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Power-Aware QoS Provisioning in OFDMA Small Cell Networks

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Abstract—**Orthogonal frequency-division multiple-access (OFDMA) small-cell networks of next-generation Long-Term Evolution (LTE-Advanced) standard, is perhaps a key factor to efficiently provide beneficial usage of expensive radio resources, while maintaining adequate network capacity. Network capacity is without doubt a critical resource for LTE networks. At the same time, real-time multimedia transmission requires effective quality-of-service (QoS) provisioning, as well as power admission. This paper proposes a traffic-aware OFDMA hybrid small-cell deployment for QoS provisioning and an optimal power admission control strategy for 4G cellular systems. By performing real-case scenario simulations of user-type multimedia transmission, we show that the implemented framework achieves high QoS levels of performance, increased throughput capacity, lower delay levels and optimally adapted network traffic.**

Keywords— Small Cells; Power Control; LTE; quality of service (QoS); traffic scheduling

I. INTRODUCTION

The emergence of high demanding novel applications in terms of throughput and latency, has lead modern mobile operators to increase wireless coverage and capacity of their mobile networks. Undoubtedly, high definition multimedia communications and real-time traffic have become essential among them. To confront issues like delay-sensitive quality-of-service (QoS) requirements and traffic provisioning, the Long-Term Evolution Advanced (LTE-A), which is a part of the 4G cellular system deployments, can be seen as a reliable solution. Specifically, the existing wireless cellular architecture that consists of a single macrocelllayer can be covered by several LTE-A-based small cells, which are deployed by lower-power small-cell base stations. These LTE-A small cells (SCNs) prove to increase network capacity, through the spatial reuse of spectrum as well as improve indoor cellular coverage [1], [2].

Technical concerns and challenges, however, for SCNs cannot be unavoidable. Undoubtedly, a critical and crucial problem facing SCNs is the presence of interference among neighboring SNCs, and between the SNCs and the macrocell LTE network, as well. LTE networks’ power resources are the most cost-effective resources and behave as a performance evaluation criteria for wireless cellular systems. The main purpose of an efficient power control is to minimize the transmitted power, fairly adjust offered power levels among mobile users and eliminate intercell interference. QoS effectiveness among traffic users is also another often addressed key factor. QoS levels can become easily degradable on small cell networks without any provisioning. The QoS degradation is particularly large when the number of mobile users increases or when the mobile users are running bandwidth-demanding applications [3].

There are several studies that investigate the OFDMA small-cell schemes in different perspectives. From the traffic engineering perspective, a quite popular approach to QoS scheduling is the utility-based form. Scheduling rules based on maximizing utility, which represents the amount of satisfaction that can be obtained by scheduling a resource for a user, have been thoroughly proposed in [6], [7], [8] and [9]. The utility functions here are defined as decreasing functions of the packet delay in the queue. In [2], a novel optimal subcarrier-allocation algorithm is being proposed in order to perform QoS-based scheduling using traffic utility as the cost function. An admission control algorithm based on the proposed traffic utility function is also being illustrated. The area of power control in SCNs is not thoroughly investigated in the literature. A joint admission and power control algorithm where the small cells can determine jointly their admissibility and transmit powers autonomously is introduced in [12]. Authors in [13] present a study of Power control in two-tier femto cell networks, where an algorithm that reduces transmission powers of the strongest femto cell interferers is proposed. A distributed algorithm for downlink resource allocation in multicarrier small cell networks is also introduced in [14]. In this algorithm, each home base station selects the resource allocation strategy to maximize a surplus function comprising both, own cell utility and interference prices (interference that is caused to neighboring cells).

However, in the majority of the previously mentioned literarute studies, the traffic characteristics and channel conditions, like the Signal-to-Interference Noise Ratio (SINR), are not taken into account, while performing the scheduling and access controls in LTE-A small cells. Such considerations, though, tend to be really crucial when needed to obtain most QoS optimal small-cell deployment.

