Dynamic Power Control Mechanism for Femtocells Based on the Frame Utilization

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***Abstract*— The femtocells are very promising concept for wireless networks to significantly enhance system capacity. Nevertheless, a lot of challenges must be still addressed. The paper focuses on a power control mechanism and proposes a novel approach for dynamic adaptation of transmitting power of femtocell access points. The basic idea is to adapt the transmitting power of femtocells according to current traffic load and signal quality between mobile stations and femtocell in order to fully utilize data frame. The advantage of this approach is its potential to decrease interference to users of macro cell or adjacent femtocells at light traffic load. Performed analytical evaluations of our proposed scheme in comparison to the existing power control mechanisms show that femtocell's transmitting power can be significantly reduced while the same Quality of Service level is still guaranteed to the femtocell users.**

Keywords-femtocell, frame utilization, interference, power control, signal leakage.

I. Introduction

In the recent years the demand for wireless higher data rates is unrelenting, and has been driven by introduction of new wideband services for mobile users. From the contemporary studies was demonstrated that more than 50% of voice calls and more than 70% of data traffic originates from indoors [1]. The main problem of current wireless networks is poor indoor coverage, i.e., to support high quality multimedia services in such scenarios is quite a challenge. The promising way how to guarantee high data transmission for indoor's users is by means of femtocell access points (FAP). The FAPs are portable low cost base stations deployed in the households. The connection of FAPs with the cellular network is ensured over broadband connection such as digital subscriber line (DSL), cable modem or wireless connection (e.g., WiMAX backhaul). Many technical studies have been already performed to analyze the advantages of femtocells implemented in the network [2][3]. Technical challenges, which must be solved to fully utilize femtocells potential, are described in [4].

One of the most important issues that must be addressed regarding femtocells is how to avoid the harmful interference either to a macro BS (MBS) or to neighbor FAPs if the same spectrum is utilized by the MBS and FAPs. The effective way for interference avoidance is an appropriate power control mechanism. The power control mechanism may be implemented either in uplink or/and in downlink direction. In the former case, a transmission power of Mobile Station (MS) is adapted (this issue is addressed, e.g., in [5][6][7]). In the latter case, an adaptation of FAP's transmission power is accomplished. As the paper only focuses on power control in downlink direction, already proposed mechanisms dealing with control power in downlink will be described in more details.

In [8] and [9] authors suggest auto-configuration and self-optimization schemes. While auto-configuration schemes provide an initial power setting of FAP, self-optimization schemes try to optimize FAP transmitting power during normal operation. Authors distinguish three auto-configuration schemes; i) fixed power, ii) distance based and iii) measurement based. When fixed power configuration scheme is utilized, the transmitting power is set to fixed value (authors consider -10 dBm). Disadvantage of this method is that the FAP's coverage strongly depends on the distance from macro BS. This drawback is eliminated by distance based or measurement based approaches. In this case, the FAP power is configured so that the received signal from the strongest macro cell and FAP is the same at a defined target cell radius. Usually the target cell radius corresponds to the maximum distance from the FAP where a MS attaches to the FAP rather than to the MBS. The purpose of the self-optimization scheme is to minimize mobility events, i.e., to minimize redundant handovers initiation. To achieve this goal, the FAP adjusts transmitting power accordingly.

In [10], the authors contemplate another way of FAP power adaptation taking into consideration activity/inactivity of users. If no users of FAP are currently active (no voice or data are transmitted), the transmitting power of FAP is decreased by 10 dB. An adaptive coverage adjustment (ACA) algorithm is introduced in [11]. The paper further improve self-optimization scheme based on [8] to minimize mobility event and reduces signal leakage. In case that users from MBS is in close vicinity of FAP, the FAP itself iteratively decrease it's transmit power. Nevertheless, this scheme is not able to fully mitigate redundant handovers since the decrease of power is done after reception of handover request at the side of FAP.

Another self-optimization scheme allowing FAP to adaptively adjust its transmitting power is introduced in [12]. The authors consider that the FAP is located at the centre of building with defined radius. The transmit power control is composed of two steps. While in the first step self-configuration of FAP's transmitting power is accomplished, in the second step adaptation of current transmitting power according to radio environments obtained by measurements is performed. The aim of the authors is similar as described in [8], i.e., to adapt transmitting power of FAP in order to cover by femtocell area of certain pre-defined radius.

