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# The Study of Handover Procedure in LTE-based Femtocell Network

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*Abstract*—Wireless systems have the capability to address broad geographic area without the costly infrastructure deployment. However, the main drawback resides in the bandwidth limitation and the coverage for single access point. The deployment of Femtocell as the promising wireless access technology becomes one of the possible solution. In this paper the handover procedure in femtocell network is studied. The 3GPP LTE based handover is analysed in three scenarios: hand-in, hand-out and inter-FAP. In addition, the reactive and proactive handover strategy is also proposed as the handover decision policy to diminish the very frequent and unnecessary handovers.

*Keywords – femtocell, HNB, HeNB, handover, hand-in, hand-out, reactive HO, proactive HO.*

## I. INTRODUCTION

Nowadays, handover has turned out to be an obligatory functionality on all mobile wireless systems. Continuous connection during user mobility among cells is allowed due to handover procedure, but on the other hand, the handover also brings a significant increase of Medium Access Control (MAC) overhead and also increases the delay of packet delivery to the destination user.

The implementation of the new emerging network technology i.e., femtocell at home and residential area is expected to cover the "blank spot" and to boost the utilisation of wireless capacity which is not covered by conventional macrocell base station. However, the availability of hundreds femto access points (FAPs) in a particular area most likely increase the technological challenges in handover procedure. Another challenge is the mitigation of unnecessary handover since it can trigger the very frequent handovers even before one already initiated handover procedure is completed.

Work on handovers in macrocell network has been going extensively. Most of the researches are in the field of cellular networks and done by the mobile operators focused on network-controlled horizontal handover to enhance the handover execution between adjacent cells in the same network. In term of internet protocol (IP)-based wireless network, the research on handover has been done typically in wireless local area network (WLAN) based on IEEE802.11 WiFi. The development of various broadband wireless access technologies, e.g., 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, forced the client-based handover began to be investigated. Accordingly, the inter-system handover or vertical handover is going investigated intensively. The research in both L1 (physical layer) and L2 (MAC layer) is undertaken in order to achieve the most efficient handover and reduce the handover overhead.

In term of femtocell network, several research works have been published. In reference [1], the authors outlined the characteristic of Home-eNodeB (HeNB), the official 3GPP terminology for FAP. Their work described the mobility support in 3GPP LTE, including 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 overviewed. The paper is concluded with the recommendation for further work to deal with the issues.

The optimisation of efficient route for femtocell-based all IP networks is carried out in [2]. The Session Initiation Protocol (SIP) signalling routes and packet route of FAP resided in IP domain was compared with the FAP connected to Internet protocol Multimedia Subsystems (IMS) core network through a Radio Access Network (RAN). For this purpose, the authors created the testbed for each FAP scenario. The end-to-end system delays were measured and reported. Unfortunately, the authors did not provide the analysis on the delay budget of the system. Moreover, handover is also not concerned in their work.

More comprehensive works on handover in femtocell network have been published in [3], [4] and [5].

The authors in [3] focused the macro-tier to the femto-tier handover mechanism in CDMA network. They revealed that the User Equipment (UE) required to scan the whole femto radio spectrum when switched from macrocell to femtocell, which 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 aim of this scheme is to obtain the most recently visited order of FAPs that have been stored in the cache. Each FAP data in the cache is limited to 28 byte only; therefore not too much memory and time consumed to capture the most recently visited FAP in the cache. The scheme seem 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.

The handover procedure in macrocell/femtocell integrated network has been done in [4]. Some modifications on existing network and protocol architecture of Universal Mobile Telecommunication

System (UMTS) based macrocell network has been proposed in order to integrate the femtocell into the system. The modifications included the change of signal flow for handover procedures and the measurement of signal-to-interference noise 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 that the call admission control (CAC) scheme is effective to prevent the unnecessary handover.

