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Handover procedure and decision strategy in LTE-based femtocell network

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Abstract Wireless systems have the capability to serve users over broad geographic area without using a costly network infrastructure. However, the main drawback of these systems represents the bandwidth restrictions and coverage. Deployment of femtocell as the emerging promising wireless access technology becomes one of possible solution how to overcome some of the drawbacks. In this paper, we investigate the handover procedure in femtocell network considering, both types of handovers, horizontal and vertical. The 3GPP LTE based handover procedure is analysed for three scenarios: hand-in, hand-out and inter-FAP. In addition, the reactive handover decision policy, based on the prediction of user movement and the prediction of target-FAP, is proposed as a way to eliminate frequent and unnecessary handovers.

Keywords LTE · Femtocell · Handover · Prediction of user's movement

1 Introduction

Femtocell is an emerging mobile network technology that operates as small-scale cellular base stations. The main device of a femtocell is known as Femto Access Point (FAP) which is categorised as a new type of Customer Premises Equipment (CPE). The FAP is specified 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 over the fixed broadband connection, such as the Digital Subscriber Line (DSL) or cable/fibre to the home (FTTH/FTTx). The FAP, also known as Home eNode B (HeNB) in the 3GPP LTE terminology, is specifically designed to be used in home, office or residential area. Femtocells allow mobile operators to improve indoor coverage, mainly in case where access is limited or even unavailable. The coverage ranges of the FAPs are in order of tens of meters [1].

There are two types of FAP devices: *integrated* and *standalone*. The integrated FAP includes Radio Access Network (RAN) and the Femto Gateway (Femto-GW) functionalities that are integrated in a single CPE device. On the other hand, the standalone FAP only integrates the RAN functionalities. It is physically connected with the FGW which is placed somewhere in the mobile operator premise via an Ethernet/Internet connection. The RAN functionalities enable a FAP to support the Radio Resource Management (RRM) and mobility management, including the handover mechanism.

On one hand, the handover makes possible continuous connection while user is moving among cells. On the other hand, the handover also introduces a non-negligible increase of signalling overhead and increases the delay of packet delivery to the destination.

Traditionally, the handover occurs in the conventional macrocell network when an User Equipment (UE) is moving from one cell to another one. The handover should also be supported by femtocell-based network. In this paper, we describe interaction between femtocells and macrocells in term of handover. The availability of hundreds of FAPs in a

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particular area introduces technological challenges such as the mitigation of unnecessary handovers since a large number of FAPs can trigger the very frequent handovers even before the currently initiated handover procedure is completed. Considering limited frequencies for femtocells, the soft handover will not be likely implemented [2]. Moreover, due to technological challenges and system operator requirements, the initial 3GPP specifications mainly focus on the handover from femtocell to macrocell [3].

In this paper we consider the hard handover mode. A new handover procedure, based on 3GPP LTE technology, is proposed to prevent those technical issues and to provide the optimised decision strategy for handover process in femtocell network.

Despite of having some constraints, there are three possible handover scenarios in the femtocell environment (Fig. 1):

- Hand-in; represents the handover scenario where an UE connection is handed over from Macro Base Station (MBS) to FAP.
- Hand-out; represents the handover that is performed from FAP to MBS.
- Inter-FAP; represents the handover scenario where an UE connection is handed over from FAP to FAP In this scenario, all FAPs are assumed to be placed in the same area and operated by the same service provider.

The rest of the paper is organised as follow. Section 2 gives an overview of the state of the art related to handover procedure. Section 3 describes the LTE-based handover in the femtocell network. In Sect. 4, we introduce our propose handover procedures in the femtocell network, including the horizontal and vertical handovers. In addition, some handover scenarios and optimisations are presented as well. In Sect. 5, the performance analysis based on mobility prediction is provided. Section 6 outlines the proposed handover optimisation algorithm and provides performance evaluation. Finally, we conclude our work in Sect. 7.

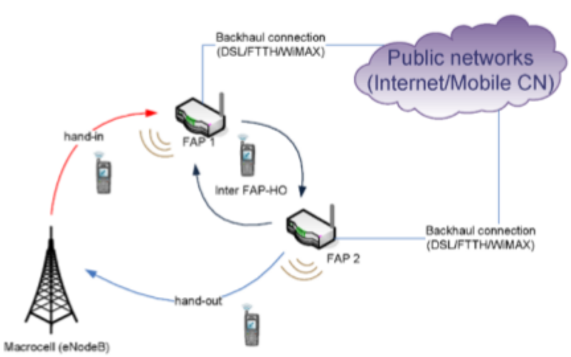

Fig. 1 Handover scenario in the femtocell-based network

2 Related works

Research and technological development on handovers procedure in the macrocell network have been going extensively in the last several years. Most of the works focuses on network-controlled horizontal handover where the handover procedure is executed between adjacent cells of the same network.

2.1 Horizontal handover

The characteristic of 3GPP HeNB including the description of mobility support and the handover procedure are carried out in [4]. The mobility management issues such as mechanism for searching HeNB in the Closed Subscriber Group (CSG), cell reselection and handover decision parameters based on Received Signal Strength Indicator (RSSI), service cost, load balancing or UE speed are also described by the authors.

The optimisation of Session Initiation Protocol's (SIP) routing for femtocell-based all Internet Protocol (IP) networks is carried out in [5]. The authors developed two testbeds for FAP connection scenario i.e., the connection through all-IP network and the connection to Internet protocol Multimedia Subsystem (IMS) through a RAN. The SIP signalling routes and packet routes of the FAP (in both scenarios) are observed and compared. The end-to-end system delays are also measured and reported. However, the authors do not analyse the handover procedure itself.

More comprehensive works on handover in the femtocell network are done in [6–8]. Authors in [6] focus on the macro-tier to the femto-tier handover mechanism in the CDMA network. They show that an UE needs to scan the whole femto radio spectrum when switching from macrocell to femtocell which is assessed as a timely expensive operation. To deal with this, the cache scheme for femtocell reselection procedure is proposed. By considering the random walk movement, three user movement models are applied to obtain the UE's movement history. The history reports include the number of FAP that the UE visited. The report contains the most recently visited FAPs that have been stored in the cache. Each FAP data only takes 28 bytes in the cache; therefore there are not too much memory and time consumed to capture the most recently history of visited FAPs. The scheme seems to be effective in the Open Subscriber Group (OSG) femtocell's environment containing plenty of FAPs. However, the proposed scheme is relatively inefficient in the CSG femtocell's environment or in the case of the UE visits just a few number of FAPs.

To integrate femtocells into the network, some modifications on existing network and protocol architecture of Universal Mobile Telecommunication System (UMTS) based macrocell network is proposed in [7]. The modifications include the enhancement of signal message flow during the handover procedure and the measurement process of signal-to-interference ratio when providing handover between macrocell and femtocell. The frequent and unnecessary handovers are also taken into consideration. The analysis is fulfilled on the concentrator-based and without concentrator-based femtocell network architecture. The obtained results indicate that the use of call admission control mechanism is an effective way to avoid unnecessary triggered handovers.

The updated handover procedure between HeNB and eNodeB (eNB) based on the UE speed and Quality of Service (QoS) is proposed in [13]. Three different speeds environments are considered: low (0–15 km/h), medium (15–30 km/h) and high speed (>30 km/h). In addition, the real-time and non-real-time traffics are considered as QoS parameters. The analysis reveals that the proposed algorithm has a better performance than the traditional one from the point of unnecessary triggered handovers. However, the considered speeds seem unrealistic since the HeNB only deals with the very low speed terminals (0–5 km/h).