A drawback of all above mentioned mechanisms is that they consider the coverage of FAP is of sphere radius and that the FAP is positioned specifically in the middle of the building. Nevertheless, since the FAP will be deployed by users alone, the position of FAP may be more or less anywhere in the household. This could cause significant leakage of the FAP signal when deployed for example close to house boundaries. This drawback can be noticeable mitigated by our proposed power adapting scheme where transmitting power of FAP is dynamically adapted according to MSs' activity and their position with respect to the FAP. The goal of the scheme is to decrease transmitting power of FAP in order to maximize frame utilization, if possible, while keeping guaranteed Quality of Service (QoS) level to the users. The advantage of the scheme is its potential for decrease of signal leakage probability (decrease of interference and mobility events). The performance of the proposed scheme is analytically evaluated for LTE system. However, the general principle may be used by other technologies such as WiMAX or LTE-A.

The rest of the paper is organized as follows. The next Section briefly describes the frame structure considered in LTE, which is essential for understanding of the paper. The third Section is dedicated to introduction of proposed scheme. The system model and results of analytical evaluations are presented in the two following Sections. The last Section gives are conclusion and intended future work.

II. DESCRIPTION OF FRAME CONCEPT IN LTE

In LTE technology, the data can be transmitted either in TDD or FDD manner. In this Section only FDD frame structure will be described as FDD is a target transmission mode considered in the paper. More than that, since the paper focuses on adaptation of FAP transmitting power, only downlink frame structure is contemplated in this Section. In downlink direction, OFDMA (Orthogonal Frequency Division Multiple Access) modulation is implemented.

According to [13] the frame in time domain is composed of 20 slots with 0.5ms duration as indicated in the Fig. 1. Every two slots create one subframe, i.e. one LTE frame contains ten subframes. Furthermore, one slot includes 7 OFDM symbols (or 6 OFDM symbols if extended cyclic prefix is considered). Depending on channel bandwidth, the frame structure could be decomposed in frequency domain into certain number of subcarriers. The subcarriers in LTE systems have a constant spacing of 15 kHz and every twelve subcarriers form one resource block. The resource block is the smallest unit that could be allocated for data transmission of one user. The data are carried by means of the Physical Downlink Share Channel (PDSCH).

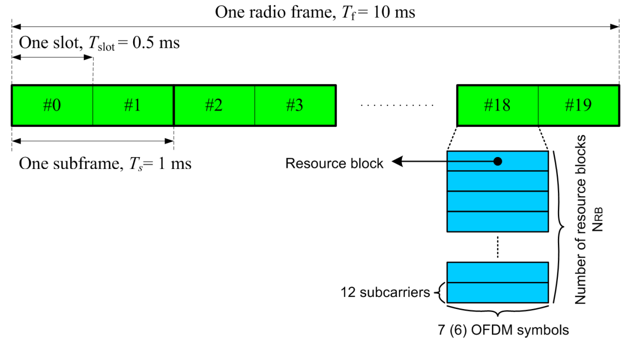

Figure 1. Structure of LTE FDD frame.

Nevertheless, not all resource blocks in the frame are used primarily for data transmission. Some of them are designated for transmission of control information carried via control channels. For that purpose several additional downlink control channels are defined. The most important one is the Physical Downlink Control Channel (PDCCH) located in the first OFDM symbols of the subframe (up to 4 OFDM symbols can be dedicated for PDCCH). The main purpose of PDCCH is to send scheduling information to the users (information on other channels can be found, e.g., in [13][14]). Besides the downlink channels, primary and secondary synchronization signals used for channel estimation are transmitted within every frame. Nonetheless the majority of overhead due to control information is caused by PDCCH as the other overhead is negligible. From the basic knowledge of the frame structure can be estimated current frame utilization necessary for the proposed power control method described in next Section.

III. PROPOSED POWER CONTROL MECHANISM

The fundamental idea of the proposed mechanism is based on the fact that the bandwidth of the FAP is underutilized. If we assume for instance that FAP is using bandwidth of 10 MHz up to 35 Mbit/s (considering best modulation and coding scheme) can be transmitted between MSs and its serving FAP. Nevertheless, femtocells are supposed to serve up to four active users simultaneously [4] and so high requested data transmission will be imposed on FAP only occasionally. Thus, the goal is to decrease power of FAP while still guaranteeing that all users can attach to the FAP and all current data can be still send (i.e., QoS interposed on the FAP is satisfied). The advantage of this approach is that at low traffic load, the power of FAP can be significantly reduced. Consequently, the probability of signal leakage out of the residential house is decreased as well. This fact guarantees both mitigation of harmful interference to adjacent FAP or to MBS's users and reduction of unwanted mobility events (i.e., reduction of generated overhead caused by handover procedure).

