# Optimization of Power Control Algorithm for Femtocells Based on Frame Utilization

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*Abstract*—**The paper is focused on power adaptation algorithm based on frame utilization of femtocells. To decrease its computational complexity and to minimize generated signaling overhead, adaptation interval should be prolonged. The problem of existing power adaptation algorithm is an increase of the number of mobility events with extension of adaptation interval length. Thus, the main objective is to propose a new adaptation algorithm able to cope with this problem. The possible disadvantage of new algorithm consists in longer interval of femtocell's overloading. We suggest mitigating this drawback by appropriate selection of target frame utilization, which is also contemplated in this paper. The performance of the algorithm is analyzed in terms of number of generated mobility events and femtocell's overloading time. The results show that the proposed adaptation algorithm outperforms the existing one for longer adaptation periods.**

***Keywords-Power control; femtocell; target frame utilization; optimization***

## I. INTRODUCTION

The problem of emerging wireless networks utilizing frequency bands in order of GHz such as LTE or WiMAX is poor indoor coverage. This issue could be solved by implementation of Femtocell Access Point (FAP). The FAP is portable low cost base station located in a user's premises or in an office. The connection of the FAP with a cellular network is ensured over a broadband connection (e.g., DSL or fiber optic).

In comparison to conventional Macro Base Station (MBS), the access to FAPs can be restricted for certain users. To that end, three access modes are introduced; closed access, open access, and hybrid access. The closed access mode allows only specific users to enter the FAP. On the other hand, the open access enables connection to all passerby users. The hybrid mode is a kind of compromise between both above mentioned types (see, e.g. [1], for more details). Various options of frequency allocation are considered for the FAPs and MBS [2]: i) the MBS and the FAPs use separated bands, which lowers spectrum efficiency), ii) the MBS and FAPs utilize the same spectrum, which increases co-channel interference between the MBS and the FAPs, iii) specific amount of the bandwidth is partially shared by the MBS and FAPs while the rest of the bandwidth is solely dedicated to the MBS.

Deployment of FAPs introduces several problems that must be solved to ensure high Quality of Service (QoS). One of the most important problems in case of the close access is a possibility of high interference if the same spectrum is occupied by the MBS and FAPs. Contrary, the open access generates significant amount of signaling overhead due to excessive number of mobility events. To solve this issue, an appropriate power control mechanism enabling adaptation of FAPs' transmitting power, i.e., power control in downlink (DL) direction, should be used. Generally, two different approaches are followed regarding the DL power control in femtocell's environment. According to the first approach, the main objective is to completely cover a specific area of certain radius, e.g., to ensure full house coverage. The advantage is that users are always able to connect to the FAP inside the building. Nevertheless, the signal leakage out of the building boundaries may be significant. Thus this approach can introduce serious interference to the MBS's users. Hence it is used only for initiate setting of FAP's transmitting power [3][4]. The primary goal of the second approach is to set the transmitting power of FAP to minimize interference to passerby's users or neighboring FAPs. The disadvantage of this approach is that the full house coverage of building is not always assured. Several representatives of the second approach (denoted as self-optimization schemes), are proposed, e.g., in [3]–[6]. In general, all those schemes aim to minimize the number of mobility events based on their counting. Consequently, the FAP must be able to collect statistical information regarding the mobility events. The numerical results demonstrate that self-optimization schemes are noticeably more effective in mitigation of mobility events than representatives of the first approach. However, the main weakness of all self-optimization schemes is that Users Equipments (UEs) inside the house are not always able to attach to the FAP as the full house coverage is not ensured. Thereupon, the MBS has to serve those UEs. It decreases overall system throughput.

As both above mentioned approaches have some drawbacks, a method trying to find the tradeoff between these two by elimination of their weaknesses is proposed in [7]. 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. At the same time, the goal is to keep the same QoS level for the FAP's users as in the case of the first approach. The basic idea is to adapt the transmitting power of FAPs according to current traffic load and signal quality (with consideration of interference) between UEs and the FAP to fully utilize FAP's frame. The simulation results show significant reduction of the number of mobility events while the QoS for indoor users is comparable to the first approach. Nonetheless, several open issues related to this approach still need to be addressed.

