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Power-Aware and QoS Provisioned Real Time Multimedia Transmission in Small Cell Networks

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ABSTRACT

The recent emergence of ultra-high-speed and high-definition data and video services has pushed wireless network capacity to its limits. Cellular network capacity is therefore a valuable resource, whereas indoor coverage poses itself as a challenging issue. At the same time, real-world paradigms of multimedia transmission require effective Quality-of-Service (QoS) provisioning as well as power admission. To confront issues like delay-sensitive QoS requirements and traffic provisioning, as well as meet the mobile customer needs, this paper presents a traffic-aware Orthogonal Frequency-Division Multiple-Access (OFDMA) hybrid small-cell deployment for QoS provisioning and an optimal admission control strategy for 4G cellular systems. The traffic awareness in the proposed framework is provided by a utility function, which differentiates the traffic QoS levels with the user's grouping priority indexes, channel conditions, and traffic characteristics. To further enhance the proposed framework, an admission power control algorithm based on an efficient algorithm handover is also proposed.

KEYWORDS

LTE, Power Control, Quality-of-Service (QoS), Radio Resource Allocation, Small Cells, Traffic Scheduling

1. INTRODUCTION

The recent growth of high demanding novel applications in terms of throughput and latency, has forced modern mobile operators to increase wireless coverage, boost data rates and capacity of their mobile networks. Undoubtedly, high definition multimedia communications and real-time traffic have become essential among them, thus issues like delay-sensitive Quality-of-Service (QoS) requirements and traffic provisioning are critical. The Long-Term Evolution Advanced (LTE-A), which is a part of the 4G cellular system deployments, can be seen as a reliable solution to fulfill these sophisticated requirements of multimedia and data traffic. More specifically, the existing wireless cellular architecture that consists of a single macrocell layer can be covered by several LTE-A-based small cells, which are deployed by low-power small-cell base stations. In the LTE terminology, Home evolved NodeB (HeNB) provide indoor cell coverage. The HeNB is a low power evolved NodeB's (eNB) that will be used in small cells. Home eNBs (HeNBs) are also known as femto cells, thus the terms HeNB and femto cell will be used equivalently in this paper. These LTE-A small cells (SCNs)

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tend to increase network capacity through the spatial reuse of spectrum as well as improve indoor cellular coverage (Hoydis, Kobayashi, & Debbah, 2011), (Valcarce, de la Roche, & Jie, 2009).

Technical concerns and challenges, however, for SCNs are still unavoidable. Undoubtedly, a critical and detrimental problem facing SCNs is the presence of interference among neighboring SNCs, and between the SNCs and the macrocell LTE network. Total power capacity, being one of the most valuable resources inside SCNs, behaves as a performance evaluation criterion for wireless cellular systems. Inside traditional LTE networks, the eNB transmission power is a valuable and limited resource and must be fairly shared among all users in a cell. Thus, a beneficiary solution to deal with interference in SCNs is through power control optimization. The main purpose of power control is to minimize the transmitted power, thus avoiding unnecessary high power levels and eliminating intercell interference, as previously discussed. By appropriately adjusting the downlink transmission power per Resource Block (RB) that is required to obtain a target bit rate in femto cells, the overall generated interference in the SCN could be significantly reduced. In other words, Home evolved NodeB (HeNB) adjusts its transmission power so as to satisfy home user (HUE) Quality-of-Service (QoS), while protecting macrocell users (MUEs) in its vicinity, by keeping the interference below a threshold. QoS effectiveness among traffic users is also another key factor. QoS levels are easily mishandled 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-hungry applications (Balakrishnan, & Canberk, 2014).

This paper makes a contribution by proposing an admission control procedure, inside a sophisticated LTE-A simulation framework, for efficient power allocation in SCNs. The proposed total framework efficiently controls systems' interference while on the other hand guarantees user QoS. The power admission control part of our implementation dynamically updates the HeNB power setting in real time based on the topology of the macro and home users as well as the requested traffic scenario by the users. An efficient handover over three standardized power control algorithms (3GPP TR 36.921, 2012) is being performed here from the dynamic determination of the most effective power switching points. It is proven that, depending on the examined traffic scenario, the power control mechanism can provide better protection (in terms of interference) either on macro users or on home users. Furthermore, we suggest 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 to handle fair allocation toward achieving end-user QoS. The implementation is evaluated through a user-friendly graphical tool designed to reproduce and calculate the optimal transmission parameters, via a graphical representation of the entire topology for a highly customizable network configuration.

2. RELATED WORK

A major portion of the existing literature has investigated the interference management issues of integrated LTE and Small Cell deployments. For example, Lopez-Perez et al. (2009) propose a scheme that adapts radio frequency parameters taking into account all the user and channel conditions. A novel backhaul-aware approach to interference management in wireless small cell networks is proposed in (Samarakoon, Bennis, Saad, & Latva-aho, 2013). The proposed approach enables macrocell user equipments to optimize their uplink performance, by exploiting the presence of neighboring small cell base stations. These studies have consistently shown that a coverage-hole exists when co-channel femto cells are deployed in a macrocell overlay network. Additionally, the studies have shown that although a femto cell can cause interference to other users in the system, the interference can be well controlled on both the downlink and uplink if proper interference management techniques are used. Another way to deal with interference in SCNs is to perform power control. The goal that is achieved by performing power control is twofold. On the one hand, power control deals efficiently with the problem of interference mitigation in SCNs, while on the other hand, it guarantees the optimal usage of available power resources at HeNB. The latter is critical, since power is the scarcest resource in wireless networks. 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 by Nai et al. (2012). Chandrasekhar et al. (2009) 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 (Ahmed, Dowhuszko, & Tirkkonen, 2012). 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 mostly all of the previously mentioned literature studies, the traffic characteristics and channel conditions, like the Signal-to-Interference Noise Ratio (SINR), are not considered while performing the scheduling and access controls in LTE-A small cells. Such considerations, though, are proven to be really crucial when needed to obtain most QoS optimal small-cell deployment.

3. ADMISSION-CONTROLLED MULTIMEDIA TRANSMISSION IN SMALL CELL NETWORKS

3.1. Small Cell Networks (SCNs)

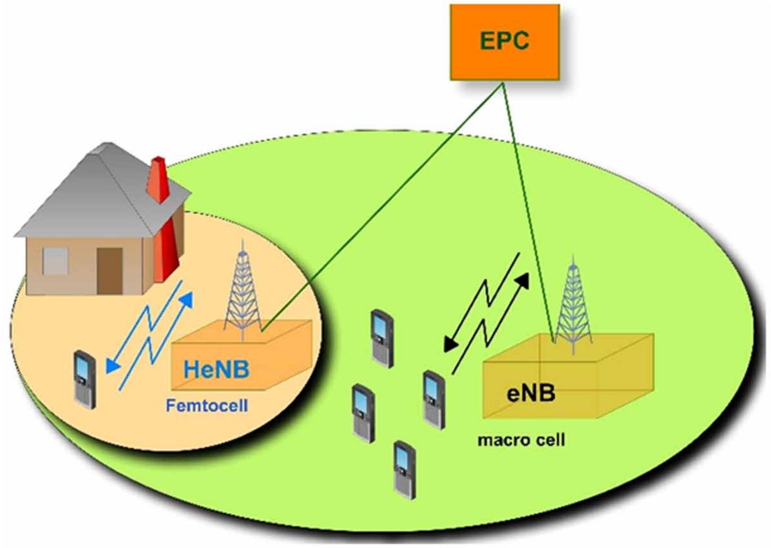
Next, we focus on a more detailed description of a typical Frequency Division Duplex LTE Small Cell HeNB. A characteristic topology of such a network is presented in Figure 1. HeNBs provide indoor cell coverage, in small buildings, homes or offices. The HeNB will be owned by the customer, deployed and 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 the macro cell and it, offers signalling interconnectivity with the Evolved Packet Core. An 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 more simplicity. A femto cell uses the same frequency bands as an LTE macro cell. The number of allocated frequency subcarriers can be decided based on the number of the mobile users inside the SCN. A frequency band of 2MHz supports wireless access for the wireless users in each femtocell (Balakrishnan, Canberk, & Akyildiz, 2013), (Balakrishnan, & Canberk, 2014), (3GPP TR 36.921, 2012), (3GPP TR 25.967, 2012).

