Handover Scenario and Procedure in LTE-based Femtocell Networks

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***Abstract*—The deployment of Femtocell as the emerging wireless and mobile access technology becomes a solution for the bandwidth limitation and coverage issues in conventional mobile network system (macrocell). In this paper the handover procedure in femtocell network is investigated. The procedure is based on 3GPP LTE specification. Three handover scenarios: hand-in, hand-out and inter-FAP are considered and analysed. In order to achieve the optimize procedure, the handover decision policy based on mobility prediction is introduced and proposed. The reactive and proactive handover strategy is also proposed to mitigate the frequent and unnecessary handover. The result shows that reactive handover is the potential mechanism to mitigate the unnecessary handover.**

Keywords - handover; femtocell; 3GPP-LTE; reactive handover; proactive handover.

I. INTRODUCTION

Femtocell is the emerging network technology, which is defined as a low-cost, low-power cellular base station that operates in licensed spectrum to connect conventional, unmodified mobile terminals to a mobile operator's network. The coverage ranges of femtocells are in the tens of meters. They utilize broadband Digital Subscriber Line (DSL) or cable/fiber to the home (FTTH/FTTx)) Internet connections for backhaul to the operator's core network [1].

The Femto Access Point (FAP), also known as Home Base Station (HBS) or Home Node B (HNB) in 3GPP LTE terminology, is a main device in femtocell network that provides radio access network (RAN) functionality [1]. The FAPs were initially designed for residential use to get better indoor voice and data coverage, improving at the same time the macrocell reliability and promise to be a cost-effective

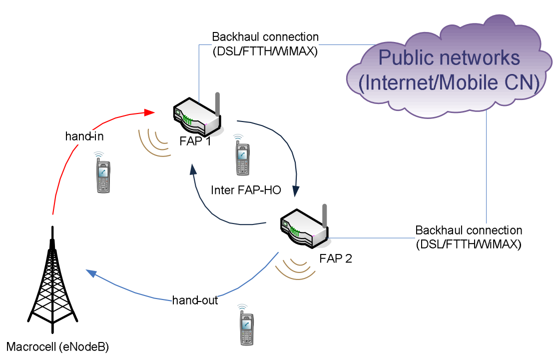

Figure 1. Handover scenario in femtocell networks

solution. It also increases the peak-bit rate in low coverage areas.

Femtocells and the conventional macrocells are seen as isolated networks, but they are not. In this paper, we describe the interaction between femtocells and macrocells in term of handover. The implementation of femtocell may cover the "blank area" and to increase the utilization of wireless capacity which is not covered by macrocell base station. Nonetheless, the availability of hundreds of FAPs in a particular area most likely increases the technological challenges in handover procedure. Another challenge is the mitigation the unnecessary handover since large number of FAPs can trigger the very frequent handovers even before the current initiated handover procedure is completed.

Research and technological development on handovers in macrocell network has been going extensively to provide better Radio Resource Management (RRM). Most of the researches are in the field of cellular networks focused on network-controlled horizontal handover where handover is executed between adjacent cells of the same network.

In term of IP-based wireless network, the research on handover has been done typically in wireless local area network (WLAN) based on WiFi IEEE802.11. Moreover, the client-based handover began to be investigated when the Worldwide Interoperability for Microwave Access (WiMAX) IEEE802.16 networks, 3GPP Long Term Evolution (LTE)/Long Term Evolution-Advanced (LTE-A) as well as Mobile IPv4/IPv6 are introduced. In addition, the inter-system handover or vertical handover is also going investigated intensively. The research in both layer-1 (L1-physical) and layer-2 (L2-Medium Access Control - MAC) is undertaken in order to achieve the most efficient handover and to reduce the handover overhead.

In this paper, the handover between femtocell and macrocell is investigated. Three handover scenarios are considered as shown in Fig. 1. Handover procedure is based on 3GPP LTE specification.

