section III illustrated the proposed HO method. While section IV presents the performance of the proposed method. Finally, section V concludes the paper.

II. System Model

The system model used in this paper consists of one MC base station as depicted in Fig.1, with dense SCs and UEs.

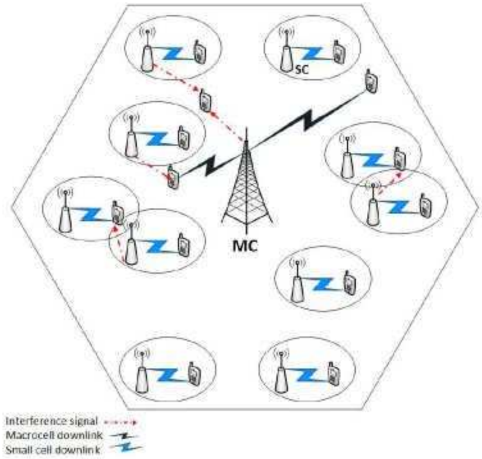

Figure 1: System model

SCs are deployed randomly under the MC coverage and are likely to overlap due to dense deployment. UEs are also distributed randomly and uniformly within the simulation area. The mobility of the UE can be expressed using two parameters: UE velocity, V_k, and UE direction, θ_k. These two parameters can be defined as Gaussian distribution and are updated accordingly by the following two equations [8]

$$V_k = \mathcal{N}(V_m, V_{std}), \tag{1}$$

$$\theta_k = \mathcal{N}\Big(\theta_m, 2\pi - \theta_m \tan(\frac{\sqrt{V_k}}{2})\Delta t\Big), \tag{2}$$

where V_m represents the UE's mean velocity, V_{std} denotes the UE's velocity standard deviation, θ_m is the UE's previous direction, Δt is the period between two updates of the mobility model, and $\mathcal{N}(x, y)$ is a Gaussian distribution with mean x and standard deviation y.

Taking into account the heterogeneous network architecture, different path loss models defined in [9] were used.

The path loss between the MC and the UE is

$$\delta_{m\to ue_k} = 128.1 + 37.6\ \log_{10}(d_{m\to ue_k}), \tag{3}$$

where $d_{m\to ue_k}$ is the distance between the UE and the MC base station in kilometres.

If the UE is outside the coverage area of SC i, its path loss to SC i is as follows

$$\delta_{sc_i\to ue_k} = \max\Big(15.3 + 37.6\ \log_{10}(d_{sc_i\to ue_k}), \\ 37 + 20\ \log_{10}(d_{sc_i\to ue_k})\Big) + qW + L, \tag{4}$$

where $d_{sc_i\to ue_k}$ is the distance between the UE and SC i in metres, q is the number of walls between the SC and the UE where $q \in \left\{0,1,..., \left\lfloor \frac{d^p_{sc_i\to ue_k}}{d} \right\rfloor\right\}$, $\lfloor x \rfloor$ means the floor of x, i.e. the largest integer less than or equal to x, $d^p_{sc_i\to ue_k}$ is the part of $d_{sc_i\to ue_k}$ inside SC i coverage area, d is chosen to be 2m [9], and W is the wall partition loss, and L is the outdoor penetration loss.

When the UE is inside the SC i coverage area, its path loss to the SC i is calculated as

$$\delta_{sc_i\to ue_k} = 37 + 20\ \log_{10}(d_{sc_i\to ue_k}) + qW. \tag{5}$$

If the UE is inside the coverage area of SC i, its path loss to SC j ($j \neq i$) is as follows

$$\delta_{sc_j\to ue_k} = \max\Big(15.3 + 37.6\ \log_{10}(d_{sc_j\to ue_k}), \\ 37 + 20\ \log_{10}(d_{sc_j\to ue_k})\Big) + qW + 2L, \tag{6}$$

where $d_{sc_j\to ue_k}$ is the distance between the UE and SC j in metres, $q \in \left\{0,1,..., \left\lfloor \frac{d^p_{sc_i\to ue_k} + d^p_{sc_j\to ue_k}}{d} \right\rfloor\right\}$, and $d^p_{sc_j\to ue_k}$ is the part of $d_{sc_j\to ue_k}$ inside SC j coverage area.