In this paper, we propose an admission control procedure, inside a sophisticated LTE-A simulation framework, for efficient power allocation in SCNs. The proposed framework efficiently controls systems’ interference while on the other hand guarantees user QoS. Furthermore, we present a novel optimal allocation algorithm to perform QoS-based scheduling using traffic characteristics parameters, as well as real-time network conditions. It is experimentally proven that when the number of femto users in the cell increases or when the traffic arrivals are outside the capacity region, the scheduler manages

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to handle fair allocation toward achieving end-user QoS. The suggested framework is being evaluated and examined through a High Definition (H.264/MPEG-4) video input [12], VoIP conversational [13] and data stream trace files.

The paper is structured as follows: Section II provides a brief description of SCNs, as well as the network traffic models for OFDMA hybrid small cells. Section III tackles the issue of optimal traffic scheduling of mobile users by deploying an admission control utility function, a power control method, and a minimal algorithm to perform the QoS optimization. Section IV is dedicated to the evaluation of the proposed. Finally, Section V concludes the paper.

II. ADMISSION-CONTROL IN SMALL CELL NETWORKS

A. *Small Cell Networks (SCNs)*

In the remaing of the paper, we focus on the description of a typical Frequency Division Duplex LTE Small Cell HeNB. A typical topology of such a network is presented in Fig. 1. In the LTE terminology, Home eNBs (HeNBs) are also known as femto cells, thus the terms HeNB and femto cell will be used equivalently in this paper. HeNBs provide indoor cell coverage, in small buildings, homes or offices. The HeNB is a low power eNB that will be used in small cells, or femto cells as mentioned earlier. It will be owned by the customer, deployed and connected to the Evolved Packet Core (EPC). EPC accounts for the framework that provides converged voice and data on 4G LTE networks. Macro eNB is serving both the macro and femto cell environments, offers signaling interconnectivity with the Evolved Packet Core. eNB is typically the main hardware to provide connection between the UE (User Interface) and the rest of the network, like in the form of a base transceiver station (BTS). Traditionally, it contains the minimal functionality, thus providing more simplicity [10].

Finally, from the LTE networks power allocation perspective, the most common power algorithms for HeNB Downlink Power Control as defined by the 3GPP standards are presented below:

Algorithm 1. Fixed HeNB power setting mode [10].

Algorithm 2. Smart power control based on interference measurement metric from macro NodeB [10] [11].

Algorithm 3. HeNB power control based on HeNB-MUE (Macro UEs) total path loss [11].

B. *Network Traffic Modeling*

For the scope of our simulation experiments, we consider a time-varying, bursty, and position-dependent wireless channel. The latter poses a major challenge in achieving optimal QoS performance and scheduling. We design our proposed framework taking into consideration the time variation of several system dynamics, such as channel conditions, location, queue state, and application layer requirements to achieve satisfying QoS levels.

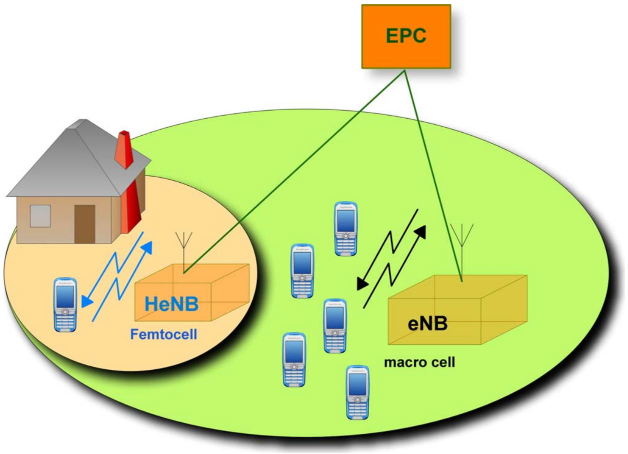


Fig. 1. Topology of an FDD LTE Small Cell HeNB

Using this information, the optimal throughput and required power, for each user category, in every time slot, is being determined. Based on these parameters, the scheduling algorithm, inside a specified core Utility Function, performs resource scheduling to achieve the QoS objectives. The illustrated framework contains three queues which correspond to each of the three traffic priority classes every user belongs to. During our simulation phase, we decided to utilize three versatile trace files in terms of bit rate per second and traffic load. The first one contains a high quality video definition (HD) data, the second conversational voice and the latter includes data torrent. The users served under the mobile system are separated into three classes, using three different queuing characteristics. These classes are as follows.