2.2 Vertical handover

Due to relatively new technology, the intensive research on the vertical handover in femtocell networks has not been profoundly done. Several works were done for macrocell environment where the vertical handover between difference platforms are carried out.

A seamless integration of mobile WiMAX in the evolved 3GPP networks and the seamless handover mechanism between them are described in [9]. In this work, a mechanism called single-radio solution is proposed. The mobile device is assumed to have capabilities to transmit and receive only on one radio frequency at a given time. Thus, the radio frequency coexistence issues faced by a dual-radio solution is eliminated, however it requires the implementation of more intelligence mobile device and at network side as well. The single-radio handover solution is built around a new functional element in the Evolved Packer Core (EPC) network, called Forward Authentication Function (FAF) that is accessible by UEs over the interface S14. Along with the Access Network Discovery and Selection Function (ANDSF) element, the FAF emulates RNC and BSC network entities as well as the mobile WiMAX ASN-GW. Thus, an UE can transmit on the 3GPP side while operating on the WiMAX side, and vice versa.

The previous work is extended in [10]. It has been discovered that the use of FAF and ANDSF resulted in the data losses and abnormal disconnection events. To cope with this issue, the authors introduce an additional network element called Data Forwarding Function (DFF) that eliminates the data losses during the vertical handover execution. The DFF resolves the interconnection problem at the source network side while the FAF does the same at the target network side.

The vertical handover between 3GPP LTE and WLAN systems is analyzed in [11]. The integrated RRM and seamless handover across the heterogeneous access network are provided by implementing Generic Link Layer (GLL). The GLL layer is based on Common Radio Resource Management (CRRM) entity that includes a policy based and Multi Criteria Decision Making (MCDM) entities. The CRRM supports seamless mobile services across heterogeneous RATs by managing all radio resources in a unified and coordinated way. The GLL, individually, enables formatting different signals coming from the physical layer into a unified format before transmitting them to the CRRM server. Moreover, the MCDM controls several parameters regarding the handover decision such as signal strength, speed and type of service (e.g., voice and data services). The proposed solution is analyzed in term of throughput, service cost and handover success rate.

Authors in [12] use testbed-based experiments to investigate a possible integration of femtocells into WiFi and WiMAX systems. The authors provide comprehensive measurements of vertical handover delay where the vertical handover functionalities are deployed via SIP protocol. It concluded that the substantial delay is incurred by the DHCP mechanism, the authentication process in WiMAX and the probing process in WiFi. However, there is no a clear description how WiFi and WiMAX systems can be integrated particularly at the MAC layer.

To our best knowledge, no works have analyzed the vertical handover in the typical femtocell's handover scenarios such as hand-in, hand-out and inter-FAP.

3 LTE-based handover in femtocell

The 3GPP LTE mobile system specifies the handover procedure [13] that supports different types of user's mobility.

A handover process, in general, is divided into four parts as shown in Fig. 2: (1) UE measures downlink signal strength, (2) UE processes the obtained measurements (3) UE sends the measurement reports to the serving eNB

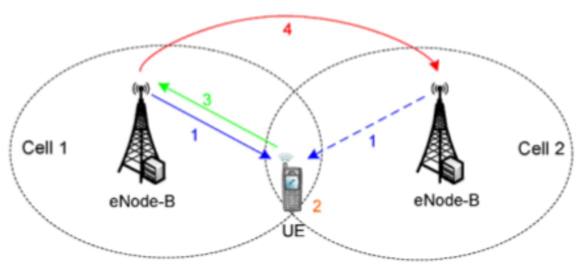

Fig. 2 Handover process in the 3GPP-LTE network

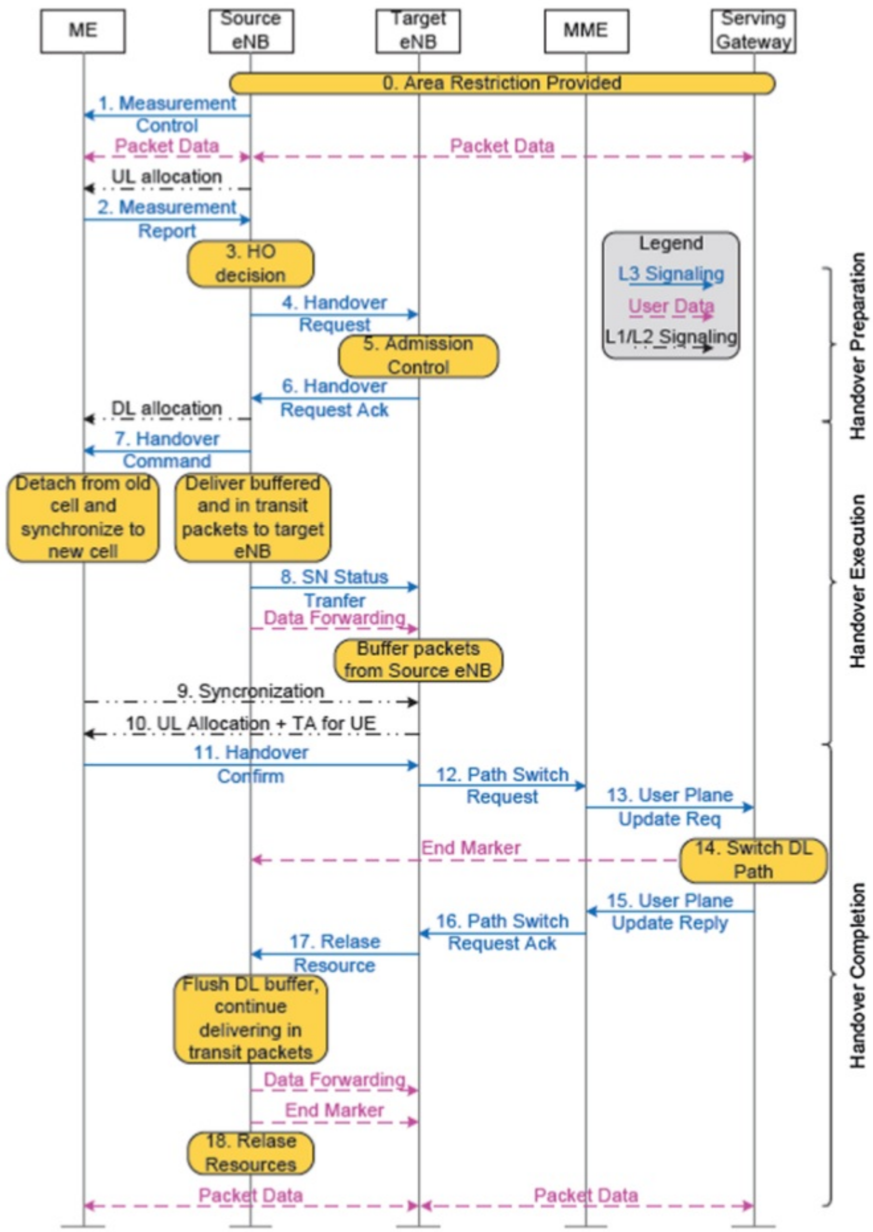

Fig. 3 Messages flow diagram of handover procedure in 3GPP-LTE [6]

and finally (4) the serving eNB then decides about the handover based on the received reports. The message sequence diagram of the LTE handover procedure is detailed in Fig. 3.

The handover procedure consists of 3 phases:

- Handover preparation; this phase the UE, the serving eNB and the target eNB make preparation before the UE connect to the new cell. The main messages and processes are described as follows:

1. Measurement control/report (messages 1/2).
   The serving eNB configures and triggers the UE measurement procedure and the UE sends the measurement report to the serving eNB.
2. Handover decision (messages 3/4).
   The serving eNB decides about the handover based on the received measurement report.
3. Admission control (messages 5/6).
   The target eNB performs the admission control pro-

cess depending on the QoS information and prepares handover at the L1/L2 level.