3.2. Power Control in LTE Small Cells

The most common power algorithms for HeNB Downlink Power Control, as defined by the 3GPP standards, which will be deployed inside our power admission control mechanism for power adaptation, are presented below:

- **Algorithm 1.** Fixed HeNB power setting mode (3GPP TR 36.921, 2012).
- **Algorithm 2.** Smart power control based on interference measurement metric from macro NodeB (3GPP TR 36.921, 2012), (Barbieri et al. 2012).
- **Algorithm 3.** HeNB power control based on HeNB-MUE (Macro UEs) total path loss (3GPP TR 36.921, 2012).

Figure 1. Topology of an FDD LTE Small Cell HeNB



3.3. Network Traffic Modeling

For the scope of our simulation experiments, we consider a time-varying, bursty, and position-dependent wireless channel. To confront all these challenges, 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. Under such conditions, the transmission time is slotted, and the wireless channel is assumed to be divided by a certain value of a Resource Block, which corresponds to the slot length. At the beginning of each slot, or Resource Block, the scheduler obtains the channel dynamic conditions, like instant power consumption and target throughput for each priority traffic class, topology state and traffic prioritization. Using this information, the optimal throughput and required power for each user category in the time slot is being determined. Based on these parameters, the scheduling algorithm, inside the Utility Function, performs resource scheduling to achieve the QoS objectives.

During our simulation phase, 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 guaranteed, or at least 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 video traffic, which belongs to the medium bit rate trace, 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 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 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.

4. PROPOSED FRAMEWORK

4.1. Motivation

The proposed framework is embedded into our simulated mobile system and is shown in Figure 2. It has four main parts: the *QoS Classification* of the real-time streaming traffic, the calculation of the *Utility Function*, the *Traffic-Aware Admission Control*, and *Power Constraint Scheduling*. The *QoS classification* of the heterogenous traffic block dynamically considers the UE or User traffic requests, as shown in Figure 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 mitigate 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. After the functionality of the Utility Function, takes place the *Power Constraint Scheduling* or *power admission control*. Inside its scope, the previous control mechanism has the capability to sense the topology and traffic scenario requirements in real time and as a result to select inside each time slot the power algorithm(s) that best fit to the current topology instance and traffic scenario, previously inputted into the first part of the total mechanism. All the stages of our framework can easily co-function, by providing the best allocated system throughput capacity to each user traffic type without adding system overhead.

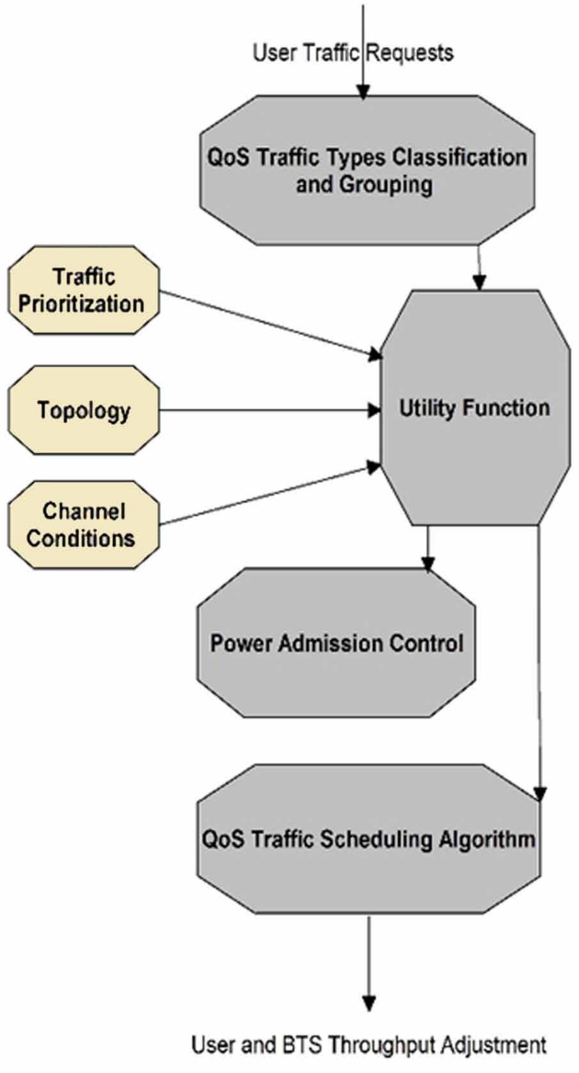
4.2. Real-time QoS Traffic Scheduling

Admission control algorithms, from the research bibliography, tend to focus on balancing the load on the mobile system based on a set of rules. It is possible that in a time-varying multicarrier system, some users experience poor channel gain for a significant amount of time. As a result, the scheduler needs a large number of resource block allocation offered to these users. The rest of the users see a significant drop in the data rate achieved. Furthermore, their queue traffic type can potentially become unbounded. Similarly, when a new user requests for resources within the mobile system, the admission control procedure must evaluate if scheduling can be performed for the new user without affecting the QoS of the existing users. If the new user is a high-priority user, the algorithm must decide which among the existing connections need to be released or, even further, assigned with lesser resources. Due to this dependence between the scheduler and the admission control procedures, we introduce the joint functioning of scheduling and admission control procedures.

The objective of the admission control procedure, therefore, must be to admit as many users as possible while preserving the correct functionality and fairness of the scheduler. The total set of the traffic types has been discussed in section 2. Utility Function provides a sense of how the user is performing in a given time slot. At the same time, the instantaneous utility function can be misleading because the same user with lesser utility in a given time slot may have a greater utility due to better channel conditions in the next 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 Figure 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