- *Video-Streaming Users–(Best Effort-BE queue)*: It corresponds to the HD resolution video. The mobile operator has an expectation to deliver on time. Our traffic management scheme is typically manipulated in such a way that the quality of service of these selected uses is prioritized over other classes of traffic. These users are modeled using Gamma Distribution with shape parameter s and a G/G/1 queuing system.
- *VoIP Conversational Users–(Variable Bit Rate-VBR queue)*: Here, the voice traffic is not sensitive to Quality of Service metrics (jitter, packet loss, latency), due to its lower quality nature. We simply use M/M/1 queuing system to model and simulate the traffic class.
- *File Streaming Users–(Constant Bit Rate-CBR queue)*: Inside this class, we transmit the streaming file using an M/G/1 queueing system.

Our objective is to stabilize the queues of all user traffic classes when the arrivals are inside the capacity range of our system. In addition, we want to offer QoS performance for different file streaming traffic types, in terms of maximizing throughput and minimizing delay. These objectives together present an interesting case of QoS provisioning.

III. PROPOSED FRAMEWORK

The proposed framework is embedded into our simulated mobile system and is shown in Fig. 2. It has four main parts: the *QoS Classification* of the real-time streaming traffic, the calculation of the *Utility Function*, the *Power Constraint Scheduling*, and the *Traffic-Aware Admission Control*.

The *QoS classification* of the heterogenous traffic block dynamically considers the UE or User traffic requests, as shown in Fig. 2, to calculate the average waiting time of each user types. In order to provide a fair traffic allocation among the different quality traffic classes, an improved scheduling rule that deal with their unique attributes, is being proposed. In this paper, we propose a novel traffic-aware *utility-based scheduling policy (TA-Utility)* for small cells to effectively provision QoS and provide adequate system capacity. The scheduler takes as input information of the channel state and the traffic information to make scheduling decisions at every time slot, based on the computations of the utility function. The results are proven to migitate end-to-end delay, increase system throughput as well as the total capacity per user(s)/cell(s), as a result of better QoS provisioning.

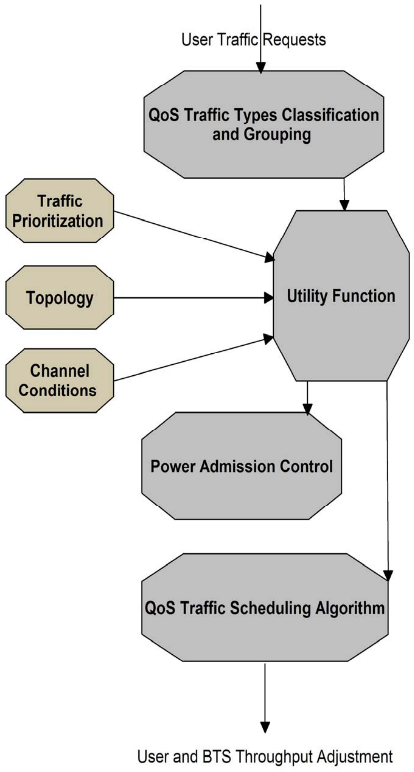
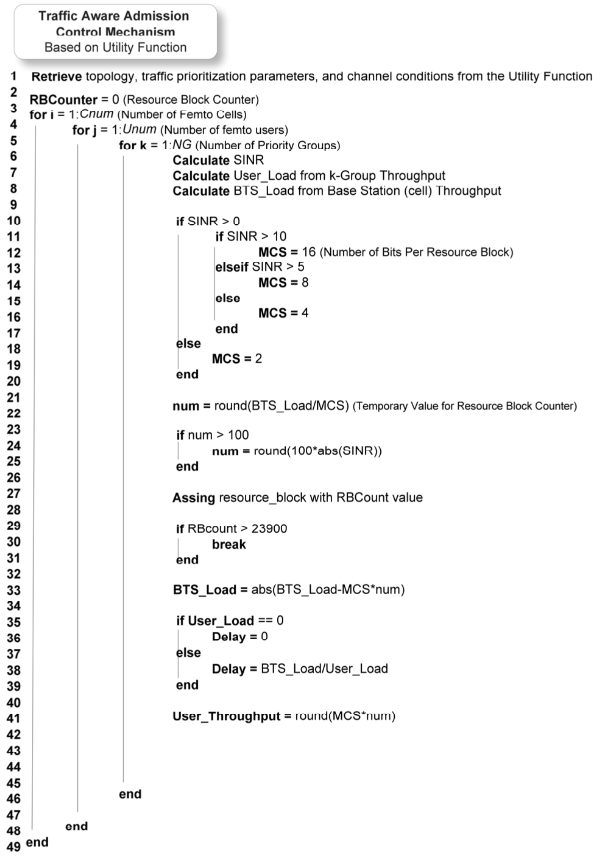


