Femtocell Communications and Technologies:

Business Opportunities and Deployment Challenges

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Chapter 9

Handover Procedure in Femtocells

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ABSTRACT

Implementation of small base stations, known as femtocells, increases the throughput of indoor as well as outdoor users. However it brings several issues that need to be addressed. This chapter is focused on mobility management and problems closely related to the handover procedure. The main challenge is to guarantee efficient handover from/to/between femtocells. It means to ensure minimum signaling overhead due to unnecessary handovers, to minimize handover interruption, and to mitigate interference caused by elimination of redundant handovers. The basic principle of the handover is explained together with the main challenges concerning the handover in a scenario with deployed femtocells. Furthermore, individual issues are described in detail and possible ways to solve them are contemplated. The chapter does not stick to any specific standard; however, it is focused on the general principles and problems of the handover procedure from the femtocell's point of view.

INTRODUCTION

In wireless networks, a user's mobility is ensured by a handover procedure. This procedure manages a change of a current serving station to a proper target station during user's movement across the cells boundaries. Basically, two types of handovers can be distinguished; hard handover and soft handover.

If the hard handover is performed, a User Equipment (UE) firstly closes all connections with the current serving station. As soon as the connections to the serving station are terminated, new connections with the target station are established. Therefore, this type of handover is also known as break-before-make since a short interruption

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in communication between the UE and the network is introduced. It results in decrease of user's throughput as no data are transmitted during this break (Zetterberg et al., 2010). More than that, Quality of Service (QoS) experienced by users is also lowered (Becvar et al., 2009). The duration of the handover interruption depends on the management message flow exchanged between the UE and the network. Thus the length of the interruption depends on several factors such as used wireless technology (e.g., LTE, or WiMAX), physical layer frame length, or network load. In general, the duration of the interruption varies from tens to hundreds of milliseconds in networks according to IEEE 802.16e or 3G networks. However, the maximum interruption should be shorter than 25 ms in 4G networks (ITU/R 5D/Temp/89r1, 2008) to meet user's requirements on QoS.

The second type of handover, soft handover, enables simultaneous connection of a UE to several Base Stations (BSs). Consequently, no handover interruption is observed by users during communication. This handover is also known as make-before-break. The soft handover can be realized as a Macro Diversity Handover (MDHO) or a Fast Cell Selection (FCS) also denoted as a Fast Base Station Switching (FBSS). Both types of soft handovers are defined in former standards for GSM/UMTS (3GPP 25.922, 2007) or WiMAX (IEEE 802.16e, 2006) networks. In MDHO, the macro diversity combining of signals received from several BSs included in active set (in WiMAX denoted as diversity set) is performed. The significant drawback of this approach is high complexity and complicated implementation. In the case of FCS, the best frame simultaneously received from all stations included in active set is selected and processed. Even if the implementation is simpler comparing to MDHO, it is still essentially more complex than in the case of hard handover. Therefore, hard handover is considered as mandatory in mobile networks while soft handovers are optional. Thus this chapter is focused only on hard handovers.

The handover is controlled via management messages of Medium Access Control (MAC) layer. The management message flow is standard dependent. Hence, the overall overhead generated due to the handover procedure can also vary for each standard, scenario, or network status as in the case of the handover interruption. In general, the overhead originated due to handover is roughly in kilobits (see e.g. [IEEE 802.16e, 2006]).

By deployment of large amount of small base stations, so called Femto Access Points (FAPs), handover may be initiated more frequently. This is due to the fact that the UE may perform multiple handovers even within the same macrocell as it crosses cell boundaries of deployed FAPs. As a consequence, the signaling overhead is increased and at the same time the QoS experienced by users is decreased. Therefore, an efficient handover management consisting in proper handover decision and initiation should be defined for networks with femtocells.

This chapter gives an overview on issues related to the handover procedure in networks with femtocells. First, the principle of the handover management is described in the following section. The Section Three gives an overview on the issues related to handover and mobility management in the femtocell networks. The next section tackles possible approaches to ensure efficient implementation and execution of handovers. The Section Five indicates the most critical problems necessary to be solved in the near future to enable more efficient and comfortable dense deployment of femtocells. The last section presents conclusions.

HANDOVER PROCEDURE

This section describes the basic principle of handover procedure in wireless mobile networks. First, the general handover procedure in networks without femtocell is explained. Further, the specific aspects of handover in femtocell networks are introduced.

Handover Principle in Conventional Networks without Femtocells

The major purpose of handover in mobile networks is to either ensure continuous connection with high QoS or balance load in network. In order to determine the optimum time instant for performing handover, the channel conditions have to be continuously monitored by the UE. This stage of handover is known as a neighborhood scanning. The UE scans all neighboring stations included in so called Neighbor Cell List (NCL). The measurement results are reported back to the network. The reporting can be performed periodically or even triggered. The results obtained by the measurement are processed by BSs. The processing results are used for handover decision and its initiation. In this step, the possible target BS is selected based on channel parameters and offered QoS. In the simplest case, the samples of signal levels received from the neighboring stations are compared and the handover procedure is initiated if:

$$\overline{s}_t[k] > \overline{s}_s[k] + \Delta_{HM} \tag{1}$$

where Δ_{HM} represents the hysteresis margin, $\overline{s}_t[k]$ corresponds to the signal level received from the target station, and $\overline{s}_s[k]$ is the signal level received from the current serving station. Signal levels $\overline{s}_t[k]$ and $\overline{s}_s[k]$ are determined from the signal received by the UE as follows:

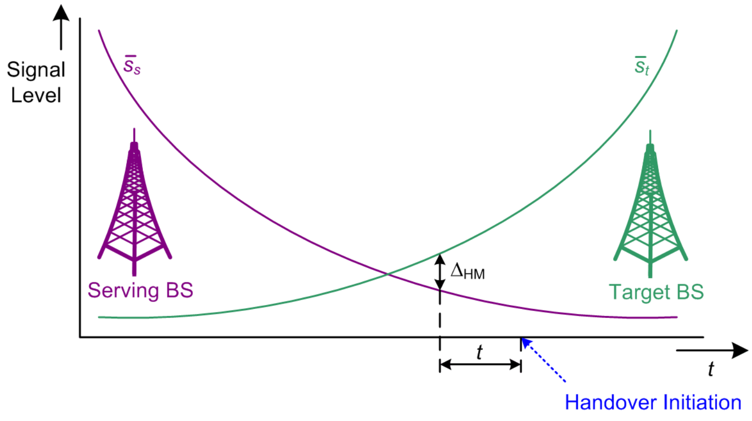
$$\begin{aligned} \overline{s}_t[k] &= s_t[k] * w[k] \\ \overline{s}_s[k] &= s_s[k] * w[k] \end{aligned} \tag{2}$$

where *w[k]* represents a windowing function for elimination of signal fluctuation.