4. Handover command (message 7).
   The serving eNB sends to the UE the handover command.

- Handover execution; during this phase, the following step is done:

5. Detachment from the old cell and synchronisation with the new one (messages 8–10).
   The UE synchronises with the target cell and accesses the target cell.

- Handover completion; this phase includes the following steps:

6. Handover confirmation and path switching (messages 11–16).
   The serving-gateway hands over the downlink connection to the target eNB. To do this, the serving-gateway exchanges the massages with Mobility Management Entity (MME).
7. Release of resources (messages 17/18).
   Upon reception of the release message, the serving eNB can release radio resources. Subsequently, the target eNB can continue with the downlink data transmission.

4 Proposal of handover procedures in femtocell network

4.1 Horizontal handover procedure

The LTE-based handover procedure within the femtocell network is intended to minimise the interruption time. It is also designed to be seamless when occurring to/from other technology platforms (e.g., 2G/3G, WiMAX, etc.).

Several network 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 [14]. The E-UTRAN consists of a single eNB or HeNB/FAP that also include Radio Resource Control (RRC) layer that manages the handover procedure.

The E-UTRAN interacts with the EPC system consisting of Mobility Management Entity (MME), Serving Gateway (SGW) and Femto Gateway (Femto-GW). Interactions between E-UTRAN and EPC are depicted in Fig. 4.

The MME is the key control node in the LTE network [15]. In handover process, the MME is responsible for choosing the serving-gateway at the UE initial attachment.

Other network element that takes part during the handover process is the SGW that provides routing and forwarding of data. The SGW is also acting as the mobility anchor entity for the user plane during handover and as the anchor entity for mobility between LTE and other 3GPP technologies.

The last network element involved in the process is Femto-GW. It serves as a gateway through which the FAP is connected to the mobile operator's core network. The Femto-GW is responsible for protocols conversion and creates a (virtual) RNC entity from the point of core network. It is physically located at the mobile operator premises [16].

In addition, 3GPP specifies two standard interfaces between RAN and CN: X2 and S1 interface. The X2 interface supports radio interface mobility and shall support the exchange of signalling information among eNB macrocells. Thus, in case of handover between eNBs, the EPC is not involved in the procedure. Signalling messages are directly exchanged between eNBs using the interface X2. On the other hand, the S1 interface supports many-to-many relations between EPC's elements (MME/SGW) and eNB. Moreover, the interface S1 is also used for the communication between FAP/HeNB with the MME/SGW through the Femto-GW.

4.1.1 Hand-in procedure

The handover from macrocell to femtocell is quite challenging since there are plenty of possible target FAPs. During the hand-in procedure, the UE needs to select the most appropriate target FAP. Generally, the basic criteria in the handover decision is the interference level. In this paper, we introduce the mobility prediction as an additional criteria in the handover decision mechanism in order to optimise the handover procedure. The signalling message flow of the proposed handover procedure for hand-in scenario is shown in Fig. 5.

4.1.2 Hand-out procedure

The handover procedure from FAP to (macrocell) eNB is relatively simple. The UE has no really option when selecting the target cell since there is just one possible eNB. If the RSSI value measured from eNB is higher than the one from FAP, the UE is directly connected to the eNB without a complex interference calculation and authorisation checking as in the hand-in scenario. The handover signalling message flow is depicted in Fig. 6.

4.1.3 Inter-FAP procedure

The inter-FAP handover procedure is similar to the hand-in, since there are again plenty of possible targets FAPs. For this scenario, we also propose d the mobility prediction mechanism to be used.

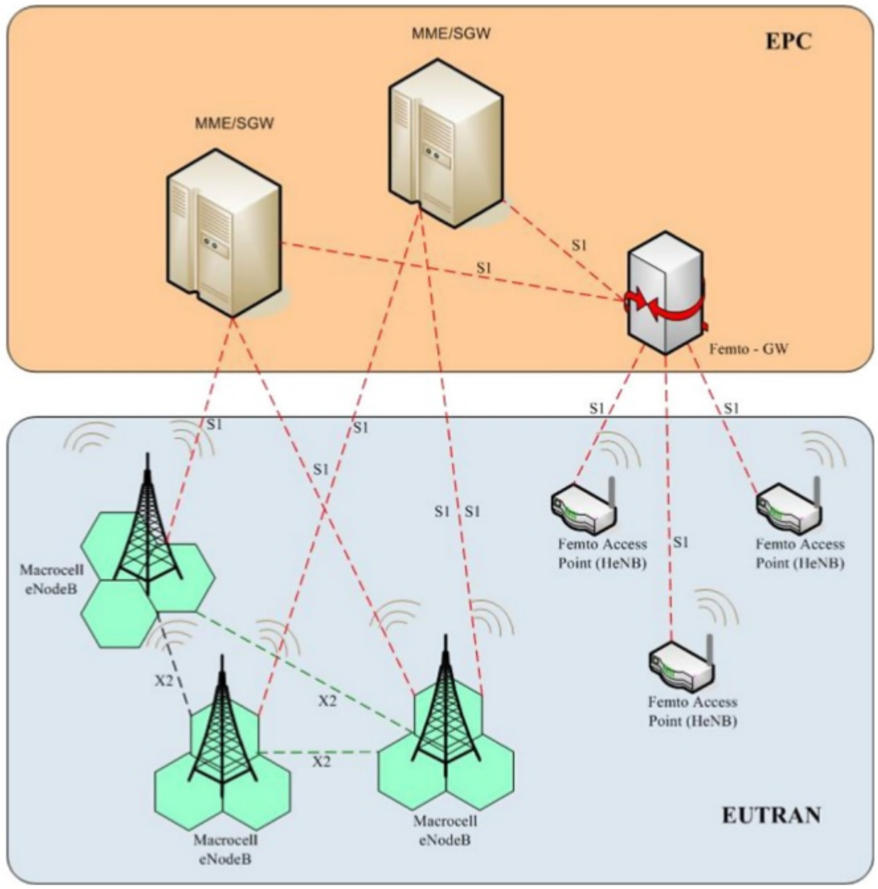

Fig. 4 The deployment of femtocell in E-UTRAN architecture

4.2 Vertical handover procedure

The 3GPP standards specify three types of vertical handovers in the LTE systems [17]:

– Inter-RAT handover that refers to the handover between LTE and earlier 3GPP technologies (e.g., UMTS, GPRS/EDGE, GSM).
– Inter-LTE handover that refers to the handover between LTE cells (including the handover between LTE and LTE-A) where the MME and SGW entities are not the same.
– Inter-technology handover that refers to the handover between LTE and non-3GPP technologies (e.g., WiMAX or WiFi).

The handover decision of vertical handover can be established in the following ways:

– Network-based handover: the decision to provide a handover is done by network.
– Macro User Equipment[1] (MUE)-based handover: the MUE makes the handover decision and informs the network about it. Upon receiving the information, the network makes the final decision based on RRM strategy.

According to the development of LTE standard, a hybrid approach is used to decide the handover in LTE network, where the MUE will assist in the handover decision by measuring signals of the neighboring cells and reporting the measurements to the network. In turn, the network decides to perform the handover based on handover timing and the target cell. The measured parameters and the use of thresholds are set up by network.

In this paper, we consider inter-RAT and inter-LTE vertical handovers. Moreover, though there are three handover scenarios as described in previous section, only hand-in is considered.

[1] In this section the MUE terminology is used instead of UE to indicate the user equipment that handed over from macrocell to femtocell.