Fig. 2. Block diagram of the proposed admission-controled mechanism

The *Power Constraint Scheduling*, or *Power Admission Control* behaves as a power control mechanism for future SCNs, which operates inside the core of our framework [11]. The mechanism has the ability to sense the topology and traffic scenario requirements, in real time, and as a result, to select each time slot the power algorithm(s) that best fit to the current topology instance and traffic scenario. Inside this scope, we use the methodology of *Priority Grouping*, in which each HUE in the topology is assigned to one of the available power groups with different priorities related to power requirements and traffic load. The use of priority groups can result to a power algorithm handover, thus combined usage of more than one power control algorithms from the HeNB depending on the traffic scenario. This as a major advantage means that HeNB performs a more efficient power allocation and interference mitigation [11].



Traffic Aware Admission Control Mechanism
Based on Utility Function

```
Retrieve topology, traffic prioritization parameters, and channel conditions from the Utility Function

RBCounter = 0 (Resource Block Counter)
for i = 1:Cnum (Number of Femto Cells)
    for j = 1:Unum (Number of femto users)
        for k = 1:NG (Number of Priority Groups)
            Calculate SINR
            Calculate User_Load from k-Group Throughput
            Calculate BTS_Load from Base Station (cell) Throughput

            if SINR > 0
                if SINR > 10
                    MCS = 16 (Number of Bits Per Resource Block)
                elseif SINR > 5
                    MCS = 8
                else
                    MCS = 4
                end
            else
                MCS = 2
            end

            num = round(BTS_Load/MCS) (Temporary Value for Resource Block Counter)

            if num > 100
                num = round(100*abs(SINR))
            end

            Assing resource_block with RBCount value

            if RBcount > 23900
                break
            end

            BTS_Load = abs(BTS_Load-MCS*num)

            if User_Load == 0
                Delay = 0
            else
                Delay = BTS_Load/User_Load
            end

            User_Throughput = round(MCS*num)




        end
    end
end
```

Fig. 3. The Traffic Aware Admission control mechanism pseudocode.

The *Traffic-Aware Admission Control* or *QoS Traffic Scheduling Algorithm* mainly implements the previous discussed assumptions. Particurarly, it can provide a sense of how the user is performing in a given time slot. Therefore, inside our framework, we define a new performance metric that will be used in making admission control decisions. Thus, the traffic scheduler, as schematically depicted in Fig. 3, utilizes the performance metric of *Signal-to-Interference-to-Noice Ratio (SINR)* in order to distinguish the traffic prioritization of the traffic classes, as well as to provide more fairness with a better resource block allocation strategy. For each User Equipment (UE) in each priority category, it instanteously calculates the SINR value, in each given time slot. According to several empirical SINR thresholds, it provides a certain number of bits per resource block (MCS). Then, it reallocates the Resource Block value, and restimates the given per user(s)/cell(s) throughput in order to better classify the traffic classes and provide QoS admission.

The *Utility Function*, more analytically depicted in Fig. 4, is aimed at achieving the heterogenous objectives of QoS realized by different user traffic types. It can be seen as the core and control functionality of our total framework. It is generally perceived that as the waiting time of the packet of a user becomes large, the QoS requirement of that user is high. Hence, this particular user has a higher priority during traffic scheduling. Inside our admission controlled multimedia transmission, we enforce QoS differentiation between services.

