Adaptive Hysteresis Margin for Handover in Femtocell Networks

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***Abstract*—The challenge of elimination of redundant handovers is getting more significant while femtocells with small radius are deployed in networks. The utilization of the femtocells results to more frequent initiation of a handover procedure. This paper focuses on an adaptation of actual level of hysteresis margin according to the position of the user in a cell. The hysteresis margin is commonly used parameter for elimination of redundant handovers. The purpose of this paper is to propose mechanism with minimum requirements on conventional network and user's equipment and with a simple implementation. Evaluations of proposal in term of efficiency of the redundant handovers reduction as well as an impact on the user's throughput in 4G wireless networks are carried out. The results show significant reduction of the amount of handovers while reducing the impact on the throughput.**

Keywords-femtocell; handover; hysteresis margin; Long Term Evolution; throughput

I. Introduction

The purpose of femtocells' implementation into the mobile wireless networks is either to reduce a cost of connection or to enable better coverage in specific area such as house, flat or building [1]. The femtocells are represented by Femto Access Point (FAP) that enables mobile wireless users to connect to the network. The FAP is generally connected to the backbone through a cable connection, e.g., xDSL (Digital Subscriber Line) or optical fiber. The range of FAP's coverage is assumed to be very small (meters or tens of meters) in order to cover house, office or flat and to produce minimum interference to its neighborhood. The major difference between the conventional Node-B (or Base Station − BS) and the FAP is not only in coverage range but also in the fact that the FAP is partially controlled by a user such as e.g., Wi-Fi router. The user can replace the FAP to the other room, turn the FAP on and off or to disconnect/reconnect it from/to the network.

The FAP can provide several types of access: close access, open access, or hybrid access. The close access allows entering the FAP's only to a user equipment (UE) of the FAP's owner or to a very small group of users. The group of users with access to an individual FAP is defined by the FAP's owner. Other users are excluded from the access the network via the FAP. On the other hand, the open access enables all users to share a capacity provided by the FAP. The hybrid access is a combination of both. It affords other UEs to access the network whereas a part of FAP's capacity is permanently dedicated to the FAP's owner. While the close access should ensure minimum interference to reduce the throughput decrease of other UEs in its neighborhood, the open access can increase the throughput or coverage in specific area [2].

The open (or hybrid) access can lead to very often initiation of a handover procedure in areas with high density of FAPs. The minimization of redundant handovers is presented in [3] [4]. The authors propose to apply a time interval, during which the signal level conditions for the handover must be fulfilled to perform it. As presented in both papers, this solution reduces an amount of the redundant handovers; however negative impact on the throughput is not taken into account. The solution of a proper assignment of a user to the target station is presented in [5]. This paper considers the asymmetry between FAP and BS transmission power in a handover decision mechanism. The proposed technique increases the probability that the user will be correctly assigned to the femtocell with best signal quality. On the other hand, the mechanism slightly increases the number of handovers as well. Two proposals on reduction of the signaling cost of the handover by FAP's gateway are described in [6]. Both proposed methods differ among other by purpose of the gateway. In the first one the gateway acts as a mobility anchor to control handovers among femtocells while in the second method the gateway acts as a relay. The first solution results in lower signaling cost (up to 30%) than the second method. In [7], the authors compare the probability of UE's assignment to the FAP that do not provide the best signal quality. The paper shows tradeoff between a minimum duration of signal averaging and probability of error assignment. The proposal of a power control improvement for the reduction of a number of redundant handovers is presented e.g., in [8] [9] [10]. The reduction of the transmission power of FAP eliminates the redundant handover. Nevertheless, the advantage of throughput gain due to the open/hybrid access is also suppressed. The optimization of hysteresis margin (HM) technique for elimination of redundant handovers is defined in [11]. The authors evaluate so called adaptive HM in scenario with macro BSs. The paper assumes exact knowledge of distance among an UE and its serving BS and exact and invariant radius of macrocells. The radius of all cells is assumed to be the same. Nevertheless, the radius is slightly varying in time in practice. Moreover, the radius of individual cells is largely different if FAPs are deployed and the exact position of FAPs is not defined by operator as it is in charge of the user. Thus, the cell radius of FAPs cannot be precisely estimated. Therefore technique proposed in [11] cannot be applied into the networks with femtocells.

