Adaptive Techniques for Elimination of Redundant Handovers in Femtocells

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***Abstract*—Dense deployment of femtocells in mobile wireless networks can significantly increase the amount of handover initiations. This paper analyzes new approach to elimination of redundant handovers. The innovative way dynamically updates current value of techniques commonly used for elimination of redundant handovers. The goal is to investigate the efficiency of two handover elimination techniques, i.e., windowing and handover delay timer. Both techniques are modified to enable adaptation of their parameter according to the channel quality related to the users' position in the cell. Furthermore, the impact of proposed modifications on the user's throughput is examined. All simulations are performed in scenario of 4G networks with femtocells. The results show no benefit of adaptive windowing comparing to conventional one. However, the performance improvement is achieved by adaptation of the handover delay timer.**

Keywords-femtocell; handover; Handover Delay Timer, windowing; LTE-A

I. INTRODUCTION

The studies performed in recent year's show that more than 70% of users' traffic is generated from indoors and this ratio is still rising [1]. Deployment of so called femtocells can cope with limited indoor coverage and the cost of the connection in emerging 4G networks. The femtocell is represented by Femto Access Point (FAP) that provides connection of mobile wireless users to a network. The FAP is generally connected to the backbone through a cable connection, xDSL (Digital Subscriber Line) or optical fiber.

The FAP can offer three types of access: close, open, and hybrid. In case of the close access, only a User Equipment (UE) of the FAP's owner (or subscriber) or very small group of users is allowed to enter the FAP. The group of users with access to the FAP is defined by FAP's owner and it is denoted as Close Subscriber Group (CSG). Other users can not access the network via the FAP. Contrariwise, the open access is designed to share full capacity of the FAP by all UEs in its area. The hybrid access combines both open and close accesses. In hybrid access mode, a part of capacity is permanently dedicated to the FAP's owner or to the CSG. The rest of transmission resources can be consumed by other UEs. The open access enables to increase the throughput in specific area by offloading the macro cell [2]. On the other hand, it increases interference in the close area of the FAP.

The deployment of plenty of FAPs can significantly influence the handover decision procedure. The handover is initiated more often since UEs can receive the signal not only from Base Stations (BSs), but also from all FAPs in its neighborhood. In conventional networks without femtocells, the several techniques are defined to eliminate redundant handovers. The most widely used are: Hysteresis Margin (HM), windowing (also known as signal averaging) [3], and Handover Delay Timer (HDT) [4][5], which extends conventional Time-To-Trigger. These techniques can be implemented also in femtocell networks as presented, e.g., in [6][7]. Both papers demonstrate reduction of an amount of the redundant handovers by investigated techniques. However the authors do not investigate a negative impact of techniques on the throughput. In [8], the authors compare the probability of UE's assignment to the FAP that do not provide the best signal quality. The paper shows some tradeoff between a minimum duration of signal averaging and probability of error assignment.

Another approach of elimination of redundant handovers is to adapt the transmission power of FAPs. The proposals of a power control improvement to reduce the number of redundant handovers in femtocells is presented, e.g., in [9][10][11]. All proposals are able to eliminate the redundant handovers. Nevertheless, the advantage of throughput gain due to the open/hybrid access, as illustrated in [2], is also distinctively suppressed.

A modification of HM, which purpose is to eliminate higher ratio of redundant handovers, is defined in [12]. The authors evaluate so called adaptive HM in scenario with macro BSs. The paper assumes precise knowledge of distance between a UE and its serving BS as well as invariant and accurately known radius of macrocells. The radius of all cells is assumed to be the same. Nevertheless, the radius is varying in time and it is neither regular nor symmetric 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 [12] cannot be applied into the networks with femtocells. The above mentioned weaknesses are eliminated by considering RSSI

(Received Signal Strength Indicator) or CINR (Carrier to Interference plus Noise Ratio) for adaptation of HM value as presented in [13].

The goal of this paper is to investigate the possibility of application of the adaptation into other techniques for handover elimination. The paper investigates impact of the dynamic adaptation of an actual value for windowing and HDT. The simulations performed in this paper are in line with networks according to LTE-A (Long Term Evolution – Advanced) release 10.

