Capacity guaranteed sleep mode algorithm for 5G femtocell tier

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***Abstract*—The upcoming 5G networks require an advanced planning in terms of coordinating various mechanisms to achieve the highly expected performance growths that they pledge. This coordination becomes more challenging due to the increased density in urban environments of the deployment of small radius base stations, such as femtocells. In this paper we test our proposed mechanism for sleep mode power control in femtocell networks, over a widely used simulated traffic model, adjusted to our scenario. Our sleep mode strategy has been developed for femtocell clusters with the goal of reducing the number of operating femtocells without compromising the data rate performance of their subscribers. Our simulations reaffirm the benefits of our algorithm, especially the reduced number of operating femtocells and the increased offered capacity, when tested in realistic environments.**

***Index Terms*—Femtocells, sleep mode, Hybrid Access, 5G, 4IPP Traffic models**

I. Introduction

The next generation of mobile networks (5G) will introduce new services and enhance the existing ones, leading to increasing user satisfaction but also the requirements as well. In order to suffice these demands of user expectations, especially in terms of data rate and overall capacity, a large number of base stations, will be required, creating heterogeneous networks. In urban scenarios where the demand of capacity is multiplied, one type of base station that is expected to be heavily utilised is femtocells.

Femtocells [1] are a very attractive type of small cell, because of its low cost private-based maintenance and operation. However, they introduce several challenges, as well, such as the increased need for interference management due to its adhoc deployment or the high energy consumption as a result of their large number per area unit. In order to face this challenges, several approaches previously focused on macrocell tier are being investigated for the small cell tier. Sleep mode is one of those techniques, which like for the macrocell base station, it allows femtocells to operate in an intermediate state of low power, between full activation and turned off state [2]. While switching off some of their components, femtocells achieve reduced accumulative interference for all the users in their area and economy in power consumption.

An early investigation in the matter of sleep mode applied in dense small cell networks can be found on [2], where it is concluded that a sleep mode mechanism can lead to significant energy efficiency, with the right base station selection. A continuation of these researches can be met at [3], where cluster usage is included, in order to utilize an opportunistic mechanism. The authors in [4] test different sleep policies with the aim to maximize energy efficiency while in [5] the authors propose a sleep policy based on location of the small cells and the user density to reduce the total power consumption.

In [6] the authors propose a mechanism that adds to the above researches the capacity incentives to femtocells to sleep, even when their subscribers are active. This idea can be seen as an extended form of hybrid access mode for femtocells with a specific policy of spectrum management among the users.This policy guarantees the increased performance of the involved parts regarding either individual data rates or the entire cluster capacity. The authors show benefits in overall capacity in full buffer traffic.

In this paper, we check the performance of the aforementioned mechanism, against a realistic traffic model. The traffic model we suggest, is an advanced version of the discrete traffic model which is proposed in [7]. In order to achieve a higher level of accuracy in terms of simulating a users' behavior, we included more traffic generation processes. The adjustment of the mechanisms of this particular traffic model were made with the intention of simplicity regarding the comprehension of its application, but in the same time the effectiveness in terms of simulating a user's traffic load. Furthermore, it is a discrete time mechanism, which sets it ideal for our simulation scenarios. The addition of the above traffic model to the evaluation of our proposed sleep mode

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strategy lead to a more accurate depiction of its possible benefits in terms of capacity gains and possibly power savings.

The rest of the paper is structured as follows: Section 2 contains the system model we were based on to construct our traffic model. Section 3 presents our proposed mechanism and the adjustments we did to the traffic model for our simulations. In Section 4 we evaluate our proposition through simulations. Finally, in the last section we summarize our conclusions and we suggest future research goals.

II. System model

In order to evaluate our mechanism we are measuring the users' performance, while simulating their behaviour with the proposed traffic model. The evaluation of the throughput and Signal-to-interference-plus-noise ratio (SINR) metrics can be found in [6] with respect to the directives found in [8] for Long Term Evolution Advanced (LTE-A) in urban environments. The sleep mode utilized in our proposition is based on [2] and [9]. This operational mode, allows most components of the femtocell to switch off. As a result, power savings are achieved, and the components that remain active are the ones required for connection with the back-haul network and the ones needed to detect when a nearby subscribed user is transmitting in order to turn back the femtocell to full operational mode when needed. Enabling this mode can lead to a reduction in power consumption close to 40%. Finally, below we describe the traffic model we were based on.