The goal of this paper is to exploit an idea of the adaptive HM to be easily implemented to the networks and also to modify the procedure of HM adaptation to be applicable in networks with femtocells. The paper proposes to utilize conventionally reported metrics such as RSSI (Received Signal Strength Indicator) or CINR (Carrier to Interference plus Noise Ratio) for the dynamic adaptation of an actual value of HM. The method of adaptive HM proposed in this paper is evaluated in environment of LTE (Long Term Evolution) wireless networks according to release 9.

The rest of paper is organized as follows. Next section describes the principle of HM and its dynamic adaptation including proposed modification. The third section defines simulation scenario and parameters used for evaluation of the adaptive HM performance. The section four includes the results of simulations. Last section presents our conclusions and future work plans.

II. Adaptation of Hysteresis Margin

While HM is implemented, the handover decision and initiation is based on a comparison of one or several signal parameters (e.g., CINR or RSSI) of a serving and a target BS as shown in Fig. 1. The handover is initiated if the signal parameter of the target BS exceeds the signal parameter of the serving BS at least by HM level.

$$S_t^{Tar} > S_t^{Ser} + HM \tag{1}$$

where S_t^{Tar} and S_t^{Ser} represents a signal quality parameter of the serving and target BS respectively in a time instant t.

In the conventional HM, the level of the hysteresis is constant. The adaptive HM is based on the modification of actual HM value according to the position of the user in the cell. The HM is decreasing with UE's moving closer to the cell boarder. It is presented in equation (2) (defined in [11]).

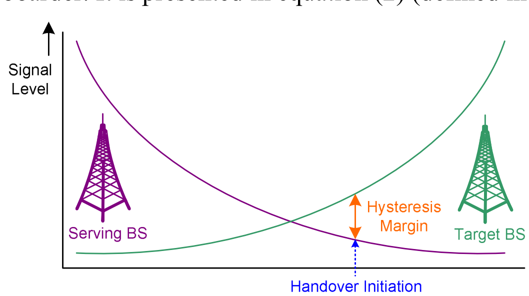

Figure 1. Principle of the conventional hysteresis margin.

$$HM = \max\left\{ HM_{\max} \times \left(1 - \frac{d}{R}\right)^4 ; 0 \right\} \tag{2}$$

where HM_{max} is the maximum value of HM that can be setup (in the middle of the cell); d is the distance between the serving BS and UE; R is a radius of the serving BS's cell. As mentioned in the previous section, the parameters d and R cannot be easily obtained or determined neither by the network nor by the UE. Especially when FAPs are deployed in networks, its exact position is user's dependent and it is not known to the operator. Therefore, this paper proposes to replace these parameters by another metric that can be utilized more easily and effectively.

The most of path loss models describe the relation between the distance d of a UE from a BS and a path loss (PL) in the following way:

$$PL(d) \sim X(f) + N \log_{10}(d) \tag{3}$$

where $X(f)$ represents the dependence of the PL model on the frequency and other terms usually used in models; and N is a coefficient related to the type of environment. Function $X(f)$ and N are dependent on the individual path loss model.

The level of received signal at a specific distance ($RSSI(d)$) depends on path loss and transmission power of the station of interest (TP_{st}) as defined in the next formula:

$$RSSI(d) = TP_{st} - PL(d) \tag{4}$$

Furthermore, the distance d can be expressed as an exponential function based on (3) and (4) as follows:

$$\begin{aligned} RSSI &= TP_{st} - \left(X(f) + N \log_{10}(d)\right) \\ d &= 10^{\frac{1}{N}(TP_{st} - X(f) - RSSI)} \end{aligned} \tag{5}$$