Algorithm 1: Utility based traffic-aware Admission Control Algorithm

```
for each time slot t
    for each user traffic request u
        Determine time-average utility Functionality $E[U_u(t)]$ based on system's
        dynamic state
        Determine maximum utility Functionality threshold $U_{th}$

        if $E[U_u(t)] < U_{th}$
            Preemt User request u
        end

    end


    if a new user traffic request v arrives
        Determine new instant time-average utility Functionality $E[U_v(t)]$

        if $E[U_v(t)] < U_{th}$
            Do not Admit User request v yet
        else
            Admit User request v and inititate traffic scheduling mechanism
            and Power admission control
        end
    else
        continue
    end
end
```

Fig. 4. The Utility-based function algorithm pseudocode.

The utility-based algorithm obtains the optimal traffic allocation strategy in linear time, when the number of users is not considerably large, and while the femto users move close to the Base Station infostructure. Handover requests and user movement far from the center of the femto cell requires more load balancing, thus decreases QoS performance and total system capacity. This is a reasonable assumption since small cells, on average, support a few hundrends of users. Yet our mechanism, although affected by such service degradation, still manages to outerperform across these worst case scenarios and offer satisfying differentiation levels.

IV. PERFORMANCE EVALUATION

A. Simulation Parameters

For the needs of the results' presentation, we conducted the following experiment in MathWorks MATLAB environment. The necessary simulation parameters for the conduction of experiments are presented in Table I. The SCN topology consists of multiple adjacent macro cells, multiple femto cells that are uniformly distributed inside the network and multiple macro and home users (see Fig. 5). Macro users are uniformly distributed in the topology and they can move to any direction, whereas, home users are placed closed to the border of femto and they can move toward the femto cell center. For our experimentation needs, we obtained the Cost 231 Hata Model as for simulating our total path loss. This particular version of the Hata model is applicable to the radio propagation within urban areas. Lastly, we have provided, three priority groups with initial bandwidth levels at 1.2, 0.2, and 0.05 Mbps respectively. The source code of the framework is available in [17].

TABLE I. SIMULATION PARAMETERS

Parameter	***Units***	***Value***
System bandwidth	MHz	10
Subcarriers		60
Subcarriers' bandwidth	KHz	375
Carrier frequency	MHz	2000
Cell Radius	m	1000
Correlation distance	m	40
Channel model		Typical Urban
Users' speed	km/h	3
Path loss	dB	Cost 231 Hata
BS transmit power	dBm	43
HeNB max transmit power	dBm	20
HeNB min transmit power	dBm	0
Antenna Gain	dBi	14
Fixed Power for Algorithm 1	dBm	-3
HeNB operation mode		Closed Subscriber Group
NG (priority groups)		3

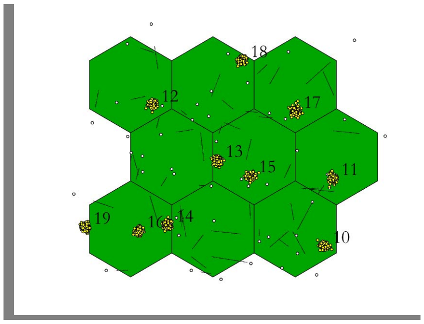


Fig. 5. Topology for the scenario's experiment.

Fig. 5 displays an overview of the entire SCN topology. In order to efficiently present the results, we focus on femto cell numbers 14, 15, and 19 of the topology depicted on Fig. 5.

B. Traffic Scenarios

The trace file inputs were arbitrary selected from real case scenarios in order to most realistically simulate real-time multimedia transmission in femto cells. Particularly, for the

HD Video, an H.264 encoded trace was selected from [15]. To simulate the conversational audio conference, we downloaded a sample audio file in MP3 format from [16]. Finally, we produced the file streaming network service with a randomly uniformed variable as its traffic load. For the needs of results' presentation, we conducted the following experiment.

