Dynamic UE-based Hysteresis-adjusting Algorithm in LTE Femtocell Networks

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Abstract

In LTE Femtocell networks, hysteresis is one of the main parameters which affects the performance of handover with a number of unnecessary handover, including ping-pong, early, late and incorrect handover. In this article, we propose a hybrid algorithm that aims to obtain the optimised unique hysteresis for individual mobile user moving at various speeds during the inbound handover process. This algorithm is proposed for two-tier scenarios with Macro and Femto. The centralised function in this article evaluates the overall handover performance indicator. Then, the Handover Aggregate Performance Indicator (HAPI) is used to determine an optimal configuration. Based on the received Reference Signal to Interference plus Noise Ratio (RS-SINR), the distributed function resides on UE is able to obtain an optimal unique hysteresis for the individual UE. Theoretical analysis with three indication boundaries are provided to evaluate the proposed algorithm. A system-level simulation is presented, and the proposed algorithm outperformed the existing approaches in terms of handover failure, call-drop, redundancy handover ratios and also achieved better overall system performance.

Index Terms

LTE, Dynamic Hysteresis, Distributed, Inbound handover.

I. INTRODUCTION

FEMTOCELLS have been introduced into the mobile wireless networks by 3GPP to improve the poor coverage for indoor users [1]. Due to the two-tier structure of Femtocell and Macrocell deployment, the handover scenario differs consideration from conventional LTE networks, e.g. the coverage of the Femtocell is much smaller than the Macrocell's, the handover between Macrocell and Femtocell would experience more severe Signal-to-Interference Noise Ratio (SINR) degradation than the handover between Macrocells. Therefore, inbound handover (handover from Macrocell to Femtocell) is one of the challenging issues in Femtocell network deployment [1]. During the inbound handover process, ping-pong, Radio Link Failure (RLF) (include early and late handovers) and handover to an incorrect cell may occur due to the sub-optimal handover parameters in the system. Consequently, 3GPP has proposed the Mobility Robustness Optimisation (MRO) that focuses on autonomous selection and optimisation of handover parameters to overcome those issues [2].

In [3], [4] and [5], the performance of using various hysteresis and Time-to-Trigger (TTT) were studied. The results indicated that the optimal hysteresis and TTT could effectively reduce the RLF and ping-pong respectively. However, those papers only provided a general analysis to find the optimal handover parameters. In [6], the authors proposed a Dynamic Hysteresis-Adjusting (DHA) method. This method uses the allowed maximum RLF ratio to find the optimal hysteresis in order to reduce

the ping-pong and call-drop ratio. However, it cannot find a suitable hysteresis to reduce the RLF ratio. In [7] and [8], the authors provided a rule based dynamic handover optimisation algorithm. In order to evaluate the overall system performance, taking into account of multiple factors, such as ping-pong effect, RLF, and call-drop, the authors defined a weighting function to combine these factors. By recording and updating the target overall performance, the approach is capable of adjusting the control parameters (hysteresis and TTT) to reduce handover, RLF and ping-pong ratios. In [9], authors provide a centralised scheme that optimises hysteresis (handover margin) and TTT, in order to reduce the handover and call-drop ratios. Through a fuzzy logic controller, this scheme can obtain a good trade off between handover and call-drop ratios. [7], [8] and [9] only consider the centralised handover parameter optimising which means that the UEs within each cell share the same handover triggering parameters. However, each UE moves at different speed, its handover triggering parameters should not be the same. Those centralised parameters cannot guarantee suitable handover performance for the individual UE. In [10], authors provide a scheme to adjust the hysteresis value by considering speed, load and service-based adaptive methods in LTE networks. The scheme can provide an optimised hysteresis for the individual UE, in order to reduce the RLF ratio. [10] considered the factor of the UE's speed in the handover, but it still not have enough analysis how it obtains the speed-based adaptive method. Moreover, the scheme only considered the RLF and uses the speed parameter directly in the optimising process. However, RLF is not the only metric to evaluate the handover performance and the accurate speed of the moving UE is very difficult to be obtained from the cellular networks. In [11], the authors proposed an cooperation mechanism scheme. This scheme enables a Femtocell to request its neighbouring Femtocells to transfer the data traffic for its user in order to reduce the inter-interference. This would effectively reduce the unnecessary handover between Femtocells and results in lower RLF and ping-pong effect. However, [11] only considered the handover scenario of Femto-to-Femto. Inbound handover differs from the scenario considered in [11] due to the different path losses incurred for Femtocells and Macrocells. In [12], the authors provide a distributed dynamic adjustment of TTT and hysteresis for different speed of UEs, in order to balance MRO and Mobility Load Balancing (MLB). The article provided handover condition inequality group and handover performance metric which considers the RLF, ping-pong effect and handover failure ratios to find the optimal hysteresis and balance between MRO and MLB. However, this scheme is still a rule based optimisation algorithms, it does not give enough analysis of the relation between hysteresis and UE's speed. Therefore, in order to offer the unique optimised hysteresis for individual UEs with different speeds at inbound handover scenario, in this article, the inbound handover scenario and relation between speed and hysteresis have been investigated, and a hybrid dynamic hysteresis adjusting algorithm has been proposed.