In this paper, we enhance existing power adaptation algorithm by new congestion strategy for case when the FAP's become overloaded. This strategy is evaluated over two cases: i) prolongation of power adaptation interval $\Delta t$, and ii) various target frame utilizations $\vartheta_{target}$. Finally, several suboptimal recommendations for different scenarios are derived at the end of the paper.

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The rest of the paper is organized as follows. The next section briefly explains the principle of power control mechanism and analyzes the impact of above mentioned aspects on number of mobility events and FAP's congestion. Section three focuses on description of simulation scenario and obtained results. The last section summarizes the outcomes and concludes the paper.

## II. POWER CONTROL

### A. *Principle of QoS-guarateed power control*

The main purpose of the power control mechanism described in [7] is to minimize the number of initiated mobility events. The high number of mobility events would generate excessive amount of signaling overhead and could entirely overload the network. The number of mobility events can be decreased if the FAP's power can be lowered as the mobility event is initiated if:

$$P_{t,FAP} - u_{t,FAP}(t) > P_{t,MBS} - u_{s,MBS}(t) + \Delta_{HM}, \quad t \in < t, t + HDT > \tag{1}$$

where $P_{t,FAP}$ and $P_{t,MBS}$ is transmitting power of FAP and MBS respectively, $u_{t,FAP}(t)$ and $u_{s,MBS}(t)$ represents radio channel model (including path loss, shadowing, and fading) of FAP and MBS respectively, $\Delta_{HM}$ stands for hysteresis margin, and *HDT* represents Handover Delay Timer [8]. Since the FAPs are supposed to serve only up to four active users [9], it could be assumed that the radio resources allocated to the FAP are not exploited most of the time (see left part in Fig. 1). Thus, the general principle of the power control is to utilize more radio resources of the FAP by decreasing its transmitting power. In other words, the purpose of the power control is to get higher FAP's frame utilization $\vartheta^k$. The frame utilization that the power algorithm tries to achieve is defined as target frame utilization $\vartheta_{target}$ (in Fig. 1, full frame utilization is assumed, i.e., $\vartheta_{target}$=1). The FAP's frame utilization $\vartheta^k$ in frame $k$ can be expressed as:

$$\vartheta^k = \frac{n_{OH}^k + n_D^k}{n_{SC} \times n_{SMB}}. \tag{2}$$

where $n_{OH}^k$ and $n_D^k$ represent the number of resource elements appointed to control information and data respectively, $n_{SC}$ stands for the number of subcarriers, and $n_{SMB}$ represents the amount of OFDM symbols per frame. Note that ODFMA system based on LTE-A release 10 [10] is considered. In (2), the only parameter depending on transmitting power is $n_D^k$:

$$n_D^k = \sum_{j=0}^{n} \frac{TL_j^k}{\Gamma_j^k}. \tag{3}$$

where $n$ is the number of active users attached to the FAP, $TL_j^k$ is the amount of data sent to user $j$, and $\Gamma_j^k$ is transmission efficiency of user $j$. The $\Gamma$ parameter determines the amount of bits sent via one resource element, that is, the number of bits sent over one subcarrier in the frequency domain and duration of one OFDM symbol in the time domain. The $\Gamma$ is dependent on selected Modulation and Coding Scheme (MCS) assigned according to the Carrier to Interference and Noise Ratio (CINR). Thus higher CINR at the side of UE results in higher $\Gamma$. Consequently, more robust MCS has to be utilized to deliver the same amount of data if $P_{t,FAP}$ decreases. This causes an increase of $n_D^k$ (see (3)) and $\vartheta_{target}$ (see (2)). Still, the constraint on FAP's power is to enable all active UEs to receive signal with satisfying quality.