The rest of the paper is organized as follow: Section 2 reviews some related works of handover in femtocel network. Section 3 describes the LTE-based handover in femtocell network. The handover scenarios and optimization proposal are presented as well. In Section 4, the handover signalling flow is analyzed in each scenario. Section 5 provides the proposal of handover optimization algorithm and a performance evaluation of the proposed algorithm, as

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well as a result of the performance evaluation. We conclude our work in Section 6.

II. RELATED WORK

In the femtocell network, several research works have been published. The authors in [2] overviewed the 3GPP LTE and the characteristic of Home-eNodeB (HeNB). Their work included the description of mobility support in 3GPP LTE, the handover procedure in LTE and the deployment scenario of HeNB. In addition, some mobility management issues such as handover scenario, mechanism for searching the HeNB in the Closed Subscriber Group (CSG), cell reselection and handover decision parameters have also been described. The work concluded with the recommendation for further work to deal with such issues.

More detail works on handover in femtocell network have also been published. In [3], the work focused on the handover from the macro-tier to the femto-tier in CDMA network. It has been revealed that the User Equipment (UE) may be required to scan the whole femto radio spectrum when switch form macrocell to femtocell, however it is assessed as an expensive operation. To deal with this issue, the cache scheme for femtocell reselection is proposed. By considering the random walk movement, the three user movement models were applied to obtain the UE's movement history. The history included the number of FAP that has been visited. The idea behind this scheme was to obtain the most recently visited order of FAPs stored in the cache. The scheme seems effective in the open subscriber group (OSG) femtocell with plenty of FAPs, however it is relatively inefficient in the femtocell's CSG or in the few number of FAPs.

In order to integrate the femtocell into the system, some modifications on existing network and protocol architecture of Universal Mobile Telecommunication System (UMTS) based macrocell network has been proposed in [4]. The modifications included the change of signal flow for handover procedures and the measurement of signal-to-interference ratio for handover between macrocell and femtocell. The frequent and unnecessary handover is also considered. The analysis is taken on the concentrator-based and without concentrator-based femtocell network architecture. The result shown, the call admission control (CAC) scheme is effective to prevent the unnecessary handover.

In [5], the handover procedure between the HeNB and eNodeB has been proposed to be modified. A new handover algorithm based on the UE's speed and Quality of Service (QoS) is proposed. Three different velocity environments have been considered in the algorithm i.e., low speed (0-15 km/h), medium speed (15-30 km/h) and high speed (>30 km/h). In addition, the real-time and non-real-time traffics have been considered as QoS parameters. The comparison analysis shown that the proposed algorithm has a better performance then traditional handover algorithm in order to reducing the unnecessary handovers and the number of handovers. However, the assigned user velocities seem unrealistic since the HeNB at home deals only with the very low speed (0-5 km/h).

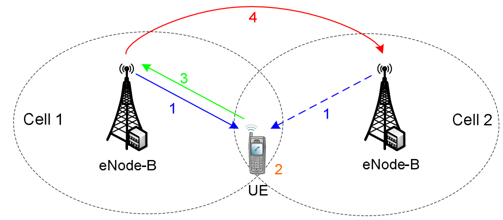

Figure 2. Handover process in 3GPP-LTE

III. HANDOVER IN FEMTOCELL NETWORK

A. *Handover in 3GPP-LTE Macrocell*

The 3GPP LTE for the 4G mobile system specifies the handover procedure and mechanism that support various users' mobility [6] [7]. Handover process is divided into four parts as shown in Fig. 2: UE measures downlink signal strength (blue line 1), processing the measurement results (2) and sends the measurement report to the serving eNodeB (green line 3). The serving eNodeB then makes the handover decisions based on the received measurement reports (red line 4).