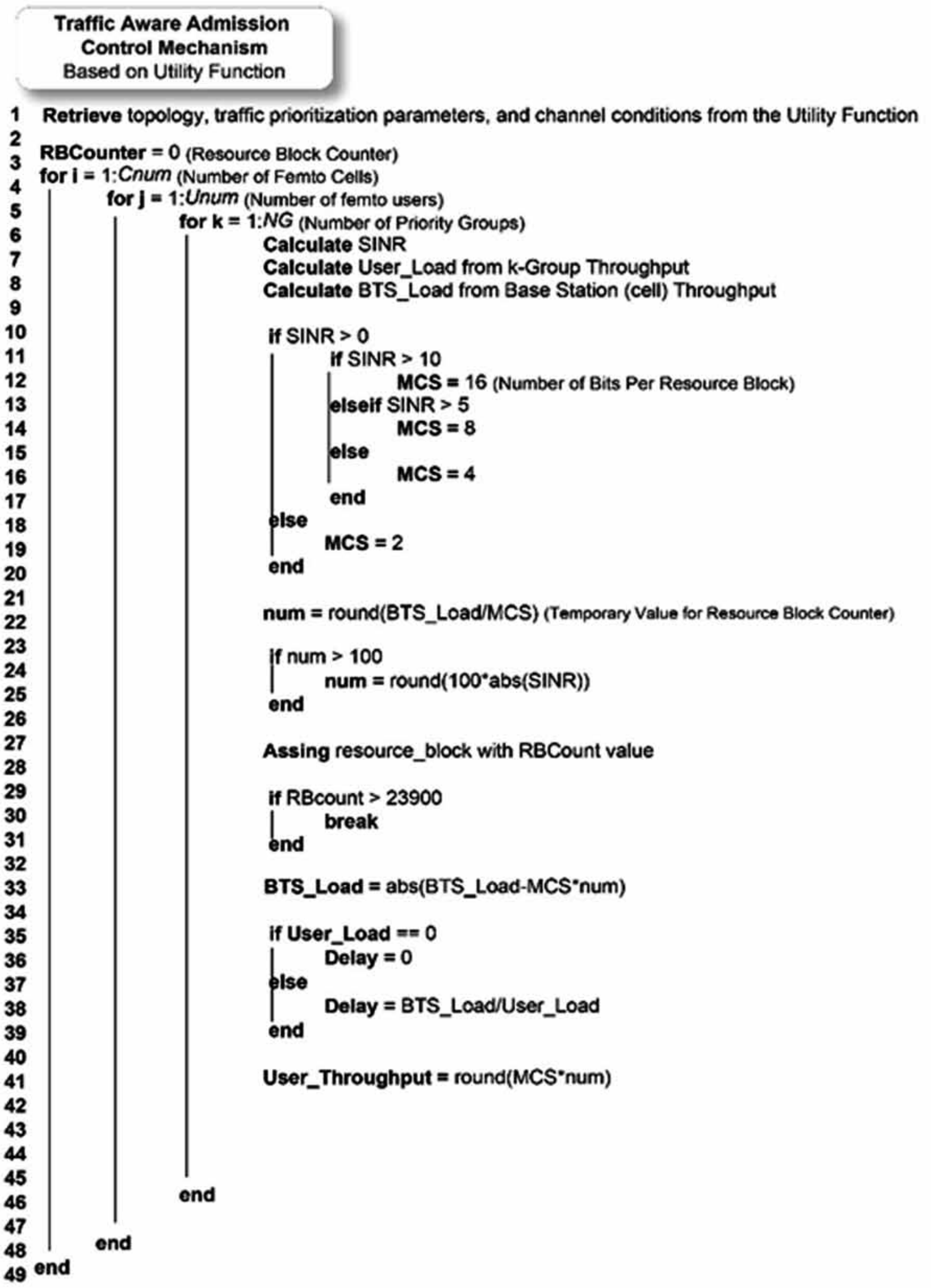
Figure 2. Block diagram of the proposed admission-controlled mechanism



block allocation strategy. For each User Equipment (UE) in each priority class, it instanteounsly 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- modulation and coding scheme, where each SINR level, which depends on the interference of the neighbouring cells corresponds to a matching MCS, or scheduling algorithm). 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 time-average utility functionality provides a long-term view of how the user traffic session is performing. A low value of time-average normalized utility indicates that the user is most likely the candidate to be released as the scheduler is not able to meet the QoS requirements of the user.

It can be argued that the fraction between the average normalized utilities of different users and the fraction of the average absolute utilities are fairly comparable. Based on this concept, we manage to provide a long-term view of the system's QoS performance.

Figure 3. The Traffic Aware Admission control mechanism pseudocode



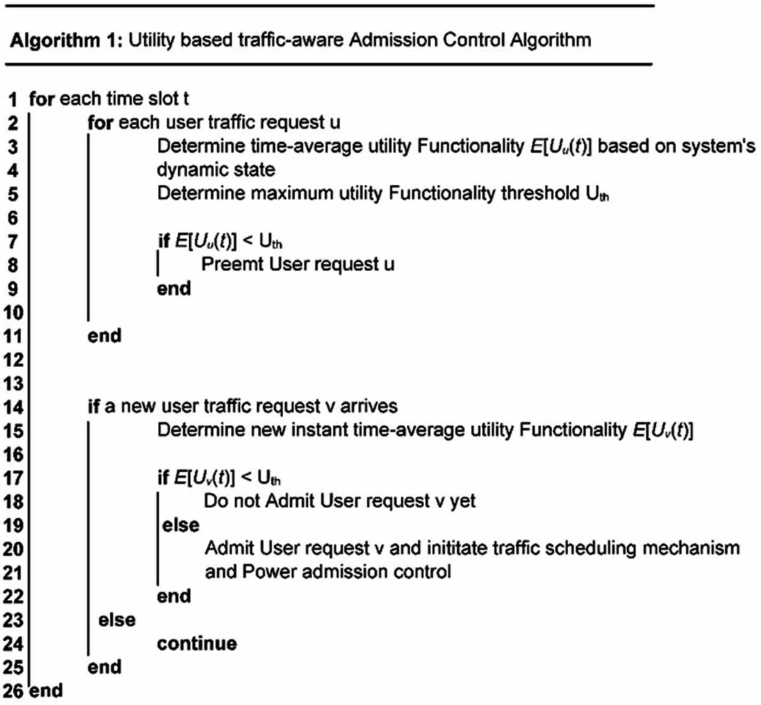
Traffic Aware Admission Control Mechanism
Based on Utility Function

```
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
```

4.3. Minimal Algorithm for Utility-Based Functionality

The utility function depicted in Figure 4 is aimed at achieving the homogeneous objectives of QoS realized by different user grouping types. It is generally perceived that as the waiting time of the packet

Figure 4. The Utility-based function algorithm pseudocode



```
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
```

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. For the real-time users, particularly for the HD video transmission the delay performance is critical, and they have a strict deadline on the waiting time of the packet. For lower priority user types, the throughput and delay performance are important, but still less critical. Since different users have varying degrees of delay bounds, varying the values of instant Utility Functionality metric value specifies that the adjacent queue needs to be served more urgently. It can be observed that inside the scope of utility-based algorithm all users will be served in a Round-Robin manner. This mainly happens due to the homogeneous type of user traffic, since we solely choose to transmit video streaming, and the fairness we also need to provide due to the previous QoS limitations.