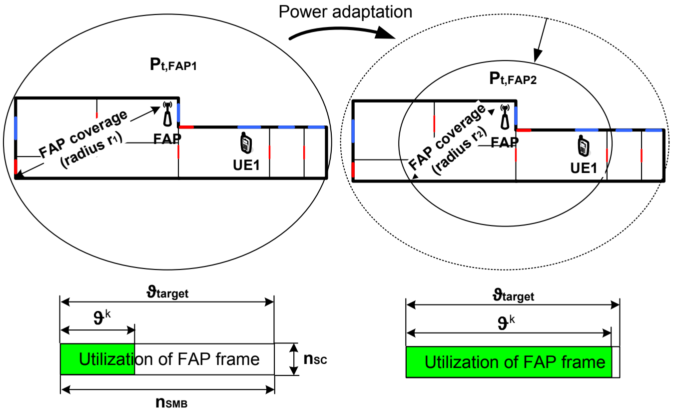

Figure 1. Power adapation principle

### B. *Impact analyzis of $\vartheta_{target}$ and congestion strategies*

A performance of the power control based on frame utilization is highly influenced by several parameters and factors. The first parameter is target frame utilization $\vartheta_{target}$, i.e., the frame occupancy reached when the power control is adjusted. The second parameter is adaptation interval $\Delta t$. It corresponds to the minimum interval between two changes of power. The last parameter, power adaptation step $\Delta P$, represents the absolute value for which the transmission power can be usually changed in one step. At the same time, the important aspect is how the algorithm should deal with the FAP's overloading. The influence of power adaptation by above mentioned aspects is depicted in Fig. 2. This figure illustrates requirements of all FAP's users denoted as $\vartheta$ (upper figure) in relation with FAP's transmitting power $P_{t,FAP}$ (bottom figure). As long as the $\vartheta$ < 1, generated data are transmitted with no additional delay. In the opposite case, the data have to be stored in FAP's buffer and thus a delay is introduced.

Fig. 2a shows the situation when $\vartheta_{target}$ = 1 as it is assumed in [7]. In this case, the whole bandwidth allocated to the FAP is utilized. Consequently, the transmitting power can be set to lower values without degradation of users QoS. This helps to mitigate interference to neighboring FAPs and MBS's users. However, any increase of UEs' requirements or switching to more robust MCS by one or several users (e.g., due to lower signal quality) can temporally overload the FAP. Then, the FAP is not able to transmit all data packets at designated time. This decreases QoS experienced by FAP's users. In case of the strategy considered in [7], denoted as CS-A, the FAP's

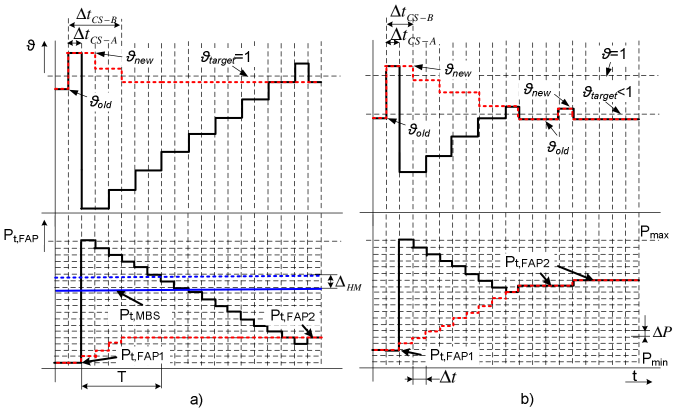

Figure 2. Impact of several aspects on power adaptation algorithm

transmitting power is set to its maximal allowed level whenever FAP's become overloaded. In the subsequent steps, the power is continuously decreased until the FAP's buffer is emptied. This strategy is represented by solid black curve in Fig 2. The proposed congestion strategy, CS-B, deals with the FAP's overloading differently. Instead of setting the transmitting power to maximal value, the FAP increases its transmitting power gradually (in Fig. 2 represented by dotted red curve). The advantage of proposed CS-B over former CS-A strategy is that the probability of new mobility event initiation is lower. In case of CS-A, new mobility event is initiated on the following condition:

$$T > HDT \text{ where } T = \frac{P_{\max} - P_{t,MBS} + \Delta_{HM}}{\Delta P} \times \Delta t \qquad (4)$$

where $P_{max}$ is maximum allowed transmission power of FAP. Since the FAP's power in case of CS-B is increased continuously, no mobility event occurs if:

$$P_{t,FAP2} < P_{t,MBS} + \Delta_{HM} \qquad (5)$$

where $P_{t,FAP2}$ stands for FAP's transmitting power after adaptation (see Fig. 2).