In other work, the handover procedure between the HeNB and LTE eNB has been proposed to be modified in [5]. 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 mobile state (0-15 km/h), medium mobile state (15-30 km/h) and high mobile state (>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 better performance then traditional handover algorithm in order to reducing number of handovers and the unnecessary handovers.

The rest of the paper is organised as follow: Section 2 describes the LTE-based handover in femtocell network. Some handover scenarios and optimisation proposal are presented as well. In Section 3, the handover signalling flow is analysed in each scenario. Section 4 provides the proposal of handover optimisation algorithm and a performance evaluation of the proposed algorithm. We conclude our work in Section 5.

## II. LTE-BASED HANDOVER IN FEMTOCELL

### A. eNodeB Macrocell Handover

The 3GPP LTE for the fourth generation (4G) mobile system specifies the handover procedure and mechanism that support various user's mobility [6]. The handover procedure on 3GPP LTE is defined in [7].

A handover process, in general, is divided into four parts as shown in Fig. 1: UE measures downlink signal strength (1), processing the measurement results (2) and sends the measurement report to the serving eNodeB (3).
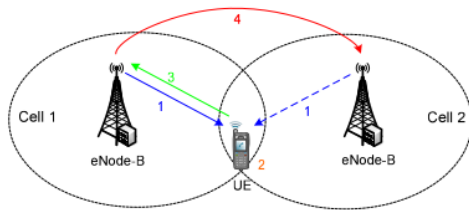
Figure 1. Handover process in 3GPP-LTE

The serving eNodeB then makes the handover decisions based on the received measurement reports (4).

The message sequence diagram of the LTE handover procedure is shown in Fig. 2. 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 performs the handover decision based on received measurement report message from UE.
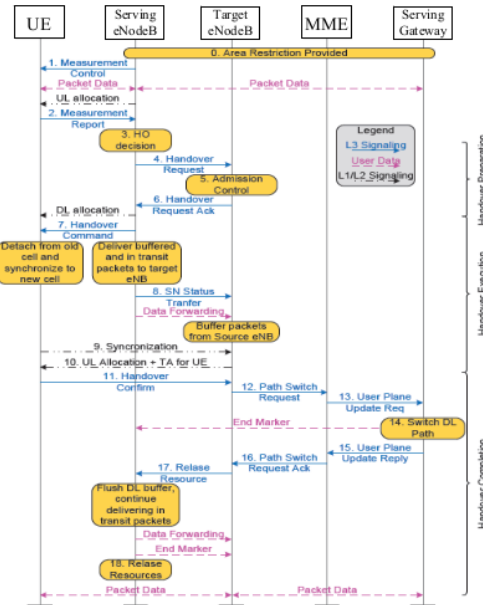
Figure 2. Message sequence diagram of handover procedure in 3GPP-LTE [6]

  3. Admission control (messages 5/6)

  The target eNodeB 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 synchronise 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

Handover procedure is critical to support the user's mobility in all recent mobile systems including the femtocell network. Handover allows communication during user's movement in the network. However, it generates significantly the signalling overhead in the network.
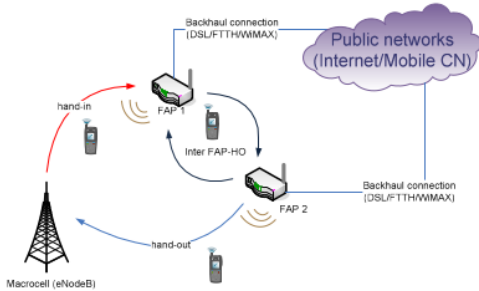


Figure 3. Handover scenario in femtocell network

According to [8], due to limited frequency allocation for femtocells, it most likely that the soft handover will not be implemented. Moreover, 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. 3:

- Hand-in; represents the handover scenario 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 the same area and served by the same service provider.

### C. Handover Decision Policy

Handover decision mechanism is a challenge in the handover procedure. 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.

Basically 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 eNodeB macrocell.