The message sequence diagram of the LTE handover procedure is shown in Fig. 3. The handover procedure consists of 3 parts:

- Handover preparation; in this part, UE, serving eNodeB and target eNodeB make preparation before the UE connect to the new cell. The main message and process are described as follows:
  1. Measurement control/report (messages 1/2); the serving eNodeB configures and triggers the UE measurement procedure and UE sends measurement report message to serving eNodeB.
  2. Handover decision (messages 3/4); the serving eNodeB offers the handover decision based on received measurement report message from UE.
  3. Admission control (messages 5/6); the target eNodeB

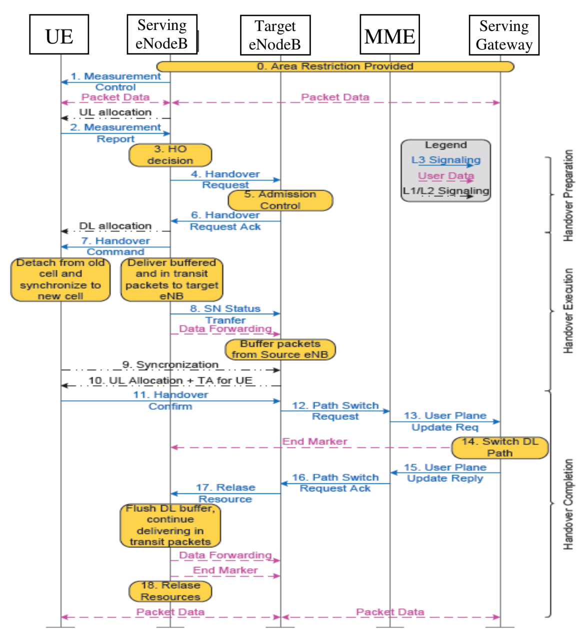

Figure 3. Message sequence diagram of handover Procedure in 3GPP-LTE [6]

performs the admission control dependent on the quality of service (QoS) information and prepares handover with L1/L2.

4. Handover command (message 7); the serving eNodeB sends the handover command to UE.

- Handover execution; on the execution part, the processes are described as follow:

5. Detach from old cell and synchronize to the new cell (messages 8 – 10); UE performs the synchronization to the target cell and accesses the target cell.

- Handover completion; this part includes the following processes:

6. Handover confirm and path switch (messages 11 – 16); the serving-Gateway switches the path of downlink data to the target side. For this, the serving-Gateway exchanges massage with Mobility Management Entity (MME).
7. Release resource (messages 17/18); upon reception of the release message, the serving eNodeB can release radio and control of related resources. Subsequently, target eNodeB can transmit the downlink packet data.

B. *Handover Scenario in Femtocell Network*

All mobile systems including the femtocell network implement a handover procedure to support the user's mobility. The handover, in one side allows communication during user's movement in the network. On the other side, it significantly increases signalling overhead in the network.

According to [8], it most likely that the soft handover will not be implemented in femtocell due to limited frequency allocation for femtocells. In addition, due to technological challenges and system operator requirements, the initial 3GPP specification for handover in femtocell focused on one direction only that is from FAP to macrocell eNodeB [9].

Despite having some constraints, in this paper we consider all possible handover scenarios between eNodeB and FAP and between FAPs. There are three possible handover scenarios in femtocell, as depicted in Fig. 1:

- Hand-in; this scenario presents the handover where an UE switch out from macrocell eNodeB to FAP.
- Hand-out; represents the handover that is performed from FAP to macrocell eNodeB.
- Inter-FAP handover; it corresponds to the scenario of handover from one FAP to another FAP. In this scenario all FAPs are assumed to be placed at the same location and served by the same service provider.

C. *Decision Policy of Handover*

One of the challenges in the handover procedure is corresponded to the handover decision mechanism. The common metrics for handover decision mechanism include carrier to Interference-and-Noise Ratio (CINR), Receive Signal Strength Indicator (RSSI) and Quality of Service (QoS). However, those metrics are quite demanding to deal with advanced handover requirement, for instance the fast handover in femtocell network that consist hundreds of possible target FAP. Therefore, the new handover decision mechanism metrics is necessary to be determined.

