Unnecessary Handover Minimization in Two-Tier Heterogeneous Networks

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***Abstract*—Ultra-dense deployment of small cells can be foreseen in 5G network under the coverage area of the macrocell. A mobile user equipment (UE) should be able to discover adjacent small cells to perform the handover. This process can be done by frequent neighbour cell scanning. However, extensive scanning for every small cell in a dense deployment scenario is a resource wasting strategy, which results in a power dissipation of the UE battery and also lowers the throughput gain. This also means that a high number of small cells would be available for the UE to handover to. Hence, the probability of unnecessary handover will increase and in turn degrade the user's quality of service (QoS). This paper aims to minimize unnecessary handovers in two tier heterogeneous network with dense deployment of small cells. In the proposed method, we utilise the actual distance between the UE and the small cells and the UE angle of movement to construct a shortened candidate list which helps in reducing the signal overhead of scanning and the number of unnecessary handovers. UE's movement velocity threshold based on average human walking speed is used to control the handover to the small cell. Simulation results show that the proposed algorithm outperformed the conventional handover method with reduced unnecessary handovers and increased throughput for the network particularly for medium to high speed users resulting in good UE QoS.**

I. Introduction

Data traffic demand around the globe is sharply increasing due to the increasing number of smart user equipments [1]. Increasing the number of macrocell base stations is usually costly and inefficient to deal with this demand. One of the most recent methods for capacity boosting and coverage extension is the deployment of small cells [2]. Basically, small cells are recognised by their lower transmit power, smaller coverage, and size [1].

Despite their huge benefits in providing network coverage in the gaps that could not be covered by macrocells and their promising capacity enhancements, the dense deployment of small cells is expected to introduce a very high number of handovers because of the high-speed users. Hence, the overall QoS of the mobile network would be degraded. There have been some works accomplished to address this problem in the two-tier heterogeneous network. The majority of handover algorithms use the received signal strength (RSS) metric for handover decision [3]. Authors in [4] used an exponential window function to eliminate the rapid RSS changing rate between macrocell and femtocell. The two windowed RSS of macrocell and femtocell are then combined to form a handover decision criteria. One of the drawbacks of this algorithm is that the optimization of its performance in real life network deployment is a challenge. In [5] the authors proposed a single-macrocell single-femtocell scenario for inbound handover to femtocell when the RSRP of femtocell is offset greater than that of the macrocell and the velocity of the user is below a predefined threshold. Compared to the traditional methods, this method tends to minimize the probability of unnecessary handover for fast moving users. However, the choice of the speed threshold has not been justified. In [6] the authors proposed an adaptive hysteresis margin algorithm to minimize the probability of unnecessary handovers for UE inbound mobility to femtocell. The algorithm compares the received signal quality (RSQ) of the target and serving cells by utilizing an adaptive handover margin (HM). The HM is measured based on the RSQ at the UE side and the path loss. In [7] authors presented a handover decision algorithm that uses an adaptive hysteresis margin which is adjusted periodically according to user movement. However, the use of these handover metrics in both [6] and [7] have increased the signalling overhead in the network.

In this paper, the actual distance between the UE and the small cells and the UE angle of movement are used to extract a shortened candidate list to reduce both scanning process and unnecessary handovers. In addition, signal to noise ratio (SNR), and velocity threshold, which is based on average human walking speed, are used to minimize the unnecessary handover. The time of stay metric is used to evaluate the performance of the proposed method in terms of unnecessary handover.

The rest of this paper is organised as follows; section II describes the system model. Section III illustrated the proposed handover scheme. While section IV discusses the performance of the proposed algorithm. Finally, section V concludes the paper.

II. System Model

The two-tier hierarchical network model usually has a number of small cells which are randomly deployed under the macrocell coverage area. In this paper, system model consists of 7 hexagonal macrocells as illustrated in Fig.1, and dense open access mode small cells. Indoor small cells are deployed randomly under the macrocell coverage area. The mobility model of the user in the simulation area follows a random way point model [8]. The path loss between a user and a cell is different in different scenarios as detailed in [9].