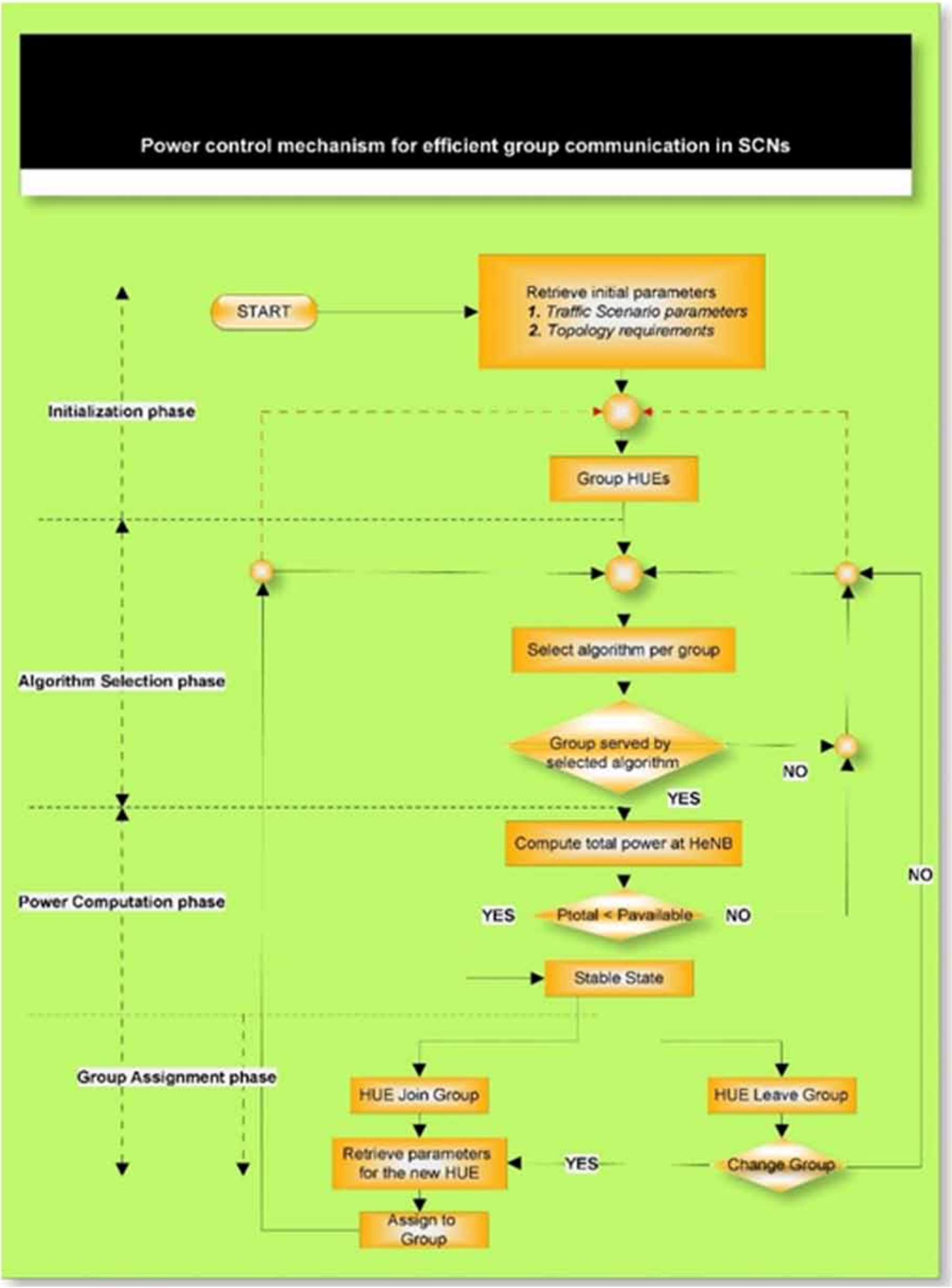
The utility-based algorithm obtains the optimal traffic allocation strategy in linear time when the number of users is not considerably large, and while the femto users move close to the Base Station infostructure. Handover requests and user movement far from the center of the femto cell requires more load balancing, thus decreases QoS performance and total system capacity. This is a reasonable assumption since small cells, on average, support a few hundreds 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.

4.4. Power-Constrained Utility-Based Scheduling

In this section, we present the power control mechanism for future SCNs, which operates inside the core of our framework. A block diagram of the mechanism is presented in Figure 5.

Our mechanism has the capability 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

Figure 5. Block diagram of the proposed power adaptation mechanism

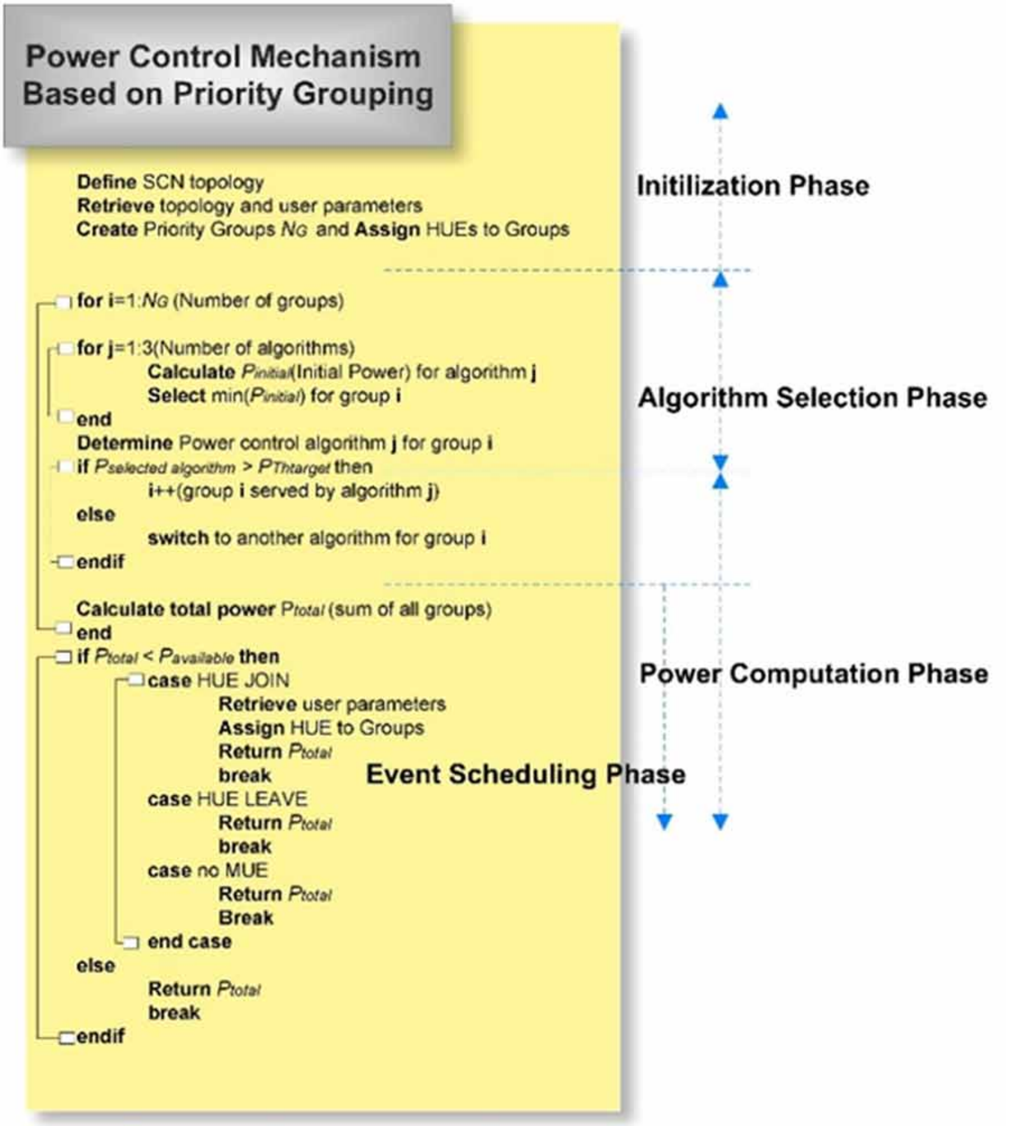


topology instance and traffic scenario. Inside this scope, we introduce the methodology of Priority Grouping, in which each HUE in the topology is assigned to one of the available groups with different priorities related to power requirements and traffic load. The use of Priority Groups can result to 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.

More specifically, the scheme consists of four distinct operation phases. These are: Initialization phase, Algorithm Selection phase, Power Computation phase, and Group Assignment phase. HeNB is the responsible node of the SCN architecture for the operation of this mechanism.

Regarding the Initialization phase (Figure 6), at first, the mechanism categorizes the HUEs that lie inside the topology based on their traffic requirements to a predefined number of N_G priority groups. In each of those groups, a target mean HUE throughput (Th_{target}) is also set. The main purpose of this categorization is to distinguish between the HUEs that their traffic scenario require increased power resources and those HUEs that have reduced power demands.