Considering (5), the formula (2) can be modified in the following manner:

$$\begin{aligned} HM &= \max\left\{ HM_{\max} \times \left(1 - \frac{10^{\frac{1}{N}\times(TP_{st} - X(f) - RSSI)}}{10^{\frac{1}{N}\times(TP_{st} - X(f) - RSSI_{\min})}}\right)^{EXP} ; HM_{\min} \right\} \\ &= \max\left\{ HM_{\max} \times \left(1 - 10^{\frac{1}{N}\times(RSSI - RSSI_{\min})}\right)^{EXP} ; HM_{\min} \right\} \end{aligned} \tag{6}$$

where EXP represents the exponent (in the former adaptive HM defined by (2) equal to 4); and HM_{min} is the minimum HM that can be set up (in (2) equal to 0). Parameters EXP and HM_{min} can influence the performance of the HM adaptation. However, the investigation of the optimal setting of both parameters is out of paper's scope due to the limitation of the paper length. The values of EXP and HM_{min} utilized in further analysis are taken over from [11].

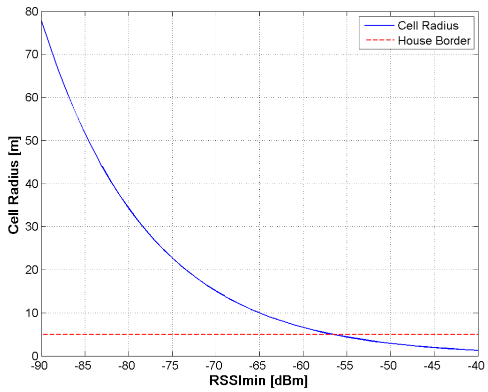

Figure 2. Cell radius over $RSSI_{min}$ accoding to the ITU-R P.1238 path loss model.

The cell radius is typically defined as the distance where the minimal allowed level of RSSI, denoted as $RSSI_{min}$, is reached. The typical value of RSSI at cell's edge equals to $-90\ dBm$ [12]. However in case of FAP, the cell radius is in order of tens of meters if the ITU-R P.1238 path loss model [13] is considered (see Fig. 2). Note that wall loss of 10 dB is included at house boundaries in Fig. 2. The impact of FAPs radius defined by different $RSSI_{min}$ on the redundant handovers elimination is analyzed later in the paper.

In fact, the border of cells are neither regular circles nor hexagons since the system is not distance or signal level limited but it is interference limited. Therefore, the shape of the cells is strongly influenced also by the interference. Hence, this paper further proposes to implement CINR instead of RSSI for calculation of the actual level of HM. Generally, a signal level influenced by the interference and noise (IN) can be described according to the next equation:

$$CINR = TP_{st} - PL - IN = RSSI - IN \tag{7}$$

The CINR level is in different range of values than RSSI. Thereupon, it has to be related to the difference between maximum and minimum CINR in the observed area. Thus, the actual HM level according to CINR is derived as follows:

$$HM = \max\left\{ HM_{\max} \times \left(1 - 10^{\frac{CINR_{act} - CINR_{\min}}{CINR_{\min} - CINR_{\max}}}\right)^{EXP}; HM_{\min} \right\} \tag{8}$$

where $CINR_{act}$ is the actual CINR measured by a UE; $CINR_{min}$ and $CINR_{max}$ are minimum and maximum values in the investigated area respectively.

The actual CINR of UE can be easily measured during UE's operation. It is usually performed with purpose of handover decision and initiation. However, also the minimum and maximum CINR values have to be known for the utilization of the adaptive HM. The $CINR_{min}$ corresponds to the cell radius and to the CINR level, at which the UE is able to receive data. Therefore, it is set up as a fix value for each FAP and BS. The $CINR_{max}$ can be determined by two ways: i) measurement of CINR by a FAP at the point of its location; or ii) monitoring and reporting of CINR by all UEs connected to the given FAP and than selecting the highest CINR from all known values as the $CINR_{max}$. The first way implies to equip all FAPs with ability to measure CINR. Hence it is not furthermore considered in the paper. The second approach utilizes the knowledge of previous CINR values in the area reported by UEs. Since the channel is time variant, the time interval for selection of the $CINR_{max}$ should be determined. The parameter $CINR_{win}$ represents a number of latest samples utilized for the $CINR_{max}$ derivation. The optimum value of $CINR_{win}$ is further analyzed in this paper.