A. Traffic model

The traffic model we utilized is an extension of the DBMAP-based model introduced in [7]. We added more parameters on the initial proposition, in order to construct a more realistic and reliable traffic model. We are including a brief presentation of the Interrupted Poisson Process (IPP) traffic model, as we will utilize its parameters in order to simulate the users' behaviour through a discrete equivalent, a DBMAP-based traffic model. The traffic model we utilized is a superposition of 4 Interrupted Poisson Procedures. We will present the basic mechanisms of an IPP traffic model, in order to ground our analysis.

IPP-based traffic models have been utilized in past papers to produce Internet traffic throughout different technologies. In [11], an IPP traffic model is used to produce typical Ethernet and Internet traffic over a wireless network. Likewise, an IPP-based ON-OFF model proposition was made for the prominent IEEE 802.16 [12] networking standard. An ON-OFF model using an interrupted Poisson process in coordination with a sleep mode mechanism is used in [13] for the performance evaluation of the IEEE 802.16 sleep mode mechanism. Another contribution regarding an IPP traffic model is used for the end-to-end delay evaluation of IEEE 802.11 standard in [14]. The aforementioned appliances of IPP traffic models are a sample of the widespread use of IPP traffic models in terms of producing internet traffic for simulations. To present the mechanisms of an IPP traffic model, we take into consideration the HTTP traffic model recommended by [15].

We have to examine the packet distribution during a session in order to construct a model to mimic that behaviour. The main concept here is that a typical session can be considered as a sequence of ON and OFF periods during which the traffic is produced and not produced, respectively. The durations of ON and OFF periods are distributed exponentially. It can easily be concluded that the mean duration of the ON period is $1/C1$ and the mean duration of the OFF period is $1/C2$ [7] . The probability that the model is in the ON state is $P_{ON} = C2/(C1 + C2)$. Similarly, the probability that the model is in the OFF state is $P_{OFF} = C1/(C1 + C2)$.

The IPP is also called as the ON-OFF traffic model [10], which is a Markov chain with two states, which can be easily pictured. The chain's behaviour is completely described by three parameters: the transition probability rate from the OFF state to the ON state, the packet arrival rate in the ON state and the transition probability rate from the ON state to the OFF state. The transition probability rate is defined as the number of transitions from a state to another per a unit of time.

The values of $C1$ and $C2$ are the transition probabilities between the ON and OFF states. During the ON state, the mechanism generates data packets according to the Poisson distribution with the arrival rate of l_{ON}. As a result, the packet inter-arrival time is distributed exponentially according to the distribution function:

$$F(t) = 1 - e^{(-l_{on}*t)} \tag{1}$$

In order to construct a more advanced traffic model, we can include the superposition of several IPPs. The conventional notation dictates that the number of processes included is placed before the name of the model. The traffic model we will utilize is a combination of four IPPs, so we will name it a 4IPP traffic model. The intermediate step from an IPP traffic model to our proposed traffic model, is the application of the DBMAPs' mechanisms, in order to extract a number of parameters that we will utilize in order to simulate each user's state.

The next step of our traffic model analysis is about the presentation of the basic parameters of the DBMAP, as it is crucial factor in the construction of the proposed traffic model. The DBMAP has been utilized widely to model network traffic, while it is proved that many well-known arrival processes such as the Bernoulli arrival process, the Markov Modulated Bernoulli Process (MMBP), the batch Bernoulli process with correlated batch arrivals and others are special cases of the DBMAP.

In order to examine DBMAP's mechanisms, we need to separate the time axis into equal time intervals, named slots [7]. We assign to each slot an increscent number, so that we refer to the time interval $[t-1,t)$ with the slot number t. A stochastic process, denoted as S holds the discrete state t space. We assume that each slot is put into one-to-one correspondence with a state from the considered state space: $S^t eS$. As well, each slot t is put into one-to-one correspondence with an integer non-negative number Xt, which is the number of new packet arrivals during the slot t we described above. We note that in the most general case, the number of new arrivals n during a slot is unbounded.

The probability of n new arrivals during the slot t and the transition of the considered stochastic process from state i to state j in the end of the slot t is:

$$Pr\{X^t = n, S^{t+1} = j | S^t = i\} = b_{ij}(n) \tag{2}$$

A more analytic presentation of the DBMAP's mechanisms is presented in [7], where it is conducted that as these matrices are aperiodic and irreducible, we can introduce the stationary probability p_i of finding the process S^t in the state i, with the condition that in the initial slot the process started from the state j:

$$p_i = \lim_{t\to\infty} Pr\{S^t = i | S^1 = j\} \tag{3}$$

The mean arrival rate, which is a term that interests us in the upcoming analysis, is the mean number of new packet arrivals during a slot:

$$l = \sum_i l_i p_i \tag{4}$$

In a more practical manner, we can calculate the mean traffic arrival rate as the number of newly arrived packets during some sufficiently long interval T related to the duration of this interval, that is:

$$\lim_{T\to\infty} \sum_{t=0}^{T-1} X^t / T = l \tag{5}$$

The key to the following analysis, is that in the end we will be able to apply a DBMAP-based traffic model mechanism, by using the parameters of an 4IPP continuous-time traffic model. The transition from the IPP to the DBMAP will be presented in the next section. Having analyzed the components that our traffic model constitutes of, we are able to examine the traffic model we utilized in the next section.