The pilot RSRP is calculated as follows

$$P^r_{i_p\to ue_k} = \frac{p^t_{i\to ue_k} g_i g_{ue_k}}{lo_i lo_{ue_k} \xi_{i\to ue_k} \delta_{i\to ue_k}}, \tag{7}$$

where $P^r_{i_p\to ue_k}$ is the pilot RSRP received from a target cell i at user k, $p^t_{i\to ue_k}$ is the transmitting power of the base station i, g_i is the antenna gain of the base station i, g_{ue_k} is the antenna gain of user k, lo_i is the base station i equipment loss, lo_{ue_k} is the UE equipment loss, $\xi_{i\to ue_k}$ is the shadow fading with a log-normal distribution with zero mean and 3 dB standard deviation [10], and $\delta_{i\to ue_k}$ is the path loss between base i station and user k.

The UE measures RSRP every 40 ms and averages it over 5 samples i.e. every 200 ms [1] so that

$$P^r_{i\to ue_k} = \frac{1}{5}\sum_{s=1}^{5} P^r_{i_p\to ue_k}(s), \tag{8}$$

where $P^r_{i\to ue_k}$ is the average RSRP over 5 samples.

Whereas the interference power received by user k from its adjacent base stations is expressed in the following equation

$$P^r_{j\to ue_k} = \frac{p^t_{j\to ue_k} g_j g_{ue_k}}{lo_j lo_{ue_k} \xi_{j\to ue_k} \delta_{j\to ue_k}}, \tag{9}$$

where $P^r_{j\to ue_k}$ is the power received from the interfering base station j, $p^t_{j\to ue_k}$ is the transmitting power of the interfering base station j, g_j is the antenna gain of the interfering j, lo_j is the interfering base station equipment loss, $\xi_{j\to ue_k}$ represents the shadow fading between interfering base station and user k, and $\delta_{j\to ue_k}$ is the path loss between the interfering base station j and user k.

The signal to interference plus noise ratio (SINR) measured at user k is obtained as follows

$$\gamma_{i\to ue_k} = \frac{P^r_{i\to ue_k}}{\sum_{j=1, i\neq j}^{nj} P^r_{j\to ue_k} + \sigma^2}, \tag{10}$$

where n_j is the total number of interfering base stations, and σ is the noise power.

Substituting (8) and (9) in (10), we get the final SINR as follows

$$\gamma_{i\to ue_k} = \frac{\frac{1}{5}\sum_{s=1}^{5} P^r_{i_p\to ue_k}(s)}{\sum_{j=1, i\neq j}^{nj} \frac{p^t_{j\to ue_k} g_j g_{ue_k}}{lo_j lo_{ue_k} \xi_{j\to ue_k} \delta_{j\to ue_k}} + \sigma^2} \tag{11}$$

The realistic cell border is neither circular nor hexagonal, but it depends on different factors such as interference, geographic environment and obstacles. The shape of the cell coverage area is highly affected by these factors. Therefore, the radius of the SC, R_i, could be estimated when the UE enters the coverage area of the SC [11] i.e. when the UE starts receiving the minimum required signal power indicated by service continuity, (P_{th}), hence, we can express the SC radius as

$$R_i = \left(\frac{p^t_{i\rightarrow ue_k}\ 10^{\xi/10}}{P_{th}}\right)^{\frac{1}{\zeta}}, \tag{12}$$

where ζ is the path loss exponent.

In order to find the expected traveling distance of the UE inside the SC coverage area, d_s, we use the geometry shown in Fig.2. The expected UE traveling distance inside the SC can

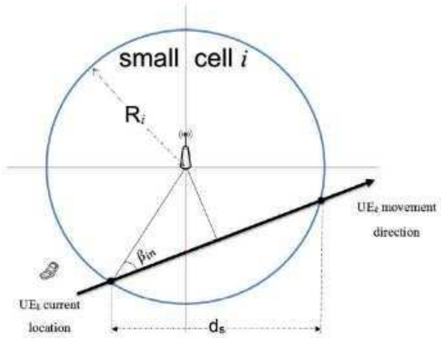

Figure 2: Estimated ToS measurement

be expressed as

$$d_s = 2R_i\cos(\beta_{in}) \tag{13}$$

The expected time of stay of user k, $ToS^{est}_{ue_k}$, can then be calculated using the UE velocity, V_k, and the traveling distance, d_s, and is expressed as

$$\begin{aligned} ToS^{est}_{ue_k} &= \frac{1}{\pi}\int_{-\frac{\pi}{2}}^{\frac{\pi}{2}} \frac{d_s}{V_k} d\beta_{in} \\ &= \frac{1}{\pi V_k}\int_{-\frac{\pi}{2}}^{\frac{\pi}{2}} 2R_i\cos(\beta_{in})d\beta_{in} \\ &= \frac{4R_i\sin(\frac{\pi}{2})}{\pi V_k} \\ &= \frac{4R_i}{\pi V_k}. \end{aligned} \tag{14}$$