Besides hysteresis, also so called time-to-trigger can be considered in handover procedure. This parameter is represented by a time interval (in Figure 1 denoted as *t*) between fulfillment of (1) and the handover initiation. This approach is used to eliminate redundant handovers performed due to, for example, fast fading or ping pong effect (continuous switching of the UE between two adjacent BSs).

While the handover is initiated, the UE synchronizes with a downlink channel of the target BS. Before the synchronization is completed, the connection with the serving BS has to be closed. In the meantime the UE can neither receive nor transmit user's data. As soon as the synchronization with the downlink of the target BS is completed, the UE starts the next stage of handover: network re-entry procedure. During the network re-entry, the UE is supposed to perform ranging,

Figure 1. Conventional handover decision



re-authorization and re-registration. The UE obtains information on uplink channel and ranging parameters such as transmitting power, timing information or frequency offset. After successful authorization and registration the UE can continue with the normal operation, it means, user's data can be exchanged.

Handover in Femtocell Environment

In general, the handover in femtocells follows the same principle as described in previous section. Nevertheless, several new aspects and issues arise due to the femtocells specifics such as very low transmitting power, varying backbone connection's capacity, or expected high density of FAPs deployment. By introduction of the FAPs into conventional network, three new handover scenarios can be distinguished depending on the type of serving and target Access Station (AS) as depicted in Figure 2; hand-in, hand-out, inter-FAP handover. Note, that in this chapter, we use the abbreviation AS like a general notation and it can represent either a FAP or a Macrocell BS (MBS).

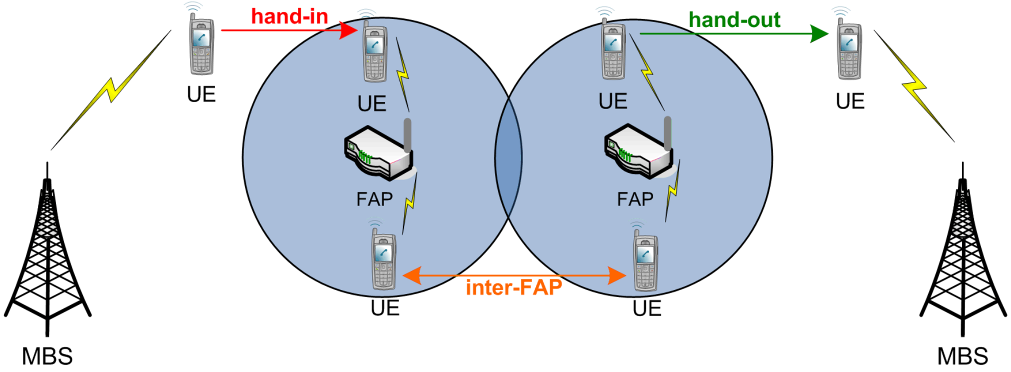
The first type of handover is represented by a switching of the UE from a serving MBS to a target FAP. This handover is denoted as hand-in. In this particular scenario, the FAP admits the UE according to provided type of FAP's access (close, open, or hybrid) as explained later. Successful execution of hand-in further depends on the available backbone capacity of the target FAP.

The second type of handover is called hand-out. It is a consequence of the foregone hand-in, that is, the UE is disconnected from the FAP and it is going to be served by the MBS. A selection of a proper target MBS is managed according to the common admission process for handover. However, the admission procedure should consider the fact that the UE would eventually lose the connection to the FAP due to high interference originated from the MBS if handover to the MBSs is not performed.

The last handover type corresponds to the situation when handover from a FAP to another FAP is executed. For this handover type, the admission procedure follows the similar policies as in the case of hand-in.

To initiate hand-in and inter-FAP handover, the crucial factor is the access mode of the target FAP. If the FAP provides closed access, only users belonging to so called Closed Subscriber Group (CSG) are allowed to execute handover to the FAP. The CSG list is completely managed by FAP's owner. The owner can decide, independently on the operator, to whom the access is granted (3GPP 22.220, 2010). The CSG list may consist of, for example, family members or employees of company where the FAPs are installed. As the result, other Macrocell UEs (MUEs) (i.e., the us-

Figure 2. Handover possibilities in networks with femtocells



ers served by MBS) are denied to access the FAP if closed access is utilized. The FAP's resources are shared only by the CSG members and thus this approach is more effective and preferred by customers (Carlaw, 2008). On the contrary, the close access introduces several major problems from the perspective of the operator. The major issue is an interference generated by the FAPs to the MUEs, which are close to the FAP and which are not members of the CSG (Cheng et al., 2010; Espino & Markendahl, 2009).

On the other hand, in the case of the open access a FAP works in similar principle as a regular operator's MBS. The UE can perform hand-in if the FAP is able to satisfy its requirements and demands. Otherwise, the handover is rejected. The advantage of the open access scheme consists in significant increase of the throughput compared to the closed access since a part of user's data is transmitted via FAPs. This approach reduces interference and also alleviates MBS's load. Consequently, the open access is preferred especially by operators (de la Roche et al., 2010). Nonetheless, the problem of the open access FAP is in increasing number of initiated handovers. Thereby excessive signaling overhead is generated and the probability of handover failure is increased as well (Lopez-Perez et al., 2010).

The hybrid access combines both above mentioned access strategies. While the certain amount of FAP's resources is dedicated primarily for the CSG users, the rest of the FAP's capacity is available for other users. The hybrid access is the most challenging one from the handover management point of view. The handover decision is strongly related to the rules defined for sharing of the FAP's backbone and allocation of radio resources among outdoor and indoor users. The ratio of the resources available for the outdoor users can be limited to a fixed level. The drawback of this approach is that resources unused by indoor users are wasted. On the other hand, the sharing of whole bandwidth (radio as well as backbone) can decrease QoS of the indoor users. This method is not convenient for indoor users as they have to pay for backbone connection and thus they should be in some way treated preferentially. Therefore, some sort of compromise must be found.