When a macrocell UE is outdoor, the path loss between the macrocell and the UE is:

$$\delta = 128.1 + 37.6 \ \log_{10}(d_m), \quad (1)$$

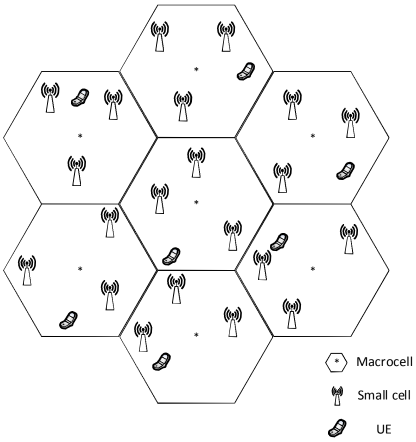

Figure 1: System model

where d_m is the distance between the UE and the macrocell in kilometres. And its path loss to the small cell is calculated as:

$$\delta = 37 + 20\ \log_{10}(d_{sc}) + q_{sc} \cdot W + L, \tag{2}$$

where d_{sc} is the distance between the UE and the small cell in metres, q_{sc} is the number of walls between the small cell and the UE, W is the wall partition loss, and L is the outdoor penetration loss.

When the UE is inside a house (small cell user), its path loss to the small cell is calculated without considering the outdoor penetration loss as:

$$\delta = 37 + 20\ \log_{10}(d) + q_{sc} \cdot W. \tag{3}$$

The downlink reference signal received power (RSRP) is calculated as follows:

$$P^r_{i \to ue_j} = p^t_{i \to ue_j} + g_{bs} - \delta_{i \to ue_j} - \xi_{i \to ue_j}, \tag{4}$$

where $P^r_{i \to ue_j}$ is the measured reference signal received power of the target cell at the UE side, $p^t_{i \to ue_j}$ is cell transmitting power, g_{bs} is the base station antenna gain, $\delta_{i \to ue_j}$ is the path loss between user j and base station i, and $\xi_{i \to ue_j}$ is the shadow fading with a log-normal distribution with zero mean and 3 dB standard deviation [10].

The radius of each small cell i, R_{sc_i}, could be estimated when the UE enters the coverage area of the small cell [11] i.e. when the UE starts receiving the minimum required signal for service continuity (P_{th}), as defined below:

$$R_{sc_i} = \Big(\frac{p^t_{i \to ue_j}\ 10^{\xi/10}}{P_{th}}\Big)^{\frac{1}{\beta}}, \tag{5}$$

where β is the path loss exponent.

From the geometry of Fig.2 we can see the expected distance UE stays inside the cell is between A and B. Where A and B are respectively the entry and the exit points of the UE to and from the small cell.

The UE's angle of entry to the small cell, θ, is measured as in (6):

$$\theta = \arctan\Big(\frac{y_2 - y_1}{x_2 - x_1}\Big). \tag{6}$$

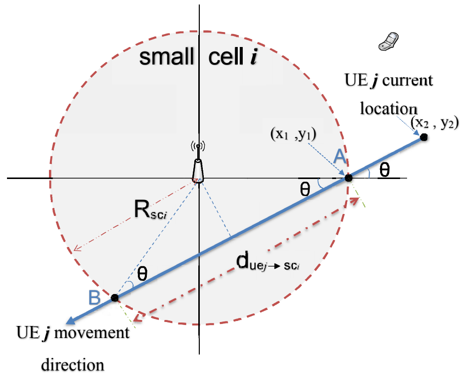

Figure 2: Small cell ToS measurement

Then, the user j staying distance inside small cell i, $d_{ue_j \to sc_i}$, can be estimated as:

$$d_{ue_j \to sc_i} = 2R_{sc_i} \cdot cos(\theta), \tag{7}$$

III. Proposed Scheme

In this section, we propose a method to minimize the probability of unnecessary handover and to reduce the neighbour cell scanning for small cell heterogeneous network. The proposed method uses shortened small cell list and different metrics for handover decision including SNR, velocity, and the actual distance between the UE and the small cell denoted as ($d^{ue_j \to sc_i}_{act}$).