The rest of this article is organised as follows: Section II analyses the inbound handover and demonstrates the drawback of conversational centralised hysteresis approach. Section III details the proposed hybrid dynamic hysteresis algorithm and a theoretical analysis is provided to evaluate the proposed algorithm. In Section IV, a system level simulation is given. Finally, we conclude this article in Section V.

II. INBOUND HANDOVER ANALYSIS

We analyse the inbound handover scenario that consists of one Macrocell, j , and one Femtocell, i . Let d denotes the distance from the Macrocell to the Femtocell. The areas and boundaries of handover for different stage, such as late, early and hysteresis

Fig. 1. Architecture of inbound handover in one Femto and one Macro Scenario

are shown in Figure 1.

In Figure 1, a Macrocell and a Femtocell (circle ①) locate at $(0, 0)$ and $(d, 0)$ with coverage radius of R_j , R_i , and transmit powers P_j , P_i , respectively. When an UE is served by the Macrocell and locates at (x, y) , its receive powers from the Macrocell and Femtocell, defines as $P_{r,j}$ and $P_{r,i}$, respectively. Therefore, $P_{r,j}$ and $P_{r,i}$ are calculated as follows [13]:

$$P_{r,j} = P_j C_j^{-1} d_j^{-\alpha} = P_j C_j^{-1} (x^2 + y^2)^{-\frac{\alpha}{2}} \quad (1)$$

$$P_{r,i} = P_i C_i^{-1} d_i^{-\beta} = P_i C_i^{-1} ((x - d)^2 + y^2)^{-\frac{\beta}{2}} \quad (2)$$

where α and β are the Macrocell and Femtocell path-loss exponents, C_j and C_i are the path-loss reference distances for the Macrocell and Femtocell, and $d_j(d_i)$ is the distance from the UE to Macrocell(Femtocell).

A. Early and late inbound handover boundaries

According to (1) and (2), the UE receives $SINR_i(SINR_j)$ from Femtocell(Macrocell) which can be summarised by (3) and (4).

$$SINR_i = \frac{P_{r,i}}{P_{r,j} + N_o} \approx \frac{P_i C_i^{-1} ((x - d)^2 + y^2)^{-\frac{\beta}{2}}}{P_j C_j^{-1} (x^2 + y^2)^{-\frac{\alpha}{2}}} \quad (3)$$

$$SINR_j = \frac{P_{r,j}}{P_{r,i} + N_o} \approx \frac{P_j C_j^{-1} (x^2 + y^2)^{-\frac{\alpha}{2}}}{P_i C_i^{-1} ((x - d)^2 + y^2)^{-\frac{\beta}{2}}} \quad (4)$$

where N_o is the noise power. Since the noise power is much lower than that of the interference signal, we ignore the noise [11]. In the 3GPP standard [14], it proposed that the early or late handover happens when receiving target cell SINR or serving cell SINR is less than -6 dB. Therefore, we can rewrite the (3) and (4) into the (5) and (6).

$$\frac{P_i C_i^{-1} ((x - d)^2 + y^2)^{-\frac{\beta}{2}}}{P_j C_j^{-1} (x^2 + y^2)^{-\frac{\alpha}{2}}} \geq 10^{-\frac{6}{10}} \approx \frac{1}{4} \quad (5)$$

$$\frac{P_j C_j^{-1} (x^2 + y^2)^{-\frac{\alpha}{2}}}{P_i C_i^{-1} ((x-d)^2 + y^2)^{-\frac{\beta}{2}}} \geq 10^{-\frac{6}{10}} \approx \frac{1}{4} \quad (6)$$

Then, according to (5), we obtain (7).

$$\frac{P_i C_j d_i^{-\beta}}{P_j C_i d_j^{-\alpha}} \geq \frac{1}{4} \quad (7)$$

Assume $d_{jE}(d_{iE})$ is the distance from a point $E(x,y)$ (UE) to Macrocell(Femtocell). Since we only consider that $x \geq 0$ and $y \geq 0$ in the architecture of inbound handover, we can denote $d_{jE}/d_{iE} = \lambda_E$, then we have $d_{iE} = d_{jE}/\lambda_E$. By substituting them into (7), we got (8):

$$\lambda_E \geq \left(\frac{P_j C_i d_{jE}^{\beta-\alpha}}{4 P_i C_j} \right)^{\frac{1}{\beta}} \quad (8)$$

Since d_{jE}, d_{iE} and d can be considered as the three edges of the triangle in circle of Apollonius [15], the point E follows the feature of the circle of Apollonius with different λ_E and the trace of each of those points can be drawn as the curve ②, as shown in Figure 1. The centre and radius of this curve ② will only depend on the d and λ_E . Moreover, if $\alpha = \beta$, then $d_{jE}^{\beta-\alpha} = 1$ based on (8). In that case, those E points have the same λ_E which turns this curve into a circle according to the feature of circle of Apollonius. According to [13] and [16], we have $1 < \alpha/\beta \leq 2$, and $\beta - \alpha < 0$. Thus, in terms of the (8), if d_{jE} increases, λ_E would decrease. As mentioned earlier, with different λ_E , the trace of each of the points can be drawn as a closed curve. Moreover, if we define a point $L(x,y)$ and its distance $d_{jL}(d_{iL})$ from Macrocell(Femtocell) satisfied $d_{jL}/d_{iL} = \lambda_L$, similar to (5), (7) and (8), we can rewrite the (6) as (9):

$$\lambda_L \leq \left(\frac{4 P_j C_i d_{jL}^{\beta-\alpha}}{P_i C_j} \right)^{\frac{1}{\beta}} \quad (9)$$