A possible drawback of CS-B over CS-A consists in longer overloading time caused by power adaptation algorithm. In case of CS-A, the overloading time inflicted by the power adaptation ($\Delta t_{CS\text{-}A}$) is at the most equal to $\Delta t$ (it is assumed that FAP is always able to serve its users at least at $P_{max}$). If CS-B is utilized, a time during which the FAP is overloaded can be expressed as:

$$\Delta t_{CS-B} = \frac{P_{t,FAP2} - P_{t,FAP1}}{\Delta P} \times \Delta t \qquad (6)$$

The overloading time caused by the proposed CS-B can be notably reduced by consideration of higher $\Delta P$. Nonetheless, higher $\Delta P$ brings another disadvantage as it reduces the number of possible FAP's discrete transmitting power levels, i.e., it is harder to utilize frame exactly at the selected $\vartheta_{target}$. The second option for avoiding FAP's congestion, or at least to mitigate its duration, is by setting $\vartheta_{target}$ to the values lower than 1 (see Fig. 2b) since the FAP is not temporarily overloaded if:

$$\left|\vartheta_{old} - \vartheta_{new}\right| < 1 - \vartheta_{\text{target}}. \qquad (7)$$

Hence the probability of FAP's congestion is decreased for lower values of $\vartheta_{target}$ as the difference between $\vartheta_{new}$ and $\vartheta_{old}$ could be higher without any overloading. However, the drawback of this approach is in higher probability of initiation of new mobility events. The reason is as follows. If the $\vartheta_{target}$ is decreased, the less radio resources are available and data has to be transmitted with higher efficiency (see (3)). Therefore, the transmitting power of the FAP ($P_{t,FAP}$) has to be increased appropriately to achieve higher $\Gamma$. Thus the probability of new mobility events is higher according to (1).

The goal now is to find optimal settings of $\vartheta_{target}$. To formally describe the problem, we denote two objective functions: $f_{me}(\vartheta_{target})$ as an objective function of number of generated mobility events, and $f_{ot}(\vartheta_{target})$ as an objective function of FAP's overloading time. The aim is to find such $\vartheta_{target}$ when both objective functions are minimized. Nevertheless, higher values of $\vartheta_{target}$ decreases the $f_{me}(\vartheta_{target})$ while the $f_{ot}(\vartheta_{target})$ is increased. Since the minimum of these two does not correspond to the same value of $\vartheta_{target}$, some tradeoff has to be found. In addition, the influence of power adaptation algorithm by various adaptation intervals $\Delta t$ is derived. On one hand, short duration of $\Delta t$ cuts down the time of adaptation. On the other hand, signaling overhead due to reporting and computational complexity is reciprocal in proportion to the length of $\Delta t$. To that end, simulations are performed to determine appropriate setting of $\vartheta_{target}$ and $\Delta t$.

## III. SYSTEM MODEL AND SIMULATIONS

### A. *System model*

All simulations are performed in MATLAB with parameters' setting as indicated in Table 1. The simulation platform is based on FDD LTE-A standard release 10 [10]. The system model contains one hundred terraced houses with structure according to [3]. The FAPs are deployed uniformly in a half of the houses. A disposition of individual houses and MBSs placement is illustrated in Fig. 3. The outdoor users are moving only within sidewalk's boundaries from the south to the north with speed of 1 m/s along straight trajectories. Their distance from the house is selected randomly with equal distribution in range from 1 m to 3 m off the house. The intensity of UEs arrival to the system follows Poisson distribution and it corresponds to approximately 70 passing users per one hour.