The general principle of the proposed scheme is depicted in Fig. 2. In the left figure is shown the case when the transmitting power of FAP is adjusted to achieve target CINR at radius *r1*, which could for example correspond to the house boundaries. If the received CINR1 at the side of both MSs is distinguishable better than target CINR and the frame of FAP is underutilized (some resource blocks are empty), FAP's transmitted power is adapt accordingly. The power is adapted to such value that the received signal from FAP at the side of both MSs is still acceptable (in Fig depicted as CINR2) and that all data can be still transmitted via one frame (i.e., frame utilization is lesser or equal to 100% while no data are lost or unnecessarily delayed).

In order to estimate current appropriate transmitting power of FAP P_t current frame utilization must be known at the side of FAP. Since the FAP has to be able to schedule all data transmission (via PDCCH), it could be assumed that this information is known to the FAP. Generally, the frame utilization is the function of the following parameters,

$$\Omega : (\Phi, \Theta, \Gamma) \text{ where } \Phi, \Theta, \Gamma \in R \tag{1}$$

where Φ is the number of resource blocks in the frame and depends on system setting as indicated in the following formula,

$$\Phi = n_{RB} \times n_{SLOT} . \tag{2}$$

where n_{RB} stands for the number of resource blocks per one slot (depend on selected channel bandwidth) and n_{SLOT} corresponds to the amount of slot per one frame. To determine current frame utilization, it is necessary to figured out the number of resource blocks appointed to control and data information. The number of resources blocks carrying data is,

$$\Phi_D = \Phi - \Phi_C - \Phi_{NU} . \tag{3}$$

where Φ_c represents the amount of resource blocks utilized for control information and Φ_{NU} is the number of resource blocks used neither for data nor for control information. As already stated in previous Section, the major part of control information is due to PDCCH. To that end, the size of Φ_c can be expressed as follows,

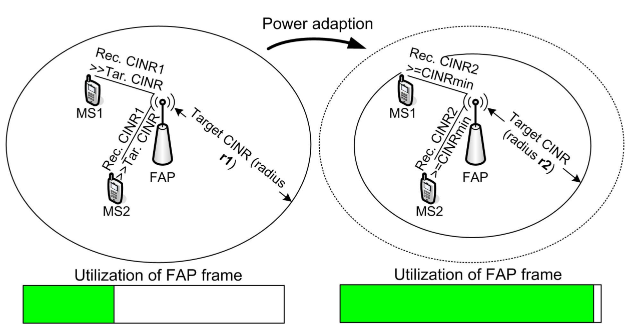

Figure 2. Basic principle of the proposed scheme.

$$\Phi_C \approx n_{RB} \times (n_{PDCCH} / n_{SS}) \times n_S . \tag{4}$$

where n_{PDCCH} corresponds to the number of OFDM symbols used for PDCCH per one subframe in downlink direction, n_{SS} stands for the number of OFDM symbols per one subframe, and n_S is the number of subframes per one frame.

The second parameter in (1) influencing frame utilization corresponds to the amount of data currently send to FAP's users. This parameter could be derived as follows

$$\Theta = \sum_{j=0}^{n} TL_j . \tag{5}$$

where n is the number of users attached to the FAP and TL_j is current amount of data send to j user. The last parameter in (1) $\Gamma = [\gamma_1, \gamma_2, ..., \gamma_n]$ represents the set of transmission efficiencies for individual users. By transmission efficiency is meant the number of bits that could be transmitted per one subcarrier within one OFDM symbol. The parameter Γ is dependent on chosen Modulation and Coding Scheme (MCS) assigned according to the received CINR (Carrier to Interference and Noise Ratio). In the paper, MCS is selected in the line with [15] (see Tab. I).