HANDOVER ISSUES INTRODUCED BY FEMTOCELLS

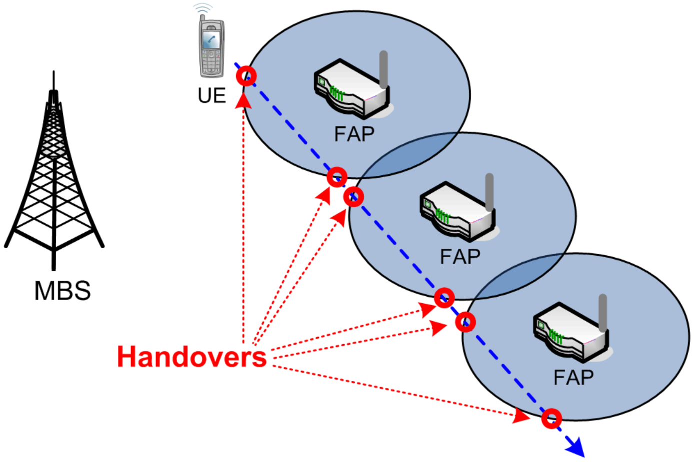
By introduction of the FAPs into a network, several new issues from perspective of handover and mobility management have to be tackled. The most critical problem consists in minimization of redundant handovers. This results in decrease of a signaling overhead and in avoidance of handover interruption. Further, efficient creation and maintenance of NCL and proper assignment of Physical Cell Identifier (PCI) to individual FAPs are discussed in this chapter even if both are not directly connected to the handover procedure. However, both significantly influence user's mobility support. Some other problems regarding handover procedure such as reduction of the handover interruption or reduction of the overhead generated during handover can be identified. Nevertheless, these issues are not directly related to the deployment of femtocells. Those problems can be solved by common approaches already investigated for MBSs and thus are not described in detail in the rest of this section.

Significant Amount of Redundant Handovers

As stated before, several important issues need to be tackled if FAPs are deployed. The most crucial one is an amount of the handover initiations (see Figure 3), which leads to increases management overhead and at the same time to considerable drop of user's QoS.

In conventional networks without femtocells, several techniques eliminating redundant handovers are defined. The most commonly used are: Hysteresis Margin (HM), windowing (also known

Figure 3. Problem related to the dense femtocell deployment



as signal averaging) (Zonoozi et al., 1997), and Handover Delay Timer (HDT) (Hoyman et al., 2007), which extends conventional Time-To-Trigger (TTT) (IEEE 80.16e, 2006; 3GPP 25.922, 2007). These techniques can be implemented also in femtocell networks as presented, for example, in (Kim & Lee, 2010). The paper demonstrates drop of the number of redundant handovers by above mentioned techniques. However, a negative impact of those techniques on the throughput is not considered. This is taken into account in (Zetterberg et al., 2010). The paper proofs that all of these techniques cause significant drop of user's throughput. A lower throughput is due to the fact that the UE is connected to a station, which does not provide the best channel quality for a certain time interval before handover initiation. The similar conclusion can be derived from the paper (Joshi et al., 2010). The authors compare the probability of UE's assignment to the FAP that does not provide the best signal quality. The paper shows some tradeoff between a minimum duration of the signal averaging and the probability of error assignment.

Both papers show low efficiency of these common techniques. Hence, there is a need of some other approaches for handover decision in networks with femtocells.

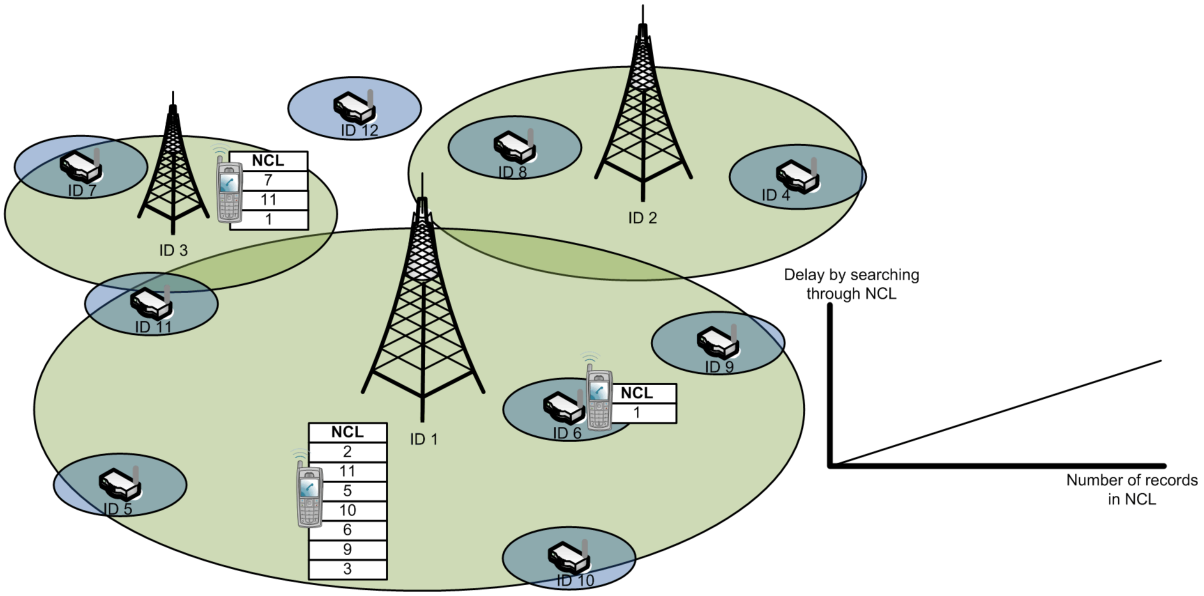
Neighbor Cell List

Another issue concerning handover in femtocells is closely related to the NCL. The NCL contains the list of all UE's neighboring stations as presented in Figure 4. All stations included in the NCL should be periodically scanned with purpose of selection of the best candidates for the target AS. This list is provided to the UE by its serving BS.

If the NCL is not used, the scanning process is significantly prolonged (Han et al., 2010). Therefore, the length of the NCL should be maintained as short as possible. Nonetheless, the NCL has to include all surrounding cells. If any of neighbors is not included in the NCL of the AS, the transition of the UE to that cell will lead to the higher rate of handover failures (Zhou, 2009). Contrary, if the NCL contains records of the cells, which are not the current neighbors, the time consumed by scanning all listed ASs is unnecessarily prolonged (Kim et al., 2010). This may again increase the probability of handover failure.