Instead of considering a fixed HM for all cells and to make sure that the ping-pong HO (which is the type of UHO between the serving and destination cells back and forth) is highly reduced, we modified the used expression in [12] to calculate the HM, to be dynamic, such as the following

$$HM = \left(1 - 10^{P^r_{sc\rightarrow ue_k} - P_{th}}\right)^{\epsilon}, \tag{15}$$

where $P^r_{sc\rightarrow ue_k}$ is the RSRP from the SC received at user k, and ϵ is a constant exponent used as in [12] which is a value of 4.

III. Proposed Method

The proposed method uses multiple metrics for HO decision in order to control both UHOs and HOFs in the dense SC HetNet environment. These metrics are RSRP with HM, ToS, a time threshold, SINR, and SC capacity. The proposed method is described in the pseudo code,

where $P^r_{m\rightarrow ue_k}$ is the RSRP from the MC received at user k, TC_{th} is the critical time threshold (which is equal to two HO times i.e. hand-in and hand-out), $\gamma_{m\rightarrow ue_k}$ and $\gamma_{sc_i\rightarrow ue_k}$ are the SINR received at user k from the MC and SC i respectively, and finally γ_{th} is the outage threshold (γ_{th} = 5dB [13]).

The proposed method begins when a MC UE moves towards the SCs coverage area. High-speed UEs usually stay in the SC

Algorithm 1 Proposed Method

1: **Procedure Starts**
2: MC UE_k **moves** to SC coverage area
3: SC RSRP **monitoring**
4: **Evaluate** $P^r_{sc\rightarrow ue_k}$
5: **Estimate** $ToS^{est}_{ue_k}$
6: **if** $ToS^{est}_{ue_k} > TC_{th}$ **then**
7:     **Include** this SC in HO target cell list for UE_k
8: **end if**
9: **if** maximum ($P^r_{sc\rightarrow ue}$) from the list is $> P^r_{m\rightarrow ue} + HM$ **then**
10:     **Evaluate** $\gamma_{i\rightarrow ue}$
11:     **if** $\gamma_{m\rightarrow ue_k} < \gamma_{th}$ and $\gamma_{sc_i\rightarrow ue_k} > \gamma_{th}$ **then**
12:         **Check** sc_i resources
13:         **if** Resources available **then**
14:             **HO** to sc_i
15:         **end if**
16:     **end if**
17: **end if**
18: **end procedure**

coverage area for a very short time, thus, the received RSRP from the SC fluctuates rapidly resulting in UHOs and HOFs. Therefore, we introduce the expected UE's ToS and a time threshold metrics to control this issue. The time threshold will ensure that the UE selects a proper target for HO with sufficient signal level i.e. the UE must stay in the SC coverage area for a sufficient time that worth to HO to the SC.

The UE then starts monitoring the RSRP received from the surrounding SCs. The UE's expected ToS in the SC is measured and compared against the critical time threshold TC_{th}. If the UE's ToS is at least higher than the critical time threshold, we mark this SC as one of the HO targets. Hence, we can define a set of HO target SCs, denoted as M_{set}, at this stage as

$$M_{set} = \left\{sc_i \in N_s \mid ToS^{est}_{ue_k} > TC_{th}\right\}, \tag{16}$$

where N_s is a set representing the total number of SCs in the network. Then, the maximum received RSRP from the SC list must be offset greater than the current serving MC RSRP $\left(P^r_{sc\rightarrow ue_k} > P^r_{m\rightarrow ue_k} + HM\right)$. It is worth noting that this condition (line 9 in the algorithm) is to make sure that the SC downlink received signal still strong enough and has not been fluctuated due to shadow fading.

Then, user k measures the SINR received from both MC, $\gamma_{m\rightarrow ue_k}$, and SC, $\gamma_{sc_i\rightarrow ue_k}$, and compare them against a predefined threshold γ_{th}. When $\gamma_{sc_i\rightarrow ue_k}$ exceeds $\gamma_{m\rightarrow ue_k}$ and γ_{th}, the HO is performed to this SC providing that this SC has enough capacity (resources) to serve this UE. This process will offload the traffic from the congested MC and increase the network capacity. SC resources (see the proposed method pseudo code, line (12)) here means the number of users which can be served by the SC. Here we assume that the number of UEs served by the SC is 20 [1].