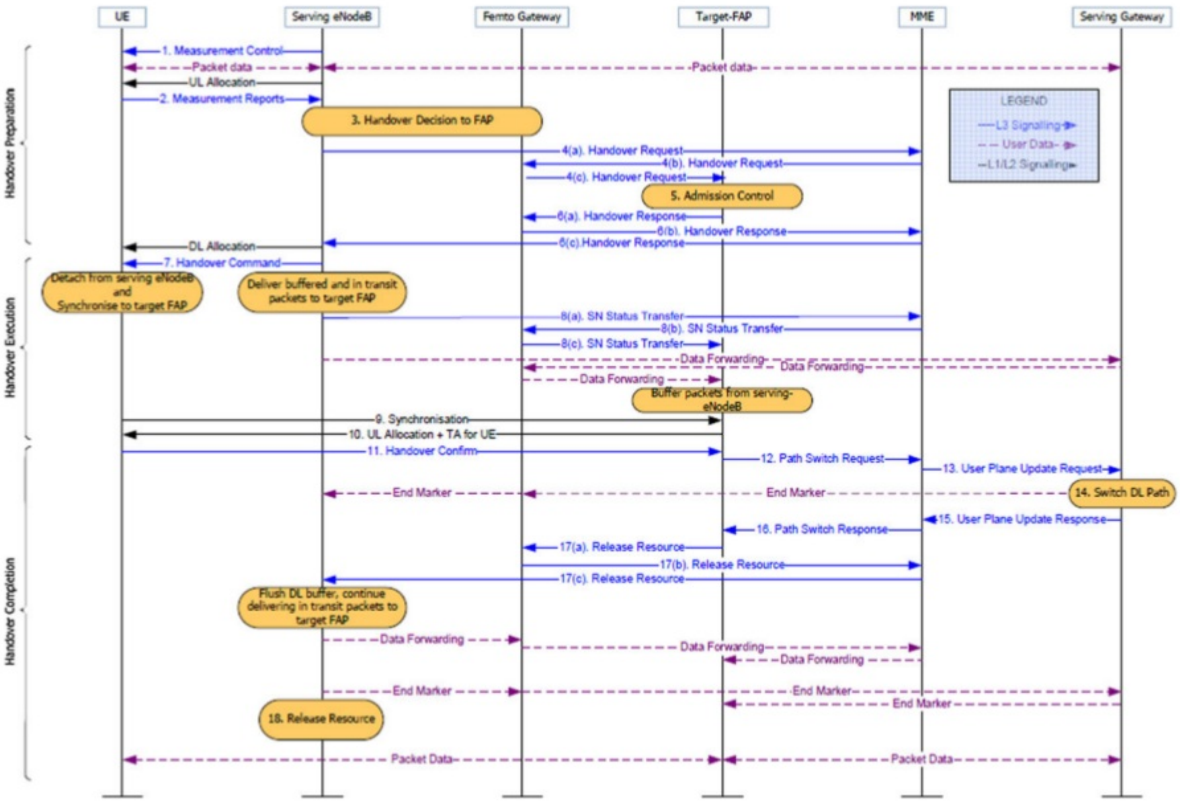

Fig. 5 Messages flow for hand-in (handover from macrocell to femtocell)

4.2.1 Inter-RAT handover: hand-in (from LTE- MBS to UMTS-FAP)

In this scenario, the source-MBS (macrocell-eNB) is connected to the source-MME and source-SGW while the target FAP is connected to the target-SGSN (Serving GPRS Support Network) and target-SGW. It is assumed that both source and target SGWs are connected to the same PGW (Packet Data Network—PDN Gateway).

Based on the standardized handover procedure (see Sect. 3) and our proposed procedure for horizontal handover (see Sect. 4.1), we enhanced the procedure for this vertical handover scenario as shown in Fig. 7. The procedure can also be divided into three phases:

– Preparation phase

- All necessary resources are reserved in the target network. Once the inter-RAT handover is decided, the source-MBS prepares and sends a HANDOVER REQUIRED message to the source-MME.
- Base on the message content, the source-MME detects that it concerns about the inter-RAT handover, and retrieves the target-SGSN details from the database based on the information in the message. Then it prepares and sends within the GPRS core network (GTP-C) signaling message FORWARD RELOCATION REQUEST to the target-SGSN.
- The target-SGSN detects the change of SGW and creates the bearer resources in the target-SGW by initiating the GTP signaling message: CREATE SESSION REQUEST. Once the resources are reserved, at the target-SGW responds to the target-SGSN with a GTP signaling message CREATE SESSION RESPONSE.
- The target-SGSN then reserves the resources at the target-FAP by sending a Radio Access Network Application Part (RANAP) signaling message RELOCATION REQUEST. The target-FAP reserves the radio resources and responds to the target-SGSN with a RANAP message RELOCATION REQUEST ACK.
- The target-SGSN creates the indirect data forwarding tunnel to the target-SGW for the downlink packet transfer from the source-SGW to the target-SGW during the handover process. After that, the target-SGSN responds to the source-MME using the GTP message: FORWARD RELOCATION RESPONSE.
- The source-MME creates the indirect data forwarding tunnels as the resources are reserved successfully in the

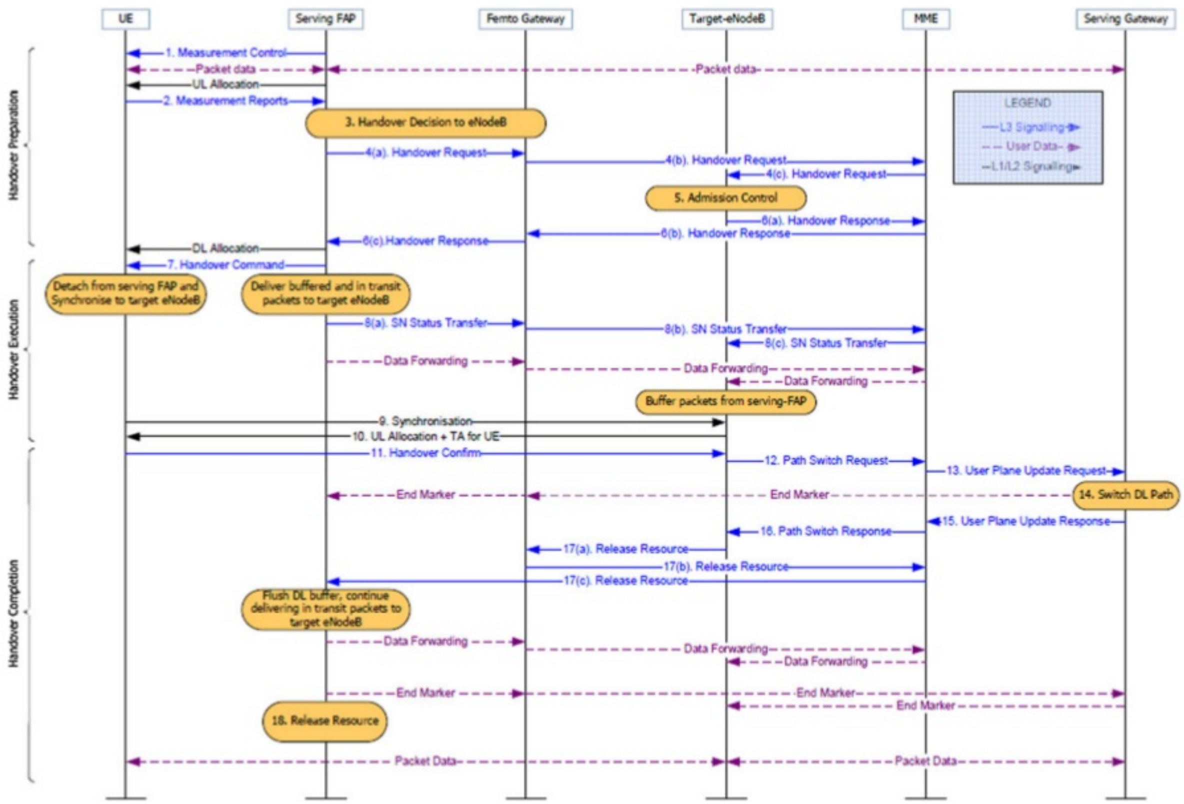

Fig. 6 Messages flow for hand-out (handover from femtocell to macrocell)

target network to forward the downlink packets to the target network.