Similar to the curve ②, the trace of each of the point L is a closed curve and it is drawn as the curve ③ in the Figure 1. The curve ② indicates that if a UE has the handover process within this curve, the received SINR from the Femtocell would be higher than -6 dB to avoid early handover. Similarly, this applies to the curve ③. If a UE have the handover process outside this curve, UE can avoid late handover. If considering both the noise and the interference from other Femtocells, the coverage of the curve ② would be decreased and the coverage of curve ③ would be increased.

Moreover, different scenarios would have different path-loss parameters, so the value of $\lambda_E(\lambda_L)$ may be less than or equal to 1. If this occurs, it means that there would be no boundary of early or late handover for the Femtocell.

B. Conventional Hysteresis and its Inbound Handover Boundary

A UE-assisted network handover procedure was defined for LTE in 3GPP standard [17]. The base station configures the UE to take measurements of the Reference Symbol Received Power (RSRP) and Reference Signal Received Quality (RSRQ) of the serving cell and the neighbouring cells. Then, it sends a triggered measurement report when an entry condition has been maintained and the following equations apply in dB units:

$$RSRP_{target} \geq RSRP_{serve} + Hysteresis \quad (10)$$

$$RSRQ_{target} \geq RSRQ_{serve} + Offset \quad (11)$$

In this paper, we only consider the adjustment of hysteresis. Therefore we focus on (10) and rewrite it to (12) with respect to (1) and (2) in linear units.

$$\frac{P_{r,i}}{P_{r,j}H} = \frac{P_i C_i^{-1}((x-d)^2 + y^2)^{-\frac{\beta}{2}}}{H P_j C_j^{-1}(x^2 + y^2)^{-\frac{\alpha}{2}}} \geq 1 \quad (12)$$

where H is the hysteresis value. if we define a point $H(x,y)$ and its distance $d_{jH}(d_{iH})$ from Macrocell(Femtocell) satisfies $d_{jH}/d_{iH} = \lambda_H$, then similarly applies to curve ② and equation (8), we can have the λ_H as given in (13) with respect to (12) and draw the curve ④ in Figure 1.

$$\lambda_H \geq \left(\frac{H P_j C_i d_{jH}^{\beta-\alpha}}{P_i C_j} \right)^{\frac{1}{\beta}} \quad (13)$$

Based on Apollonius [18], with same d and different λ , the curves cannot intersect, except when have the same λ . Moreover, According to the previous section, the curve ④ exists between curve ② and ③ since the handover process should happen between those curves. Therefore, we have (14) according to (8), (9) and (13) and the range of H is shown in (15):

$$\left(\frac{P_j C_i d_{jE}^{\beta-\alpha}}{4 P_i C_j} \right)^{\frac{1}{\beta}} \leq \left(\frac{H P_j C_i d_{jH}^{\beta-\alpha}}{P_i C_j} \right)^{\frac{1}{\beta}} \leq \left(\frac{4 P_j C_i d_{jL}^{\beta-\alpha}}{P_i C_j} \right)^{\frac{1}{\beta}} \quad (14)$$

$$\left(\frac{d_{jE}}{4 d_{jH}} \right)^{\beta-\alpha} \leq H \leq \left(\frac{4 d_{jL}}{d_{jH}} \right)^{\beta-\alpha} \quad (15)$$

Due to various values of d_{jE} , d_{jL} and d_{jH} , the range of H would be difficult to get from (15). Fluctuation in the signal strength causes the undesired handovers and hysteresis can be used to delay the handover happening until the signal strength become more stable. The hysteresis should take the highest value for the handover process. However, since UE cannot immediately complete a handover process, if a UE has a higher hysteresis and higher moving speed, it is easier to complete the handover process within the late handover boundary. Therefore, the moving speed of a UE should be considered when adjusting hysteresis value.

C. Moving Speed that affects Hysteresis

According to the 3GPP standard [19], users with different moving speeds need to be offered a different hysteresis value in LTE, normal-mobility, medium-mobility and high-mobility states. A cell would then offer the different corresponding hysteresis to the different use ranks. However, it is still a centralised hysteresis approach and cannot stratify every user. In this section, we

will demonstrate the reason why the hysteresis value should be related to speed and also the drawback of centralised hysteresis approach in the proposed model.

We define the handover process to be T_0 and a UE has speed V , therefore, an entire handover process takes $T_0 + TTT$ to be completed. The distance of handover starting should be greater or equal to $V \times (T_0 + TTT)$ for the late handover.