IV. Performance Analysis

In this section, we compare the performance of our proposed method with that of the conventional method and the methods presented in [3] and [5]. For the sake of simplicity, we abbreviate the competitive methods' names based on the authors' initial, method in [3] is abbreviated as KL and method in [5] is abbreviated as SOA.

All methods are evaluated in terms of the total number of HOs, UHO probability, and the HOF probability. Table I gives a summary of simulation parameters used. Matlab simulations have been carried out to evaluate the performance of the proposed and competitive methods.

Table I: Basic Simulation Parameters

Bandwidth	10 MHz
MC antenna gain	14 dBi
MC Transmit power	43 dBm
MC Radius	800 m
SC antenna gain	0 dBi
SC Transmit power	23 dBm
Number of SCs within MC	50
Outdoor penetration loss (L)	10 dB
Wall partition loss (W)	5 dB
P_{th}	-70 dBm
γ_{th}	5 dB
V_m	3 km/h
V_{std}	1 km/h
Δt	1 sec
ζ	3.5

The probability of HO in the conventional methods (denoted as P_{ho}^{conv}) is RSS-dependent, i.e. UE hands over to the base station with the strongest downlink received signal, and is given by the following form

$$P_{ho}^{conv} = \mathbb{P}\left[RSS^r_{m\rightarrow ue_k} < RSS^r_{sc_i\rightarrow ue_k}\right], \tag{17}$$

where $RSS^r_{m\rightarrow ue_k}$ and $RSS^r_{sc_i\rightarrow ue_k}$ are the received signal strength from the serving MC and the target SC base stations respectively.

According to our system model, we can describe the HO criteria for the conventional method to select the best SC as

$$\chi := \left\{sc_i \mid RSS^r_{sc_i\rightarrow ue_k} > RSS^r_{m\rightarrow ue_k}\right\}, \tag{18}$$

$$sc^{tar}_{conv} = \arg\max_{sc_i\in\chi} RSS^r_{sc_i\rightarrow ue_k}, \tag{19}$$

where χ corresponds to the set of all SCs in the network with $RSS^r_{sc_i\rightarrow ue_k} > RSS^r_{m\rightarrow ue_k}$, and sc^{tar}_{conv} is the conventional method's best SC within the set χ in term of strongest RSS.

The KL method [3] performs the HO to SC if its RSS is greater than a predefined threshold, RSS_{th}, for a specific time, T, and the SC's bandwidth is sufficient enough to support the UE HO. Therefore, the HO criteria for KL method can be give as

$$\begin{aligned}\Upsilon := \Big\{sc_i \mid RSS^r_{sc_i\rightarrow ue_k} > RSS_{th} \text{ for } 'T' \text{ time}\\ \wedge \text{ BW available}\Big\},\end{aligned} \tag{20}$$

$$sc^{tar}_{kl} = \arg\max_{sc_i\in\Upsilon} RSS^r_{sc_i\rightarrow ue_k}, \tag{21}$$

where Υ corresponds to the set of all target SCs in the network that satisfy the conditions in the brackets, and sc^{tar}_{kl} is the KL method's best SC within the set Υ.

The SOA method [5] performs the HO to SC if the UE speed is slow, below a threshold V_{th}, the SC's bandwidth is sufficient enough to support the UE HO, and SC's RSS is greater than that of the serving MC for a period of time T. Thus, the HO criteria for SOA method can be also simplified as

$$\begin{aligned}\Omega := \Big\{sc_i \mid V_k < V_{th} \wedge \text{BW available} \wedge\\ RSS^r_{sc_i\rightarrow ue_k} > RSS^r_{m\rightarrow ue_k} \text{ for } 'T' \text{ time}\Big\},\end{aligned} \tag{22}$$

$$sc^{tar}_{soa} = \arg\max_{sc_i\in\Omega} RSS^r_{sc_i\rightarrow ue_k}, \tag{23}$$

where Ω corresponds to the set of all target SCs in the network that satisfy the conditions in the brackets, and sc^{tar}_{soa} is the SOA method's best SC within the set Ω.