### D. 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 by serving cell in the system information broadcast. 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 cells 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):

$$p_n = [p] \text{ x } [P_{n-1}] = [p_{n-1}] \text{ x } [P] \tag{1}$$

where $p_n$ is denoted as the probability of UE's position after $n$ transitions, $p$ is the initial distribution matrix, $P_{n-1}$ is denoted as current transition probability matrix, $p_{n-1}$ is the initial distribution after $n$ transitions and $P$ is the original transition probability matrix. Detail of mobility prediction method for optimised 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. 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 encounter the very frequent and unnecessary handover since the UE moves from one FAP to other FAP repeatedly. To mitigate the generated 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 or the most probable position of UE is predicted.

### III. HANDOVER SIGNALLING FLOWS

The LTE-based handover procedure within the femtocell network is obviously intended to minimise the interruption time. The handovers are also designed to be seamless when occur to/from other technology platforms (e.g., 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) [3]. 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.
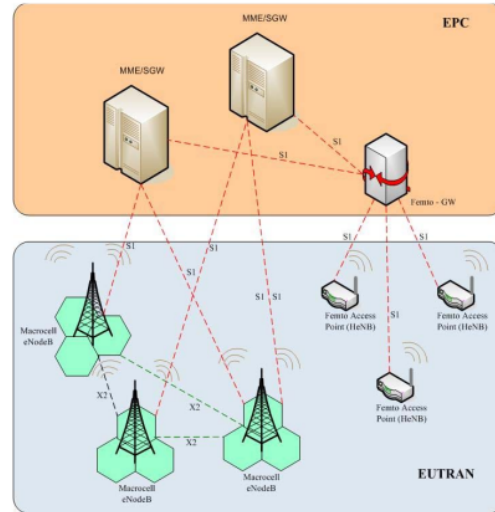


Figure 4. The deployment of Femtocell in E-UTRAN Architecture

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 Femto-GW 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 interface, for the Evolved Packet System (EPS). The X2 interface provides capability to support radio interface mobility and shall support the exchange of signalling information between eNodeB macrocells. Therefore, for handover between eNodeB macrocells, the procedure is performed without EPC involvement. Preparation and exchange of signalling 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 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 signalling flow that exchanging

from one element to others. In case of the proposed handover scenarios, we also proposed the typical signalling flow for each scenario.

### A. Hand-in Procedure

The handover from macrocell into femtocell is quite demanding and complex since there are hundred 12 of possible targets FAPs. In hand-in procedure, the 12 E needs to select the most appropriate target FAP. The interference level should be considered as a basic decision parameter. Moreover, the proposed mobility prediction is then considered in handover decision to optimise the handover procedure. The signalling flows of the proposed handover procedure for hand-in can be shown in Fig. 5.
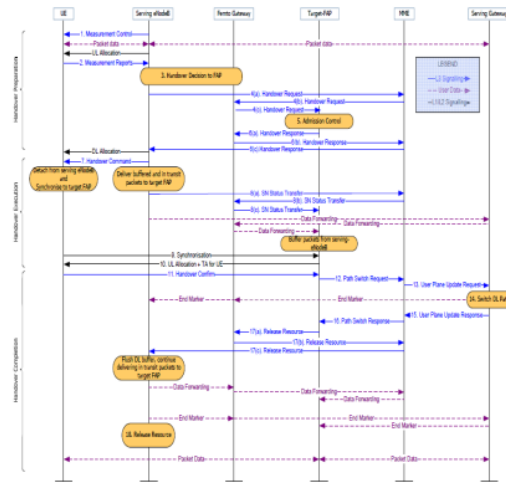


Figure 5. Hand-in signaling flow (handover from macrocell to femtocell)