III. Simulation Scenario and Parameters

The evaluation of modified adaptive technique is performed in the deployment of FAPs and macro BSs as depicted in Fig. 3. Direct street with family houses along both sides is assumed in the simulation. Overall, fifty houses are placed along the street with length of 500 m. For the simplification, regular and symmetric positions of all Access Stations (ASs) are supposed in the simulations. The AS is a common notation of BSs as well as FAPs.

The users are moving along the street in the unified direction with the speed of 1 ms^{-1}. During the simulation, the users are equally distributed over the street width with spacing of 0.2 m. The UE is moving until it reaches the end of the street. During its movement, the signal level is reported to the serving AS. The reporting interval is considered to be 0.5 s. The signal quality from FAP is evaluated according to the ITU-R P.1238 path loss model for one floor house including wall losses and channel variation due to the fast fading and shadowing with standard deviation of 4 dB as defined in [14]. The Okumura-Hata path loss model for outdoor to outdoor communication [15] is used for determination of BS's signal propagation. The transmitting power of FAPs and BSs are defined to be in line with values utilized in simulations performed by Femto Forum [15]. All simulation parameters and models are summarized in Tab. 1.

The amount of handovers is obtained as a number of initiated handovers. It means, if all conditions for the handover initiation are fulfilled, the handover is taken into account no matter if it is finished or not.

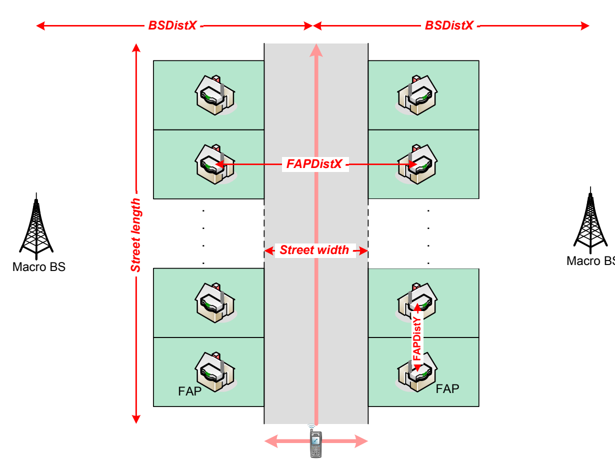

Figure 3. Deployment of FAPs and BSs for performance evaluation.

TABLE I. SIMULATION SCENARIO AND DEPLOYMENT

Parameter	Value
Frequency	2 GHz
Transmiting power of BS / FAP	43 / 15 dBm
Height of macro BS / FAP / MS	30 / 1 / 1.5 m
External / Internal Wall Loss	10 / 5 dB
FAP path loss model ITU-R P.1238	20log(f)+28log(d)-24
BS path loss model Okumura-Hata	69.55+26.16log(f)-13.82log(h_B)+(44.9-6.55log(h_B))log(d)-(1.1log(f)-0.7)h_M+(1.56log(f)-0.8)
Channel bandwidth	20 MHz
Noise for channel BW = 20 MHz	-100.97 dBm
Resource blocks per channel	100
BS Dist X / BS Dist Y (see Fig. 3)	500 / 250 m
FAP Dist X / FAP Dist Y (see Fig. 3)	23 / 20 m
Street Length / Street Width	500 / 8 m
Number of simulation drops	25
$RSSI_{min}$	−90 ÷ −70 dBm
$CINR_{min}$	−3 dB
$CINR_{win}$	10 ÷500

The evaluation of an impact of the adaptive HM on the throughput is performed for TDD frame structure of LTE release 9 with uplink–downlink (UL–DL) configuration *"1"* [16]. The frame duration is 10 ms as shown in Fig. 4. The frame is divided into 10 subframes and 20 slots. Four subframes are dedicated to DL as well as for UL transmission in UL–DL configuration *"1"*. Two subframes represent so called Special Subframes (SSs), which are separated into DL transmission part (DwPTS), Guard Period (GP) and UL transmission part (UpPTS). The ratio among all three parts depends on the type of SS configuration. Configuration *"0"* is utilized for all simulations in this paper.