– Execution phase:
  - The MUE is handed over from the source network to the target network. The source-MME sends the message HANDOVER COMMAND to the source-MBS via the S1 interface Application Part (S1AP) protocol. The source-MBS prepares and sends the message MOBILITY FROM EUTRA COMMAND to prepare the MUE for the handover toward the target network where the UMTS access procedure is prepared. After accessing the target-FAP, the MUE sends a message HO TO UTRAN COMPLETE to the target-FAP, indicating the successful handover.
  - The source-MBS forwards the downlink data packets toward the target-SGW via the source-SGW during the handover. This step can occur any time after receiving the message S1AP HANDOVER COMMAND from the source-MME. This step is executed in case a direct forwarding path is not available with the target-FAP, otherwise it directly forwards the downlink data packet to the target-FAP.
  - Once the target-FAP detects the MUE in its area, it notifies the target-SGSN about the completion of handover by sending the message RANAP RELOCATION COMPLETE.

– Handover completion:
  - The handover procedure is successfully completed when the source-MME sends to the source-SGW the GTP signaling message DELETE SESSION REQUEST which is responded with message DELETE SESSION RESPONSE.
  - Upon receiving the response, the source-MME sends to the source-MBS the message MUE CONTEXT RELEASE COMMAND which is responded with message MUE CONTEXT RELEASE COMPLETE.

The detail procedure of inter-RAT vertical handover is shown in Fig. 7.

4.2.2 *Inter-LTE handover: hand-in (from LTE-based MBS to LTE-A FAP)*

In this scenario, two MMEs and two SGWs are assumed to be involved in the handover procedure. The source-MME/SGW is LTE based and the target-MME/SGW is

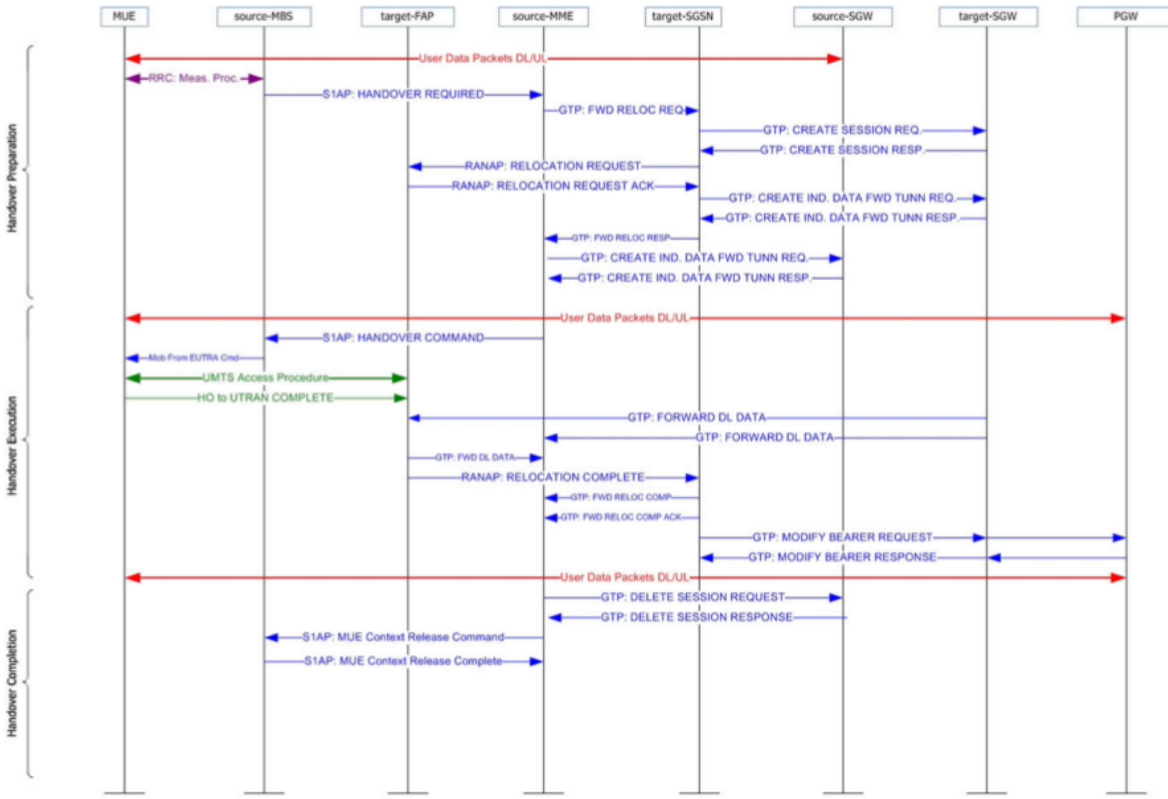

Fig. 7 Message flow for inter-RAT vertical hand-in (from LTE-based MBS to UMTS-FAP)

LTE-A based. The source-MBS is controlled by the source-MME/SGW through the S1 interface and the target-MME/SGW controls the target-FAP through the S1 interface as well. Based on the message MEASUREMENT REPORT from the MUE, the source-MBS decides to trigger the handover process. The source-MME and target-MME is assumed to communicate to each other by using the GTP signaling.

- Upon receiving the message S1AP HANDOVER REQUIRED from the source-MBS, the source-MME detects that the requested target cell is belong to another MME and initiates the message GTP-C: FORWARD RELOCATION REQUEST to be sent to the target-MME.
- As next, the target-MME detects the SGW change and initiates the bearer creation toward the target-SGW through the message GTP: CREATE SESSION REQUEST. When creating requested bearers, the target-SGW sends to the target-MME the respond through a message GTP: CREATE SESSION RESPONSE.
- In the mean time, the target-MME creates the S1 logical connection toward the target-FAP, and sends on it the message S1AP: HANDOVER REQ. The target-FAP prepares the requested resources and responds to the target-MME with message the S1AP: HANDOVER REQ ACK.
- Then, the target-MME sends to the source-MME the message GTP-C: FORWARD RELOCATION RESPONSE, to notify about the resource reservation at the target-FAP. From this point onward, the signaling message flow is similar to the handover execution procedure as described in the previous section.
- Once the target-FAP detects the MUE in its area, it notifies the target-MME by sending the message S1AP: HANDOVER NOTIFY. While processing this message, the target-MME updates the target-SGW about the target-FAP endpoint information through the message GTP: MODIFY BEARER REQUEST. Upon the completion of updating, the target-SGW responds to the target-MME with the message GTP: MODIFY BEARER RESPONSE.
- The target-MME notifies the source-MME about the completion of handover by using the message GTP-C: FORWARD RELOCATION COMPLETE.
- Upon receiving the message, the source-MME sends to the source-MBS the message S1AP: MUE CONTEXT RELEASE COMMAND in order to release all resources allocated to the MUE. The source-MBS responds to the