Only the last parameter influencing frame utilization is directly dependent on transmitted power of FAP since CINR can be calculated as follows:

$$CINR[dB] = P_t[dBm] - PL[\text{dB}] - NI[\text{dBm}]. \tag{6}$$

where PL corresponds to signal attenuation between the transmitter and receiver and NI stands for the noise plus interference. Consequently, the aim of the proposed scheme is to find transmitting power of FAP, which equals to ε value as follows,

$$\Omega(\Phi, \Theta, \Gamma(P_t = \varepsilon)) = \vartheta , \ \varepsilon \le P_{t\max} . \tag{7}$$

where ϑ is the target frame utilization. The ε value can take the values up to P_{tmax} that corresponds to the maximum allowed transmitting power of FAP. The other important

TABLE I. TRANSMISSION EFFICIENCY DEPENDING ON CINR

CINR [dB]	MCS	Transmission efficiency Γ[b/subcarrier]
-1<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	1/2 16QAM	2
10<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	2/3 64QAM	4
17<CINR<=18	3/4 64QAM	4.5
18<CINR	4/5 64QAM	4.8

condition, which must be satisfied is that for $P_t=\varepsilon$, all MSs must be able to attach to the FAP. Thus, if we denote $X=[\chi_1, \chi_2, \ldots, \chi_n]$ is the set of CINR observed at every MS, the minimal value in the set must be higher or equal to $CINR_{min}$ as indicated in following formula,

$$\min\{\chi_{(P_t=\varepsilon)}\} \geq CINR_{\min}. \qquad (8)$$

$CINR_{min}$ represents the minimal CINR value when the most robust MCS can be still utilized.

IV. System Model

To study analytically the performance of the proposed power control scheme are considered parameters depicted in Tab. II. For the purpose of analytical evaluations the structure of house according to [8] is considered (see Fig. 3). The analyses take into account two different positions of FAP. While the first position (in Fig. 3 depicted as FAP_pos1) corresponds to the same location as assumed in above mentioned proposals [8][9][11], the second position is intentionally chosen at the house edge (in Fig. 3 depicted as FAP_pos2), i.e., the case representing the worst case scenario as the interference is the most significant. Additionally, four positions of MS are considered. The individual locations were chosen so that all main rooms in the building are covered. In the evaluation, always only one MS and one FAP are placed at the chosen location. In this way we can easily determine the impact of FAPs and MSs' placement on the system performance.

To simulate path loss in indoor environment, ITU-RP.1238 model is implemented (for detail see e.g. [16]). For the sake of simplicity, the interference level from the MBS (which is dominant in our scenario) to the FAP is either of high level (equal to -75 dBm) or of low level (equal to -95 dBm). Thus, the former case corresponds to the scenario when the FAP is in close vicinity of MBS while the latter case represents the scenario when the FAP is relatively in large distance from the MBS. Nevertheless, this simplification does not affect the analytical results. To cope with fading effects, fade margin of 4 dB is assumed.

In order to determine current frame utilization Ω, following equation is used in the performed evaluations,

TABLE II. System settings

Parameter	Value
Frequency band [GHz]	2.0
Channel bandwidth [MHz]	3;5;10
Frame duration [ms]	10
Number of OFDM symbols per slot [-]	7
Max. FAP transmit power P_{tmax} [dBm]	21
Noise+interference at the edge of house [dBm]	-75;-95
$CINR_{min}$ [dB]	-1
Target frame utilization ϑ [-]	1
Generated traffic load [kb]	100-10000
Loss of internal wall/external wall/window [dB]	5/10/3
Fade margin [dB]	4
n_{PDCCH}	1

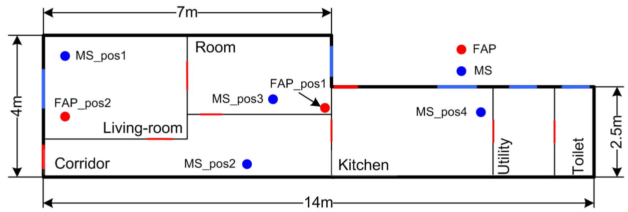

Figure 3. House structure [8]

$$\Omega = \frac{\left(\Theta / (\Gamma \times n_{RE})\right) + \Phi_C}{\Phi}. \qquad (9)$$

where n_{RE} corresponds to the number of resource element in one resource block. Thus, the term in parenthesis represents the number of resource block necessary for a transmission of all generated data.

The performance of proposed scheme (in the next Section labeled as PPC - Proposed Power Control) is compared to the already proposed schemes when the aim is to cover by FAP area of certain radius (in the next Section labeled as CPC - Conventional Power Control).