Based on Apollonius, the shortest distance from Hysteresis to curve ③ is on the x-axis on the Femtocell centre's left as shown in Figure 1. Therefore, if we denote that x_L and x_H are the points of curve ③ and ④ on the x-axis, the curve ④ exists between the curve ② and ③, we could have $x_L \geq x_H$ and the (16):

$$x_L - x_H = V \cdot (T_0 + TTT) \quad (16)$$

where (16) represent that a proper H value (hysteresis) ensures the UE to complete its handover process before the late handover boundary in the shortest handover distance. Since x_L and x_H are the points of curve ③ and ④ on the x-axis ($y = 0$), (6) and (12) can be rewritten as (17) and (18):

$$x_L = d - \left(\frac{P_i C_j}{4P_j C_i} \right)^{\frac{1}{\beta}} \cdot x_L^{\frac{\alpha}{\beta}} (x_L \leq d) \quad (17)$$

$$x_H = d - \left(\frac{P_i C_j}{HP_j C_i} \right)^{\frac{1}{\beta}} \cdot x_H^{\frac{\alpha}{\beta}} (x_H \leq d) \quad (18)$$

To substitute (17) and (18) into (16), we obtain the (19):

$$\left(\frac{P_i C_j}{HP_j C_i} \right)^{\frac{1}{\beta}} \cdot x_H^{\frac{\alpha}{\beta}} - \left(\frac{P_i C_j}{4P_j C_i} \right)^{\frac{1}{\beta}} \cdot x_L^{\frac{\alpha}{\beta}} = V \cdot (T_0 + TTT) \quad (19)$$

According to (16) and (19), we obtain the (20):

$$H = \frac{(x_L - V(T_0 + TTT))^{\alpha}}{\left(\frac{V(T_0 + TTT)^{\frac{1}{\beta}}}{\left(\frac{P_i C_j}{4P_j C_i} \right)^{\frac{1}{\beta}}} + \left(\frac{x_L^{\alpha}}{4} \right)^{\frac{1}{\beta}} \right)^{\beta}} \quad (20)$$

In (20), it calculates the H as the shortest distance in the proposed scenario. If a UE moves at a different direction to the Femtocell, the distance of its path is always greater than derived from (20). Therefore, this hysteresis satisfies all the direction UEs and ensures all UEs will completed the handover process before it cross the curve ③(late handover).

Moreover, in (20), parameters such as the powers of Macro and Femto cells, path loss parameters, d , x_L (based on equation (17)), T_0 and TTT are the constant values for a specific handover scenario. Therefore, the value of H at shortest distance handover is completed depends on the UE speed V . Due to $\alpha > \beta$, and $x_L \geq 0$, we can have its derivation as (21):

Fig. 2. The comparison of UE speeds and request hysteresis in shortest handover distance

$$f'(V) = -\frac{(T_0+TTT)\alpha(x_L-V(T_0+TTT))^{\alpha-1}}{\left(\frac{V(T_0+TTT)}{\left(\frac{P_i C_j}{P_j C_i}\right)^{\frac{1}{\beta}} + \left(\frac{x_L}{4}\right)^{\frac{1}{\beta}}}\right)^{\beta}} - \frac{(T_0+TTT)(x_L-V(T_0+TTT))^{\alpha}}{\left(\frac{V(T_0+TTT)}{\left(\frac{P_i C_j}{P_j C_i}\right)^{\frac{1}{\beta}} + \left(\frac{x_L}{4}\right)^{\frac{1}{\beta}}}\right)^{\beta+1}} \quad (21)$$

Since $f'(V)$ is less than 0, $f(v)$ is a monotonically decreasing function when $V \geq 0$. The relation of UE's speed and requested hysteresis in shortest handover distance is shown in Figure 2. The hysteresis decreases while UE's speed increases and it confirms with the 3GPP standard [19], the higher speed the lower hysteresis. Due to the different scenario of indoor and outdoor, we have the indoor and outdoor curves. The indoor curve means that the UE is already indoor and served by the Macrocell, then its handover completely happens at indoor-to-indoor scenario. The outdoor curve means that the handover occurs at outdoor-to-indoor scenario.

As shown in Figure 2, the indoor curve decreases faster than the outdoor curve. This is because that derivation of indoor scenario is less than outdoor depends on (21), and UE is more sensitive to the speed.

Moreover, some previous research such as [7], [8] and [9], offer the centralised hysteresis value for all UEs with different speed. In Figure 2, it shows that a centralised hysteresis can be determined by the degree of aggregation of the UEs (pink area), it only satisfies a part of speed range of those UEs. Therefore, the centralised hysteresis approach will not work well when the speeds of all UEs or most of them are uniformly distributed. Only the distributed hysteresis can offer the better overall handover performance than centralised hysteresis for all UEs.

III. DYNAMIC HYBRID UE-BASED HYSTERESIS ADJUSTING ALGORITHM (DHUHA)

In order to achieve optimal individual hysteresis values for all users, we propose to dynamically hybrid adjust hysteresis by giving the higher speed UE a lower hysteresis and lower speed UE a higher hysteresis. The receiving SINR from Femtocell increases when the UE moves closer to the target Femtocell, therefore, when a UE moves at a different speed and its SINR changes at different pace in a certain period.