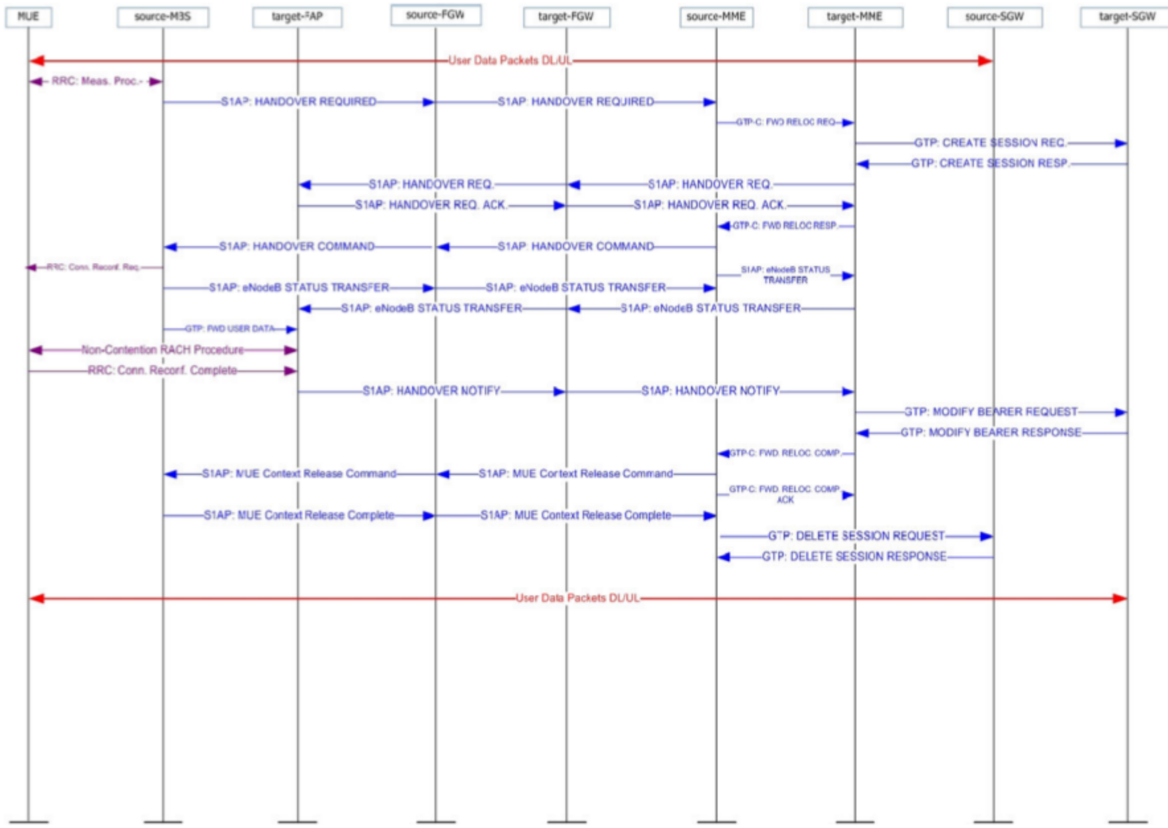

Fig. 8 Messages flow for inter-LTE vertical hand-in (from LTE-based MBS to LTE-A-based FAP)

source-MME with the message S1AP: MUE CONTEXT RELEASE COMPLETE.

- The source-MME sends to the target-MME the message GTP-C: FORWARD RELOCATION COMPLETE ACK to acknowledge the completion of handover procedure.
- After successful completion of the handover, the source-MME releases bearer resources with the source-SGW for this MUE by initiating the GTP: DELETE SESSION procedure.

The complete procedure of inter-LTE vertical handover scenario is depicted in Fig. 8.

5 Performance analysis

5.1 Handover decision policy

The handover decision mechanism is one of the challenging parts in the handover procedure. The common parameters used in the handover decision mechanism include the CINR, RSSI and QoS. However, those parameters are inadequate when dealing with advanced handover requirements such as the fast handover in femtocell network where plenty of possible targets FAP exist. Therefore, the new handover decision criteria(s) should be employed.

Nowadays, the network-controlled handover is generally implemented in the handover decision mechanism. However, the support of client-based handover policy becomes more and more common since this policy is more flexible and efficient. Parameters such as CINR, RSSI, coverage, the QoS, the probability of next position, etc., can directly be monitored by UE and use during the decision phase.

In the network controlled handover, the source-MBS decides about the handover by comparing the RSSI that is received from MUE and FAP. However, when deploying CSG femtocells, other parameters such as service cost, load balancing, and UE speed, which might influence the handover decision, should also be considered.

From the load balancing point of view when a large number of active UEs are located in a given cell, the available resources may be insufficient to meet the QoS requirements for the real time service but it may offer the sufficient quality for the best effort service.

5.2 Proposed metric

In this paper, we suggest the movement prediction mechanism as an additional parameter in the handover decision mechanism. The enhanced decision mechanism can be applied on all previously mention handover scenarios.

In this handover decision mechanism, we are assuming that the moving UE is able to periodically (e.g., every 1 s) send its position to the serving cell (either MBS or FAP). In the mean time, the serving cell maintains a database of all possible target cells to where the handover might be performed.

5.2.1 Transition probability matrix

Our analysis of prediction of user's movement reposes on use of Markov process. Let us consider an UE (connecting to the source-MBS) that is randomly moving. Based on Markovian characteristics, the movement may start at any position in its original cell (e.g. at point (x, y)) and the UE can subsequently move to any other cell/position (states) or remain at the current position with certain probability. The transition probability from *state* (i) to *state* (j) is given by the current state only [18].

In multi-cells environment, as deployed in the femtocell network, the handover can occur as the UE moving. Thus, there are several cells/positions to where the UE can move on. The number of cells involving in the prediction process is denoted as N *state*. For a *markov chains* process with N *state*, the dimension of the *transition probability matrix* (P) is given as $N \times N$ shown below:

$$P = \begin{bmatrix} p_{11} & p_{12} & \cdots & p_{1n} \\ p_{21} & p_{22} & \cdots & p_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ p_{n1} & p_{n2} & \cdots & p_{nn} \end{bmatrix}$$

Values of transition probability matrix are derived from a diagram that is called state Markov chains diagram. Figure 9 shows how a state Markov chains diagram generates the transition probability matrix.

Let us considered the three-cells (states) scenario as shown in Fig. 10, consisting one serving-BS (mark A), and two target-BSs (mark B and C). The UE has three state probabilities:

Fig. 9 State markov chains diagram and transition probability matrix

(a) the UE remains at the actual position, i.e. $A \rightarrow A$,
(b) the UE moves from the serving-BS to the target-BS (marked B), i.e. $A \rightarrow B$,
(c) and finally, the UE moves from the serving-BS to the target-BS (marked C), i.e. $A \rightarrow C$.

The total probability of (a), (b), and (c) has to be equal to 1. The state markov chain diagram shown in Fig. 10 generates the following transition probability matrix:

$$P = \begin{bmatrix} a & b & c \\ d & e & f \\ g & h & i \end{bmatrix} \quad (1)$$

The *next transition probability* (P_n) from the serving-BS to the target-BS can be calculated as:

$$P_n = [P_{n-1}] \times [P] \quad (2)$$

where P_{n-1} is denoted as a current transition probability matrix, and n is denoted as number of state transitions. The minimum number of n should be equal to 2 (there has to be at minimum 2 cells, required for handover), therefore it can be stated that $P_1 = P$, and $n = 2, 3, \ldots$.