The probability of successful HO to a SC i in our proposed method (denoted as P^{pro}_{ho}) is

$$\begin{aligned}P^{pro}_{ho} = \mathbb{P}\Big[\, & ToS^{est}_{ue_k} > TC_{th} \;\wedge\\ & P^r_{sc\rightarrow ue_k} > P^r_{m\rightarrow ue_k} + HM \;\wedge\\ & \gamma_{m\rightarrow ue_k} < \gamma_{th} \;\wedge\\ & \gamma_{sc_i\rightarrow ue_k} > \gamma_{th} \;\wedge\\ & C_{sc_i} = 1 \Big],\end{aligned} \tag{24}$$

where C_{sc_i} is the capacity of SC i and is set to the value of 1 whenever the capacity is available and 0 otherwise.

Similarly, we can define the HO criteria for our proposed method to select the best SC as

$$\omega := \left\{sc_i \mid (\gamma^r_{sc_i\rightarrow ue_k} > \gamma^r_{m\rightarrow ue_k}) \wedge [C_{sc_i} > 0]\right\} \tag{25}$$

$$sc^{tar}_{pro} = \arg\max_{sc_i\in\omega} \gamma^r_{sc_i\rightarrow ue_k}, \tag{26}$$

where ω represents a set of all SCs, within the set M_{set}, which satisfies the conditions (11) and (13) of the method pseudo code, $[\cdot]$ is the Iverson bracket which denotes one if the condition in the bracket is true or denotes zero otherwise, and sc^{tar}_{pro} is the optimal SC in the set ω which satisfies all the conditions of the proposed algorithms.

The probability of UHO is measured based on the real time of stay, denoted $ToS^{real}_{ue_k}$, that user k will actually spend inside SC i after HO and the critical time threshold TC_{th}. In our proposed method, we defined the HO as unnecessary when the UE's real ToS, $ToS^{real}_{ue_k}$, is less than or equal to the critical time threshold TC_{th}.

Then, the UHO probability, P^{pro}_{uho}, is

$$P^{pro}_{uho} = \mathbb{P}\left[ToS^{real}_{ue_k} \leq TC_{th}\right]. \tag{27}$$

Based on Fig.3 we can measure the real ToS as

$$\begin{aligned}ToS^{real}_{ue_k} &= \frac{\mid \overrightarrow{L_{in}L_{out}} \mid}{V_k}\\ &= \frac{2R_i\cos(\alpha)}{V_k},\end{aligned} \tag{28}$$

where L_{in}, and L_{out} are respectively the entry point of UE to SC, and the exit point of UE from SC.

We can get the following from Fig.3

$$\frac{\mid L_1L_0 \mid}{\sin(180-\alpha)} = \frac{R_i}{\sin(\theta)}, \tag{29}$$

where L_0, and L_1 are respectively the SC location, and the previous location of the UE.

From the law of Sines we have $\sin(180-\alpha) = \sin(\alpha)$, therefore, equation (29) can be rewritten as

$$\sin(\alpha) = \frac{\mid L_1L_0 \mid \sin(\theta)}{R_i} \tag{30}$$

Given that $\cos(\alpha) = \sqrt{1-\sin^2(\alpha)}$, therefore

$$\cos(\alpha) = \sqrt{1 - \frac{\big(\mid L_1L_0 \mid \sin(\theta)\big)^2}{R_i^2}} \tag{31}$$

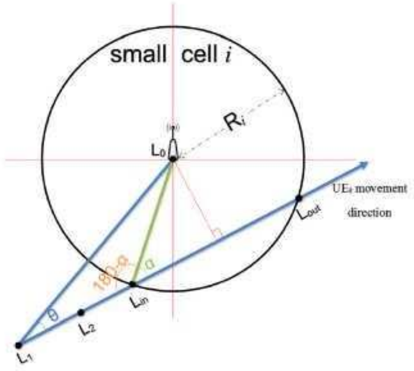

Figure 3: Real ToS measurement

The angle between the UE trajectory and the SC, θ, can also be calculated as

$$\theta = \arccos\left(\frac{\overrightarrow{L_1L_0}\cdot\overrightarrow{L_1L_2}}{\mid\overrightarrow{L_1L_0}\mid\times\mid\overrightarrow{L_1L_2}\mid}\right), \tag{32}$$

where L_2 is the current location of the UE.