For the cases when the FAPs are not implemented, the records are added to the NCL either manually during the installation of the cell or automatically on the basis of calculating a signal propagation in a particular environment. However, this procedure cannot be used when the FAPs are

Figure 4. Neighbor cell list

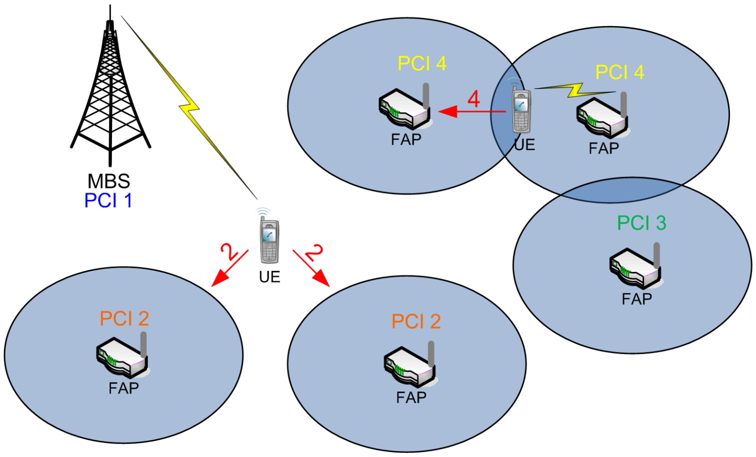


deployed. The main reason is that the FAP can be placed at any location within the house depending on customer's requirements. Moreover, the location of the FAP does not have to be necessarily fixed but it could be changed from time to time. Neither the operator nor the network is generally able to determine the FAP's position and the impact on signal levels in FAP's neighborhood. Therefore, the neighboring FAPs cannot be determined as easily as in conventional networks with MBSs (Han et al., 2010).

Femtocell Identification

The current state of the research does not provide any easygoing solution for hand-in procedure since the MBS cannot uniquely identify and assign measurement reports to individual FAPs when a PCI appears more than once in the network. The major problem consists in limited number of cell identifiers available for all cells in the network. The LTE enables to distinguish up to 504 cells due to primary and secondary synchronization signals (for more information, see (3GPP 36.300, 2010)). For WiMAX, the maximum limit is 767 cells. By deploying more than 504 LTE based FAP's (or more than 767 WiMAX based FAPs), some PCI has to be repeated in the network. If this situation happens, the network cannot recognize which of several cells with the same PCIs is the one that reports the measurement results. Simultaneously, the network is not able to distinguish which station is the real target of handover as showed in Figure 5. Basically, two types of problems are related to the cell identification: confusion and collision. The confusion occurs if at least two FAPs with the same PCI are neighbors of a cell (the case of PCI 2 in Figure 5). The collision represents the case when a PCI is not unique in coverage area of a cell (i.e., the area is covered with at least two cells with the same PCI [the case of PCI 4 in Figure 5]). Consequently, in order to implement FAPs into the existing networks, it is essential to find some solution to this problem.

Figure 5. Determination of target station with limited amount of PCIs



STATE OF THE ART SOLUTIONS FOR HANDOVER IN FEMTOCELLS

This section discuses possible ways addressing the most critical issues introduced in the previous section. The approaches proposed originally for the network without femtocells and their suitability for femtocells are contemplated. As well, the methods and techniques devised primarily for the femtocells are tackled.

Elimination of Redundant Handovers

The problem of the redundant handovers appears if either open or hybrid access is used for femtocell (i.e., users accidentally passing close to a FAP can experience better signal quality from this FAP than from the MBS). In this case, the handover from the FAP to the MBS (or vice versa) can be initiated. This could result in high signaling overhead or lower QoS due to unsuccessful or redundant handovers. To deal with this issue, several approaches could be adopted. The first group of approaches is based on improvement (or enhancement) of conventional techniques for the elimination of redundant handovers. The second area is focused on an adaptation of power control.

Improvement of Conventional Techniques

First, the extension of the common techniques for elimination of redundant handovers can be modified or extended. This way is presented for example in (Kim & Lee, 2010). The authors propose a procedure for managing the handover in the hybrid access. The proposed procedure takes into account the type of users (CSG or non-CSG), received signal level, duration of the received signal level above the critical threshold, ratio of signal to interference, and radio and backbone capacity of the FAP. Primarily it is considered if the signal received from the FAP is being stronger than decision-making level and at the same time if the UE is pre-registered (members of CSG) to this FAP. If this is the case, the signal received by the UE has to remain stronger than the decision level for more than a certain time T. The handover of the pre-registered users (members of CSG) is performed immediately after fulfilling the hysteresis level. For all other users, the TTT with significantly prolonged duration is applied. The results show that the amount of handovers is reduced noticeably. The proposed method is focused only on a reduction of the number of handovers, but it neglects the possible interference and negative impact on user's throughput, which is supposed to be major.

The enhancement of the conventional HM, so called adaptive HM, for the scenario with MBSs is investigated in (Lal & Panwar, 2007). The results show significant reduction of the area where handover is initiated. However, an assumption of precise knowledge of the distance between the UE and its serving MBS together with assumption of invariant and accurately known radius of macrocells are not realistic for implementation in real networks. This drawback is more emphasized if the FAPs are deployed. The above mentioned weaknesses can be eliminated by considering CINR (Carrier to Interference plus Noise Ratio) for the adaptation of current HM value in femtocells as presented in (Becvar & Mach, 2010). The actual level of hysteresis is derived according to the next formula:

$$HM = \max\left\{ HM_{\max} \times \left(1 - 10^{\frac{CINR_{act} - CINR_{\min}}{CINR_{\min} - CINR_{\max}}}\right)^{EXP} ; HM_{\min} \right\} \quad (3)$$

where HM_{max} is the maximum value of HM (in the middle of the cell); EXP represents the exponent; and HM_{min} is the minimum HM; $CINR_{act}$ is the actual CINR measured by a UE; $CINR_{min}$ and $CINR_{max}$ are minimum and maximum values in the investigated area respectively. This approach improves user's throughput and enables implementation of the adaptive HM to the networks with femtocells. The proper selection of HM_{max}, EXP and HM_{min} is not presented in the paper; however it obviously influences the overall performance.

The adaptation can be considered also for other techniques such as HDT or signal averaging as described in (Becvar & Mach, 2011). As the results of both before mentioned papers show, the adaptation is considerably profitable also in case of HDT technique. On the other hand, no gain in performance is observed by adaptation of the window size for the signal averaging. This fact can be expected since window size is not related to the CINR level.

The handover mechanism for femtocells considering asymmetry of the FAP's and the MBS's transmitting power is introduced in (Moon & Cho, 2009). The mechanism compares the average signal from the FAP with received signal level from the MBS in case that signal of the FAP is under predefined threshold in the same manner as defines (1). Otherwise, the signal from the MBS (including hysteresis) is compared with combination of both signals from the MBS and the FAP. Both signals are combined in following manner:

$$s_{pro}^{\alpha}[k] = s_f[k] + \alpha s_m[k] \quad (4)$$

where parameter *a* decreases with rising the distance between the MBS and the FAP. After comparison of individual results, either the MBS or the FAP is selected as the serving AS. The results show that the probability of the UE's assignment to the FAP is increased. Contrary, the amount of handovers is slightly higher when confronted to conventional approach. Therefore authors suggest using adaptive hysteresis.