Each slot consists Resource Blocks (RBs), which are further composed of Resource Elements (REs). The number of RE per RB (N_{RE}^{RB}) is defined by the next equation:

$$N_{RE}^{RB} = N_{SC}^{RB} \times N_{symb} \qquad (9)$$

where N_{SC}^{RB} is a number of subcarriers per RB; and N_{symb} is a number of symbols per the subcarrier. Seven symbols per subcarrier are used for a normal cyclic prefix and typically 12 subcarriers per one RB in LTE release 9. The spacing of subcarriers is $\Delta f = 15\ kHz$. The amount of bits carried in one RE depends on available Modulation and Coding Scheme (MCS). The assignment of the MCS is based on signal quality according to Tab. 2 (the values are taken from [17]).

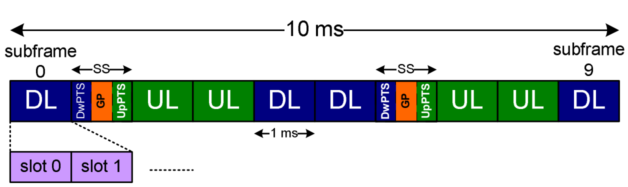

Figure 4. LTE TDD frame structure used in the simulations.

TABLE II. SELECTION OF MCS ACCORDING TO CINR

CINR [dB]	MCS	Transmission efficiency Γ [bits/symbol]
$CINR_{min}$ <CINR <= 1.5	1/3 QPSK	0.66
1.5 < CINR <= 3.8	1/2 QPSK	1
3.8 < CINR <= 5.2	2/3 QPSK	1.33
5.2 < CINR <= 5.9	3/4 QPSK	1.5
5.9 < CINR <= 7.0	4/5 QPSK	1.6
7.0 < CINR <= 10.0	1/2 16QAM	2
10.0 < CINR <= 11.4	2/3 16QAM	2.66
11.4 < CINR <= 12.3	3/4 16QAM	3
12.3 < CINR <= 15.6	4/5 16QAM	3.2
15.6 < CINR <= 17.0	2/3 64QAM	4
17.0 < CINR <= 18.0	3/4 64QAM	4.5
18.0 < CINR	4/5 64QAM	4.8

While full buffer traffic model is assumed, the DL throughput of a user is furthermore calculated according to the subsequent formula:

$$Thr_{DL} = \Gamma \times n_{RB} \times N_{SC}^{RB} \times N_{symb} = \Gamma \times n_{RB} \times N_{RE}^{RB} \qquad (10)$$

where n_{RB} is a number of resource blocks (depending on a channel bandwidth as indicated in [16]).

The throughput of UEs via wireless interface is supposed to be with no limitation caused by the FAP's backbone connection since the FAPs are supposed to be connected to the backbone through a high speed optical fiber.

IV. SIMULATION AND PERFORMANCE EVALUATION

The determination of the optimal $RSSI_{min}$ for evaluation of the actual HM is shown in Fig. 5 and Fig. 6. As the best performing $RSSI_{min}$ value should be the one enabling maximum reduction of the amount of handovers simultaneously with minimum impact on the throughput. Based on both figures, the derived optimum $RSSI_{min}$ is equal to −80 dBm. The figures also show that selection of inappropriately high $RSSI_{min}$ eliminates the positive effect of HM on the amount of handovers (see e.g., the light blue curve for $RSSI_{min}$ = −75 dBm in Fig. 5).