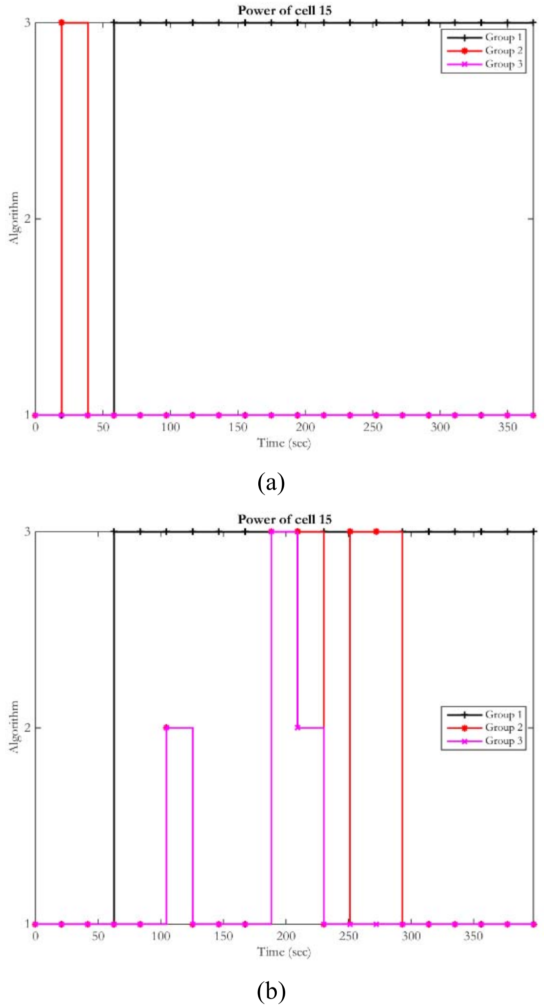
Inside the scenario, we consider a 9 macrocell and 10 femto cell network with 50 MUEs, 50 initial HUEs and approximately additional 120 HUEs gradually distributed in time domain (Fig. 5). Additionally, HUE population is increased with a constant low rate (about 5% of HUEs population) throughout the first half of our simulation, while in the second half, HUE population increased rapidly (about 10% of HUEs population). Inside the scope of our simulation scenario we performed two scenario executions using random femto user equipment positioning, with the QoS Provisioning mechanism enabled and disabled in each pair case adjacently.

C. *Results*

Firstly, we focus on the benefits of our admission control methodology from the energy perspective. Fig. 6 presents the evolution of HeNB transmit power for each power control algorithm for femto cell 15, for random user positioning and with the QoS mechanism disabled and enabled at both case. Additionally, Fig. 6 presents the algorithm (in y-axis) that is selected each time for each priority group by our framework in order to perform efficient power allocation and admission control at HeNB. By carefully observing subplots (a) and (b) of Fig. 6, we can spot several switching points occurring at each time frame of our scenario execution between the three power algorithms previously mentioned, thus an algorithm handover or power control grouping is being performed here. It is clearly depicted that despite channel characteristics, interference levels, or user equipment movement across the femto cell, when the QoS traffic scheduler is being enabled to co-work with the power admission control, see Fig. 6 (b), the algorithm switching points increase significantly. This is a result of a more beneficial admission strategy followed by a better traffic provisioning method. Power adaptation becomes more stable, available resources are being more effectively controlled and each priority group, or traffic class, is being served with a more coherent manner in terms of power selection algorithm.

Secondly, we move to the traffic characteristics assumptions for our simulation, providing the advantages in terms of throughput capacity and end-to-end average delay. In Fig.7, it is quite clear that the total throughput capacity for femto cell 19 increases significantly, almost by 50%, compared to the case when our QoS provision mechanism is not being selected. Fig. 8, on the second hand, demonstrates an efficient drop of the average end-to-end delay in femto cell 14 compared to the situation when QoS strategy is disabled. Particularly for the cases of high bitrate and low delay demand (see BE and VBR traffic classes, adjacently), our provisioning methodology tends to retain average end-to-end delay not only to acceptable but satisfyingly lower levels.

The results refer to each of the three traffic classes, or traffic priority groups, with the VBR class, or conversational, having the most significant decrease.



(a)

(b)

Fig. 6. Power selection for femto cell 15. (a) QoS Mechanism disabled. (b) QoS Mechanism enabled.