Finally, we substitute (31) and (32) in (28) to get the real time of stay as

$$ToS_{ue_k}^{real} = \frac{2R_i\sqrt{1-\frac{\left(\mid\overrightarrow{L_1L_0}\mid\cdot\sin\left(\arccos\left(\frac{\overrightarrow{L_1L_0}\cdot\overrightarrow{L_1L_2}}{\mid\overrightarrow{L_1L_0}\mid\times\mid\overrightarrow{L_1L_2}\mid}\right)\right)\right)^2}{R_i^2}}}{V_k}. \tag{33}$$

The probability of HOF for our proposed method, P_{hof}^{pro}, happens when the HO to a SC i is initiated (as user k departs the vicinity of MC coverage area i.e. $\gamma_{m\rightarrow ue_k} < \gamma_{th}$) but $\gamma_{sc_i\rightarrow ue_k}$ suddenly goes below the threshold for a period of TC_{th}. Thus, we define the probability of HOF as

$$P_{hof}^{pro} = \mathbb{P}\Big[\gamma_{m\rightarrow ue_k} < \gamma_{th} \;\wedge\; \gamma_{sc_i\rightarrow ue_k} < \gamma_{th} \text{ for } TC_{th} \text{ time}\Big] \tag{34}$$

A) Total Number of Handovers
Fig.4 depicts the total number of HOs between the MC and SCs for all four methods. The number of HOs for the conventional method linearly increases when the number of UEs moving towards the SCs increases because all UEs have to HO from the MC to SC according to the received signal power RSS. Whereas the number of HOs for our proposed method is much lower (when 30 UEs move to SC coverage area, about 40%, 15% and 11% reduction in the number of HOs is achieved in our proposed method comparing to the conventional, KL and SOA methods respectively) because the UEs do not have to perform HO frequently due to the incorporation of UE's ToS and the critical time threshold as HO triggering criteria. Due to the limited capacity of the SCs, the number of HOs in our proposed method reaches a steady level with the increase in the number of UEs moving to the SCs coverage area.

B) Unnecessary Handover Probability
The probability of UHO is shown in Fig.5. In our method, we defined the HO as unnecessary when the UE's real ToS, $ToS_{ue_k}^{real}$, is less than or equal to the critical time threshold TC_{th} as defined in (27). For both the conventional and KL methods, the UHOs increase with the increase in the number of UEs traveling to the SC coverage area. We noticed that the conventional method has the highest increase due to the fact that it depends on the signal strength level only for HO decision. Whereas our proposed method has the lowest level of UHO due to the restrictions of the UE's ToS. When the number of UEs moving to SC coverage area is 30, there are nearly 60%, 35% and 15% of UHOs respectively when the conventional, KL, and SOA methods are used. On the other hand, using our proposed method, the probability of UHO is reduced to almost 4%. The main reason for UHO reduction in our proposed method is the use of UE's predicted ToS as a triggering condition for HO, which means that high-speed users will not usually HO to the SC because they will spend very short time compared to the threshold TC_{th} in the SC coverage area. Even in the presence of interference, our proposed method ensures that the received signal from the SC is sufficient for HO through the use of SINR metric, thus, this procedure has reduced some of the UHOs in the network.

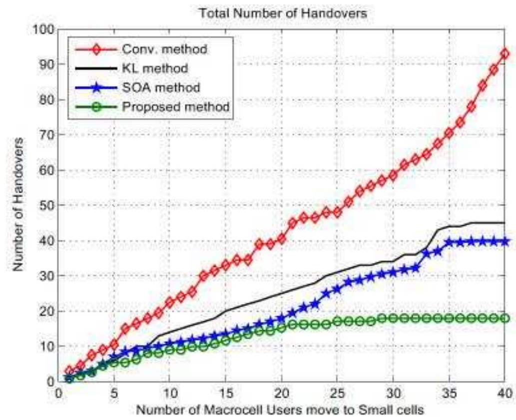

Figure 4: Total Number of Handovers

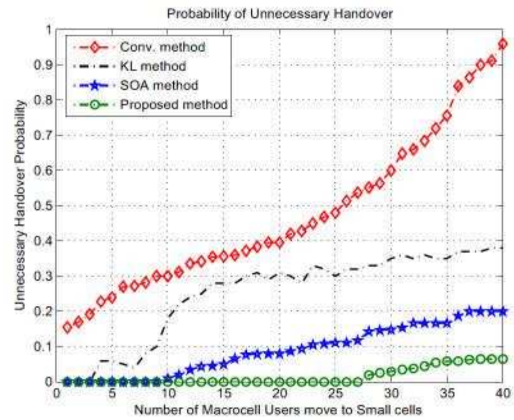

Figure 5: Unnecessary Handover Probability

C) Handover Failure Probability
The probability of HOF is depicted in Fig.6. As given in (34), the HOF in our proposed method will take place when the SINR received from both the serving MC and the target SC drops below a predefined threshold at the same time i.e. the TC_{th} is triggered and the HO is initiated but a radio link failure occurs before TC_{th}