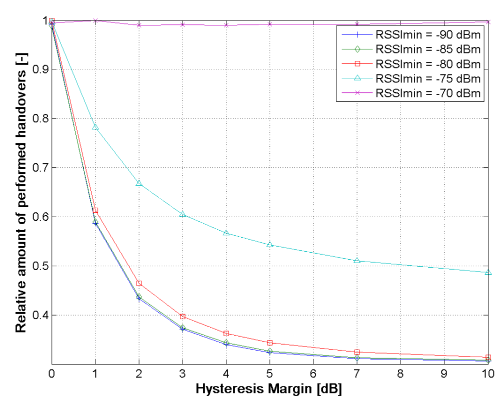

Figure 5. Average amount of handovers over HM_{max} for determination of optimum $RSSI_{min}$.

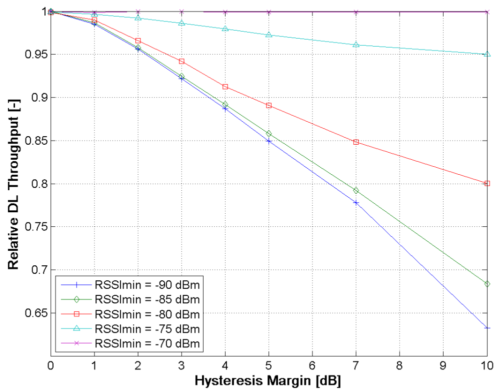

Figure 6. Average DL throughput over HM_{max} for determination of optimum $RSSI_{min}$.

As stated before, the significant weakness of the RSSI based definition of cell border is that the system is largely influenced by the interference. The comparison of different methods of actual HM derivation is presented in Fig. 7 and Fig. 8. Both figures are analogical to Fig. 5 and Fig. 6. The optimum interval $CINR_{win}$ as well as the comparison with RSSI based method and conventional fixed (non−adaptive) HM can be observed from the figures.

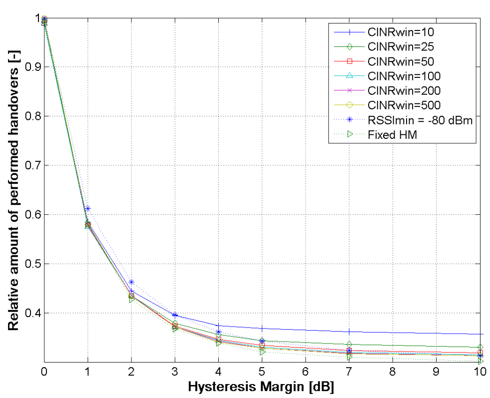

Figure 7. Comparison of an impact of different methods for determination of actual HM from the point of view of average amount of handovers.

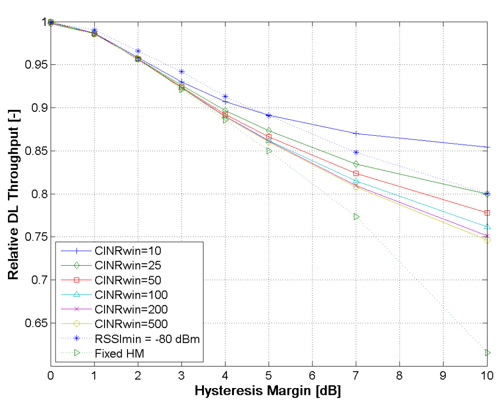

Figure 8. Comparison of an impact of different methods for determination of actual HM from the point of view of DL throughput.

The utilization of CINR can achieve the same efficiency as determination of $RSSI_{min}$ while the CINR based method is not so sensitive to the $CINR_{win}$ since the impact of $CINR_{win}$ on the number of handovers is negligible. Only the very low $CINR_{win}$ leads to the decrease of the handover elimination efficiency. From the throughput point of view, the lower $CINR_{win}$ is preferred. Nevertheless, its impact is minor. Comparing to the conventional fixed HM, the proposed solution reaches the same reduction of the number of handovers with lower negative impact on the throughput.