V. Results

Fig. 4 and Fig. 5 depict transmitting power of FAP depending on offered traffic load. Both figures consider all defined MS's positions as described in previous Section. In case of CPC, the transmitting power of FAP is constant regardless current offered traffic load and equals to 12 dBm (FAP is positioned in the middle of house) and 21 dBm (FAP is positioned at the house's edge) respectively. The reason is that according to CPC the FAP always tries to reach predefined cells coverage, which is independent on actual MS's position and current traffic load.

On the other hand if the PPC is utilized, the transmitting power of FAP could be distinguishable reduced. Logically, the most significant reduction is achieved in Fig. 4 for MS_pos3 (observed reduction vary depending on offered traffic load between 18 dB and 35 dB) and in Fig. 5 for

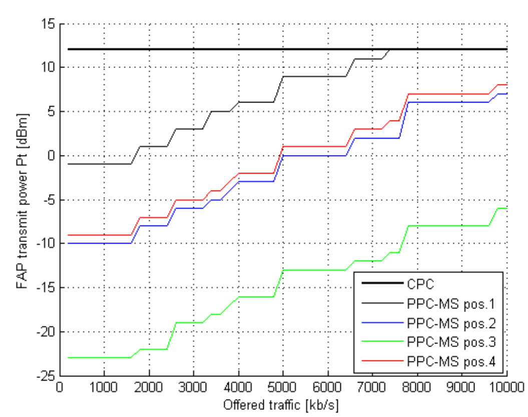

Figure 4. FAP's transmitting power depending on offered traffic (BW=3MHz, N+I=75 dBm, FAP_pos1)

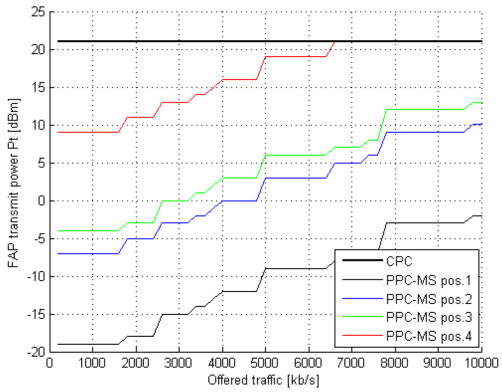

Figure 5. FAP's transmitting power depending on offered traffic (BW=3MHz, N+I=75 dBm, FAP_pos2)

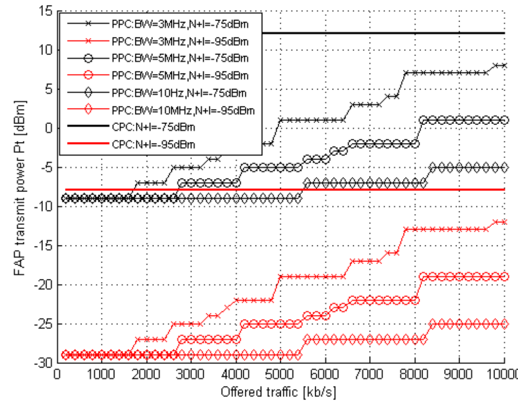

Figure 6. FAP's transmitting power depending on offered traffic (FAP_pos1, MS_pos4)

MS_pos1 (observed reduction vary depending on offered traffic load between 23 dB and 40 dB) as the FAP is located in the same room. Consequently, the signal received from the FAP is of very good quality. Nonetheless, the reduction is significant also for other MS's positions; this is true especially at light traffic load. With increasing of the traffic load, FAP transmitting power has to be increased in order to serve all generated data.

Fig. 6 and Fig.7 demonstrate how the transmitting power of FAP is influenced if different channel bandwidth is considered together with varying noise plus interference ratio. In this case only one MS's position is assumed; MS_pos4 in Fig.6 and MS_pos3 in Fig.7. From figures is apparent that more significant reduction of transmitted power can be achieved for the wider channel. This is due to the fact that generally with wider channel more radio resources are available. Thus we can decrease transmitting power more significantly and still be able to transmit all data within one frame. To be more specific when the system channel bandwidth is set to 10 MHz instead of 3MHz, we can decrease the transmitting power up to 13 dB more for the former case. Consequently, the advantage of PPC is more obvious in comparison with CPC schemes. Additionally, Fig. 6 and Fig. 7 illustrate that transmitting power is increased proportionally with increase of noise plus interference ratio as well.