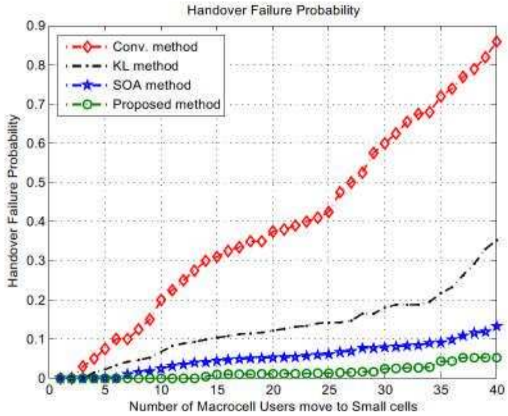

Figure 6: Handover Failure Probability

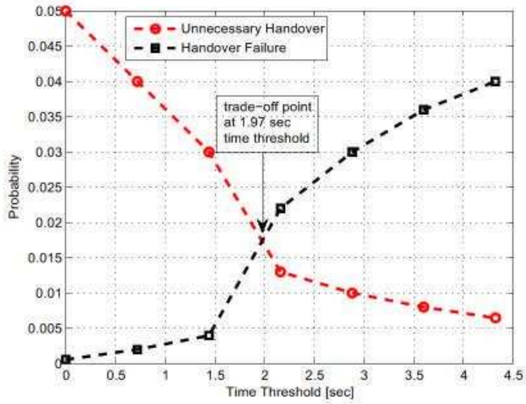

Figure 7: A Trade-off Between Unnecessary Handover and Handover failure

expires, which means that neither the serving MC nor the target SC is able to serve the UE. From Fig.6 we can see that the HOF probability for the conventional method is increasing rapidly when the number of UEs moving to the SC coverage area increases due to the high-speed mobility users in the dense SC deployment area and capacity shortage in the target SC. Hence, the HO will be initiated based on RSS but will be interrupted due to the short time that the user will spend inside the SC resulting in HOF. While the proposed method shows a much lower level of HOF because of the time threshold metric. Our proposed method also outperformed KL and SOA methods, by showing few HOFs as the number of UEs increases due to the considered interference measurements. Most of the HOFs in our proposed method will probably happen at the MC edge due to the hight interference power near the MC coverage area border. One reason for this low HOF in the proposed method is that the incorporating of capacity metric, hence, UEs will not try to perform HO to SCs without sufficient resources.

Fig.7 shows the probabilities of UHO and HOF vs. variable values of time threshold (this result is when there are 30 UEs moving to SC coverage area). High-speed UEs may pass through the SC coverage area before TC_{th} expires leading to HOF due to the degradation of SINR. Whereas high-speed UEs crossing the SC coverage area and HO to the SC causing frequent UHO. Therefore, small values of TC_{th} may cause too early HO which results in UHO. While large values of TC_{th} may cause too late HO which in turn leads to HOF.

As clearly indicated in Fig.7, a trade-off between HOF and UHO can be achieved by choosing a time metric of 1.97 seconds.

V. Conclusion

In this paper, we proposed a HO method to minimize the UHO and HOF in heterogeneous networks. The proposed method is applied to a scenario of one MC base station and dense SCs. The MC UEs travel to SCs coverage areas and perform HO according to the proposed method. The predicted time of stay, $ToS^{est}_{ue_k}$, is used to reduce the UHOs and to avoid long small cell list. Moreover, the interference and SC capacity are utilised as major metrics to minimize the UHOs and HOFs. For the proposed method, we used the real time of stay, $ToS^{real}_{ue_k}$, to evaluate the probability of UHO. Simulation results show that the probability of UHO is reduced compared to the conventional, KL and SOA methods. Moreover, our proposed method also outperformed the all methods by producing a very low probability of HOF. The time threshold along with the SINR are used to find a compromise between UHO and HOF and the results show that it is possible when using a time threshold metric of 1.97 seconds.

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