To cope with that different changing pace, we propose to use average RS-SINR (we will call it as SINR or $SINR_{target}$ in the rest of the letter) to present the speed factor. Then we introduce an additional parameter (P) to the handover procedure in

DHUA. P is defined in a weighted SINR : $P * SINR_{target}$ in linear units. $SINR_{target}$ is from UE measurement which is not in the standard but a vnder defined parameter [20]. Therefore, based on (10), DHUA can be summarised as (22) in dB units.

$$RSRP_{target} \geq RSRP_{serve} + H_{high} - (P + SINR_{target}) \quad (22)$$

where H_{high} denotes the highest hysteresis value in the current network system. P and H_{high} are calculated at Macrocell station side (centralised part) and then sent to the individual UE. The hysteresis can be calculated at UE-side (distributed part). By using $H_{high} - (P + SINR_{target})$, a suitable hysteresis which related to UE speed can be obtained for individual UE for different speed ranges. Moreover, it obviously shows that the dynamic hysteresis would decrease when the received SINR from target Femtocell increases. Therefore, this algorithm offers four advantages:

- It offers the higher hysteresis when the UE is far from the target Femtocell. Then this UE would be not easy to launch the handover process
- It offers the lower hysteresis when the UE is closed to the target Femtocell. Then this UE would be easy to launch the handover process.
- If the UE moves at a higher speed, the hysteresis would decrease faster to avoid late handover.
- If the UE moves at a lower speed, the hysteresis would decrease slowly (remain the higher value) to avoid early handover.

However, in terms of (22), we need to face two issues:

- The advantage of using SINR compared to RSRQ and RSRP which are also the parameters that reflected by speed factor.
- The adjustment of P and H_{high} .

A. Comparison of SINR and RSRQ

Both SINR and RSRQ from target cell can be used to reflect the UE speed changes. However, the RSRQ is not more reliable than SINR in the system handover process. According to [21], the reason is described below:

RSRQ is defined as (23) and RSSI is defined as (24) in linear units:

$$RSRQ = \frac{RSRP \cdot N}{RSSI} \quad (23)$$

$$RSSI = P_{interference} + RSRP \cdot N \cdot z + P_{noise_z_N} \quad (24)$$

Where N is the number of Resource Blocks (RBs) over which the RSSI is measured, typically equal to system bandwidth. A RB is the minimum allocation unit for system resource allocation on the time and frequency domains. It consists 12 sub-carriers (12*15=180 MHz) and 1 slot time (0.5 ms). A sub-carriers is defined as, in LTE, on the frequency domain, the radio spectrum is divided into a number of narrow sub-carriers of 15 kHz. The z is the number of sub-carriers that are used in the RSSI measured a RB. When $z=2$, it means that only reference signal power (uses 2 sub-carriers in a RB) is considered in the RB at

Fig. 3. Load-dependency of RS-SINR and RSRQ measurement

serving cell. This represents the resource block is empty. When $z=12$, it means that in addition to 2 sub-carriers for reference signals, the other sub-carriers are used for transferring data. This means that the resource block is fully loaded. $P_{interference}$ is the total interference from adjacent base station for these RBs and $P_{noise_z_N}$ are the total noise for these $z \cdot N$ sub-carriers that are used in measured RBs.

According to [20], SINR is calculated by (25):

$$SINR = \frac{RSRP \cdot 12 \cdot N}{P_{interference} + P_{noise_z_N}} \quad (25)$$

In equation (25), 12 refers to 12 sub-carriers in 1 RB, depends on (23) and (24), the (25) can be rewritten as (26).

$$SINR = \frac{RSRP \cdot 12 \cdot N}{\frac{RSRP \cdot N}{RSRQ} - RSRP \cdot z \cdot N} = \frac{12}{\frac{1}{RSRQ} - z} \quad (26)$$

Figure 3 illustrates the load-dependent relation between SINR and RSRQ. The RSRQ measurement may differ up to 8 dB depending on the load for the same SINR. For instance, the RSRQ may reduce 8 dB when UE starts downloading in an empty cell and has to use the all sub-carriers for transferring data. When UE turns from light traffic load to heavy traffic load, the RSRQ will reduce although neither the SINR nor RSRP have changed [21]. However, SINR is not affected by the cell traffic load. For that reason, it makes the use of RSRQ dangerous to represent the speed factor, in particular in low loaded cells. Therefore, SINR is a better parameter to use in DHUHA than RSRQ.

B. Comparison of SINR and RSRP

Both RSRP and SINR from the target cell can be used to reflect the changes of UE speed. However, the RSRP is not more reliable than SINR in the system handover process, the reason is described below:

We rewrite the equation (22) to (27) in linear units. Then we replace the SINR with RSRP in (27) and obtain the (28).

$$RSRP_{target} \geq RSRP_{serve} \cdot Hysteresis = RSRP_{serve} \cdot \frac{H_{high}}{P \cdot SINR_{target}} \quad (27)$$

$$RSRP_{target} \geq RSRP_{serve} \cdot Hysteresis = RSRP_{serve} \cdot \frac{H_{high}}{P \cdot RSRP_{target}} \quad (28)$$

where *Hysteresis* is the hysteresis value that uses in handover process. Therefore, (28) is RRSP based and (27) is SINR based. The (28) is easier to transfer to (29) as shown below:

$$RSRP_{target} \geq \sqrt{\frac{1}{p} \cdot RSRP_{serve} \cdot H_{high}} \quad (29)$$