Every FAP serves up to four UEs whose movement within the house is based on [3]. Users are moving along predefined trajectories between waypoints and points of decision as depicted in Fig. 4 (see [3] for more details on indoor mobility). Fig. 4 further shows the location of FAP considered in the simulation. Several FAP's positions are selected along arrow as indicated in Fig. 4. The position of FAP right next to the window represents the worst case scenario since it generates

TABLE I. SYSTEM SETTINGS

| Parameter | Value |
|---|---|
| Carrier frequency *f* [GHz] | 2.0 |
| MBS/FAP channel bandwidth *BW* [MHz] | 10 |
| Frame duration [ms] | 10 |
| Number of OFDM symbols per slot [-] | 7 |
| Max. FAP transmit power $P_{max}$ [dBm] | 21 |
| Min. FAP transmit power $P_{min}$ [dBm] | -20 |
| MBS transmit power [dBm] | 43 |
| Noise [dBm] | BW·4·pW/GHz |
| No. of FAPs | 50 |
| Loss of internal wall/external wall/window [dB] | 5 / 10 / 3 |
| Fade margin [dB] | 4 |
| Hysteresis margin $\Delta_{HM}$[dB] | 4 |
| HDT [ms] | 500 |
| Power adaptation step $\Delta P$ [dB] | 2 |
| Physical layer overhead [%] | 25 |
| Real-time duration of simulation [s] | 20 000 |

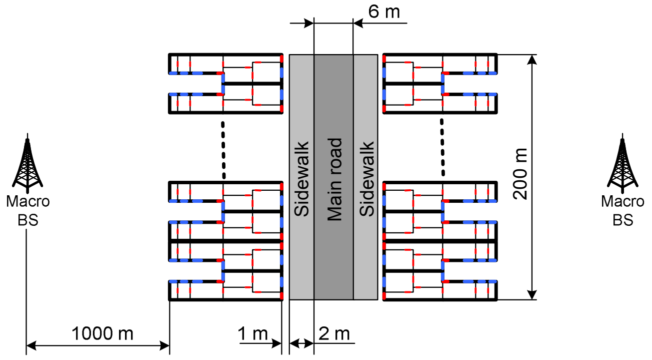

Figure 3. Simulation scenario

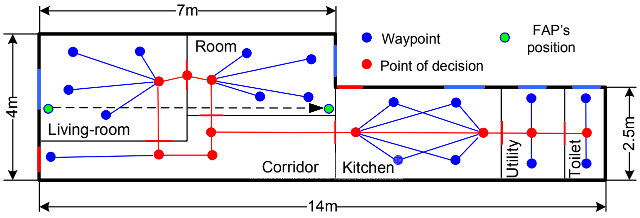

Figure 4. Indoor mobility model and FAP's deployment

the highest number of undesired mobility events. The position approximately in the middle of the household corresponds to the best scenario as the signal from the FAP, which interferes to the macro UEs, is highly attenuated by the walls and distance.

Two types of traffic models for indoor users are used in the simulation. The first traffic model type is FTP generating at the average 380 kb/s (denoted as "low traffic"). The second one is a combination of FTP model generating at the average 4.4 Mb/s and VoIP model (denoted as "high traffic"). Both model types, i.e., FTP and VoIP, are based on [11]. The path loss for indoor environment is calculated according to ITU-P.1238 model. The path loss for outdoor environment is calculated according Okumura Hata empirical model. Although Okumura Hata model is applicable only for frequencies up to 1.5 GHz, the achieved results are practically the same also for COST 231 model (i.e., outdoor model applicable also to 2 GHz). Consequently, as the femtocell performance is mostly evaluated according Okumura Hata model (see [12]), only results with this model are depicted in the next section.

### *B. Simulation results*

The first objective of performed simulations is to analyze the impact of different levels of $\vartheta_{target}$ for both congestion strategies. The investigation is primarily focused on performance of power control algorithm based on frame utilization. Nevertheless, for certain point of reference and comparison, two additional schemes taken from [3] are considered. While the first one represents auto-configuration scheme (ACS) the second one corresponds to self-optimization scheme (SOS).