Fig. 8 and Fig. 9 analyses the amount of FAP's signal leakage out of house in dependence on traffic load. By leakage of the signal is meant the area out of house where the signal from the FAP is stronger than the signal from the MBS. In case when the FAP is located in the middle of the house, the leakage of the signal is negligible. For CPC scheme the leakage is approximately 20m^2 while for PPC scheme only up to 6.5m^2.

On the other hand if the FAP is positioned at the edge of the house (see Fig. 9), the signal leakage is much more profound. Especially for CPC scheme, extensive interference can be induced to users attached to MBS or to adjacent FAPs. More than that, it could cause initiation of unnecessary handovers of moving MS. In this scenario the utilization of PPC scheme largely reduces harmful interference as the leakage of the signal could be mitigated. Even at heavy traffic load (10 000 kb/s) and for narrow channel bandwidth (3 MHz), signal leakage is roughly four times smaller than in case of CPC.

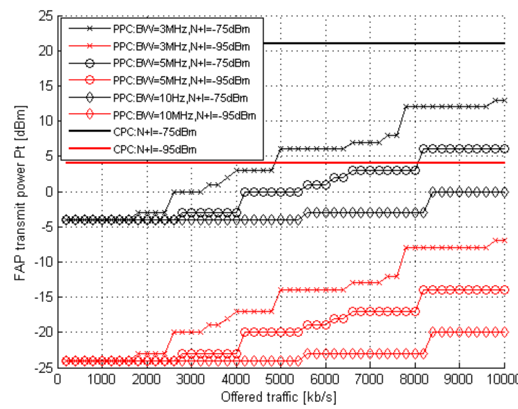

Figure 7. FAP's transmitting power depending on offered traffic (FAP_pos2, MS_pos3)

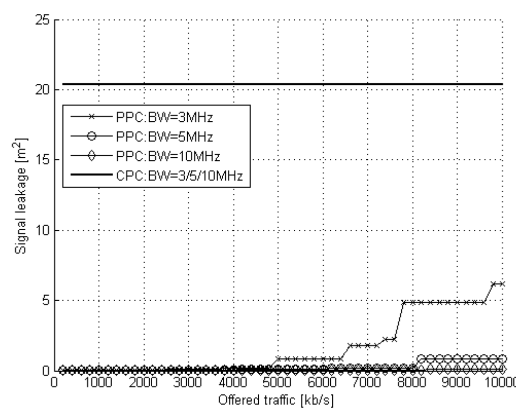

Figure 8. Signal leakage depending on offered traffic (FAP_pos1, MS_pos4, Noise+Intereference=-75 dBm)

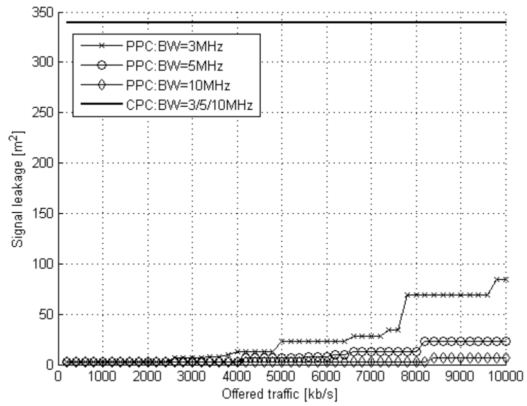

Figure 9. Signal leakage depending on offered traffic (FAP_pos2, MS_pos3, Noise+Intereference=-75dBm)

VI. Conclusion

The paper proposed a power control procedure, which dynamically adapts transmitting power of FAP depending on the current traffic load and CINR received by MSs. The basic idea is to decrease the transmitting power of FAP to such a level that enable to guarantee the required QoS to the users while utilization of the whole data frame is achieved. The analytical evaluations demonstrate that by means of proposed scheme significant reduction of transmitting power could be achieved when compared to the existing power control schemes. Consequently, leakage of the FAP's signal out of the house is dramatically mitigated. The proposed scheme proves its effectiveness especially for the scenarios when the FAP is located near of the house's edge.

Great potential of proposed mechanism can be seen from the performed evaluation. Nevertheless, it is necessary to investigate its performance also under more realistic conditions (e.g., to implement indoor mobility model for users, to implement traffic models, etc.) by means of simulation at system level, which is our future work plan.

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