The rest of paper is organized as follows. The next section describes the principle of elimination of redundant handovers and its modifications to enable dynamic adaptation. The third section defines simulation scenario and parameters used for evaluation of throughput. The section four contains the results of simulations and their discussion. Last section presents our conclusions and future work plans.

II. Elimination of Redundant Handovers

A redundant handover (or unnecessary handover) represents a case when the handover is initiated; however it is not completed before a next handover decision is performed. Also the handover frequently repeated between two adjacent cells in short time intervals can be considered as the redundant handover. The redundant handovers are caused by short time channel variation (e.g., fast fading) or by movement of MSs along the edge of the two neighboring cells. As mentioned in previous section, several techniques can be utilized for minimization of the number of redundant handovers. All common methods are based on delaying of the handover execution for some time interval. During this interval, the MS is not connected to the station providing the best quality of communication channel. Therefore, it has negative impact on quality of service offered to the MS due to the utilization of channel with worse quality than a quality of channel available from other BS.

In this paper, two techniques are considered, i.e., windowing and HDT. The third one, HM, was already investigated in [13].

A. *Principle of common windowing and HDT*

In case of windowing, the handover decision is done if the average value of observed signal parameter (e.g., RSSI, CINR, etc.) from the target BS drops under the average level of the same parameter at the serving BS (see formula (1)). The average value is calculated over a number of samples denoted as Window Size (*WS*).

$$\frac{\sum_{i=1}^{WS} S_i^{Tar}}{WS} > \frac{\sum_{i=1}^{WS} S_i^{Ser}}{WS} \tag{1}$$

where S_i^{Tar} and S_i^{Ser} represent the level of observed signal parameter at the target and serving BS respectively.

The purpose of HDT is to cope especially with temporary drops of a signal level due to fast fading or when a user is located in shadowed places for a short time interval.

Implementation of the HDT is based on the insertion of a short delay between the time when the handover conditions are met and the time when handover initiation is executed. This delay is labeled HDT. The handover conditions have to be fulfilled over the whole duration of HDT to initiate the handover. Generally, the handover is performed if:

$$S_t^{Ser} < S_t^{Tar} \big| t \in (t_{HO}, t_{HO} + HDT) \tag{2}$$

where *HDT* represents the duration of the handover delay timer; and t_{HO} is the time instant when the handover conditions are fulfilled.

B. *Adaptive techniques*

In the conventional techniques for elimination of redundant handovers, the threshold value (HM, WS, or HDT) is not related to the users' position. Hence, it can be considered as invariant since it is modified by a network only rarely. The adaptive techniques are based on the modification of actual HM value according to the position of the user in the cell. The proposal on adaptive HM is defined in [12]. According to [12], the current HM value is decreasing with the UE's moving closer to the cell boarder as presents the next formula:

$$HM = \max\left\{ HM_{\max} \times \left(1 - \frac{d}{R}\right)^4 ;0 \right\} \tag{3}$$

where HM_{max} is the maximum value of HM that can be reached (this value can be set up only in the middle of the cell); *d* is the distance between the serving BS and the UE; and *R* is the radius of the serving BS. A modification of adaptive HM is proposed in [13] as the parameters *d* and *R* cannot be easily determined neither by the network nor by the UE. This modification considers the signal characteristics (RSSI or CINR) to derivation of current value of HM. The analogical modification should be done for adaptation of WS and HDT. The derivation of actual values for both adaptive techniques is defined by the following equations:

$$WS = max\left\{ WS_{max} \times \left(1 - 10^{\frac{CINR_{act} - CINR_{min}}{CINR_{min} - CINR_{max}}} \right)^4 ;0 \right\} \tag{4}$$

$$HDT = max\left\{ HDT_{max} \times \left(1 - 10^{\frac{CINR_{act} - CINR_{min}}{CINR_{min} - CINR_{max}}} \right)^4 ;0 \right\} \tag{5}$$

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

The $CINR_{act}$ is measured periodically by UEs to monitor the channel state. It is usually performed with purpose of the handover decision. As well as in the case of adaptive HM, the minimum and maximum CINR values have to be determined for the utilization of the adaptive WS and HDT.