The handover decision option basically are network-controlled handover in which the decision to implement handover is taken by the eNodeB (in case of hand-in) or FAP (in case of hand-out and inter-FAP) to which the UE is currently attached. However, the support of client-based handover in which initiated by the UE becomes more common. This option gives the handover process more efficient, since any changing of necessary parameters or events (such as CINR, RSSI, coverage, the QoS provided by the network, the probability of next position, etc.) can be monitored by the UE from its wireless interfaces, then use them to decide to trigger the handover.

In network controlled mode, the serving eNodeB decides to perform handover to target FAP by comparing the RSSI that received by UE and the RSSI from the FAP. However, when the CSG is deployed, other parameters e.g., service cost, load balancing, and speed status of UE, which might influenced the handover decision should also be considered. Since the femtocell system offers the different billing models, the user's billing is sum up by whether user is using the FAP. Therefore it is important for UE to handover to the accessible FAP fast.

In the load balancing point of view, when a large number of active UEs are located in a given cell, available resources may be insufficient to meet the QoS for the real time service. But, it may offer the good performance for the best effort service. Particularly, in the FAP case where the available user is limited, if the available resource is too short for UE to handover to CSG cell, then it needs to handover to another accessible FAP or to macrocell eNodeB.

D. *Proposed Mobility Prediction*

The mobility prediction of UE may also be considered for the handover decision. In this paper we introduced the movement prediction mechanism as an additional parameter for handover decision procedure. This parameter is sent in the system information broadcast of serving cell. This decision mechanism can be applied on all handover scenarios.

Knowing the current position and velocity of an UE can obviously help to estimate where the UE is heading, thus the next position of UE to where the handover might be performed can be predicted.

In this handover decision procedure, it is assumed that the UE is able to periodically (e.g., every 1s) send its position to the serving cell (either eNodeB or FAP) during its moving. In the mean time, the serving cell maintains database of all possible target cell to where the handover might be performed. The probability of transition from one cell to another is modelled as a Markov process as approximated in (1):

$$\boldsymbol{p}_{\mathbf{n}} = [\boldsymbol{p}] \times [\mathbf{P}_{\mathbf{n-1}}] = [\boldsymbol{p}_{\mathbf{n-1}}] \times [\mathbf{P}] \qquad (1)$$

where $\boldsymbol{p_n}$ is denoted as the probability of UE's position after $\boldsymbol{n}$ transitions, $\boldsymbol{p}$ is the initial distribution matrix, $\boldsymbol{P_{n-1}}$ is denoted as current transition probability matrix, $\boldsymbol{p_{n-1}}$ is the initial distribution after $\boldsymbol{n}$ transitions and $\boldsymbol{P}$ is the original transition probability matrix. Detail of mobility prediction method for optimized handover process can be found in [10].

Using this method, the likely path of an UE can be estimated in advance, so both the handover probability and the remaining time before handover can be derived.

Upon receiving the prediction result, serving cell seeks all possible target cells. One of the neighbouring cells is assigned as the predicted target cell, to where the handover is triggered. Serving cell then performs coordination with the predicted target cell via backbone. If the target cell is available for handover, the UE will proceed the handover process.

E. Proposed Proactive and Reactive Handovers

Since the handover procedure may be initiated by either the cell (eNodeB/FAP) or the UE, therefore two handover strategies i.e., proactive and reactive handover [11] [12], are proposed to be applied to trigger the handover

a) Proactive Handover

In the proactive handover strategy, the handover may occur any time before the level RSSI of current eNodeB reaches the handover hysteresis threshold (HHT). The proactive handover strategy attempts to estimate network characteristics of a specific position before the UE reaches that position. Assumed the UE discovered that the new target eNodeB's RSSI (or FAP's RSSI) overpasses the origin one from its serving eNodeB/FAP. The UE calculates the time left before the normal handover is triggered, then triggering the handover earlier before HHT. This strategy is expected to minimize packet loss and high latency during handover.

b) Reactive Handover

Due to small FAP's coverage, its lower power and the density of FAPs, the UE in femtocell system will facing the very frequent and unnecessary handover since the UE will move from one FAP to other FAP repeatedly. To mitigate the overhead of handover, the reactive handover scenario is applied. Reactive handover tends to postpone the handover as long as possible, even though it has discovered the new RSSI signal. The handover is triggered only when the UE (almost) lose its serving eNodeB/FAP signal.