Based on (25), we can rewrite (27) to (30) as shown below:

$$RSRP_{target} \geq \sqrt{\frac{P_{interference} + P_{noise_z_N}}{12pN} \cdot RSRP_{serve} \cdot H_{high}} \quad (30)$$

Comparing (29) and (30), it obviously shows that the SINR based algorithm, the inequality is not only dependent on the adjustment by P , but also depends on interference and noise from the scenario. Therefore, RSRP is not reliable as it only represents the signal strength and does not represent the signal quality. For instance, as shown in (28), when the UE moves to the neighbour cell, hysteresis value increases quickly as well as $RSRP_{target}$ increases. Therefore, UE is easier to handover to the cell which may have higher interference. On the other hand, as shown in (27), the hysteresis value would not decrease very quickly if the target cell has higher interference due to lower $SINR_{target}$. This means that UE is not likely to handover to the cell which have higher interference and has worse Quality of Service (QoS). Therefore, SINR is a better parameter to use in DHUHA than RSRP.

C. Determination of Proposed P and H_{high}

In the previous description, we set P and H_{high} are the centralised values that wireless station sends to UEs and the determination of a proper P and H_{high} values will describe in this section. According to (1), (2) and (3), we can convert (22) to linear units and rewrite it to the (31):

$$\frac{P_{r,i}}{P_{r,j} \frac{H_{high}}{P_{r,i}}} = \frac{P_{r,i}^2 P}{P_{r,j}^2 H_{high}} = \frac{P_i^2 C_j^2 ((x-d)^2 + y^2)^{-\beta}}{H_{high} P_j^2 C_i^2 (x^2 + y^2)^{-\alpha}} \geq 1 \quad (31)$$

Based on (31) and similarly, this applies to (16) and (17), we could have the (32) and (33):

$$x_L - x_{H'} = V(T_0 + TTT) \quad (32)$$

$$x_{H'} = d - \left(\frac{P^{\frac{1}{2}} P_i C_j}{H_{high}^{\frac{1}{2}} P_j C_i} \right)^{\frac{1}{\beta}} x_{H'}^{\frac{\alpha}{\beta}} (x_{H'} \leq d) \quad (33)$$

To substitute (17) and (33) into (32), we could obtain the (34):

$$\left(\frac{P^{\frac{1}{2}} P_i C_j}{H_{high}^{\frac{1}{2}} P_j C_i} \right)^{\frac{1}{\beta}} x_{H'}^{\frac{\alpha}{\beta}} - \left(\frac{P_i C_j}{4 P_j C_i} \right)^{\frac{1}{\beta}} x_L^{\frac{\alpha}{\beta}} = V(T_0 + TTT) \quad (34)$$

According to (32) and (34), we can obtain the (35):

$$H_{high} = \frac{P(x_L - V(T_0 + TTT))^{2\alpha}}{\left(\frac{V(T_0 + TTT)}{\left(\frac{P_i C_j}{P_j C_i} \right)^{\frac{1}{\beta}}} + \left(\frac{x_L}{4} \right)^{\frac{1}{\beta}} \right)^{2\beta}} \quad (35)$$

where according to (20) and (35), we can have the (36):

$$P = \frac{H_{high}}{H^2} \quad (36)$$

where P is able to be calculated from the H_{high} and hysteresis. If H_{high} is a constant value and H is the minimum value, the P would get the highest value. On the contrary, a highest P can ensure that all hysteresis can be reduced to minimum H value. Since H value is minimum hysteresis at the shortest handover path as mentioned earlier, a highest P could ensure that H_{high} for UEs with different location can be reduced to H value before they arrives the late handover boundary. However, considering the noise and interference from other Femtocells, we need to find an optimised P in realistic scenario for inbound handover.

Moreover, H_{high} could be any value, but if H is a constant value and H_{high} has a higher value, the P would has higher value. This would lead the difficult to do minor adjustments in order to find the optimised P value for system. Therefore, we recommend that H_{high} should be the hysteresis in lowest speed boundary at the mobility state as mentioned in section II.

D. Handover Aggregate Performance Indicator (HAPI)

Since we did not consider the neighbour Femtocells interference, noise, ping-pong and incorrect handover on the inbound handover analysis in section II, we need to adjust the P to reflect these factors. There are three performance criteria proposed in [7] and [22], such as Handover failure ratio (H_{fr}), Ping-pong ratio (P_{pr}) and Call-drop ratio (C_{dr}). However, it is complicate to satisfy those criteria together as it is a multi-parameter optimisation issue. In order to evaluate the performance of proposed DHUHA against the existing approach, we propose a Handover Aggregate Performance Indicator (HAPI), as the overall performance, defined in (37) and (38):

$$HAPI = W_1 H_{fr} + W_2 P_{pr} + W_3 C_{dr} + W_4 R_{hr} \quad (37)$$

$$W_1 + W_2 + W_3 + W_4 = 1 \quad (38)$$

In (37), R_{hr} represents the redundancy handover ratio. It is defined as the ratio of the number of incorrect handover (handover to wrong cell). R_{hr} reflects the efficiency handovers in the network, thus according to MRO, the lower R_{hr} provides lower handover ratio and also offers lower associated signalling load for the network.