The second way for redundant handovers elimination is represented by inclusion of other conditions to the handover decision stage. For example, the combination of user's speed and QoS requirements for improvement of the handover decision is presented in (Zhang et al., 2010). The paper proposes new algorithm, which modifies the decision as well as the management messages exchange flow. The authors define three states of mobility based on the actual speed of users. Handover is initiated only for the low speed users (i.e., users moving up to 15 km/h) or for the medium speed users (i.e., users moving between 15 km/h to 30 km/h) who utilize real-time services. All other users who do not fulfill both above mentioned conditions cannot perform handover. Furthermore, the handover decision is more sophisticated as besides the conventional signal level, the capacity of the MBS and the FAP together with the amount of users served by the target station are considered. Although the number of unnecessary handovers is reduced by this proposal, user's throughput is negatively influenced as well.

In addition, the interference to MUEs introduced by neighboring FAPs can be taken into account in the handover decision. Several papers investigate exploitation of handovers for purposes of excessive interference mitigation. It means the handover is initiated according to the interference level. In (Lopez-Perez et al., 2010), authors define the procedure for mitigation of interference by performing so called intracell handover. Combination of this approach with power control decreases the outage probability of nonsubscribers as presented in the paper. Another handover policy for the purpose of interference mitigation in femtocell networks where the FAPs and the MBS share the same bandwidth is discussed in (Chandrasekhar & Andrews, 2009). Authors proof that the interference avoidance can be improved by using a femtocell exclusion region and a tier selection based femtocell handover.

Power Control Approach

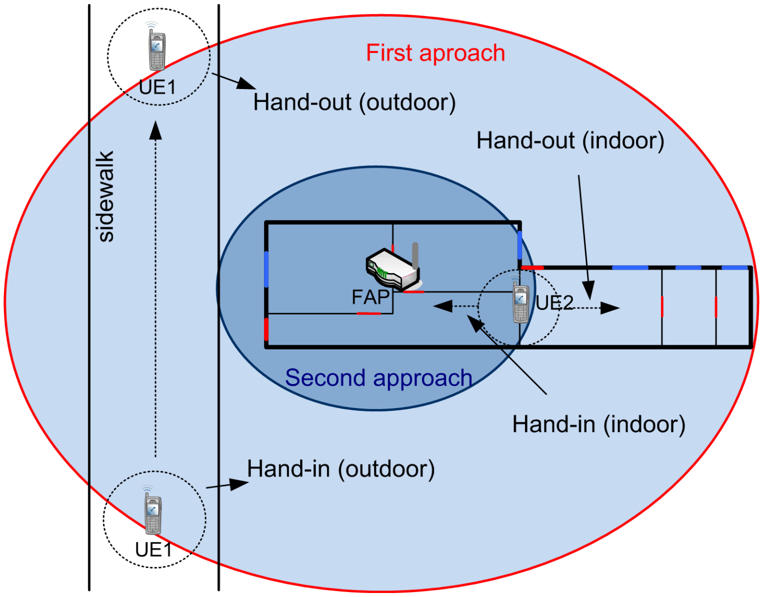
The problem of high amount of handovers in femtocell can be also solved by appropriate power control algorithm. In other words, the main purpose of existing power control techniques is to set power of a FAP in order to minimize the amount of handovers.

Generally, two different approaches are followed regarding the downlink power control in femtocell's environment (see Figure 6). According to the first approach, the main aim is to completely cover a specific area of certain radius (e.g., to ensure the whole house coverage). The advantage is that users are always able to attach to the FAP when inside the building. Nevertheless, the signal leakage out of the building boundaries may be significant. This is illustrated in Figure 6 where two handovers are performed just due to UE2 moving close to the house boundary. This drawback is significantly mitigated by utilization of the second approach. The primary goal of this approach is to set a transmitting power of the FAP to minimize interference to passerby's users or neighboring FAPs. Nonetheless, a weakness is that the coverage of whole building is not always assured, especially if the FAP is positioned close to the building boundary. More than that, its implementation can result in high amount of so called "indoor handovers," that is, handovers performed within users' premises caused by transition of the UE from the area covered by the MBS to the area covered by the FAP and vice versa.

In (Claussen et al., 2009), authors suggest auto-configuration schemes (representatives of the first approach) and self-optimization schemes (representatives of the second approach). While the auto-configuration scheme provides an initial power setting of the FAP, the self-optimization scheme tries to optimize the FAP's transmitting power during a normal operation.

Authors distinguish three auto-configuration schemes; 1) fixed power, 2) distance based, and 3) measurement based. When the fixed power configuration scheme is utilized, the transmitting power is set to a fixed value. The main disadvantage of this method is in strong dependence of the FAP's coverage on the distance from the MBS. Consequently, if the FAP is located far from the MBS, the MUEs experience high interference from the FAP. This drawback can be eliminated by the distance or measurement based approaches. In these cases, the FAP's power is configured so that the received signal from the strongest macro cell and the FAP is the same at a defined target cell radius. Usually the target cell radius corresponds to the maximum distance from the FAP where an UE attaches to the FAP rather than to the MBS. To that end, in the case of distance based auto-

Figure 6. Power control and its influence on handovers



configuration scheme, the FAP's transmitting power is set to:

$$P_{femto,pilot} = \min(P_{macro,pilot} + G_{macro} - L_{macro} + L_{femto}(r), P_{pilot,\max}) \tag{5}$$

where $P_{macro,pilot}$ is the transmitting power of the MBS, G_{macro} represents the gain of the MBS antenna, L_{macro} corresponds to the estimated path loss between the MBS and the FAP, $L_{femto}(r)$ stands for the path loss experienced by a UE at the target cell radius r, and finally $P_{pilot,max}$ is the maximal allowed transmitting power of the FAP. The main disadvantage of this scheme is that the setting of appropriate cell radius can be problematic as obstacles (i.e., walls, doors) have to be considered. Hence, the realization of this principle is not easy. When the FAP power is adjusted with regards to the measurement based auto-configuration scheme its pilot transmitting power is set according to next equation:

$$P_{femto,pilot} = \min(P_{Rx-pilot,macro} + L_{femto}(r), P_{pilot,\max}) \tag{6}$$

where $P_{rx\text{-}pilot,macro}$ is the measured received signal from the BS. Thus, the principle is analogical to the distance based principle but instead of estimation of the path loss, in built measurement capabilities of FAP are assumed.

Although the distance and measurement based methods outperform simple fixed power auto-configuration scheme, the number of handovers would be still too high especially for the scenarios when the FAP is positioned close to the house boundary. As a consequence, the auto-configuration schemes are used only for initial setup of the FAP's transmitting power. Additional necessary improvement is achieved by introduction of the self-optimization schemes.