Figure 6. Pseudo code of the proposed mechanism



Power Control Mechanism Based on Priority Grouping

```
Define SCN topology
Retrieve topology and user parameters
Create Priority Groups $N_G$ and Assign HUEs to Groups

for i=1:$N_G$ (Number of groups)
    for j=1:3(Number of algorithms)
        Calculate $P_{initial}$(Initial Power) for algorithm j
        Select min($P_{initial}$) for group i
    end
    Determine Power control algorithm j for group i
    if $P_{selected\ algorithm} > P_{Thtarget}$ then
        i++(group i served by algorithm j)
    else
        switch to another algorithm for group i
    endif
    Calculate total power $P_{total}$ (sum of all groups)
end
if $P_{total} < P_{available}$ then
    case HUE JOIN
        Retrieve user parameters
        Assign HUE to Groups
        Return $P_{total}$
        break
    case HUE LEAVE
        Return $P_{total}$
        break
    case no MUE
        Return $P_{total}$
        Break
    end case
else
    Return $P_{total}$
    break
endif
```

In Algorithm Selection phase, the mechanism selects the algorithm that requires minimum initial power as the starting algorithms of the group. Following this, in each priority group the mechanism checks if the starting algorithm could serve the dedicated for the group traffic load, taking into account the mean HUE throughput per group (Th_{target}), the number of HUEs in each group as well as their location positioning within the femto cell.

In each group, if the selected algorithm has enough power level to support the traffic demands of the group, the mechanism then enters the Power Computation phase.

In Power Computation phase, the total power (P_{total}) is calculated in HeNB as the total sum of the required power in each of the N_G priority groups. Following this, P_{total} is compared to $P_{available}$ in order to secure that the system's total power is kept in an acceptable level. If $P_{total} < P_{available}$ the mechanism enters a power stable state which means that all users in the topology are served well with respect to their traffic requirements. In case where $P_{total} > P_{available}$, the mechanism is needed to reduce the system's total power either:

- by reselecting the power control algorithm per group or
- by performing a total system regrouping (reduce number of groups or re-distinguish HUE keeping the NG as is).

On stable state, in each priority group the algorithm that results to minimum total power of the HeNB is selected.

Group Assignment phase is dedicated to perform the assignment of HUEs to the available priority groups. For any new HUE that is emerged within the coverage area of the Home eNB, the mechanism performs an HUE assignment to the available priority groups depending on the traffic requirements of the new HUE. On the contrary, if an HUE leaves the coverage area of the home environment, the mechanism removes the corresponding HUE from the priority group that was assigned. Finally, the pseudo code of our proposed power control mechanism is also depicted in Figure 6.

5. SIMULATION SETUP

5.1. Simulation Parameters

The necessary simulation parameters for the conduction of the traffic scenario experiment are presented in Table 1. The SCN topology consists of multiple adjacent macro cells (the green hexagons), multiple femto cells that are uniformly distributed inside the network and multiple macro and home users. 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 mechanism is available in (An admission control, 2016).

Figure 7. displays an overview of the entire SCN topology. In order to efficiently present the results, we focus on femto cell numbers 14, 15, 17 and 19 of the **topology** depicted on Figure 7.

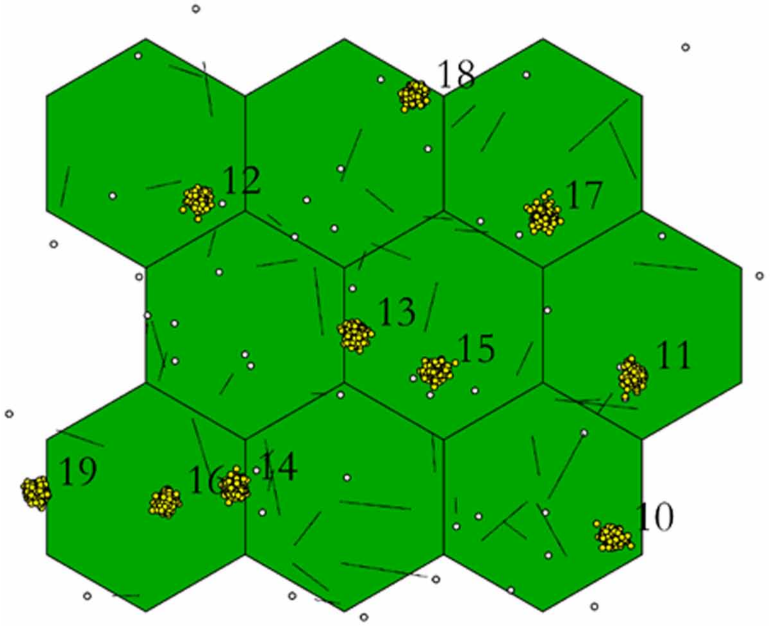
5.2. Traffic Scenarios

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 (Van der Auwera, Prasanth, & Reisslein, 2008). To simulate the conversational audio conference, we downloaded a sample audio file in MP3 format from (Audio trace files, 2016). Finally, we produced the file streaming network service with a randomly uniformed variable as its traffic load.

Table 1. 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

Figure 7. Topology for the scenario's experiment



For the needs of the results' presentation, we conducted the following experiment in MathWorks MATLAB environment. 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 (Figure 7). 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). In specific, we deployed the experiment scenario in three phases. In the first, we retained the total group target throughput (Th_{target}) as if in Table 1, and we performed two scenario executions using random femto user equipment positioning, with the QoS provisioning mechanism enabled and disabled in each pair case adjacently. In the second phase, we kept the cell radius value stable at 1000m and we almost tripled the target rates (Th_{target}) at each priority group. During this simulation stage, we repeatedly performed our experiments with and without the QoS differentiation and traffic scheduling functionality to show how target bandwidth for each priority group affects the traffic provisioning in SCNs. Finally, we conducted another simulation instance using the exact parameters of Table 1, with border user equipment positioning, at this time, inside each femto cell (third phase). Again, we chose to preselect and then ignore the traffic scheduler operability, in order to demonstrate the worst case in a traffic provisioning scenario, where the positioning of femto users becomes more distant from the center of the cell, thus cell interference and traffic delay increases. At each scenario execution case, we evaluated three metrics: the total average group throughput capacity, the average end-to-end traffic delay, and power algorithm selection handover in all previously defined femto cells. The exact positioning of each cell, upon their construction, is based on a uniformly random function, thus, we tend to focus on the corresponding small cells, as illustrated and evaluated in the following graphs, in a mere random manner.

6. SIMULATION RESULTS

In each time slot, the utility and power metrics along with the global and local power constraints are computed and provided as input to the algorithm. The output of the algorithm is the newer adjusted per-femto cell throughput capacity. The entire simulation sequence is run for 500sec, which is used to compute the performance metrics. Each simulation step number corresponds to approximately 25 secs. We highlight for this section the performance results of our scheduling policy in terms of throughput, power adaptation, and delay. The results also highlight how the performance of the TA-Utility scheme can be enhanced with the help of the traffic aware Utility-based admission control scheme. Figure 8 shows the time average throughput achieved by the users per simulation step number. As shown in the figure, the average throughput capacity increases gradually due to the rapid increase of femto user equipments, with this increase to dramatically occur since the half of our simulation duration, as previously mentioned. These users achieve a time-average throughput of approximately 0.75 Mbps.

6.1. First Phase

Firstly, we focus on the benefits of our admission control mechanism from the *energy perspective*. Figure 9 presents the evolution of HeNB transmit power for each power control algorithm for femto cell 15, during the first execution phase of our scenario simulation for random user positioning and with the QoS mechanism disabled and enabled at both case. Additionally, Figure 9 presents the algorithm that is selected (y-axis) each time for each group by our mechanism in order to perform efficient power allocation and admission control at HeNB. By carefully observing both subplots of Figure 9, 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.