In (37) and (38), the W_1, W_2, W_3 and W_4 are defined as weights and the sum of the values of them should be equal to 1. The values of W_1, W_2, W_3 and W_4 would vary depends on system specific requirement. However, In this paper, the scenario of normal LTE Femtocell is considered, therefore, in general, W_1 should outweigh W_2 since RLF has more pronounced effect than ping-pong for user experience and introduces more signalling overhead [24] [8]. Call-drop has stonger effect on the system

performance than RLF [24] [7], so W_3 should outweigh W_1 . This is because when RLF occurs the UE can reconnect to a good quality cell instead, and therefore maintains the call connection. For the W_4 , R_{hr} reflect the efficiency handover ratio which is the third object in MRO as mentioned earlier, therefore the value of W_4 should be smaller than W_3 and greater than W_1 and W_2 .

Overall, the values of weights can also be changed depending on the system requirements in order to achieve the better performance for specific networking.

E. Proposed DHUHA Process

Centralised and distributed processes have been proposed in the proposed algorithm as shown below:

Algorithm 1 DHUHA process

Require: Centralised Function

- 1: Mobility Management Entity(MME) Calculates the distances of the Femtocells and Macrocell
- 2: MME choose the proper path loss modes for Macrocell and Femtocell and calculate the minimum required hysteresis depends on equation (20).
- 3: MME choose the H_{high} and calculate P values depends on equation (36).
- 4: MME choose the highest P value as the initial P and send to Macrocell with the H_{high} .
- 5: Macrocell uses a certain step, such as +0.1/-0.1 dB to extend that initial P to a range of P values.
- 6: Macrocell creates/updates P-HAPI table by training each P in distributed function.
- 7: **if** Macrocell receive the handover failure report **then**
- 8: Macrocell calculates HAPI depends on equation (37) and updates the P-HAPI
- 9: **end if**
- 10: Macrocell choose the P with lowest HAPI value in the table as the optimal p .
- 11: Macrocell sends the H_{high} and P to UEs via system information

Require: Distributed Function

- 12: UE calculates the optimised unique hysteresis according to equation (22).
 - 13: According to this hysteresis, a optimal A3 event can be triggered and handover is able to start.
 - 14: **if** Handover process is successful **then**
 - 15: handover completed
 - 16: **else**
 - 17: UE reports ping-pong, RLF, call-drop or incorrect handover (handover failure report) to the centralised function and redo the process 6.
 - 18: **end if**
-

IV. EVALUATION OF THE PROPOSED DHUHA

In the simulation, 1 macro station and 20 femtocells randomly locate in the Macrocell coverage. 300 UEs are randomly located in Macrocell coverage area with random moving speeds and direction. Handover between Femtocells is not considered. We also assumed that each UE can easily decide its serving cell and target cell. We also set that the RLF occurs when SINR from serving cell drops below -6 dB before the handover procedure completes [3]. Call-drop occurs when both of SINRs from serving and target cells drop below -6 dB before the handover procedure completes. In the comparison, we use the algorithms that proposed in [7] as the conventional method. The parameters for simulation are summarised in Table 1. These parameters are recommended by [16].

A. Comparison of Theoretical and Simulation Results

Figure 4 shows that the average dynamic hysteresis value at different locations of the Femtocell. The curve ② and ③ represent the hysteresis changes with the theoretical P and the optimal P value depends on the HAPI, respectively. Moreover, according to the optimal P by simulation, it is able to draw three boundaries such as early, late and critical. Early handover boundary is SINR = -6 dB, therefore we could calculate the hysteresis via (22). Similarly, this applies to the late handover boundary SINR = 6 dB (received Macrocell SINR = -6 dB) and critical handover boundary SINR = 0 dB. Critical boundary

TABLE I
USED PARAMETERS IN THE SIMULATION

Carrier frequency/ system bandwidth	2000 (MHz)/ 10 (MHz)
Tx power of macro/ femto	46 (dBm)/ 20 (dBm)
Macro/ femto radius	500 (m)/ 20 (m)
Wall Loss(WL)	10 (dB)
Macro path loss	$15.34 + 37.6 * \log_{10}(d(m)) + WL$ $10(m) \leq d \leq 20(m)$ $15.3 + 37.6 * \log_{10}(d(m))$ $d \geq 20(m)$
Femto path loss	$38.46 + 20 * \log_{10}(d(m)) + 0.7d_{min}$ $10(m) \leq d \leq 20(m)$ $38.46 + 20 * \log_{10}(d(m)) + 0.7d_{min} + WL$ $d \geq 20(m)$
Log-normal shadowing	Macro standard deviation 8 (dB) Femto standard deviation 4 (dB)
Macro/ femto antenna gain	14 (dBi)/ 5 (dBi)
Antenna pattern/ UE moving pattern	Omnidirectional/ Straight
Macro/ femto noise figure	5 (dB)/ 8 (dB)
UE speeds	3, 4, 5, ..., 15 (km/h)
Hysteresis/ TTT/ Cell offset	0, 1, 2, ..., 9 (dB)/ 100 (ms)/ 0 (dB)
H_{high} [3][25]	10 (dB)
Cell Received Signal Strength Indication (RSSI)	-70 (dBm)
Handover process period	300 (ms)
Internal time for ping-pong detection [26]	2 (s)

Fig. 4. The trend of average UE hysteresis value in the simulation

represents the line of $P_{r,j}$ is equal to $P_{r,i}$. Due to the definition of hysteresis, in the ideal case, most of the handover should happened after this critical boundary. According to Figure 4, it is obviously to see that in our approach, the hysteresis is decreasing while UE is closed to the Femtocell. The hysteresis is able to have the higher value while the UE resides on early/critical handover boundary. Meanwhile, the hysteresis is able to have the lower value while the UE is closed to the late handover boundary.