### 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.
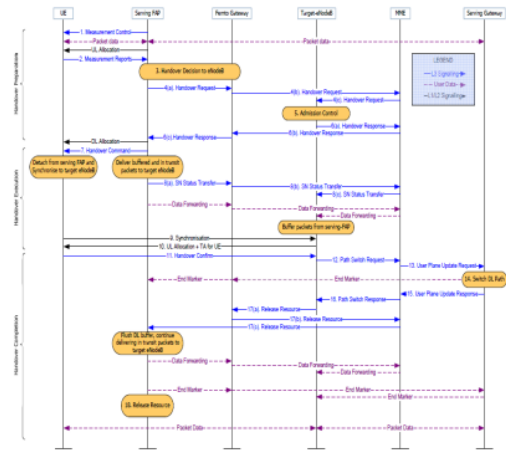


Figure 6. Hand-out signaling flow (handover from femtocell to macrocell)

When the RSSI from eNodeB is stronger than FAP's RSSI, the UE will connected directly without a complex interference calculation and authorisation check as in hand-in scenario. The handover signalling 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.

## IV. HANDOVER OPTIMISATION ALGORITHM

### A. Optimization Algorithm

As already discussed, hand-in and inter-FAP are more complex than the hand-out. 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] 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 for 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 optimisation algorithm can be seen below. For the UE speed, we consider the maximum speed of 10 km/h.

```
1.  INITIALISATION # HO algorithm
2.  EXAMINE RSSI/CINR # either RSSI or CINR
3.  IF RSSI_BS < RSSI_FAP
            Perform HAND-IN
4.  ELSE
            No HAND-IN
5.  EXAMINE V        # V is the speed of UE
6.  IF V > 10 Km/h
            NO HAND-IN
7.  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
8.  ELSE IF Traffic =Real-Time
            PERFORM PROACTIVE HO
            IF Traffic = Non Real-Time
                    PERFORM REACTIVE HO
9.  ELSE
            PERFORM NORMAL HO
    RETURN
```

### B. Preliminary Result and Discussion

In order to verify the performance of handover procedure, the proposed algorithm has been analysed. 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) and [10]. The random way point has been used for the mobility model, however it can be assumed that a MS does not walk randomly, but rather several paths could be followed. Number of FAP and eNodeB macrocell is assumed to be 20 and 3 respectively. 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. The movement of the UE is assumed to across the FAPs, from FAP #1 to FAP #20. The result is depicted in Fig. 7 and Fig. 8.
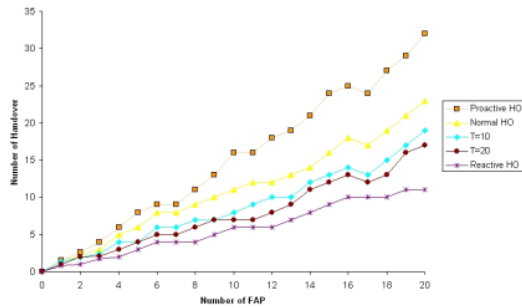


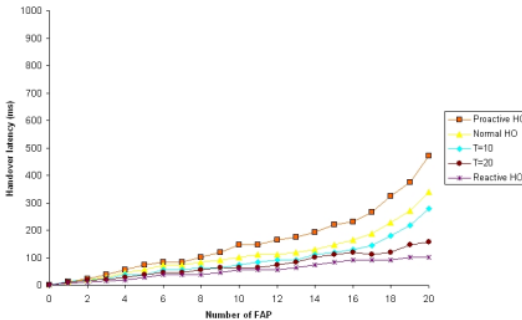Figure 7. The performance of handover in term of number of handover



Figure 8. The performance of handover in term of handover latency

As can be seen on Fig. 7, 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. In addition, Fig. 8 shows that reactive handover scheme has the lowest handover latency. 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.

### V.  CONCLUSIONS

In this paper the handover procedure on LTE-based femtocell has been studied and overviewed in three different scenarios, i.e. hand-in, hand-out and inter-FAP. The handover signalling flows have also been analysed. 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 optimise handover procedure by integrating the proposed scheme and algorithm with the handover decision criteria specified by the standard.

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