A Real-Time Services Performance and Interference Mitigation for Femtocell Scenarios in LTE Networks

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***Abstract*—In order to enhance the Quality of Service in LTE, femtocell architecture has been proposed as a promising solution. However, interference is the main weak point in femtocell scenarios which causes a serious impact on multimedia services performance. Femtocell interference mitigation in LTE networks is the principle objective of this paper. We propose an enhancement of the well known four-coloring method for interference mitigation by combining it with cooperative game theory. Our proposed scheme aims to provide a solution to effectively achieve femtocell interference mitigation while guaranteeing the bitrate application for real-time services. The basic metrics of quality of service (QoS) such as throughput, Packet Loss Ratio (PLR), delay and Signal-to-Interference-plus-Noise-Ratio (SINR) are investigated. Our simulation environment is derived from realistic scenarios in order to study the performance of real-time service like Video and VoIP applications. Throughout our numerical results, we demonstrate the improvement of QoS constraints along with balancing between interference reduction requirement and resource allocation efficiency for real-time applications.**

***Index Terms*—Wireless networks, quality of service, long term evolution, cooperative game theory, shapley value, femtocell.**

I. Introduction

Mobile telecommunications technologies such as Universal Mobile Telecommunications System (UMTS) and General Packet Radio Service (GPRS) have mainly focused their QoS on voice and non real time services. The evolution of actual applications for mobile devices is focusing on multimedia services. Due to the growth of Internet, multimedia and real-time services, Long Term Evolution (LTE) technology has been proposed to perform this ambitious task. LTE uses Orthogonal Frequency Division Multiple Access (ODFMA) in the downlink. OFDMA divides the frequency band into a group of mutually orthogonal sub-carriers, thereby improving the system capabilities by providing high data rates, supporting multi-user diversity and creating resistance to frequency selective fading of radio channels. The Quality of Service (QoS) in LTE must be satisfied by giving users the optimal balance of utilization and fairness. Non-Real-Time (NRT) services must have a minimum bitrate and Real-Time (RT) services need a high QoS level.

In LTE architecture, the QoS management is handled by the base station called eNodeB or eNb (macrocell for this work). The resource allocation is performed at the eNb. The eNb experiments hard problems due to geographical position of users. When a user is close to the eNB it will experience a very good QoS. On the other hand, when a user is located in a very poor signal coverage place, its performance might not be as expected specially when using non elastic services due to a bad QoS.

In the LTE specifications [4], a femtocell architecture has been proposed to strongly improve the Quality of Service of next generation wireless technology. Due to macrocell limitations to serve users that are geographically situated in bad signal reception places, femtocell architecture has been proposed as a potential solution to serve a small range indoor access points. Femtocells in the LTE standard are called HeNb (Home EnodeB). They are installed by users and back-haul data through a broadband over the Internet. The main goal of HeNbs is to provide a private mobile coverage inside buildings to free radio resources on the outdoor network, consequently increasing the total capacity of the mobile system by avoiding several wall penetration losses. Furthermore, the radio technology used in indoor scenarios is the same as the one used in outdoors scenarios. Although femtocells grant to users a better quality of signal to users, the resource allocation performance is subject to interference. OFDMA divides the total bandwidth into several sub-bands which will be granted to users at each Time Transmission Interval (TTI). The main interference issues in femtocell scenarios are essentially focused on macro-femto interference and femto-femto interference. According to handover process between macrocells and femtocells, for access control mechanisms, open-access and closed-access are

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identified. In open-access femtocells, macro-users are allowed to be handed over to the corresponding femto base station. In closed-access the femto base station only grant access to a particular set of authorized users. It is the closed-access system that causes the most harmful interference. Macro-femto interference can be well explained in a scenario where macro-users utilize the same sub-band than any femto-user at the same time. The consequence of this particular issue is the loss of transmission caused by this interference to the femto-user.

Femto-femto interference is caused by neighboring issues. The geographical distribution of buildings does not follow any standard, therefore HeNbs will be positioned in a random manner. This causes home cell edge interference between apartments and offices in small coverage areas. A user using a high data rate service (i.e., video) in his room will experiment strong interference issues in the case that the neighbor HeNb is installed on the other side of the wall. Unlike the macrocell, femtocell can be installed by users in their own premises (i.e., in a random manner), making it difficult to handle the femto-femto interference problem.