If the traffic is low, the number of generated mobility events is approximately the same independently on selected $\vartheta_{target}$ as indicates Fig. 5. In addition, no notable difference between CS-A and CS-B strategies is observed. The reason is that the FAP is underloaded for most of the time at low traffic load. Thus, the FAP's transmitting power is practically the same for all investigated values of $\vartheta_{target}$. The situation is different for higher FAP's load. The number of initiated mobility events is increasing with lowering level of $\vartheta_{target}$. This is caused by the fact that the efficiency of the algorithm is proportionally decreased as well (see explanation in previous section). Nonetheless, the amount of mobility events is still not rising rapidly with lowering $\vartheta_{target}$. Furthermore, the Fig. 5 demonstrates negligibly higher performance of CS-B over CS-A for all considered levels of $\vartheta_{target}$ and high traffic. Fig. 5 also indicates that the worst performance is obtained always for ACS scheme. If power control based on frame utilization is compared to SOS scheme, the results for FAP's position close to the house boundary are in favor of SOS. Nonetheless, the drawback of SOS consists in worse QoS experienced by FAP's users (see [7]).

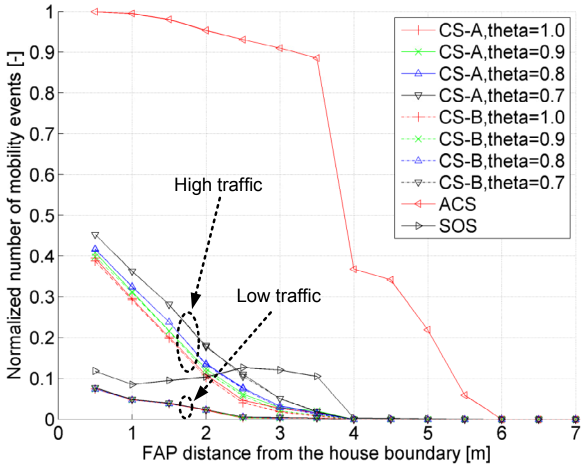

Figure 5. Impact of various $\vartheta_{target}$ on performance of power adaptation algorithm based on frame utilization

As already described above, the possible drawback of the power adaptation algorithm based on frame utilization is that it can temporally overloads the FAP. Table II shows the results for both congestion strategies at low and high traffic. It is demonstrated that the FAP's overloading is practically non existent for low traffic as the total amount of overloading time is just up to 0.05 s (that is, duration of five frames) out of 20 000 s of simulation time. The same outcomes can be stated for the high traffic generated by users. Although the time during which the FAP is overloaded increases as well, still only small portion of overall simulation time is negatively affected (up to 6.6 s out of 20 000s). If both congestion strategies are compared, the CS-A slightly outperforms the CS-B. Nevertheless, from the global point of view the FAP's overloading time is insignificant for all investigated scenarios. Moreover, the overloading time can be effectively reduced by selection of lower target frame utilization $\vartheta_{target}$. However this is at the cost of slight rise of mobility events.

So far we have assumed that the adaptation period $\Delta t$ is set to 10 ms according to [7], which corresponds to the duration of one LTE-A frame. In other words, the FAP has to be able to change its transmitting power every 10 ms. In order to do that, the UEs should report the channel quality experienced in DL every adaptation interval. To decrease signaling overhead due to reporting and also to lower computational complexity of the algorithm, the adaptation interval $\Delta t$ should be prolonged.

The performance of both congestion strategies over various adaptation periods $\Delta t$ is illustrated in Fig. 6. For this purpose, all target frames utilization $\vartheta_{target}$ as in Fig. 5 were considered. Fig. 6 and Table III represents only results for $\vartheta_{target}$ = 0.9 as the algorithm reaches the best results for this value. In case of light traffic load, the performance of the algorithm is not affected similarly as in Fig. 5 (evaluation of $\vartheta_{target}$). Independently on $\Delta t$, the number of observed mobility events is roughly the same for both congestion strategies. When the traffic load is increased, a prolongation of $\Delta t$ has slightly

TABLE II. FAP'S OVERLOADING TIME OVER VARIABLE TARGET FRAME UTILIZATION IN SECONDS

| | **Target frame utilization [-]** | | | |
|---|---|---|---|---|
| | **0.7** | **0.8** | **0.9** | **1.0** |
| **CS-A (low traffic)** | 0.02 | 0.02 | 0.05 | 0.05 |
| **CS-B (low traffic)** | 0.02 | 0.02 | 0.05 | 0.05 |
| **CS-A (high traffic)** | 0.68 | 3.1 | 5.39 | 6.21 |
| **CS-B (high traffic)** | 1.01 | 3.8 | 6.38 | 6.6 |