The proposed method pseudo code is shown below:

Algorithm 1 Proposed Method

```
if Strong neighbor small cell detected > P_th then
    Put the small cell in a shortened candidate list
    V_uej monitoring
    if V_uej ≤ V_th then
        if ((d_act^{uej→sci} ≤ d_th) ∧ (| α_ueji | ≤ α_in,th)) then
            Keep small cell sc_i in the shortened candidates list
        else
            Remove small cell sc_i from the shortened candidates list
        end if
    end if
    if maximum ( SNR^r_{sci→uej}) in the list is > SNR^r_{m→uej} then
        Handover to small cell
    end if
end if
```

where V_{ue_j} is the velocity of the user, V_{th} is the handover velocity threshold, d_{th} is the distance threshold to form the small cell list, $\alpha_{ue_{ji}}$ is the angle between user j and the small cell i, $\alpha_{in,th}$ is the angle threshold at which the small cells are included in the candidate list, $SNR^r_{m \to ue_j}$ is the signal to noise ratio received from the macrocell at the user side, and $SNR^r_{sc_i \to ue_j}$ is the signal to noise ratio received from small cell at the user side.

From the geometry of Fig.3 we can calculate the angle between user j and small cell i, $\alpha_{ue_{ji}}$, based on $\vec{u}$ and $\vec{v}$

vectors as:

$$\alpha_{ue_{ji}} = \arccos\Big(\frac{\vec{u}\cdot\vec{v}}{|\vec{u}|\cdot|\vec{v}|}\Big) = \arccos\Big(\frac{x_u\cdot x_v + y_u\cdot y_v}{\sqrt{x_u^2+y_u^2}\cdot\sqrt{x_v^2+y_v^2}}\Big), \forall i = 1,2,...,N_{sc}^{*} \quad (8)$$

where $x_u = x_2 - x_1$, $x_v = x_3 - x_1$, $y_u = y_2 - y_1$, $y_v = y_3 - y_1$, and N_{sc}^{*} is the total number of small cells that are located within d_{th} distance from the UE.

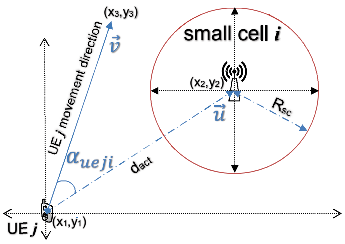

Figure 3: UE angle of movement

The algorithm starts by checking the neighbouring small cells, if their received RSRP are greater than a threshold, P_{th}, a shortened small cells list is formed containing all of these cells. Then the UE's velocity is checked, if it exceeds the threshold, V_{th}, which means that the UE is moving very fast and will potentially stay very short time in the small cell coverage area, then the UE keeps associated to macrocell. On the other hand, if the UE's moving velocity is equal to or below the threshold, we form a circle, i.e. model the small cell candidate list as a circle, whose center is the UE location and its radius is d_{th}. Then, all small cell, within this circle, that are not located within an angle range of $[-\alpha_{in,th}, \alpha_{in,th}]$ from the circle center (i.e. UE location) will be removed from the circle as shown in the blue shaded area of Fig.4. Leaving in the list only the small cells that are located at UE trajectory as shown in the white unshaded area of Fig.4. Hence, the scanned number of small cells by the UE is reduced. The evaluation of the actual distance between the UEs and the small cells, in one macrocell, can be described in the following matrix:

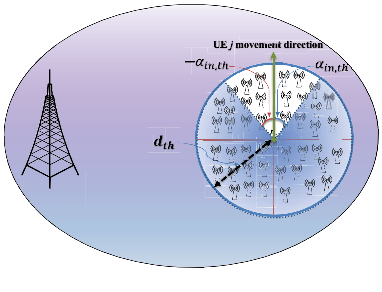

Figure 4: Removing small cells from the list

$$d_{act}^{ue_j\to sc_i} = \begin{pmatrix} d_{act}^{ue_1\to sc_1} & \cdots & d_{act}^{ue_1\to sc_{n-2}} & \cdots & d_{act}^{ue_1\to sc_n} \\ \vdots & \ddots & \vdots & \iddots & \vdots \\ d_{act}^{ue_{m-2}\to sc_1} & \cdots & d_{act}^{ue_{m-2}\to sc_{n-2}} & \cdots & d_{act}^{ue_{m-2}\to sc_n} \\ \vdots & \iddots & \vdots & \ddots & \vdots \\ d_{act}^{ue_m\to sc_1} & \cdots & d_{act}^{ue_m\to sc_{n-2}} & \cdots & d_{act}^{ue_m\to sc_n} \end{pmatrix}, \quad (9)$$

where n = 1, 2,..., N_{sc}^{*}, m = 1, 2,..., N_{ue}, N_{ue} is the total number of UEs, the rows represent the UEs, and the columns represent the small cells. Each element in the matrix is compared against its correspondent small cell radius to construct the shortened candidates list.