It is important to carefully take into account the composition of the scenario for simulation performing. The daily growth of multimedia services brings on an evolution related to the type of traffic for mobile services. When building the simulation scenarios, it is indispensable to consider the percentage of flows used and the type of the requested service. [24] relates that more than 70% of data traffic and 50% of voice calls are originated from indoors (home and offices).

A. Related Work

In this paper, we consider the important task of resource allocation in femtocell scenario in LTE Networks. This work is focused on the effect that interference causes to the performance of real-time services in downlink. Previous works propose several mechanisms to mitigate the interference problem. In [17] a coverage and interference analysis based on a realistic OFDMA macro/femtocell scenario is provided, as well as some guidelines on how the spectrum allocation and interference mitigation problems can be approached in these networks. In [18] the authors explained the importance of SINR-based model for interference mitigation focusing on important aspects that are ignored when using only SINR approximations in wireless networks.

In [16] a graph-based dynamic frequency reuse approach is introduced. The proposed method aims to mitigate the interference by dividing the available frequency band into sub-bands which are distributed among femtocells in a way that directly adjacent cells do not occupy the same sub-bands. This scheme utilizes a centrally controlled resource partitioning method which is based on graph coloring that assigns sub-bands in terms of resource efficiency. A significant improvement for cell-edge users at the expense of a modest decrease for cell center users is shown. When using this scheme it is possible to experiment a decrease of interference but the cost to pay for this is the decrease of bitrate. This throughput decrease could be tolerated if and only if applications are non- real-time services. Unfortunately, this proposed method might be hard to be adapted to the LTE requirements because the core in LTE is focused on real-time services such as video and VoIP and this work does not perform real-time services.

The issue of downlink femto to macro interference in closed access is addressed in [19]. The authors proposed a dynamic interference avoidance resource partitioning which prioritizes macro-users in OFDMA. This method reduces macro-user interference by denying access to femtocells to use the resource blocks that have been assigned by the macrocell to any macro-user. Of course this method grants a good service to particular macro-users but on the other hand femto users are neglected and the consequence of this, is the throughput decrease due to the fact that femto users are not using all femtocell resource blocks.

In [22] a mechanism to distributed interference management and scheduling for downlink over LTE is introduced. In this mechanism best effort flows and delay based flows are taken into account. This solution works based only on one round of exchange of very few bits of information in each subframe (one TTI). This scheme presents the closer approach to perform a flows class based QoS mechanism for interference mitigation. Although the authors highlight the fact that delay based flows are considered for this work, the basic well known constraints of quality of service such as PLR, Throughput, total spectral cell efficiency are not studied. Therefore, the impact of this proposed method on the performance of QoS is not clear.

B. Contributions

The contributions of this paper can be summarized as follows:

As seen in previous subsection, although there are several proposed solutions to mitigate interference, none of them takes into account real-time services for testing their performance over proposed methods. Almost all of them show the total cell spectral efficiency/total throughput gain vs interference or interference/throughput cumulative distribution function (CDF) curves. In these cases retransmissions might hide the real performance of different traffic services running in the network. In our scenario we perform real-time services such as video and VoIP. The aim of our work is to examine the behavior of real-time services over a femtocell scenario bearing in mind important QoS constraint such as PLR and throughput.

In addition, we propose a method to mitigate interference between femtocells. In this work we analyze the four-coloring method when performing real-time services. To improve this method, we use game theory to carry on a bargain between femtocell neighbors to make the sub-bands assignation depending of the bitrate service that users need.

This paper is organized as follows. Section II describes the downlink system model and the femtocell architecture over LTE. Section III describes the aforementioned cooperative game theory and its adaptation to bandwidth division. Section IV exposes our interference mitigation scheme. In section V, the simulation environment scenario is presented, where the traffic model is described and a numerical result analysis is exposed. Section VI concludes this paper.