IV. HANDOVER PROCEDURE AND SIGNALLING FLOW

The LTE-based handover procedure within the femtocell network is obviously intended to minimize the handover interruption time. The handovers are also designed to be seamless when occur to/from other technology platforms (2G/3G, WiMAX, etc.).

Several functional elements take part during the handover process. The evolved UMTS Terrestrial Radio Access Network (E-UTRAN) is the key element since it provides all system functionalities included the physical (PHY), medium access control (MAC), radio link control (RLC), and packet data control protocol (PDCP) [13]. It consists a single node i.e., eNodeB or HeNB/FAP. It also provides radio resource control (RRC) functionality that corresponds to handover procedure.

E-UTRAN interacts with the Evolve Packet Core (EPC) system that consist the Mobility Management Entity (MME), Serving Gateway (SGW) and Femto Gateway (Femto-GW). The interaction between all functional elements of EUTRAN and EPC is depicted in Fig. 4.

Mobility Management Entity (MME) is the key control node for the LTE access network [13]. In handover process, MME is responsible for choosing the serving-Gateway for an UE at the initial attach and at time of intra-LTE handover involving Core Network (CN) node relocation.

Another element that takes part in handover process is serving-Gateway that responsible to route and forward user data packets. The serving-Gateway is also acting as the mobility anchor for the user plane during handovers and as the anchor for mobility between LTE and other 3GPP technologies.

The last element is called Femto Gateway that provides the gateway through which the FAP gets access to mobile operator's core network. Femto-GW is responsible for protocol conversion and also creates a virtual radio network control (RNC) interface to the legacy network without requiring any changes to CN elements. It is physically located on mobile operator premises [14].

In addition, 3GPP also specified two standard interfaces i.e., X2 and S1 interfaces, for the Evolved Packet System (EPS). The X2 interface provides capability to support radio interface mobility and shall support the exchange of signaling information between eNodeB macrocells. Therefore, for handover between eNodeB macrocells, the procedure is performed without EPC involvement. Preparation and exchange of signaling flows in the handover procedure are directly between eNodeB using X2 interface. On the other hand, the S1 interface supports many-to-many relations between EPC's elements (MME/SGW) and eNodeB. Moreover S1 is also used for the communication

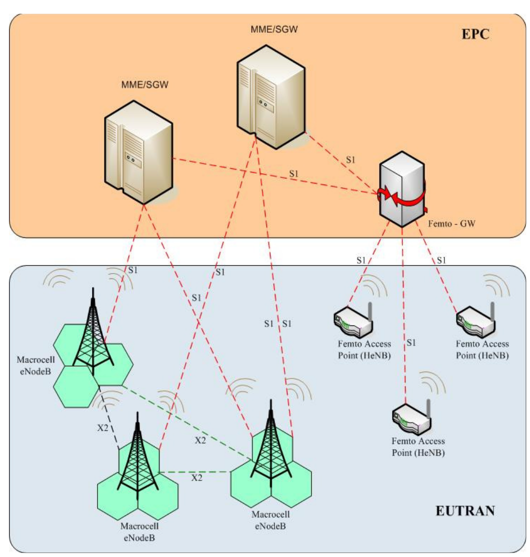

Figure 4. E-UTRAN Architecture including the deployment of Femtocell

between FAP/HeNB with the MME/SGW through the Femto-GW. Specifically, the connection to MME is using S1 control plane (S1-C) interface and the connection to SGW is using S1 user plane (S1-U) interface.

The handover within eNodeB macrocell can happen without restriction. In contrast for FAP, since the CSG is applied not every UE can access the FAP. The handover procedure consist a set of signaling flow that exchanging from one element to others. In case of the proposed handover scenarios, we also proposed the typical signaling flow for each scenario.