Three self-optimization schemes are also proposed in (Claussen et al., 2009). Generally, all self-optimization schemes aim to minimize the number of handover based on their counting.

Consequently, the FAP must be able to collect statistical information regarding the mobility events. The first scheme forces the adaptation of FAP's power according to the mobility events generated by passing outdoor users attached to the MBS. The advantage could be seen in significant minimization of the amount of outdoor mobility events. Nevertheless, the number of indoor mobility events may be too high. This weakness is eliminated by the second proposed self-optimization scheme when the FAP tries to minimize all mobility events. The last scheme exhaustively searches over all possible power settings and the power of the FAP, during which the lowest number of mobility events occurred is determined as the optimum. This approach is not really practical due to long optimization time as all possible power settings are examined step by step. The numerical results demonstrate that the self-optimization schemes noticeably outperform all the auto-configuration methods. As already stated, the main disadvantage of all self-optimization schemes is that UEs inside the house are not always able to attach to the FAP as the full house coverage is not ensured.

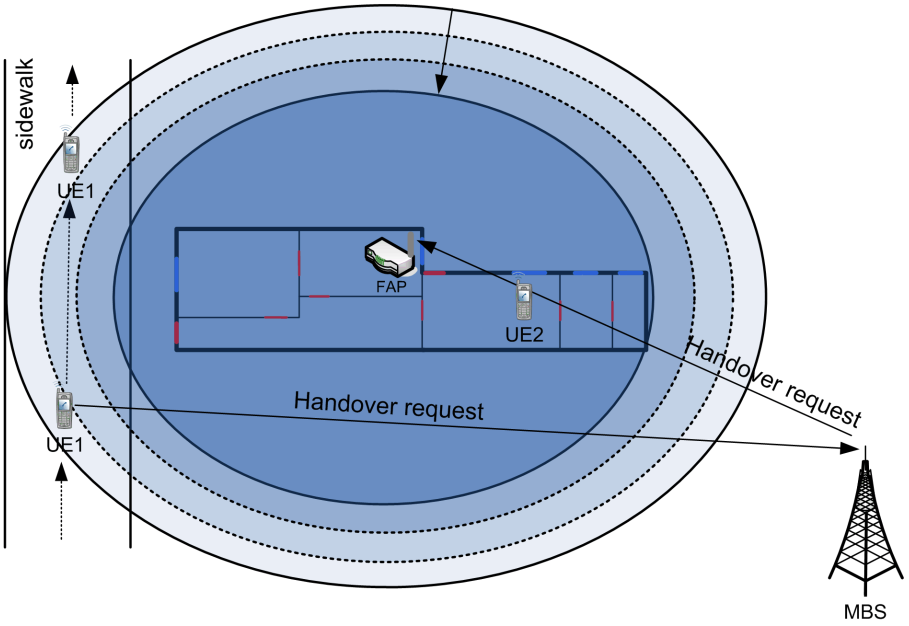
As an amendment of above mentioned schemes to further decrease the number of redundant mobility events, activity/inactivity of users can be assumed. The simplest way is introduced in (Claussen et al., 2008). To be more specific, if no users of the FAP are currently active (no voice or data are transmitted), the pilot transmitting power of the FAP is decreased by certain predefined level (e.g., in [Claussen et al., 2008]) authors propose to reduce transmitting power by 10 dB). At the same time, the UE's idle mode cell reselection threshold is also decreased by 10 dB to guarantee that the UEs remain connected to the FAP. This ensures additional mitigation of the redundant handovers while the FAP has still some coverage. More sophisticated mechanism is proposed in (Claussen et al., 2010) where authors suggest switching of the FAP to so called "idle state" when no pilot signals are transmitted at all. In order to implement this functionality, the FAP needs to have a capability to detect newly active users. Thus, if a UE in close vicinity of the FAP becomes active and if it is located within its coverage, the FAP automatically increases its transmitting power.

Another power scheme, which represents the second approach, is introduced in (Choi et al., 2009). The authors propose an Adaptive Coverage Adjustment (ACA) algorithm. The aim of the scheme is similar to the self-optimization schemes proposed in (Claussen et al., 2009), this is, to minimize amount of handovers and to reduce the signal leakage. If the UE currently attached to the MBS is in close vicinity of a FAP as indicated if Figure 7, the FAP itself iteratively decreases its transmitting power by one meter as long as the passing UE is in the FAP's range. After specific time period when the UE moves away from the FAP's coverage, the FAP increases its power to the initial value. The drawback of this scheme is similar to the distance based method (i.e., estimation of the FAP's radius could be difficult if some obstacles within the user's premises appear). In addition, this scheme is not able to fully mitigate signaling overhead due handovers since the decrease of power is done after reception of handover request at the side of the MBS and FAP.

Since both approaches have drawbacks, some kind of tradeoff between these two should be found. On one hand, the objective is to minimize the number of undesired mobility events in similar way as the proposals based on the second approach aims. However, at the same time, the goal is to keep the same QoS level to the FAP's users as in the case of the first approach (Mach & Becvar, 2011).

The general principle is depicted in Figure 8. The left part of the figure shows the case when the transmitting power of the FAP is adjusted to achieve target CINR (denoted as $CINR_T$) at the radius r_1, which could correspond, for example, to the house boundaries. If the channel quality, characterized by the $CINR_1$, at the side of both UEs is distinguishable higher than $CINR_T$ and the

Figure 7. Principle of ACA self optimization scheme



radio resources of the FAP are not fully utilized, the FAP's transmitting power is decreased while no negative impact on QoS is observed. The power is adjusted to such value when the received signal from the FAP at the side of both UEs is still acceptable (in Figure 8b depicted as $CINR_2$) and thus all data can be still transmitted. Therefore, an opportunistic decrease of the transmitting power helps to minimize the number of mobility events.