Specifically, in Figure 9 (a) subplot, even as during the phase of a more rapid arrival of mobile UEs, which takes place during the second half of the experiment (nearly after 200 secs), basically no handover or power adaptation is being noticed between the three power groups and among the new

Figure 8. Throughput performance expansion under TA-Utility-based scheduling

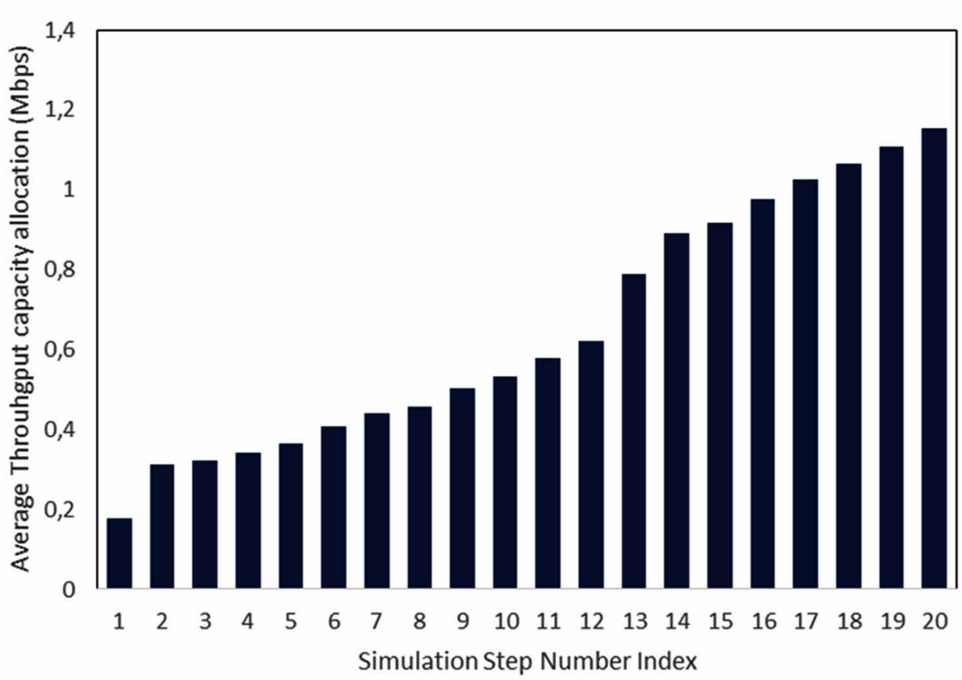
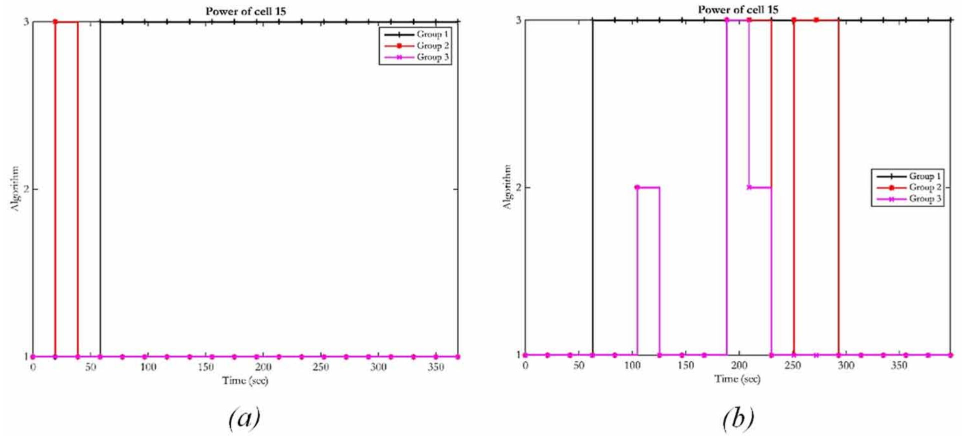


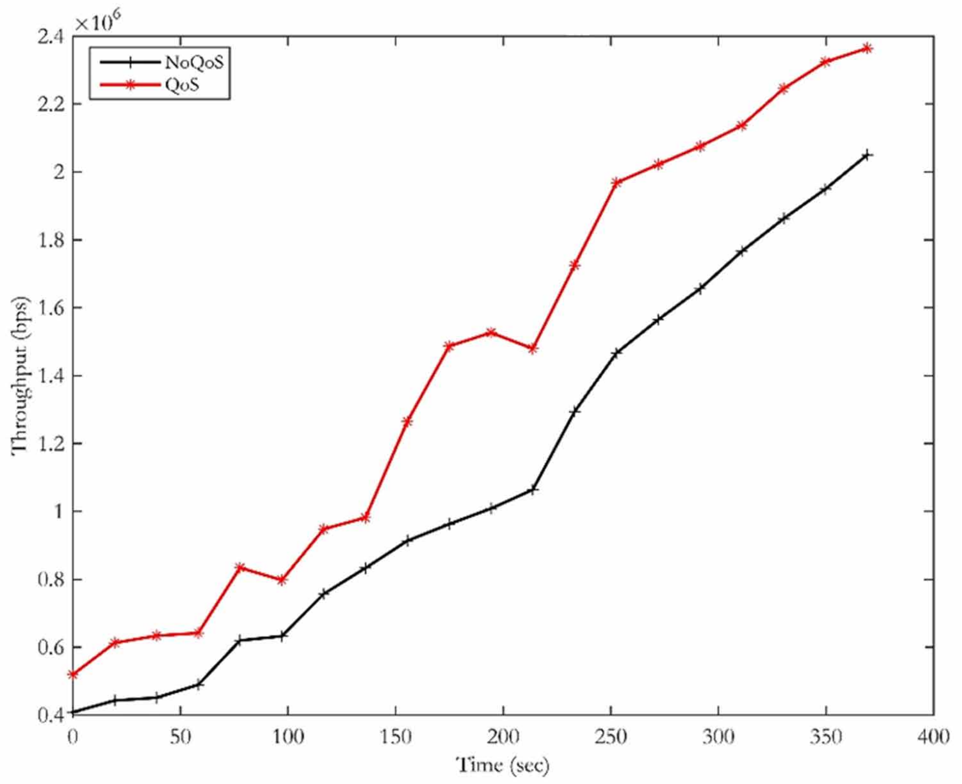
Figure 9. Power selection for femto cell 15 – Phase 1. QoS Mechanism disabled. (b) QoS Mechanism enabled.



(a) (b)

users. The growth of mobile user's population should trigger more Signal Interference between UEs inside the small cells, thus requiring a better power allocation strategy to perform an ameliorated power adaptation. This takes place in Figure 9 (b) subplot, where we decide to enable the QoS adaptation mechanism and provide a better power selection strategy for the mobile users. As more users are coming inside the cells, the power adaptation takes place faster. 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 traffic priority group is being served with a more coherent manner in terms of power selection algorithm.

Figure 10. Total Throughput capacity for femto cell 19 – Phase 1 – Random User Positioning.