III. Proposed scheme

The private-owned nature of femtocells might lead to an unplanned and random deployment that may cause severe issues to the users' experience. While they remain a very flexible option on a variety of occasions, the absence of central coordination for their placement may lead to severe problems. On the contrary, we note that the deployment of macrocell layer base stations is organized and depends on a variety of factors, such as the location and the spectral usage, in order to achieve high quality services and avoid large interference issues. It can be easily assumed that if no such forecast took place, and base stations were randomly deployed in very close distance and using same frequencies, the interference would be unbearable and handovers would be continuous.

Regarding the fact that private owned femtocells operate mostly in closed access mode, the handover option becomes unlikely to occur. This factor would lead to an excessive accumulative interference from the multiple nearby femtocells. In addition, any individual in an dense deployed area not belonging to any of the femtocells access list, would also experience negative effects on its performance. And apart from that, the exclusivity of services in private femtocells, means that the number of operating base stations does not correspond to the actual traffic demand, leading to an unnecessary power consumption.

A. User allocation mechanism

To face the aforementioned difficulties, the initial proposition in [6] utilizes two operating modes of the femtocell: The hybrid access mode and the sleep mode. As we mentioned before, sleep mode is an operational mode of the femtocell that allows some components of the femtocell to be turned off, while capable of a rapid transition to full activation when needed. During this mode we consider zero interference towards non-subscribed users and no serving of subscribed ones. On the other hand, hybrid access mode is an operation state for a femtocell, where an intermediate admission policy is adopted. While open access allows every user in its range to be adopted and closed access allows only users enlisted to its Closed Subscriber Group (CSG), hybrid access combines these two approaches. In that matter, external users might be allowed under defined restrictions, while the majority of the resources are dedicated to its CSG users.

The main obstacle that we have to surmount regarding these policies, is the users' consent. Because these mechanisms offer private owned resources to external users, we overcome the users' hesitations by guaranteeing the improvement of their performance through the adaptation of the allocation mechanism. We even allow a femtocell to turn to sleep mode, even if it has active users, as long as the mechanisms' performance conditions are met [6]. The users' reallocation is possible through the hybrid access of their neighbouring femtocells. As a result that we will present in the following sections, the users' experience remains in the same or better level, while fewer base stations remain active.

In this manner, the mechanism initially examines whether a femtocell can turn to sleep mode. The selection is made by examining clusters of femtocells and test if a reallocation to a neighboring femtocell is possible. We set the requirement that each user belonging to a candidate for sleep mode femtocell must at least regain its performance when reallocated to another femtocell. We set this condition by:

$$THR_{New} \geq THR_{Old}. \tag{6}$$

If this is true, an active femtocell will accept the users of a nearby femtocell turned to sleep mode. The reduction of the spectrum resources that the user enjoyed by its own femtocell will be compensated by the reduced interference in the area since a close by femtocell will turn to sleep. On the other hand, the base station that will adopt the allocated users, might need an increment in its power levels, in order to satisfy the newly accepted users. The required power increment is computed by [6]:

$$P_{Inc} \geq \frac{R * \left(\Delta f + \sum_{B'} P_{B'} G_{u,B'} \right) - P_{Old} * G_{u,N}}{G_{u,N}} \quad . \tag{7}$$

where $\Delta f + \sum_{B'} P_{B'} G_{u,B'}$ denotes the interference in the user when connected to the new femtocell, $G_{u,N}$ his/her gain relative to the base station he might migrate, P_{Old} the power of that station and R is:

$$R = \frac{(1 + aSINR_{Old})^{(N_2+1)/N_1} - 1}{a} \quad . \tag{8}$$

where $SINR_{Old}$ is the SINR that the user would experience if served by the original femtocell. $N2$ is the number of users served by the neighbour and $N1$ is the number of users served by the origin femtocell. Power increment is also subject to a maximum allowed power transmission of the femtocell.