5.2.2 Initial distribution matrix

The mobility prediction can be more precise if the initial probability of UE in a particular state is determined. Additionally, the prediction can be further improved if the initial status other parameters (e.g. the UE speed, distance of target, etc.) are determined as well. These parameters can be represented by initial *distribution matrix* (p).

For the size of P equal to 3×3 (as in (1)), the initial distribution matrix, p, can be written as:

$$p = [j \; k \; l] \quad (3)$$

where j, k and l designate the considered parameters (e.g., UE speed, distance, UE coordinates, etc.). If the row of p

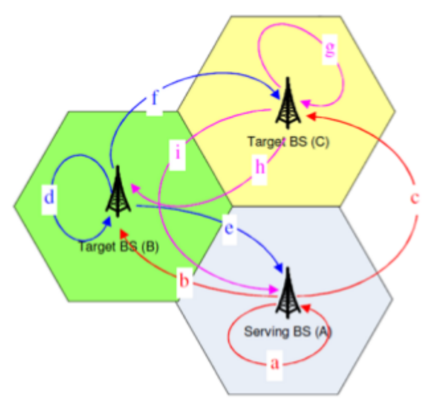

Fig. 10 Three-cells state scenario

represents the UE coordinates then the prediction of UE position in 2D (flat area) or 3D (inside the building) can be determined as:

$$\begin{matrix} x \\ y \end{matrix} \begin{bmatrix} \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots \end{bmatrix} = p, \qquad \begin{matrix} x \\ y \\ z \end{matrix} \begin{bmatrix} \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots \end{bmatrix} = p$$

The UE position after one transition step (p_1) is given as $p_1 \times P$. Thus, the UE position after n transition steps (p_n) is given as:

$$p_n = [p] \times [P_{n-1}] = [p_{n-1}] \times [P] \quad (4)$$

where p_n denotes the probability of UE position after n transition steps, p is the initial distribution matrix, P_{n-1} represents the current transition probability matrix, p_{n-1} is the initial distribution after n transition steps and P is the initial transition probability matrix. More details about the mobility prediction method can be found in [19].

In the similar way as the prediction of user's movement, we analyse macro-femto network. The network consists of twenty one cells (states) scenarios ($n = 21$); 1 source-MBS (source cell) and 20 FAPs (target-cells).

Using the Markovian process previously described, we can deduce in advance the likely path of UE. Thus, the probability of target-FAP to where the UE should be handed-over and the remaining time before handover can be estimated.

Based on this estimation, the source-MBS looks for all possible target cells. One of the predicted target cell is assigned as the target-FAP, to where the connection should be handed over. The source-MBS then contacts the predicted target-FAP via backbone to coordinate the handover process.

5.3 Movement prediction simulation

Our simulation scenario supposes certain assumptions regarding the UE mobility. As the movement model, the direct movement mobility model is used. It is assumed that no UE moves randomly rather certain numbers of paths are followed, so that the distances of next position are assumed known in advance. In the initial distribution matrix (4) d represents the distance between current position and next position (in one transition step, the UE moves d meters). The distance is assumed to uniform ($d_{\min} = d_{\max}$).

The UE, source-MBS and all target-FAPs are located in the flat movement area. The target-FAPs are un-uniformly spread over the area of 10000 m^2 (100 m × 100 m). Some of target-FAPs are assumed to have the highest probability value (to be connected). In case there are two or more target-FAPs have a same probability value, we predefined the state priority (one has the highest priority than the other one).

Table 1 Parameters used in simulation and their settings

Parameter	Value
Number of MBS	1
Number of FAP	20
Number of state transition (n)	15
MBS transmit power (dBm)	36
FAP transmit power (dBm)	15
UE speed (Km/h)	5–10
Mobility model	Direct Movement
Distance between position (m)	10
Shape of FAP coverage area	Circular
Radius of FAP coverage area (m)	10
Size of simulation area (m^2)	100 × 100
FAP density	Non uniform
Bandwidth allocation (MHz)	1.4, 5, 10, 20
Service rate (packets/s)	0–400

Table 1 summarises the parameters setting and other predefined scenarios in the simulation.

5.4 Proposed handover decision strategy

Since the handover procedure may be initiated either by network (MBS/FAP) or by UE, two handover strategies (i.e. proactive and reactive handovers [20, 21]) are proposed to be applied to trigger the handover process.

5.4.1 Proactive handover

Principle of proactive handover is shown in Fig. 11. In the proactive handover scenario, the handover may occur any time before the level RSSI of current BS reaches the Handover Hysteresis Threshold (HHT). When deploying the mobility prediction mechanisms, a Fixed Probability Threshold (FPT) is set up. The FPT corresponds to the level of RSSI for which the mobility prediction mechanism is initialised. Whereas, the Handover Probability Threshold (HPT) corresponds to the RSSI level for which the handover procedure is triggered. Once the movement prediction results are acquired, the handover can be preceded any time between the triggering FPT and HHT.

This strategy estimates the network characteristics (of the FAP) on a specific position before the UE reaches that position. The UE discovered that the new target-FAP's RSSI overpasses the origin one from its source-MBS. Instead of calculating the time left before the normal handover is triggered, the UE triggers the handover earlier before HHT. Therefore, this strategy can minimize packet loss and high latency during handover.

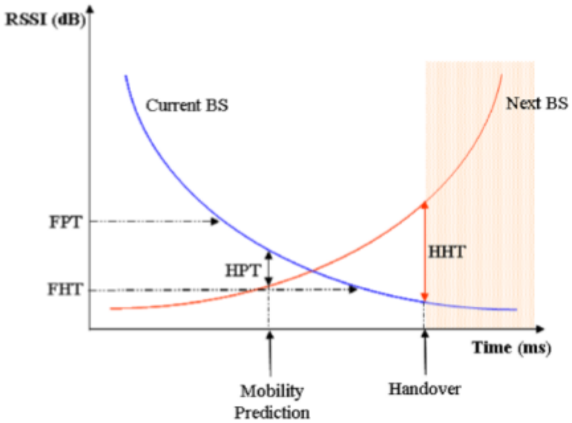

Fig. 11 Principle of proactive handover mechanism [20]

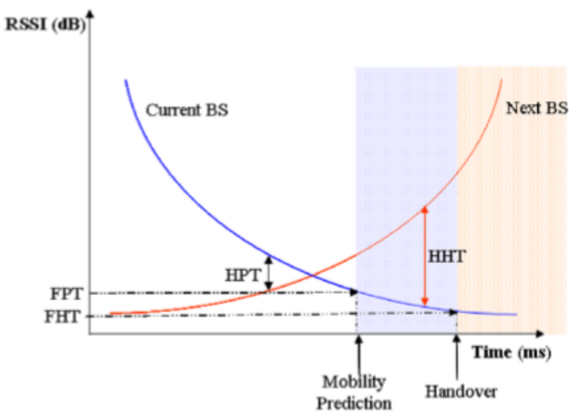

Fig. 12 Principle of reactive handover mechanism [20]

5.4.2 Reactive handover

Reactive handover, on the other hand, tends to postpone the handover as long as possible, i.e. the handover is initialized either if FHT < HHT (see Fig. 12) or if the UE fully loses the signal from the source-MBS.

Due to small FAP's coverage, its lower power and the high density of FAPs, the UE may encounters the very frequent and unnecessary handover since the UE moves from one FAP to other FAP continuously. To mitigate the generated handover signalling overhead, the reactive handover scenario is applied. The handover is triggered only when the UE (almost) lost its source-MBS signal or the most probable position of UE is predicted.