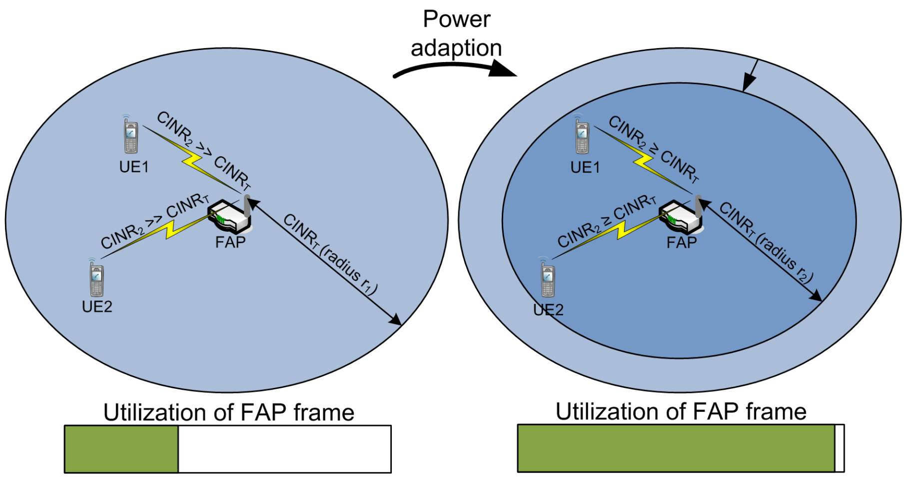
Neighbor Cell List

Most of the papers dealing with the problems related to the NCL address especially the management of the NCL for the MBS. However, the FAPs have many differences comparing to MBS. The main difference is the absence of central planning of the FAPs deployment since the owner of the FAP can place it anywhere. Therefore, many of proposed principles for the MBSs cannot be used for the management of the FAPs' NCL.

In (Li & Jantti, 2007), the authors propose a method that automatically assigns the NCL to the newly connected cells. Three categories of algorithms are defined. The categories differ among others by complexity of antenna radiation approximation and thus in computational complexity and efficiency. The proposed solution assumes knowledge of exact cells' position. Therefore, this approach is not suitable for a network with femtocells since the FAP's coordinates are not known and could be changed depending on FAP's owner at any time.

The proposal described in (Magnusson & Olofsson, 1997; Olofsson et al., 1996) is based on the creation of a testing NCL. This approach is developed for networks with the MBSs. However, it can be easily extended to the femtocell networks. Beside the frequencies corresponding to all ASs included in the NCL, the testing NCL have to contain also one or more randomly selected testing frequencies for searching new neighbors. This allows scanning the frequencies of FAPs located nearby, which are not included in the NCL so far. Testing frequencies are changed for each scanning to enable scanning whole available bandwidth. If a signal received at the test frequency is evaluated as strong enough, corresponding cell is added to the

Figure 8. Principle of power control based on frame utilization



a) without power adaptation b) with power adaptation

NCL as a new member. Ideal length of the NCL depends on the model of network infrastructure as it can be observed from simulation results. The results also demonstrate that the algorithm is able to adapt to changes in the network after roughly five hundred handovers performed in a given cell. Moreover, the speed of adaptation is highly dependent on the network model, network load, and measurement capabilities of UEs.

Another proposal is described in (Kim et al., 2010). The authors propose an algorithm through which the newly added cell can find its neighbors. The own scanning of newly added cell by the FAP is essential idea of this proposal. The authors introduce the possibility of the identification of cells in neighborhood based on the received signal level. The simulation results show how the adjustment of the threshold value $\mathrm{SINR}_{\mathrm{treshold}}$ of the received signal affects the number of records in the NCL for different types of newly deployed cells and their adjacent cells (macro and pico). If the threshold value $\mathrm{SINR}_{\mathrm{treshold}}$ is set too high, only cells from the very close vicinity with the highest SINR are chosen as members of the NCL. This brings a reduction of the overhead since cells that are not in the neighborhood are not included in the NCL. However, some cells in neighborhood can be missed in the NCL. On the contrary, if the threshold value $\mathrm{SINR}_{\mathrm{treshold}}$ is set too low, large amount of cells, which are not directly adjacent of the new cells are added to the NCL. This increases the scanning overhead. A disadvantage of the proposed solution in the network with the FAPs is limited coverage of FAPs. Consequently, two neighboring FAPs could not be able to detect each other.

The article (Han et al., 2010) addresses the creation and maintenance of the NCL in femtocells. The basic assumption of the proposed mechanism is that neighboring cells are within mutual range. The proposed method determines the approximate location of the FAPs based on the level of received signal from all neighboring FAPs. Collocation of the FAPs can be reconstructed based on knowledge of approximate position. Hidden neighborhoods caused due to an obstacle (e.g., heavy wall) between FAPs can be detected on the basis of the calculated position. The disadvantage of the proposed procedure is the assumption that the FAP is able to receive signals from all neighboring FAPs. As the radius of FAPs is expected to be very low, the fulfillment of this assumption is unlikely. Therefore the utilization of this algorithm is very limited.

A specific way to speed up the handover scanning process is represented by a cache scheme presented in (Lee & Lin, 2010). The authors propose to use a cache to store the cell information of the recently visited FAPs and use it to speed up the process when the EU returns back to the femtotier. Then, the UE scans only FAPs included in cache instead of scanning all the FAPs in the NCL. The cache scheme exploits the WMM (Wireless Mobility Management) location based approach using UE's location information for routing data for UE, as introduced in (Huang et al., 2008). The overall size of used cache is related to the amount of ASs accommodating the same frequency band.

An algorithm for dynamic adjustment of the NCL is described in (Zhou, 2009). The authors propose two algorithms for the efficient NCL maintenance based on a statistical evaluation of user's movement. This algorithm is primarily aimed on reduction of the amount of records in the NCL. The results show that the utilization of both algorithms enables lowering the amount of items in the NCL comparing to the standard approach of the NCL creation. The proposed algorithm could be used mainly for the MBSs that cover a large number of FAPs. On the other hand, the use of the shorter NCL could lead to lower efficiency of FAPs in the open access and hybrid access as some neighbors can be removed from the NCL even if the handover to this FAP can occurs in the future.

Femtocell Identification

The problem with proper cell identification in femtocell's environment makes handover procedure very difficult. The approach to reduce the probability of confusion and collision in case of hand-in considers the controlled selection of cell identifiers.

In (Amirijoo et al. 2008), the authors suggest a method for automatic configuration of the PCI. The proposed method utilizes measurement reports in order to update the NCL and to detect a local cell identity conflicts. The simulation results indicate that the local cell identity collisions can be solved. To avoid confusion and collision due to the same PCIs of two or more cells, the authors in (Bandh et al, 2009, Ahmed et al., 2010) propose to assign the PCI by means of graph coloring. Nevertheless, neither of all above mentioned methods takes into consideration the FAPs. This issue is addressed in (Lee et al., 2009) where dynamic reservation scheme for the PCI is proposed. Several types of a dynamic reservation are considered. Each reservation type differs in the number of PCI reserved primarily for the FAPs. The transition between individual types depends on either the number of deployed FAPs or the number of observed confusion events. It is demonstrated that this approach is able to shorten searching time for the FAP and thus to speed up whole handover process from the MBS to the FAP. Nevertheless, a drawback of this approach is that the confusions are not totally eliminated as the changing between individual reservation types is based on the number of generated confusions.