Fig. 9 presents the distribution of an average amount of handovers over the street width for different levels of HM_{min}. The number of handovers is average out over all simulation drops and over whole street length. The figure contains results for CINR based adaptive HM for $CINR_{min} = -3$ dB and $CINR_{win} = 25$. As can be observed the amount of handovers significantly rises with UE getting closer to the middle of the street since the difference among all CINRs from ASs on both sides is very low. On the other hand, the signal received from FAPs at the same side as the sidewalk, along which the UE is moving is distinctively higher than signal from another ASs. Therefore, the UE usually performs the handover only among adjacent FAPs. The elimination of the most handovers at the sidewalks is achieved even if the HM is equal to 1 dB while the optimum value in the middle of the street is at least 4 dB.

Fig. 10 illustrates the dependence of the average DL throughput over the street width. The drop of the throughput when the UE is moving closer to the middle is obvious. The decrease of the throughput results from lower CINR received if FAPs on both sides are roughly in the same distance.

Considering the results presented in Fig. 9 and Fig. 10, the optimum value on the sidewalks is HM = 1 dB as it eliminates almost all redundant handovers whilst throughput is not influenced. On the contrary, the optimum value in the middle of the street should be defined based on the priority either of the elimination of handovers or of the throughput. The optimum HM value is roughly up to 5 dB. For this value, the number of the handovers reaches its minimum however the throughput is still decreasing uniformly. The tradeoff between elimination of the redundant handovers and throughput should be considered in the middle of the street.

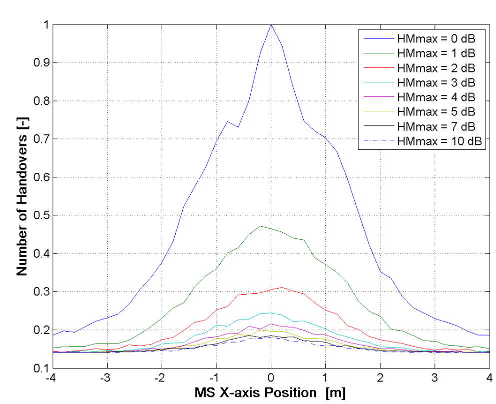

Figure 9. Average amount of handovers over the Street Width for CINR based adaptive HM.

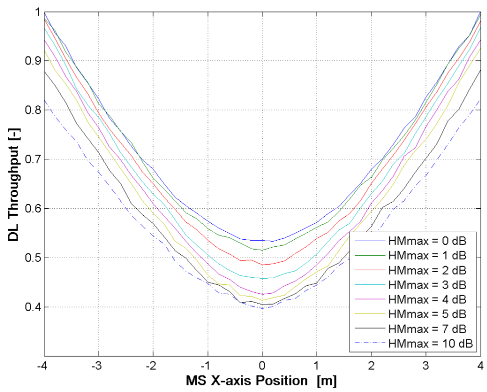

Figure 10. Average DL throughput of UEs over the Street Width for CINR based adaptive HM.

As the requirements on the HM_{max} depends on the position in the street, the decision on the determination of the general optimum value of HM_{max} in (8) should be done with respect to the usual distribution of the users along the street. In the most cases, only the pedestrians are assumed to exploit open/hybrid access since vehicular users spends very short time in the FAP's cell due to higher speed. Hence, the major part of users should be placed on the sidewalks. Consequently, the value of 1 or 2 dB for HM_{max} can be selected as the optimum value.

V. CONCLUSION

The paper proposes modification of the adaptive HM to enable its easy implementation to the networks with FAPs. The adaptive HM reduces the number of redundant handovers while keeping the throughput gain of open/hybrid access femtocells as high as possible. Comparing to the former adaptive HM assuming exact knowledge of cell radius and MS-AS distance, the proposed technique needs information neither on the UE location nor on the FAPs positions that cannot be easily obtained. The proposed solution uses either RSSI or CINR ordinarily measured by a UE during scanning of its neighborhood. The results show similar performance of both manners of HM adaptation. However, utilization of CINR is not so much sensitive on inaccurate setting of its parameters. Thus, it is preferable for implementation in the networks with femtocells. Both methods outperform conventional fixed HM.

The future work will be focused on the derivation of the optimal parameters (e.g., *EXP* or HM_{min}) for the proposed adaptive HM as well as on the further elimination of the redundant handovers by considering the prediction of the channel and user's behavior.

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