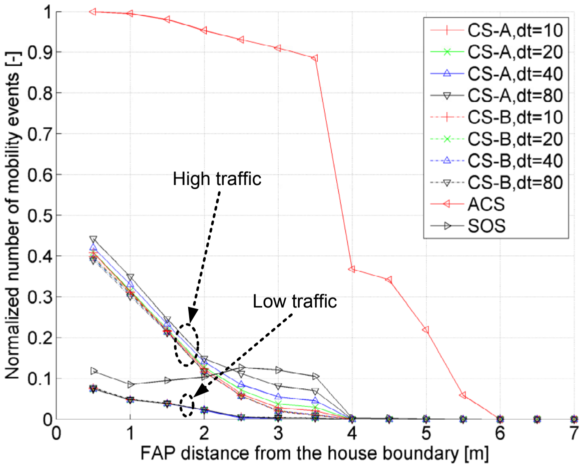

Figure 6. Impact of various *Δt* on performance of power adaptation algorithm based on frame utilization

TABLE III. FAP'S OVERLOADING OVER DURATION OF ADAPTATION STEP IN SECONDS

| | *Δt* [ms] | | | |
|---|---|---|---|---|
| | **10** | **20** | **40** | **80** |
| **CS-A (low traffic)** | 0.05 | 0.12 | 0.29 | 0.52 |
| **CS-B (low traffic)** | 0.05 | 0.13 | 0.33 | 0.6 |
| **CS-A (high traffic)** | 5.39 | 11.72 | 22.9 | 42.15 |
| **CS-B (high traffic)** | 6.38 | 11.88 | 24.38 | 48.39 |

negative impact on congestion strategy CS-A. On the other hand, performance of CS-B remains still the same even for prolonged *Δt*. The CS-A is negatively affected since the FAP's transmitting power is always set to the maximal value during congested state. In addition, the time necessary for decrease of transmitting power to appropriate value (in Fig. 2, this value is denoted as $P_{t,FAP2}$) is directly proportional to *Δt* in case of CS-A. As a consequence, more mobility events are initiated comparing to CS-B.

The better performance of CS-B over CS-A in Fig. 6 is at the cost of minor prolongation of FAP's overloading periods. This is depicted in Table III. At low traffic loads, the overloading time is negligible and varies between 0.05 s and 0.6 s out of 20 000 s. If the traffic load is increased, the FAP is overloaded much longer (up to 48.39 s for the worst case, i.e., for CS-B when *Δt* is set to 80 ms). Nevertheless, still the overloading time is insignificant taking into account the simulation duration of 20 000 s, i.e., the FAP is congested up to 0.24 % of the whole simulation time.

### *C. Discussion of congestion strategies' performance*

The following remarks can be observed from the performed simulations. At light traffic load, the performance of power control mechanism is practically the same no matter which $\vartheta_{target}$, *Δt* or congestion strategy is selected. At heavy traffic load, the lower target frame utilization $\vartheta_{target}$ results in the higher amount of mobility events. However, the FAP's overloading time can be shortened at the same time. Consequently, setting target frame utilization to 0.9 seems to be eligible compromise for all scenarios. By prolonging adaptation period *Δt*, the proposed CS-B is not affected in term of mobility events. On the other hand, the amount of mobility events rises with *Δt* for former CS-A congestion strategy. Regarding the FAP's overloading time, the proposed CS-B performs only slightly worse than CS-A at heavy traffic load.

## IV. CONCLUSIONS

The purpose of the paper is to investigate improvement of FAP's power control algorithm based on frame utilization. From the simulations can be derived following final recommendations. If the reporting period is set to 10 ms, it is always better to use former CS-A as the number of mobility events is comparable to proposed CS-B while the FAP's overloading time is shorter. However, if the main objective is to decrease signaling overhead and algorithm computational complexity, it is more efficient to use the proposed CS-B strategy. In this case the number of mobility events is significantly lower than in case of CS-A and simultaneously the FAP's overloading time is prolonged only marginally comparing to CS-A.

As a possible further research could be aimed at the investigation how the performance of the power control algorithm is affected by varying FAP's backbone capacity.

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