Thus, we can define the set of candidate small cells for user j in one macrocell, which is denoted as S_{sc}, using the following:

$$S_{sc} = \{sc_i \in N_{sc} \mid (d_{act}^{ue_j\to sc_i} \le d_{th}) \wedge (\mid \alpha_{ue_{ji}} \mid \le \ \alpha_{in,th})\}, \quad (10)$$

where N_{sc} is a set represents all small cells in one macrocell base station.

The handover is performed to the small cell, sc_i from the set S_{sc}, with the maximum SNR providing that this SNR is greater than the serving one i.e. $SNR^{r}_{sc_i\to ue_j} > SNR^{r}_{m\to ue_j}$.

Since the small cell radius, R_{sc_i}, is environment-dependent i.e. depends on the path loss, shadowing distribution and the transmit power, then the distance threshold, d_{th}, is also environment-dependent because it is a function of the small cell radius ($d_{th} = 2R_{sc_i}$).

In this way, the UEs only need to initiate the handover to a certain small cell in a shortened list which only contains certain number of small cells that have a sufficient RSRP level and are located in the UE's trajectory. Hence, the possibility of unnecessary handover will be reduced.

The introduction of shortened small cell list has an obvious effect on the performance of the proposed method. Many unnecessary handovers have been avoided because fewer number of target small cells are available for handover unlike the conventional method which considers RSRP level only for candidate list extraction (which means that the conventional small cell list contains all nearby small cells).

The UE expected time of stay (ToS) inside the small cell is measured to evaluate the probability of unnecessary handover. The ToS is compared against the time threshold $T_{threshold}$. When the user's ToS is less than the $T_{threshold}$, the handover is considered as unnecessary handover.

The expected time of stay inside a small cell i for user j, $ToS_{UE_{ji}}$, can be calculated using user velocity, V_{ue_j}, and the expected traveling distance, $d_{ue_j\to sc_i}$, and is expressed as:

$$ToS_{UE_{ji}} = \frac{d_{ue_j\to sc_i}}{V_{ue_j}} = \frac{2R_{sc_i}\cdot cos(\theta)}{V_{ue_j}}. \quad (11)$$

Depending on the hand-in and hand-out times, the time threshold is chosen so that it is equal to the sum of two handover times (hand-in and hand-out). The RSRP measurement and handover execution take about 360ms. Therefore, two handovers time (hand-in and hand-out) is approximately equal to 720ms.

IV. Performance Evaluation and Analysis

System level simulation has been carried out to evaluate the performance of the proposed algorithm. Table I gives a summary of simulation parameters used.

Table I: Basic Simulation Parameters

System bandwidth	1.228 MHz
Macrocell antenna gain	15 dBi
Macrocell transmit power	45 dBm
Macrocell radius	500 m
Small cell antenna gain	0 dBi
Small cell transmit power	2 dBm
Number of small cells within macrocell	100
Outdoor penetration loss (L)	10 dB
Number of walls (q_{sc})	Random
P_{th}	-70 dBm
V_{th}	5, 15, 20 km/h
d_{th}	$2R_{sc_i}$
$\alpha_{in,th}$	20^o,30^o,60^o

We define the number of handovers per macrocell, HO_n, as:

$$HO_n = \sum_{i=1}^{N_{sc}} HO_{n\to i}, \tag{12}$$

where $HO_{n\to i}$ is the number of handovers from macrocell n to small cell i.
Whereas the number of handovers in all deployed macrocells, NHO_m, will be:

$$NHO_m = \sum_{n=1}^{N_m} HO_n, \tag{13}$$

where N_m is the total number of macrocell base stations in the network.