The $CINR_{min}$ is derived as lowest CINR level at which the UE is still able to receive data. Hence, it is set up to a fix value. Determination of the $CINR_{max}$ is executed via 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 exact value of $CINR_{max}$ is permanently updated since the channel conditions are time variant. Therefore, the $CINR_{max}$ is acquired over several samples of CINR measured by UEs. The number of the latest samples utilized for the $CINR_{max}$ derivation is represented by parameter $CINR_{win}$. The optimum value of $CINR_{win}$ is analyzed further in this paper.

III. Description of Simulation Principle

A. *Scenario and deployment*

The same scenario and deployment of FAPs and macro BSs as in [13] are considered for the evaluation of both adaptive techniques (see Fig. 1). The scenario contains fifty houses regularly and symmetrically placed along the direct street with length of 500 m. Also all FAPs and BSs are placed symmetrically along the street in the scenario.

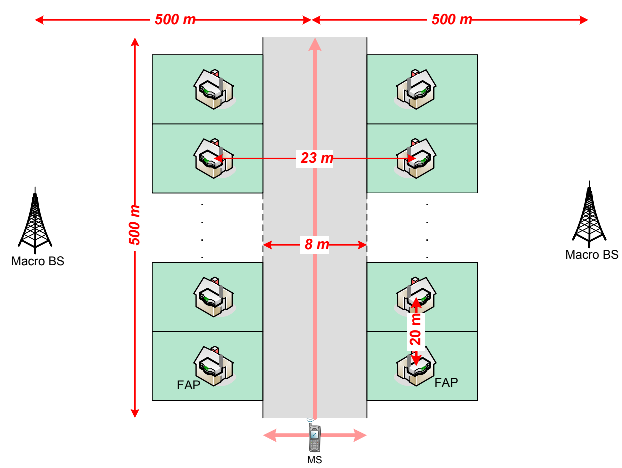

Figure 1. Deployment of FAPs and BSs for simulations.

The users are moving directly along the street with the speed of 1 ms^{-1} until they reach the end of the street. The users are equally distributed over the street width with spacing of 0.2 m. The reporting of measured CINR is executed in periodic intervals of 0.5 s. The signal level received by a UE from a FAP is calculated according to ITU-R P.1238 path loss model for single-storied house. The path loss model includes wall losses and channel variation due to the fast fading and shadowing with standard deviation of 4 dB as defined in [14]. The propagation of BS's signal is in line with Okumura-Hata path loss model for outdoor to outdoor communication [15]. As well, all other simulation parameters, presented in Tab. 1, are set up to be in line with simulations performed by Femto Forum [15].

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.

TABLE I. Simulation Scenario and Parameters

Parameter	**Value**
Frequency	2 GHz
Channel bandwidth	20 MHz
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	-100.97 dBm
Number of simulation drops	25
$CINR_{min}$	-3 dB
$CINR_{win}$	10 ÷ 500

B. *Throughput calculation*

The evaluation of throughput is performed for TDD frame structure of LTE release 10 with uplink–downlink (UL–DL) configuration *"1"* and Special Subframe (SS) configuration *"0"* (see [16] for more details).

In simulations, we assume normal cyclic prefix (seven symbols per subcarrier) and 12 subcarriers per a resource block since those are typical values defined in LTE release 10. The spacing of subcarriers is $\Delta f = 15\ kHz$. The amount of transferred bits depends on Modulation and Coding Scheme (MCS) used for the transmission. The assignment of the MCS is based on signal quality according to Tab. 2 (the values are taken from [17]).

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

The throughput of UEs via wireless interface is assumed 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. Performance Analysis

The results, obtained by own developed MATLAB simulator, are divided into two subsections according to investigated technique.

A. *Adaptive Window Size*

As it is depicted in Fig. 2, the adaptive WS leads to the significant reduction of performed handovers for low number of averaged samples (roughly up to 7 samples). Then the efficiency of the adaptive technique drops down and the handovers are performed more often. The decreasing efficiency for higher WS is due to the fact that the radius of FAP is very small. Thus, the signal received from the FAP rises and drops rapidly if the user is moving. Therefore, the high WS leads to consideration of samples obtained long time ago with respect to the small FAP radius and users' speed. These samples misrepresent the actual WS and thus the handover is initiated in improper place. Note that the *x* axis in all following figures represents the actual value of WS and HDT for conventional windowing and HDT. In case of WS and HDT with adaptation, the *x* axis expresses WS_{max} and HDT_{max} (see equations (4) and (5)).