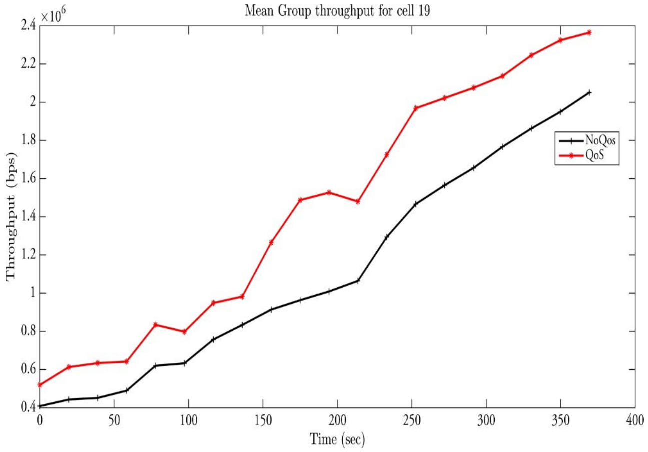
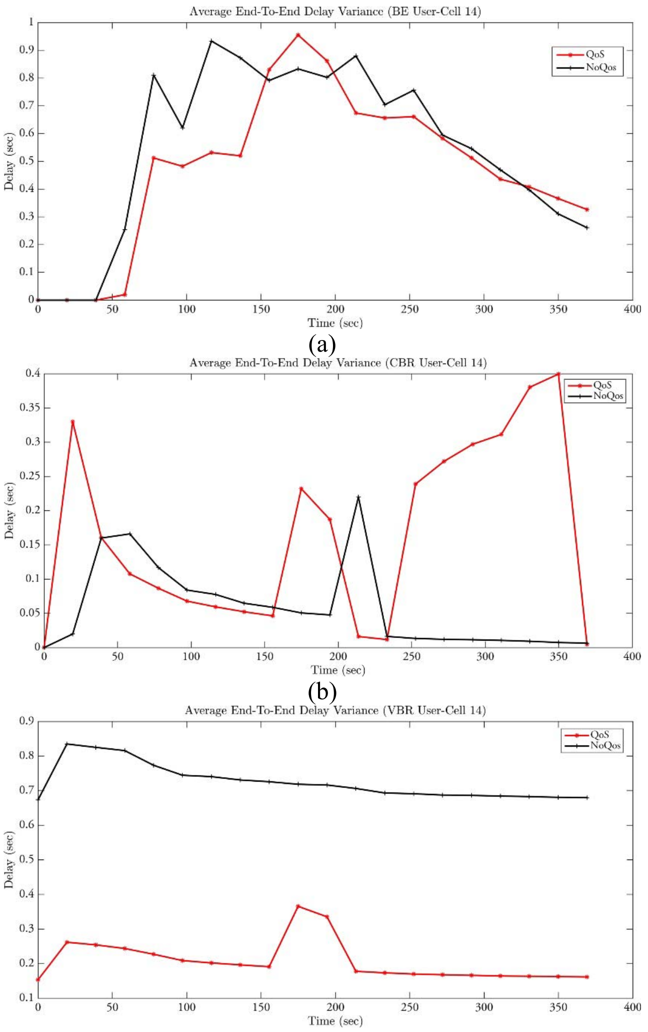


Fig. 7. Total Throughput capacity for femto cell 19.



(a)

(b)

(c)

Fig. 8. Average End-To-End Traffic Delay for femto cell 14.
(a) BE traffic class. (b) CBR traffic class. (c) VBR traffic class.

V. FUTURE WORK

For further research prospects the effective support of the femto cell power deployment through inter-cell interference coordination (ICIC) could be of high interest. Particularly for the next wireless generation, named 5G, the issue of energy harvesting for energy-efficient communication is a top priority. It is estimated that inside a 5G wireless network, energy could be harvested from ambient radio signals, which could then be used for communication inside a small cell. Due to the fact that these power signals are very sensitive and sometimes not energy beneficial, in order to deploy the previous harvesting technique, further femto cells power control methodologies could be simulated as well as applied.

VI. CONCLUSION

In conclusion, this paper presents an efficient power control framework in conjunction with a QoS traffic provisioning mechanism for SCNs. The mechanism effectively controls the available power resources at HeNB and guarantees home user QoS. By using the introduced Priority Grouping method, home users are assigned to one of the available groups with different priorities in terms of power requirements and requested traffic load. The results prove that the proposed framework results in significant power saving at HeNB, compared to existing approaches. In co-functionality with a real-time traffic scheduling methodolody, it is depicted experimentally that not only power grouping is ameliorated, but also higher throughput capacity per femto cell is achieved and traffic delay is minimized.

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