For high-speed UEs, the handover is happening between two neighbouring macrocell following the strongest received power strategy. Therefore, the number of handovers for high-speed UEs, $NHO_{m\to m}$, is expressed as:

$$NHO_{m\to m} = \sum_{k=1}^{N_m} HO_{m,k}, \tag{14}$$

where $HO_{m,k}$ is the number of handovers between two adjacent macrocell base stations.

Finally, the total number of the handovers in the network, HO_{total}, is:

$$HO_{total} = NHO_m + NHO_{m\to m}. \tag{15}$$

We express the probability of successful handover to small cells, P_{HO}, as:

$$P_{HO} = \Pr\Bigg[\begin{aligned} & V_{ue_j} \le V_{th} && \wedge \\ & d_{act}^{ue_j\to sc_i} \le d_{th} && \wedge \\ & |\,\alpha_{ue_{ji}}\,| \le \ \alpha_{in,th} && \wedge \\ & SNR^r_{sc_i\to ue_j} > SNR^r_{m\to ue_j} \end{aligned}\Bigg]. \tag{16}$$

The probability of unnecessary handover, P_{unHO}, is defined as:

$$P_{unHO} = \Pr\Big[ToS_{UE_{ji}} \le T_{threshold}\Big], \tag{17}$$

where $T_{threshold}$ is the minimum time required for hand-in and hand-out.

For the overall network throughput measurements, the following formula is used:

$$\text{Throughput} = \sum_{c\in X} \text{BW}\cdot\log_2\Big(1+\frac{P^r_{c\to ue}}{\sigma^2}\Big), \tag{18}$$

where set X={1,2,...,N_{sc},N_m}, and σ is the thermal noise density.

In this section, we compare the performance of our proposed handover algorithm with that of the conventional methods.
The handover for the conventional method happens when the RSRP of the target cell, $P^r_{sc_i\to ue_j}$, is greater than the RSRP of the serving cell, $P^r_{m\to ue_j}$, i.e. ($P^r_{m\to ue_j} < P^r_{sc_i\to ue_j}$) and can be described as:

$$\eta := \{sc_i \mid P^r_{sc_i\to ue_j} > P^r_{m\to ue_j}\} \tag{19}$$

$$sc^*_{conv} = \arg\max_{sc_i\in N^*_{sc}} P^r_{sc_i\to ue_j} \in \eta, \tag{20}$$

where η represents the set of all small cells within the candidate list circle of d_{th} radius, and sc^*_{conv} is the best small cell in set η in term of downlink received power.

Whereas the handover criteria of our proposed method can be presented as:

$$\zeta := \{sc_i \mid SNR^r_{sc_i\to ue_j} > SNR^r_{m\to ue_j}\} \tag{21}$$

$$sc^*_{pro} = \arg\max_{sc_i\in S_{sc}} SNR^r_{sc_i\to ue_j} \in \zeta, \tag{22}$$

where ζ represents the set of all small cells within the white unshaded area of Fig.4, and sc^*_{pro} is the optimal small cell in set ζ which satisfies the conditions in lines (5) and (11) of the algorithm pseudo code.

A) The Ratio of the Small Cells in the List

We evaluate the ratio of the candidate small cells in a list as a function of the distance threshold, d_{th}, taking into account the small cell radius. Given that d_{th} is defined as a function of R_{sc_i}, we can define the ratio of the small cells in a shortened candidate list, denoted ρ_{sc}, as:

$$\rho_{sc} = \frac{Number\ of\ candidate\ small\ cells\ within\ [-\alpha_{in,th}\cdot\alpha_{in,th}]}{Total\ number\ of\ small\ cells}\times 100\% \tag{23}$$

As depicted in Fig.5, the ratio of the candidate small cells in the conventional method is always the higher, compared to our proposed method, because its shortened list contains all the small cells within the UE range (i.e. all small cells within a circle of d_{th} radius). On the other hand, our proposed method has reduced the number of candidate small cells in the list for different $\alpha_{in,th}$ values. The higher the value of $\alpha_{in,th}$ the higher the ratio of small cells. The impact of the small cell list radius, d_{th}, is obvious in

Fig.5, the ratio of small cells slightly increases with the increase in d_{th}. We can clearly see from Fig.5 an achieved improvement of the ratio of the candidate small cells in our proposed method compared to the conventional method, for example at $d_{th} = 3R_{sc}$, we have an improvement of 20%, 25%, and 27% when setting $\alpha_{in,th}$ to 60^o, 30^o, and 20^o respectively.