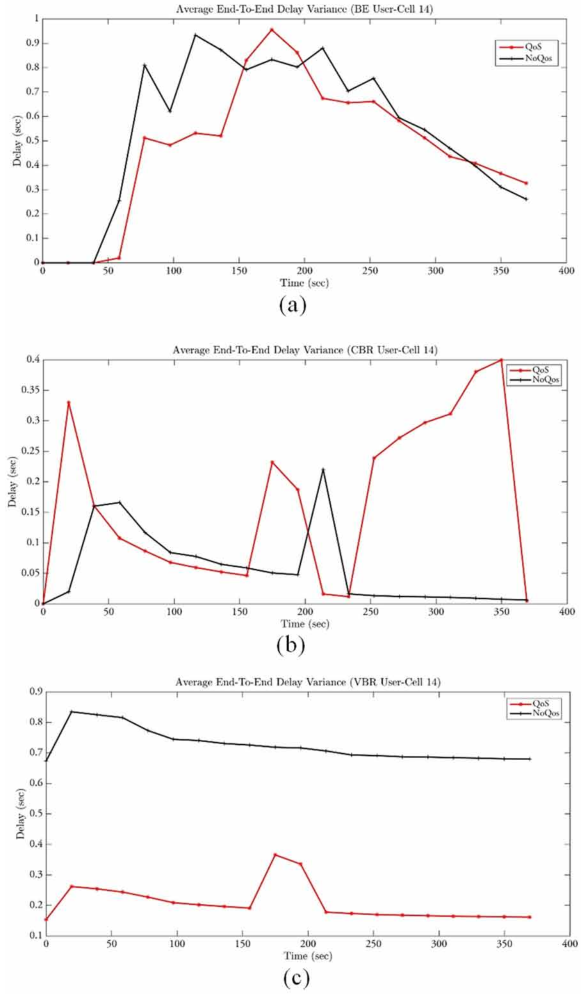
Secondly, we move to the traffic characteristics assumptions for our simulation, providing the advantages in terms of throughput capacity and end-to-end average delay, from our admission methodology.

In Figure 10 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. Figure 11, 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 only class (see CBR) where delay is less important in contrast to packet delivery fidelity, the mechanism is more successful during the first simulation steps, where the number of user requests is lower. The results refer to either three traffic classes, or traffic priority groups, with the VBR class, or conversational, having the most significant decrease.

6.2. Second Phase

For the second phase of our execution scenario, we keep the femto cell radius value stable at 1000m, and we triple the Thtarget at every priority group. The simulation results, referring to algorithm power selection, are being illustrated in Figure 12. By carefully examining the plot, we easily depict that in the current case, since the target bandwidth for each priority group has almost tripled, the required power levels to sustain the required throughput needs to be increased. The fact that many switching points, and specifically almost for each target priority group, occur, happens due to the fact that optimal power selection and adaptation is now depended on more algorithm options. While group

Figure 11. Power selection for femto cell 14 – Phase 1. (a) BE traffic class. (b) CBR traffic class. (c) VBR traffic class.

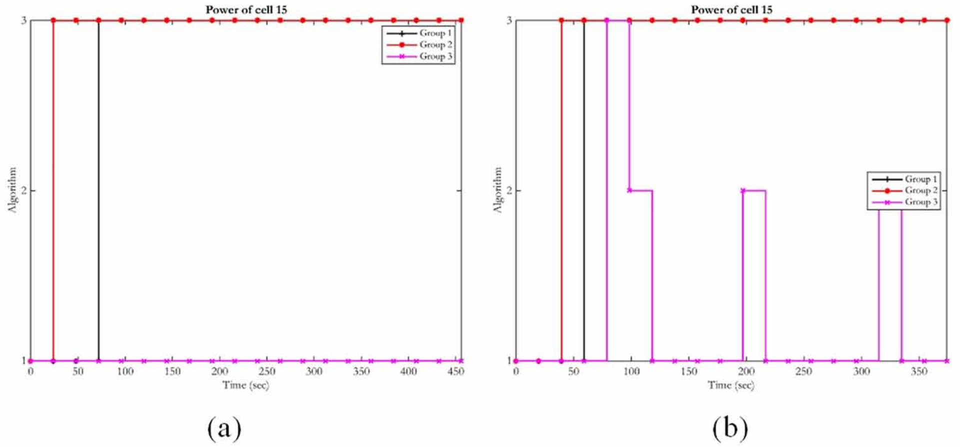


(a)

(b)

(c)

Figure 12. Power selection for femto cell 15 – Phase 2. (a) QoS Mechanism disabled. (b) QoS Mechanism enabled.



(a)

(b)

1, having the larger bandwidth demands, is statically linked and served to algorithm 3 throughout the whole experiment, groups 2 and 3, having lower throughput requirements, should obtain more freedom to adapt to either power algorithms 1 and 3. Particularly for group 3, due to the fact that it needs less power levels to achieve its traffic target, there are several algorithm handovers, thus more flexibility to adapt to different power methods and achieve better performance. Finally, it can be spotted that power adaptation seems to be stabilized after the second half of the experiment, for all priority groups. This is easily explained, since the HUE population is rapidly increased, and the fact that all users tend to move nearby the cell center, less power is needed to support the traffic request, thus algorithm 1 proved to be an ideal choice.

As we demonstrated in the previous first phase, the total number of switching points again increases significantly, and this results in better power adaptation, more robust power control and efficient usage of the valuable wireless resources. Traffic provisioning seems to be effective for increasing system throughput capacity as well. It is clearly depicted in Figure 13 that for femto cell 19 the previous throughput gain assumption becomes realistic.

We can easily observe from Figure 13 that increasing the target Throughput at every priority group, whereas having our QoS mechanism strategy enabled, results in almost double the total throughput capacity for a cell. By deploying the mechanism, we manage to outer perform in terms of wireless bandwidth allocation, proving that the growth of mobile users' population should correspond to as much better capacity consumption for the mobile system as possible.

6.3. Third Phase

To compare and contrast the previous two scenario instances with a border currently placement of femto user equipment, we depict Figure 14. We now focus on femto cell 17. At this simulation phase, the femto cell user positioning has become more distant from the center of the cell. As the femto HUE population rises, thus more power is needed to support the demanded bandwidth requirements for priority group 1. Moreover, it is worth noticing here, that the inter-switching points have longer time frames, compared to those in Figure 9, 12. This simply happens due to the longer period that the HUEs need to move from the larger femto cell edge, than before.

The result is that due to the more distance of the femto cell user from its cell center power adaptation becomes more difficult, thus less or even sparse switching points occur. On the contrary, when we choose to enable our QoS Traffic Scheduling strategy to co-operate with our power adaptation method, more handover power selection points take place. From the traffic engineering perspective, inside Phase 3, we illustrate Figure 15. Due to the presence of higher signal interference and SINR levels from the border placement of user equipment inside the femto cell, it is even more trivial for a traffic provisioning methodology to function properly and effectively. Nevertheless, when we select to enable our QoS strategy to co-function with our power admission control mechanism, the traffic provisioning results as for the total throughput capacity, remain at satisfactory levels. Thus, we observe a slight but noticeable increase in throughput capacity for femto cell 19, in Figure15.

7. CONCLUSIONS AND FUTURE WORK

In this paper, we propose an admission control procedure for efficient power allocation in SCNs. The proposed total framework efficiently controls systems' interference while on the other hand guarantees user QoS. The power admission control part of our implementation dynamically updates the HeNB power setting in real time based on the topology of the macro and home users as well as the requested traffic scenario by the users. The previous procedure is undertaken from the practical observation of the scenario's power algorithm switching points, during its operation phase. By performing an efficient handover over three standardized power control algorithms, we determine those switching points. It is proven that, depending on the examined traffic scenario, the power control mechanism can provide better protection (in terms of interference) either on macro users or on home users.

Figure 13. Total Throughput capacity for femto cell 19 – Phase 2.