The hybrid access, for the neighboring sleeping femtocells users is adopted by utilizing a similar incentive. By turning base stations to sleep mode, and facing reduced interference, we are compensating the reduced spectrum utilization due to hybrid access. The power adjustment to compensate for the reduction of further spectrum resources is similar to the previous case as can be seen in [6].

A final check is made for all the femtocells of the same cluster that do not participate in that particular user exchange, regarding the required power level. This way we ensure that no users of these base stations experiences reduction in their throughput. This scheme can be seen as a beneficial result of the deactivation of the slept femtocells, compensating the increase on their neighbour's power transmission. The user exchange is completed, if this final check proves successful.

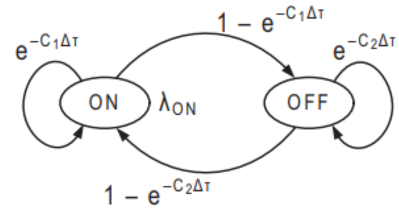

Fig. 1. Process as a Markov chain

B. The constructed 4IPP DBMAP

The extension we added to the DBMAP constructed in [7], is that we utilize the superposition of 4 Interrupted Poisson Procedures, with different parameters, in order to construct a more advanced and well-based traffic model. The fact that whereas the IPP-based model is a continuous-time model,the DBMAP-based model is a discrete-time model, is crucial for our scheme. This difference allows us to apply the traffic model in our simulations by adapting its parameters to our demands. The analysis that follows concerns the 4 Interrupted Poisson Procedures, with their distinct parameters.

For each one of the 4 processes we are utilizing, the probability that the ON period duration exceeds a threshold value of t is calculated as:

$$PrT_{ON} > t = e^{-C_1 * t} \tag{9}$$

with the corresponding probability for the OFF period to be easily conducted:

$$PrT_{OFF} > t = e^{-C_2 * t} \tag{10}$$

We note that the mean durations of the ON and the OFF periods are equal to $E(T_{ON}) = 1/C_1$ and$E(T_{OFF}) = 1/C_2$, respectively. The discretization of the IPP is carried out by separating the time axis into slots, during which the IPP state cannot change. We remind that the 4 processes that we are going to utilize have different transition possibilities, in order to mimic in a more realistic way the a user's Internet load behaviour. Each one of these processes can be pictured as a Markov chain as Fig. 1 shows, where Δt denotes the time slots intervals.

In order to add to our mechanism the presented traffic model, we utilize for each of the users between each simulation, the transition probabilities presented in a previous

Parameter	Value
Macrocells	9
Macrocell Radius	250 m
Femtocells	250|350|450|550|650
Femtocell subscribers	1-3 (per femtocell)
Initial activation	0% | 20% | 40%
Bandwidth	20 MHz
Carrier frequency	2 GHz
BS transmit power	46 dBm
FBS max transmit power	21 dBm

TABLE I: Simulation Parameters

research by Telcordia and Lawrence Berkeley Labs [10]. That way, our simulations include the elegant and plain mathematical model of a DBMAP-based model, while applying to it 4 different IPP processes.

IV. Performance evaluation

In this section we describe the simulation setup and we discuss the obtained results.

A. Simulation Parameters

In our simulations, we considered a network of 9 macrocells. We located the base station at the center of each cell and set its transmission at 46dBm and its radius at 250m. The deployment of the femtocells was determined randomly, as well as the subrcribers' position. We conducted simulations for several femtocell deployments densities, specifically of 250, 350, 450 and 550 femtocells, with each one being capable of accommodating up to 3 subscribers at the same time.

Regarding the application of the constructed traffic model, we assumed 3 use cases. The first that in the beginning of our simulations, the users were inactive, the second that 20% of them were active and for the third case, that 40% of the subscribers were active. After the initial state, the number of the active users at each simulation varied and was depended only on the possibilities of the 4IPP processes for each one of the users. Having defined these metrics, we applied the traffic model that we described in Section II between the simulations and we measured the amount of femtocells that switched to sleep mode. The rest simulation parameters' values have been based on 3GPP directives fro LTE-A and the LTE simulator in [16]. Results depicted in the figures represent the average obtained by 25 repeated simulations.

B. Simulation Results

The mechanism utilized in [6] and enriched in this particular proposition with a traffic model, preserves the same positive effects for the users in terms of performance and throughput efficiency as in the initial proposition.