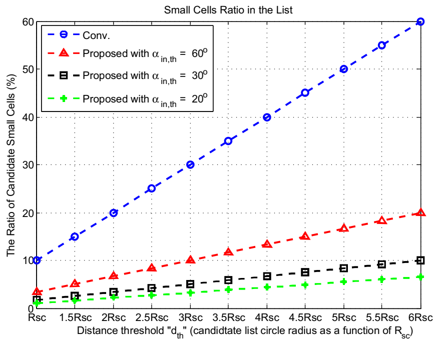

Figure 5: Ratio of the Candidate Small Cells in the List as a Function of d_{th} with Different Values of $\alpha_{in,th}$

B) Probability of Handover
The probability of handover is depicted in Fig.6. Generally, the probability of handover for the two methods increases with the increase in velocity. The conventional method has the highest increase owing to the fact that it depends only on RSRP for handover decision. The proposed method shows lower level of handover for low speed users compared to the conventional one because of the signal to noise ratio metric. At the velocity limits, 5km/h 15km/h and 20km/h, we can see that the probability of handover for the proposed method sharply goes down before it starts to climb again because the handover to small cell only happens for the UEs with a velocity less than or equal to the velocity threshold. For high-speed UEs, above the velocity threshold, the handover is happening between two adjacent macrocell base stations. In the proposed method, the effect of the velocity threshold is obvious, fewer handovers are taking place for low-speed UEs with a lower velocity threshold (5 km/h). Moreover, the proposed method shows lower level of handover probability (for all $V_{ue} < V_{th}$) because of the introduction of shortened small cell list. Hence, fewer handover target cells will result in lower handover probability and will also reduce the extensive scanning for neighbouring small cells which will eventually minimize the UE battery power consumption.

C) Unnecessary Handover Probability
Fig.7 illustrates the probability of unnecessary handover for both the conventional and the proposed methods. The performance of the proposed method outperformed that of the conventional one by showing a lower level of unnecessary handover probability. The conventional method shows a higher level of unnecessary handovers and this level slightly increase when the velocity of the user increases owning to the

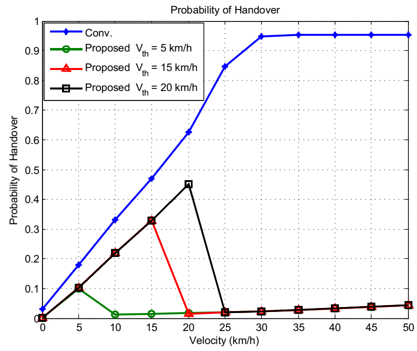

Figure 6: Probability of Handover with $\alpha_{in,th} = 30^o$

fact that the conventional method depends only on the RSRP level for neighbourhood scanning and handover decision which degrades the end user QoS by consuming the UE's battery power. The introduction of shortened small cell list has a great influence on the performance of the algorithm. By using this list a plenty of unnecessary handovers have been avoided because a fewer number of target small cells are nominated and the one with highest SNR is selected as a possible handover target making the scanning process less power consuming. As clearly shown in the figure, when using different velocity thresholds in the proposed method the unnecessary handovers are very low for small cell UEs compared to the conventional method. The utilization of the angle, $\alpha_{in,th}$, has reduced the number of small cells in the shortened list and in turn minimizes the unnecessary handover for different velocity thresholds. For example, when adjusting the velocity threshold to 5k/m, fewer unnecessary handovers are happening for low to medium-speed user (0km/h-to-25km/h). The higher the velocity threshold, the higher the unnecessary handover for low to medium-speed UEs (0km/h-to-25km/h). Thus, our method has increased the proper utilization of small cells and prevented the unnecessary handover from macrocell UEs to the small cell (i.e. has eliminated the handover for fast UEs).