The impact of $CINR_{win}$ is only minor for short length of window. The optimum WS_{max} for the adaptive WS is roughly 7 samples since the ratio of performed handovers is the lowest. The efficiency of handover elimination is rising with $CINR_{win}$. However, the results for $CINR_{win}$ equal to 50 and 500 samples are almost the same at WS = 7 samples.

The ratio of eliminated handovers behaves different for conventional windowing with fixed amount of averaged samples. In this case, the amount of initiated handovers is continuously decreasing with growing WS. Nevertheless, the efficiency improvement only by approximately 6% is achieved if WS is increased from 7 to 25 samples. Consequently, Fig. 2 does not proof any benefit in elimination of handovers by implementation of adaptive WS.

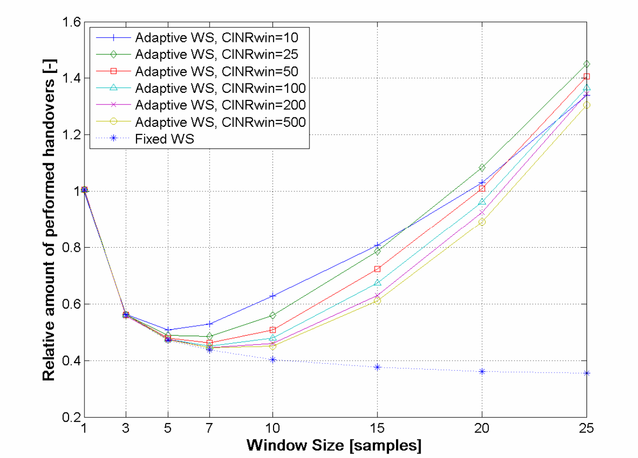

Figure 2. Impact of adaptive WS on the amount of initiated handovers.

Fig. 3 presents the impact of WS on the downlink throughput. This figure shows no considerable difference between adaptive and fixed WS size if WS value is up to 5 samples. Than, the proposed adaptive WS with shorter $CINR_{win}$ is preferable since it leads to the throughput gain.

By combining the results presented in Fig. 2 and Fig. 3 can be observed that the optimum length of $CINR_{win}$ is roughly 50 samples. Both figures further show some throughput gain of adaptive WS. However this gain is at the cost of lower efficiency of handover elimination. Thus the adaptation of WS is not profitable.

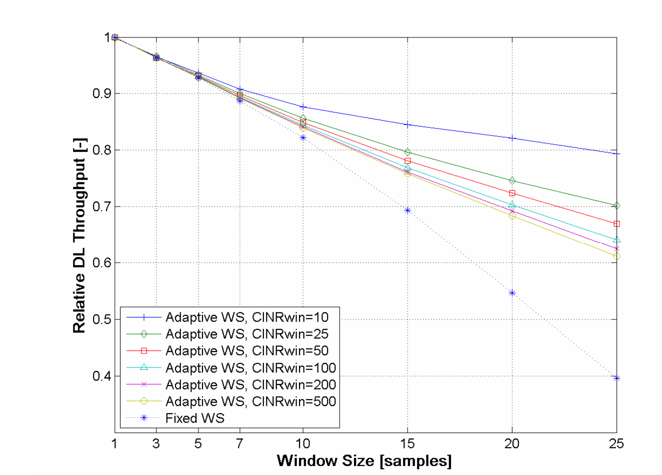

Figure 3. Average DL throughput over WS (for conventional windowing) or WS_{max} (for adaptive WS).

B. *Adaptive Handover Delay Timer*

The impact of HDT adaptation on the amount of handovers and downlink throughput is depicted in Fig. 4 and Fig. 5 respectively. The range of HDT values up to 30 s (*x* axis in Fig. 4 and Fig. 5) can be considered since only slowly moving users (pedestrians) are assumed to perform handover to a FAP. The vehicular users do not spend enough time in the femtocell to complete the handover.