A self-organization algorithm of the PCI assignment is proposed in (Wu et al., 2010). The authors suggest equipping the FAP with a receiver of signals from surrounding cells. The data on the PCI of neighboring FAPs are sent to the central entity, denoted PCI Assignment Function, which can access all necessary information from the surrounding FAPs. Based on the different FAP's access modes, the PCI Function Assignment proposes a Layer Structured PCI self-organization scheme. One layer contains the common MBSs and the FAPs in the open access; another layer contains the FAPs in the hybrid access, and the last layer includes the FAPs in the closed access. All available PCIs are distributed among various layers. The PCI is assigned to a FAP according to which layers the FAP belongs. The operational expenditure for the PCI allocation and optimization of the widely distributed FAPs can be well reduced by replacing time consuming and costly tasks with automatic mechanisms. However, the drawback of this proposal is the requirement on new entity PCI Function Assignment. On the other hand, this new entity does not increase cost of the FAPs.

Another approach is introduced in (Sang et al., 2009). This paper proposes a new physical layer frame structure for the IEEE 802.16e based femtocell. The authors modify the structure of the preamble and additionally, propose a self-initiation scheme. The self-initiation scheme assumes utilization of signals received from neighboring FAPs to select the preamble for the initiated FAP. The FAP selects a punctured-preamble, which shows the lowest cross-correlation with the symbols received from other neighboring FAPs. The cross-correlations of individual preambles are compared by differential vectors. Using the proposed preamble structure and self-initialization scheme, the MUEs can detect a MBS even though they are located very close to a FAP. Thus the probability of FAP's detection failure is significantly minimized. This approach needs no additional entity in network as the FAPs are responsible for selection of the cell identifier.

FUTURE RESEARCH DIRECTIONS

In order to reduce amount of redundant handovers, a very promising approach is an exploitation of prediction. The advantage of the prediction of individual parameters for the FAPs is simpler task, comparing to MBSs, as only short time prediction of all aspects influencing handover decision should be performed. The short time prediction is sufficient since the FAP is of the very small radius. Therefore, more precise description of user's and network behavior can be derived. Moreover, the fluctuation of predicted parameters is supposed to be lower due to the low radius of the FAP. The aspects to be considered for prediction are following: users' behavior (movement, traffic, etc); channel quality; backbone load and delay. The estimated information can be included as additional conditions for handover decision. Further, the prediction accuracy can be improved by exact determination of the FAP's position. At the current state, the FAP's position is defined with very low preciseness as the user can deploy this FAP anywhere in his house. One possible option is to equip FAPs with several additional receivers such as receiver of TV signal to reduce error in determination of the FAP's position. However, the cost of the FAP is increased. Therefore, the main challenge is to develop an algorithm or method allowing more accurate derivation of the FAP's position using only conventionally received signals.

Another approach to optimize handover procedure and improve network performance is to solve optimal sharing of available capacity among CSG and non CSG users in case of the hybrid access. This issue is especially crucial if the backbone capacity is varying in time, which is exactly the case of FAPs utilizing DSL link or cable link as a backbone connection to Internet. To that end, the power of the FAP can be adaptively changed in dependence on currently available backbone capacity. In other words, if the backbone is overloaded, it is profitable to decrease transmitting power of FAP and thus to force some outdoor users to perform handover to the MBS. On the other hand, if the load transmitted via backbone is not significant, the FAP's transmitting power can be increased and some outdoor users can be served and thus it can partially offload the MBS. In this manner, it could be guaranteed that the users performing handover from the MBS to the FAP can utilize some of its capacity. From the indoor users' point of view, they can always utilize the backbone capacity as needed and no unnecessary QoS impairment is observed.

The lower demand on the exact position of FAP's are imposed on the determination of NCL members. In this case, only knowledge of neighbors, without need of exact knowledge of their position is sufficient. On the other hand, the more precise relative position of individual FAPs can be exploited for reduction of the scanning time since the information related to the movement of user's (e.g., knowledge of user's direction) can be used for significant reduction of potential target FAPs.

To eliminate problems with limited amount of cell identifiers, the current solutions are based on self-organizing networks in which the identifiers are assigned based on the cells neighborhood. This approach can be limited by the density of FAPs. To completely solve this issue even for dense deployment of FAPs, the new concept of cell identification should be developed. As a potential way could be the design a cell identification scheme based on new physical layer frame modifications. The major constrain of this method is to ensure backward compatibility with former version of standards for wireless networks.

CONCLUSION

This chapter provides an overview on the handover procedure to enable efficient mobility of users in femtocells network.

The most important problem is represented by the frequent initiation of the handover procedure if the FAPs are deployed densely since it results in a drop of user's QoS. Three major approaches are currently under investigation: enhancement of common techniques for elimination of handovers such as hysteresis or signal averaging, exploitation of new metric or parameters in handover decision stage, and control of the FAP's transmitting power. Whereas the first way is less complex, its efficiency is also lower comparing to the other approaches.

Another important aspect regarding user's mobility is the monitoring of UE's neighborhood to reduce the time consumed by scanning. Since the FAPs are randomly distributed in the network, the conventional methods of creating the NCL consider only the MBSs. However, the most of the solutions proposed for the MBSs cannot be used in the network with the FAPs due to limited knowledge of FAP's position and limited knowledge of FAP's neighborhood. The most promising approach seems to be the one based on neighborhood sensing combined with statistical evaluation of performed handovers.

The last problem is related to identification of cells as only limited amount of ASs can be deployed under current version of mobile networks standards due to limited amount of available cell identifiers. The current approaches are focused on the self-organizing schemes, which ensure proper assignment of cell identifiers. Nonetheless, these techniques are not able to ensure error-free performance for networks with dense deployment of femtocells.

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KEY TERMS AND DEFINITIONS

Hand-In: New type of handover introduced by implementation of FAPs representing a transition from a MBS to a FAP.

Hand-Out: New type of handover introduced by implementation of FAPs representing a transition from a FAP to a MBS.

Handover: A process during which the UE moving from the area of one MBS is switched to adjacent MBS while all connections are maintained.

Handover Decision: The stage of handover procedure when it is decided whether the handover should be performed or not.

Inter FAP Handover: New type of handover introduced by implementation of FAPs representing a transition from one FAP to neighbor FAP.

Neighbor Cell List: List of all stations in the UE's neighborhood that are potential candidates to be target station for handover.

Serving Station: A station represented either by MBS or by FAP serving the UE at the present time.

Target Station: A station represented either by MBS or by FAP, which will potentially serve the UE after the handover is completed (i.e., target station becomes new serving station).