A. *Hand-in Procedure*

The handover from macrocell into femtocell is quite demanding and complex since there are hundreds of possible targets FAPs. In hand-in procedure, the UE needs to select the most appropriate target FAP. The interference level should be considered as a decision parameter. Moreover, the proposed mobility prediction is also considered in handover decision to optimize the handover procedure. The signaling flows of the proposed handover procedure for hand-in can be shown in Fig. 5.

B. *Hand-out Procedure*

Handover procedure from FAP to macrocell eNodeB is relatively uncomplicated. The UE has no option to select the target cell since there only the macrocell eNodeB. When the RSSI from eNodeB is stronger than FAP's RSSI, the UE will be connected directly without a complex interference calculation and authorization check as in hand-in scenario. The handover signaling flows is depicted in Fig. 6.

C. *Inter-FAP Procedure*

The procedure for inter-FAP handover is similar to hand-in procedure since the UE will facing hundreds of possible target when out of its serving FAP. For this procedure we also proposed the mobility prediction as the handover decision policy.

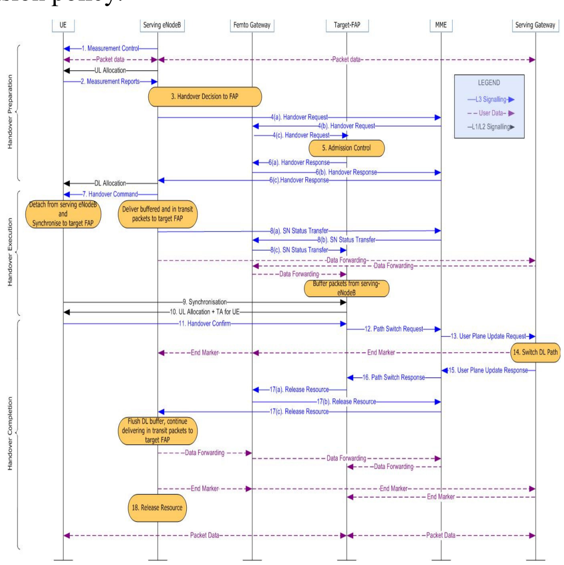

Figure 5. Signaling flow of hand-in (handover from macrocell to femtocell)

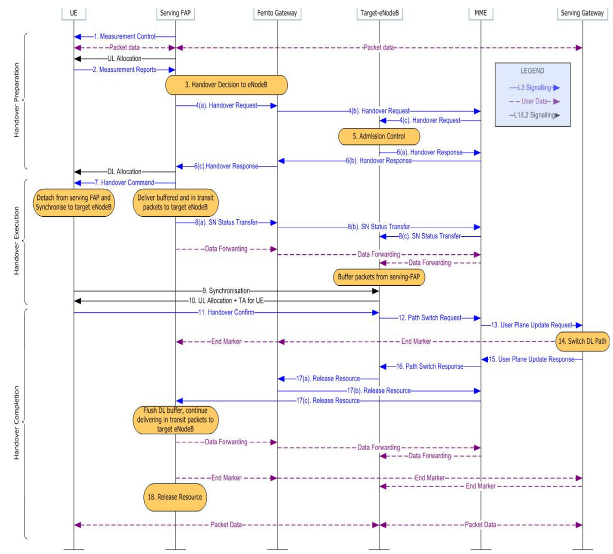

Figure 6. Signaling flow of hand-out (handover from femtocell to macrocell)

V. HANDOVER OPTIMIZATION

A. *Optimization Algorithm*

As already discussed, hand-in and inter-FAP is more complex than the handout. The main constrain on those scenarios is the handover interruption time due to delay on selection of target FAP. Another issue is the possibility of unnecessary handover and the very frequent handover due to the small coverage and low power of FAP.