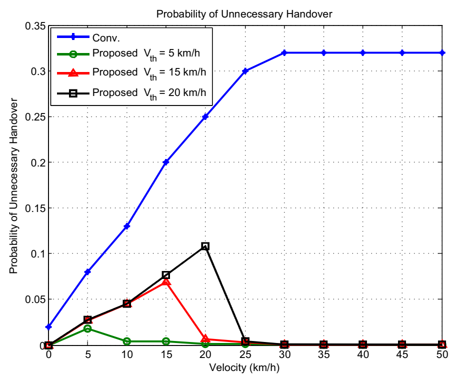

Figure 7: Probability of Unnecessary Handover with $\alpha_{in,th} = 30^o$

Fig.8 shows the influence of different angle thresholds, $\alpha_{in,th}$, on the probability of unnecessary handover. The solid curves represent the scenario with $\alpha_{in,th}$ = 30^o, whereas the dotted curves represent the scenario with $\alpha_{in,th}$ = 20^o. As clearly illustrated in Fig.8, for different velocity thresholds, the unnecessary handover for lower angle threshold is lower than that of the higher angle threshold (almost 50% reduction in the unnecessary handover is achieved with lower angle threshold). This is due to the fact that lower angle threshold will produce shorter small cell list and hence low unnecessary handover.

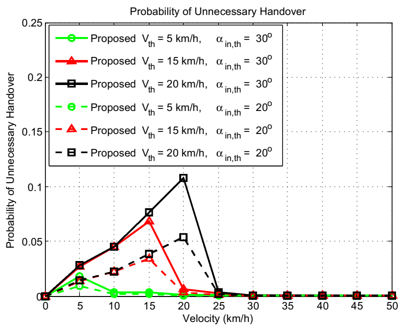

Figure 8: Probability of Unnecessary Handover for Different Values of $\alpha_{in,th}$

D) Throughput

Fig.9 illustrates the network throughput for both the proposed and the conventional methods against the velocity. For both methods, the throughput decreases with the increase in velocity. The conventional method has always the lowest throughput compared to the proposed method. The proposed method has outperformed the conventional method in terms of throughout by holding higher capacity for fast moving users because the fast moving users do not have to perform frequent handovers to the small coverage area small cell. Fig. 9 reveals that our proposed method, in addition to the unnecessary handover reduction, has increased the network throughput. At (5km/h) velocity, the throughput of the proposed method is about 23Kbps higher than that of the conventional scheme. Moreover, the proposed method continues to produce higher throughput for high-speed users, e.g. at (50km/h), the throughput is 46Kbps higher than the conventional method because the high-speed users are always associated to the macrocell. Hence, higher capacity is held for fast moving users because the signal to noise ratio for these users (served by macrocell) are nearly steady and are not fluctuated due to high-speed mobility.

V. Conclusion

In this paper, a handover algorithm for two-tier heterogeneous network was proposed and compared against the conventional handover algorithm which depends only on RSRP for handover decision. Different velocity thresholds

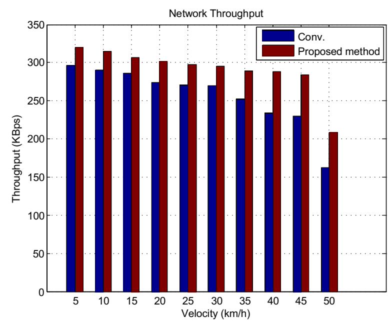

Figure 9: Network Throughput with $\alpha_{in,th}$ = 30^o

are used to control the handover to small cell. In order to identify the shortened candidate small cell list, the actual distance and small cell radius, in addition to the UEs angle of movement, were used to form the most realistic small cell handover targets. Moreover, the expected user's ToS is taken into consideration to evaluate the unnecessary handover. Simulation results showed that our proposed method reduces the number of candidate small cells in the shortened list. The proposed method also shows a low number of handovers for all UE's velocities compared to the conventional method. On the other hand, the probability of unnecessary handovers for the proposed method is less than the conventional method due to the incorporation of the shortened small cell list which in turn reduced the overall scanning for neighbouring small cells. Hence, reducing the UE battery power dissipation. Results show, the network throughput also increased for the proposed method comparing to the conventional method.

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