Similarly, early, late and critical handover boundary for each UE can be drawn in Figure 5. As we can see, cross the broad, most of the handover happened around the minimum handover hysteresis boundary and between the critical and late handover boundary. This is because:

- In terms of minimum handover hysteresis boundary, since this boundary is the theoretical boundary that expect all the UE should handover at this hysteresis. Due to the noise, interference from other Femtocells and UE's various speeds, some UE may handover early or late. The simulation results show that most of the handover hysteresis is around this boundary.

Fig. 5. The handover hysteresis and performance of each UE by the simulation

- In terms of early handover, as mentioned earlier, the proposed approach could offer the higher hysteresis when UE is not close to the Femtocell. This feature stops the UE from early handover. Moreover, near the critical boundary, some UEs have higher handover hysteresis. In terms of those UEs, in a centralised or static hysteresis approach, if hysteresis value is very small, those UEs could complete a handover before the early handover or have higher probability have the ping-pong appear.
- In terms of late handover, as mentioned earlier, the proposed P ensures the hysteresis value of a UE with various handover distance to be reduced to the minimum handover hysteresis which results in this UE can complete the handover before the it arrives below the late handover boundary. Since the noise and interference from other Femtocells, the simulation hysteresis should around the minimum handover hysteresis by theoretical. Moreover, near the late handover boundary, the UEs have lower handover hysteresis. In terms of those UEs, in a centralised or static hysteresis approach, if hysteresis value is very higher, those UEs could not complete a handover before the late handover boundary.
- In terms of speed, cross the broad, this approach offers the optimal hysteresis for UEs moving at different speed. As we can see, when the UEs move at a higher speed, they are higher probability of late handover. This similar results applies to UEs moving at a lower speed.

B. Performance Comparison of Proposed Algorithm and Centralised Hysteresis Approach

When set the $W_4 = 0$, this means that scheme has the same equation as the conventional method proposed in [7] which not considers the redundancy handover ratio. According to [7], if $W_1 = 0.3$, $W_2 = 0.6$ and $W_3 = 0.1$, that means that RLF, call-drop and ping-pong ratios are ordered by priority, thus the weight factors would be considered in normal LTE Femtocell scenario as mentioned earlier. The HAPI results are shown in Figure 6.

Figure 6 shows that compared to the conventional methods, the proposed DHUHA obviously improves the HAPI performance. In the conventional methods, without taking into account the individual UE side speed factor, it only provides the centralised hysteresis for all UEs. However, in DHUHA, every UE can have the distributed optimal hysteresis and performance would gain from every UE side.

Fig. 6. Comparison of proposed algorithm and centralised hysteresis approach base on HAPI

Fig. 7. Comparison of proposed algorithm and centralised hysteresis approach base on call-drop ratio

When we set $W_1 = 1$, $W_2=1$ and $W_4=1$ respectively, means that we consider each of RLF, ping-pong and redundancy handover ratios individually. The mean of RLF, ping-pong effect and redundancy handover ratios for DHUHA and centralised approach is list below:

- RLF: DHUHA (2.148%) and centralised approach (3.523%)
- Ping-pong: DHUHA (1.057%) and centralised approach (1.088%)
- Redundancy handover: DHUHA (1.031%) and centralised approach (1.192%)

Reflecting above, it summarises that a compromised centralised hysteresis is to blame for declined overall system performance, especially the RLF. However, it does not quite improve the ping-pong performance. This is because that hysteresis is not effective parameter to reduce the ping-pong issue compare to TTT. TTT is considered as the main factor to reduce the ping-pong ratio [3] [5] [27].

In Figure 7, we set $W_3 = 1$, means that the call-drop ratio is the only factor to be considered in this scenario. The result shows that compared to the conventional methods, the proposed DHUHA obviously reduce the call-drop ratio. This is because that optimal hysteresis can reduce RLF and incorrect handover which consequently decreases the chance of call-drop.

V. CONCLUSION

We have analysed the inbound handover process in two-tier of the Macrocell and Femtocell. By adjusting parameter and HAPI, we proposed the DHUHA to assist inbound handover for users moving at various speeds. By eliminating the drawbacks

of the conventional centralised approach, DHUHA works on both the UE-side and cell-side and applies an online hysteresis adjusting mechanism.

The proposed DHUHA has not only outperformed the existing approach with a lower value of combined evaluation parameter, HAPI, but also provides a better handover performance with a lower RLF, call-drop ratio and redundancy handover.

The current algorithm only considers the optimising hysteresis value, in the future, we would like to consider both the TTT and hysteresis together to achieve a distributed dynamic TTT and hysteresis optimisation for cross-tier handover. Moreover, we will also apply the approach where Femto-Femto handovers are allowed, where reducing unnecessary handovers are particularly desired.

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