To cope with these constraints, we proposed the mobility prediction method as mentioned in previous section. Knowing in advance where an UE is heading allows the system to take proactive steps. The mobility prediction mechanism often involves investigation how UEs physically move and it can estimate the final position of the UE. Once the final position of the UE is predicted, then the system will or decide to perform the handover to the nearest available FAP. This method will enhance the conventional handover decision mechanism which is based only on signal quality (RSSI/CINR) and QoS. The unexpected impact of handovers can be mitigated by deploying the reactive handover. In [4]

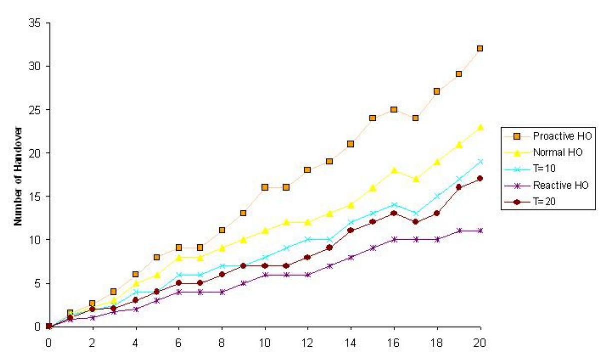

Figure 7. Preliminary performance of reactive/proactive handover

the call admission control has been proposed by forcing the UE to stay for the particular time at the new connected FAP (typically 10 seconds and 20 seconds have been assigned as the threshold time). In reactive handover, the handover will be postponed as long as possible until the UE reach the target FAP as the result of mobility prediction.

The pseudo code of optimization algorithm can be seen below. For the UE speed, we consider the maximum speed of 10 km/h.

```
1.   INITIALISATION # HO algorithm
2.   EXAMINE V       # V is the speed of UE
3.   IF V > 10 Km/h
          NO HAND-IN
4.   ELSE IF V> 5 Km/h
          PERFORM MOBILITY PREDICTION
          IF Traffic = Real-Time
                    PERFORM PROACTIVE HO
          ELSE IF Traffic = Non Real-Time
                    PERFORM REACTIVE HO
5.   ELSE IF Traffic =Real-Time
          PERFORM PROACTIVE HO
          IF Traffic = Non Real-Time
                    PERFORM REACTIVE HO
6.   ELSE
          PERFORM NORMAL HO
     RETURN
```

B. *Preliminary Result and Discussion*

In order to verify the performance of handover procedure, the proposed algorithm has been analyzed. We manage some assumption regarding the UE mobility and the femtocell. The movement prediction of UE is approximated based on Markov-chain as stated in (1). The random way point has been used for the mobility model. Number of FAP is assumed 20 and 3 for eNodeB macrocell. The shape of FAP coverage area is assumed to be circular, with the coverage radius equal to 10 m. All entities are located in the area of 1 Km^2 with non uniform FAP density. In addition, though the random waypoint mobility model is used in the prediction process, it can be assumed that the UE does not walk randomly, but rather several paths could be followed. The result based on Matlab simulation is depicted in Fig. 7.

As can be seen, the number of handover increases almost linearly when the number of FAP is increased. The reactive handover has the lowest number of handovers compared to other schemes. Though it has proven that the performance of reactive handover is better to mitigate the unnecessary handover, the further study is still needed when this algorithm is integrated with the RF and traffic criteria that have been assigned as the handover initiation policy by the 3GPP standard.

VI. CONCLUSION

In this paper the handover procedure on LTE-based femtocell has been investigated and analyzed in three different scenarios, i.e., hand-in, hand-out and inter-FAP. The hand-in and inter-FAP scenarios are quite demanding than hand-out since plenty of target FAPs were involved in the handover process. It is a challenge to make a selection of the target FAP. The mobility prediction mechanism can be used to predict the heading position of the UE and then estimate the target FAP to which the UE may be connected. The reactive handover is the potential mechanism to mitigate the unnecessary handover. The further work is needed to find the most optimize handover procedure by integrating the proposed scheme and algorithm with the handover decision criteria specified by the standard.

ACKNOWLEDGMENT

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