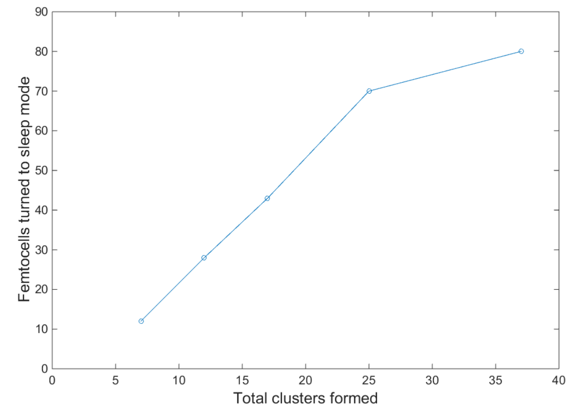

Fig. 2. Number of femtocells turned to sleep mode vs femtocell deployment density

To showcase the results, Fig. 2 shows the number of slept femtocells for a different number of deployed femtocell base stations when the mechanism is enabled. As the femtocell density increases, the chance of femtocell cluster formation is also increased as expected. The formation of the clusters favours the user reallocation that our mechanism proposes, and as a result the number of femtocells that can be switched off increases as well. Based on the figure, we can deduct that this relation is almost linear.

In Fig. 3 we display the Cumulative Distribution Function (CDF) of the throughput of the users that are subscribed to femtocells. In order to isolate the results from the femtocells that are affected by the mechanism, we consider the throughput experienced by users that belong in a femtocell cluster. From the figure we can observe that while a number of femtocells have been switched off as shown earlier, the throughput provided by the remaining operating femtocells to the same users has not been negatively affected. Instead, there is a slight improvement. The factors that lead to the improved performance are the fact that several femtocells turn to Sleep mode resulting to a reduced overall interference in the cluster, combined with the precondition that a reallocation of a user is applied in combination with power control to ensure an improvement in the users' performance.

Finally, in Fig. 4 we present how the mechanism affects the category of unsubscribed users that do not have access to any of nearby deployed femtocells. This type of users suffer the most when in environment of clusters since they experience interference from multiple nearby sources.

As the figure suggests, the mecahnism leads to an improvement in the overall throughput of these users. This is a direct consequence of the fact that multiple femtocells have switched off, reducing the overall interference. While eventually the remaining operational base stations need to increase their power output to compensate for the powered off stations, this does not surpass the positive effects of the

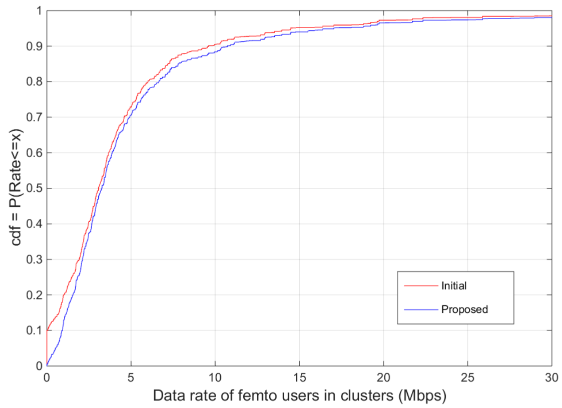

Fig. 3. Data rate of all users subscribed to femtocells that are members of clusters

reduced number of interference sources, which leads to the depicted improvement.

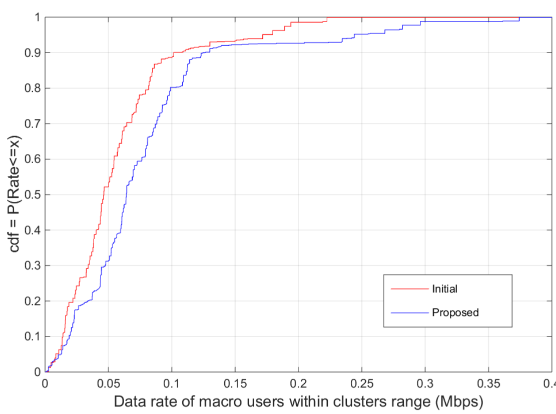

Fig. 4. Data rate of macrocell users that are within areas where a femtocell cluster has formed

V. Conclusions and Future Work

In this paper, we investigated performance gains of the mechanism in [6], with the additional parameter of a discrete traffic model. As well as in the initial proposition, the focus of the mechanism was on dense deployed femtocells with high traffic in urban environments. The mechanism achieves a reduced number of operational femtocells reducing the accumulative interference without affecting negatively their subscribers' peformance and even improving it. The latter also provides incentive to femtocells' private owners to share their resources towards a more efficient utilization of the femtocell tier. A future extension of this work could encompass an estimation of the mechanism effects on overall energy performance evaluating the positive effects of the reduction of operating femtocells against the negative effect of the increment in power transmission by the remaining ones.

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