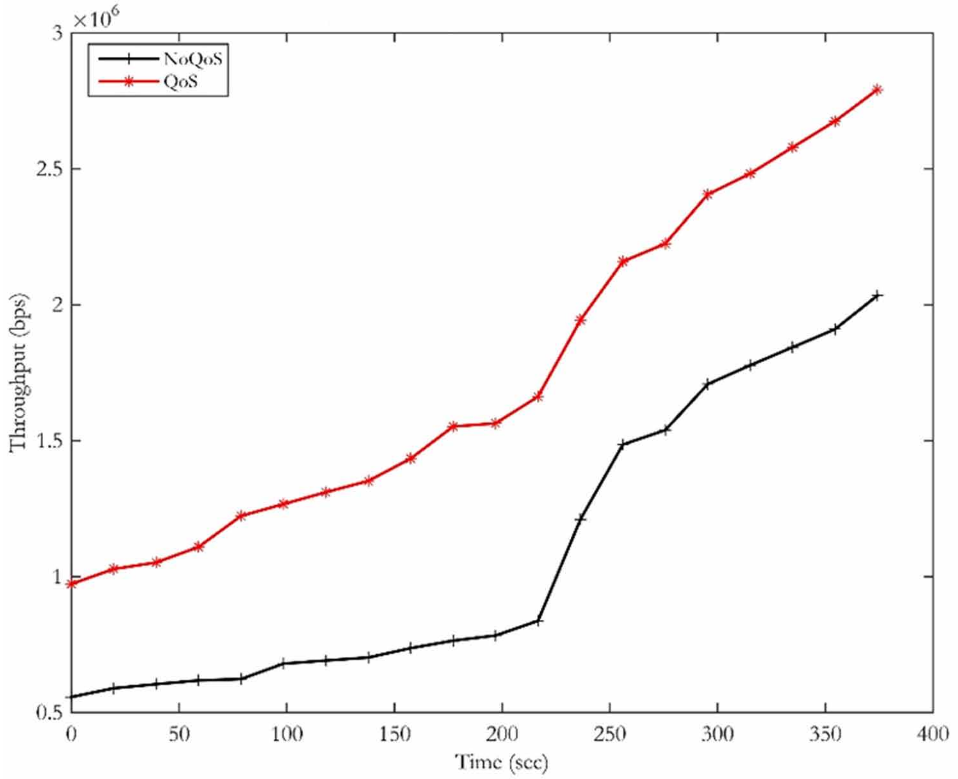
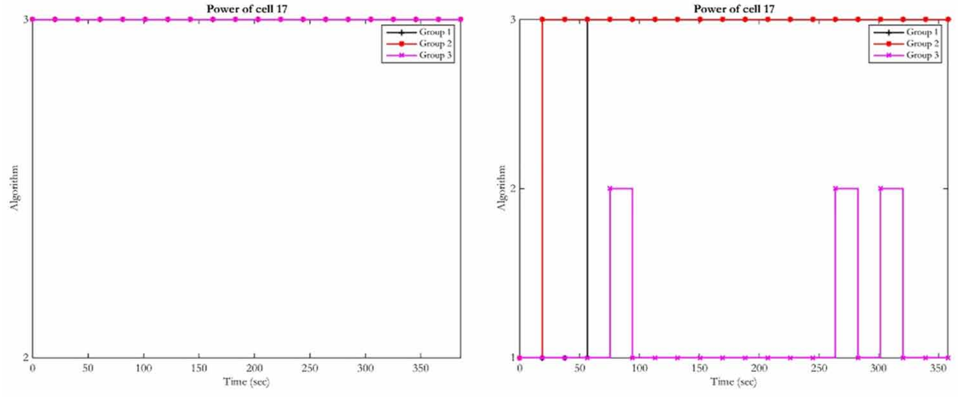
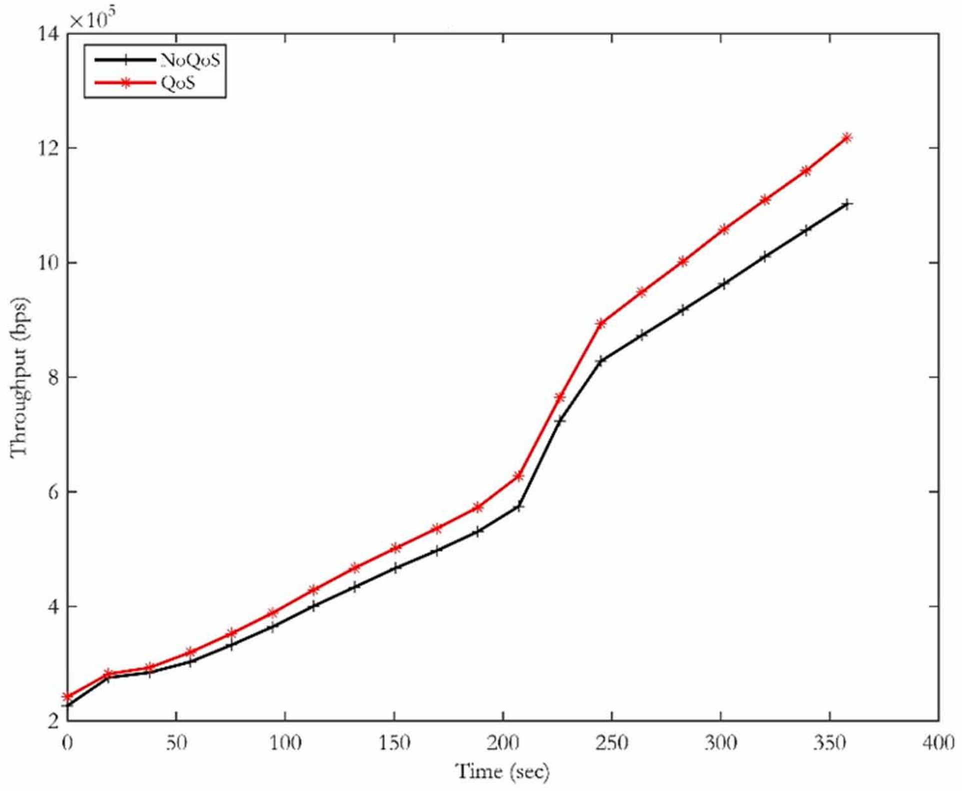


Figure 14. Power selection for femto cell 17 – Phase 3. (a) QoS Mechanism disabled. (b) QoS Mechanism enabled.



(a) (b)

Figure 15. Total Throughput capacity for femto cell 19 – Phase 3.



Furthermore, we propose an 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 to handle fair allocation toward achieving end-user QoS. Our proposed framework is evaluated and examined through a High Definition (H.264/MPEG-4) video input, VoIP conversational and data stream trace files. The implementation is evaluated through a user-friendly graphical tool designed to reproduce and calculate the optimal transmission parameters, via a graphical representation of the entire topology for a highly customizable network configuration.

8. FUTURE WORK

The steps that follow this work could be at a first level the evaluation of the mechanism through additional traffic scenarios, user distributions and network topologies. This information could be used as feedback to the mechanism in order to improve its performance. At a second level, the complexity that the mechanism inserts in HeNB due to its dynamic and periodic nature could be investigated. Algorithm Selection phase is triggered whenever one of the events of Group Assignment phase is emerged. This means that the required power per group must be computed periodically every predetermined frequency rate (f_{power}). This periodic computation inserts a further complexity in HeNB. Furthermore, additional simulations could be executed in order to estimate the algorithm switching points between the available algorithms. The switching points correspond to the specific number of HUEs per group which has a given target bit rate that the mechanisms perform any algorithm switch from one algorithm to another. Knowing a priori the information concerning the switching points, we can improve the performance of the mechanism either by performing a more efficient initial classification of HUEs to available groups or by avoiding the traffic scenarios that produce ping-pong effects between the available algorithms.

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.

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