5.4.3 Call admission control mechanism

Another way to reduce unnecessary handover is used of Call Admission Control (CAC [7]). When moving, an UE can, from time to time, receives the higher signal than the minimum level required, but in a very short time the level again rapidly decreases. When switching from MBS to FAP, the UE has to reach a certain minimum signal level for the minimum time duration "T". The threshold time level allows reducing the number of unnecessary handover by forcing the UE to stay connect to a FAP for a particular time period. In [7], the authors set the threshold period to $T = 10$ s and $T = 20$ s. The authors declare that for their simulation scenario better results are obtained by setting the period T to higher value (20 s).

To compare the performance of different handover decision strategies, the CAC mechanism from is also considered in our simulation. The values of threshold parameter T are set as in [7], to 10 s and 20 s.

6 Optimisation results

6.1 Optimization algorithm

As already discussed previously, hand-in and inter-FAP are more complex than the hand-out scenario. One of the main issues in the handover process is the handover interruption time due to delay on the selection of the right target cell (FAP). Another issue lies in the possibility of unnecessary handover and the very frequent handover due to the small coverage and low power of FAPs.

To cope with these constraints, we proposed to use the prediction of UE movement method as described in the previous section. Knowing in advance where an UE is heading allows the system to take proactive steps. The mobility prediction mechanism involves analysis on how UEs physically move and thus it is able to estimate the next UE position. Once the next position of the UE is predicted, the system can decide when and where to hand over the connection.

The very frequent and unnecessary handover can be mitigated by deploying the reactive handover. The handover can be postponed until the UE reaches the (predicted) target FAP.

The principle of optimisation algorithm can be seen in term of pseudo-code 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 $RSSI_{MBS} < RSSI_{FAP}$
   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

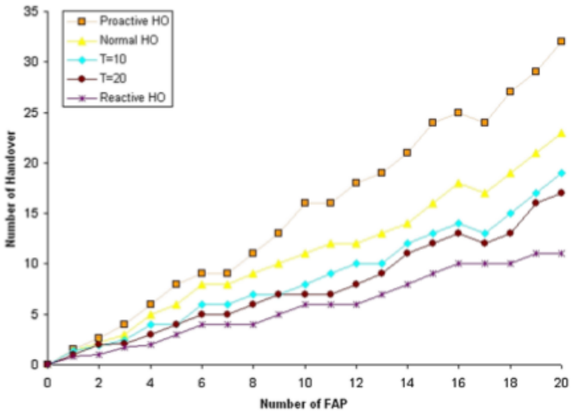

Fig. 13 Performance of handover in term of number of handover

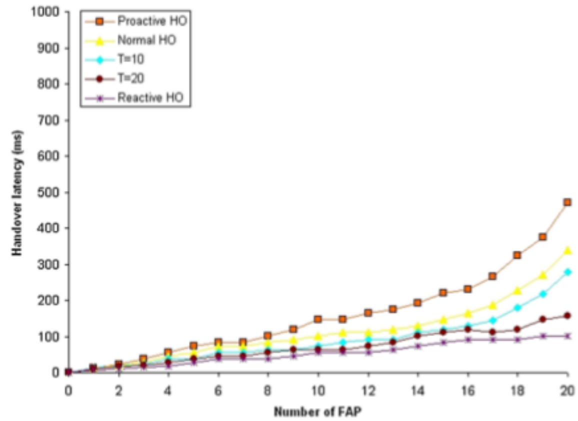

Fig. 14 Performance of handover in term of handover latency

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

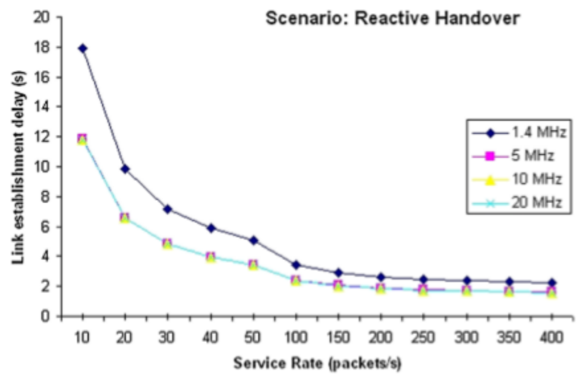

Fig. 15 Performance of reactive handover in term of link establishment delay

6.2 Result and discussion

The prediction of UE's movement is approximated based on Markov-chain method as stated in Sect. 5. The movement of an UE is modelled as series of number of FAPs from 1 to 20. Therefore the number of handovers can be obtained as number of deployed FAPs (see Fig. 13). Accordingly, the handover latency can be approximated for the particular number of deployed FAPs as depicted in Fig. 14.

The depicted results in Figs. 13 and 14 are deal with the speed and traffic constraints as stated in the optimization algorithm. As can be seen in Fig. 13, the numbers of handovers increase almost linearly as the number of deployed FAPs increase. Due to the principle to postpone the handover until the moment of losing the current signal, the reactive handover scheme provides the lowest number of handovers compared to other schemes. In addition, Fig. 14 shows that the reactive handover scheme also provides the lowest handover latency comparing to other decision strategies.

As we can see from Figs. 13 and 14, the reactive handover and CAC $T = 20$ s have better performance among others strategy. For further performance analysis, these both strategies are taken to be examined in term of link establishment delay. The link establishment delay is measured as the time between initiating a handover and switching the UE connection to the target-FAP (excluding the postponed time and threshold time of reactive handover and CAC schemes consecutively). Different channel bandwidths and service rates (see Table 1) are considered during the simulation.

As can be seen in Figs. 15 and 16, the worst results is provided by the 1.4 MHz channel bandwidth. Obviously, it is due to the lower number of available resource block in low rate channel bandwidth. The other bandwidths seem have a similar effect to the link establishment delay.

It can also be observed that for higher channel bandwidth and higher service rate (above 200 packets/s) the reactive handover and CAC ($T = 20$ s) provide similar performance. It is due to the large number of available resource blocks, so that the number of packets retrieved do not affected the delay. On the other hand, in lower service rates some inter-

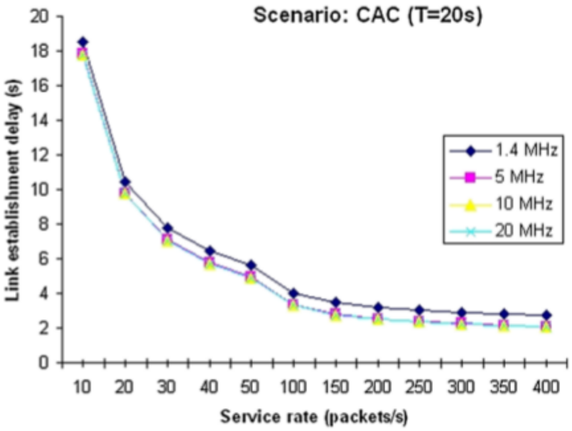

Fig. 16 Performance of CAC ($T = 20$ s) in term of link establishment delay

val time is required when fulfilling each available resource blocks. Due to its behaviour to remain stay on each connected FAP (even though, there is no assigned resource to be obtained), the CAC scheme waste the time. So it affects the overall performance of link establishment.

7 Conclusions

In this paper the handover procedure on LTE-based femtocell has been studied and overviewed. Three scenarios are considered: hand-in, hand-out and inter-FAP. The handover procedure and the signalling flows in both horizontal and vertical handovers, have also been analysed. Since plenty of target FAPs were involved in the hand-in process, in this paper, only hand-in scenario is considered to be evaluated due to its complex procedure than hand-out. 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. In addition, for the overall handover delay through link establishment delay, the reactive handover performed better than other handover decision strategies. Though it has been proven that the performance of reactive handover is better, 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. Moreover, 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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