The Fig. 4 shows that the most of handovers is eliminated by HDT of 2 s. Additional prolongation of HDT up to 6 s leads to moderate decrease of the handover amount. The HDT over 6 s does not eliminate any further noticeable portion of handovers. The $CINR_{win}$ influences the results only insignificantly if more than 10 samples is considered.

The conventional as well as adaptive HDT eliminate handovers with the similar efficiency except the HDT = 2 s. For this value, the common HDT outperforms the adaptive one roughly by 5 %. Nevertheless, the efficiency of handover elimination of both adaptive and fixed HDT can be considered as nearly the same for all other values of HDT.

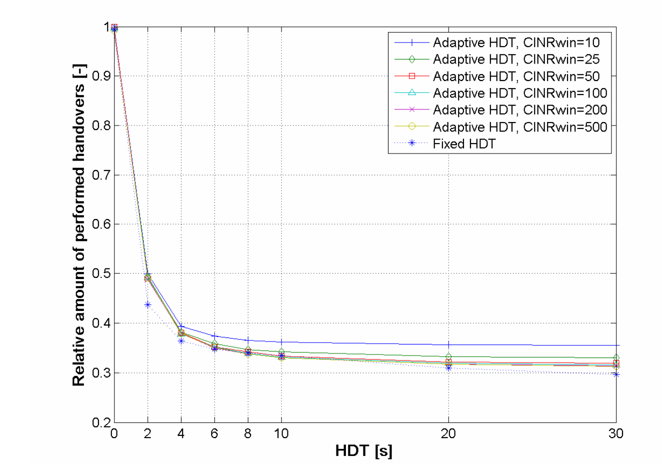

Figure 4. Impact of adaptive HDT on the amount of initiated handovers.

As can be observed from Fig. 5, increasing length of $CINR_{win}$ decreases users' throughput. Hence the shorter length of $CINR_{win}$ is suggested to eliminate throughput drop.

Comparing the fixed and adaptive HDT, significantly more negative impact on the throughput is caused by the technique with no adaptation of current HDT value. The adaptive HDT enables to reach significant gain in the throughput comparing to the conventional one. The gain noticeably rises with HDT duration.

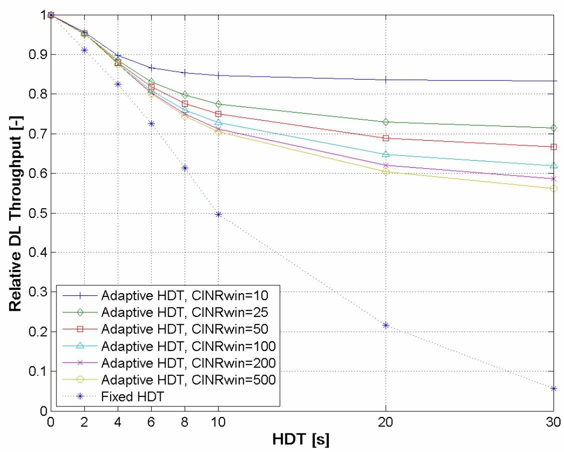

Figure 5. Average DL throughput over HDT (for conventional windowing) or HDT_{max} (for adaptive HDT).

Considering the results presented in Fig. 4 and Fig. 5, the optimum $CINR_{win}$ is roughly 25 samples. This value is same like optimal one for adaptive HM presented in [13]. The most efficient length of HDT is between 4 and 6 s. The adaptive as well as fixed HDT achieves the similar level of handover elimination. Nevertheless, the proposed adaptation of HDT enables throughput gain between 8 % and 13% for the optimal HDT and $CINR_{win}$.

V. Conclusions

The paper evaluates the efficiency of adaptive WS and HDT for elimination of redundant handovers in the networks with femtocells.

The simulation results show that the adaptation of WS provides the similar results as the windowing technique with the fixed value of WS. On one hand, the adaptive WS leads to some throughput gain, but on the other hand, it also eliminates less handovers. The adaptive duration of HDT can leads to the significant throughput gain while the same elimination of handovers as in case of fixed HDT is reached. The gain is between 8% and 13% for optimal duration of HDT. The optimal length of $CINR_{win}$ is roughly 25 samples.

The future work will be focused on the improvement of handover decision phase in femtocells by considering the handover prediction.

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