II. System Model

A. Downlink System Model

The architecture of the 3GPP LTE system consists of several base stations called "eNb" or "macrocell". Inside of the eNb coverage it is possible to install small base stations called "HeNb" or "femtocells". Packet scheduling is performed at the eNode or HeNb. The macro and micro-base stations transmit with different power. To perform the message exchange between macro-base stations the X2 interface is used, message exchange between femto base stations is made in the same way. To make the eNb - HeNb communication the S1 interface is used and the message exchange must pass by the MME / SGW or by the HeNb GW [4]. Users report their instantaneous downlink channel conditions (e.g signal-to-interference-plus-noise-ratio, SINR) to the serving eNb/HeNb at each TTI. At the eNb/HeNb, the packet scheduler performs a user selection priority procedure, based on criteria such as channel conditions, Head Of Line (HOL) packet delays, buffers status and service types. The eNb/HeNb has a complete information about the channel quality by the use of Channel State Information (CSI). The QoS aspects of the LTE downlink are influenced by a large number of factors such as: Channel conditions, resource allocation policies, available resources, delay and sensitive/insensitive traffic, interference etc. In LTE the resource that is allocated to a user in the downlink system, contains frequency and time domains, and is called resource block. The entire bandwidth is divided into 180 kHz, physical Resource Blocks (RB's), each one lasting 0.5 ms and consisting of 6 or 7 symbols in the time domain, and 12 consecutive sub-carriers in the frequency domain. The resource allocation is realized at every TTI, that is exactly every two consecutive resource blocks. In this way, resource allocation is done on a resource block pair basis.

B. Interference System Model

This paper only focus on femto-femto interference. The power transmission influence which is imposed by macrocell over femtocells is not taken into account. Each femtocell has the same bandwidth which is divided in the same number of sub-channels. In our work a resource block is considered as a sub-channel. Femtocells are connected to a femto-gateway. Interference issues occur when neighbors femtocells assign the same sub-bands to any users at the same time.

III. Cooperative Game Theory

A cooperative game is a game where groups of players ("coalitions") may enforce cooperative behavior, hence the game is a competition between coalitions of players, rather than between individual players. This discipline concerns the behavior of decision makers (players) whose decisions affect each other. A cooperative game consist of a player list and characteristic function. Given a set of players N, the players

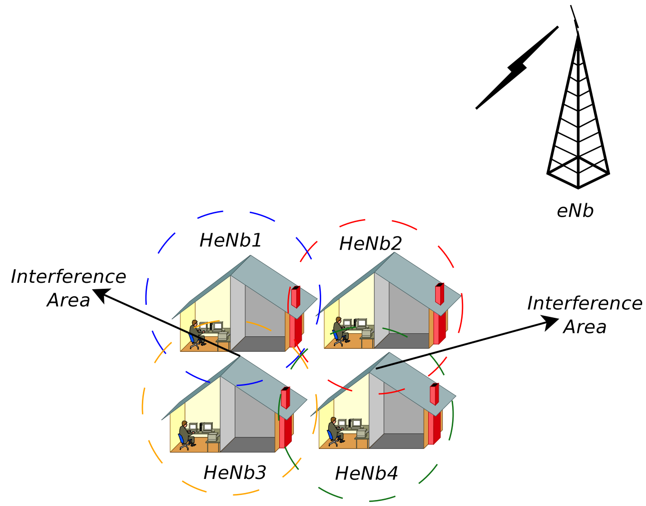

Figure 1. FemtoCell Interference Scenario

should form a coalition to transfer benefits among them. Formally, a game is a pair (N, v), where $N = \{1, ..., n\}$ is a finite set of players, $n = |N|$ and v is a characteristic function $v : 2^n \rightarrow \mathbb{R}$ such as $v(0) = 0$. Coalitions are subsets $S \subseteq N$. $N \backslash S$ denotes the complement set to N. In a game with n players, there are 2^n possible coalitions.

A. Bankruptcy games

This work is restricted to Transferable Utility (TU) games. Transferable Utility game is a scenario where one player can losslessly transfer part of its utility to another player. The bankruptcy problem is part of TU games. The analysis of bankruptcy situations tries to prescribe how to ration an amount of perfectly divisible resources among a group of players according to a profile of demands which, in the aggregate, exceeds the quantity to be distributed [12].

We model a bankruptcy situation by a triple (N, C, g), where $N = \{1, .., n\}$ is the set of players, $C \in \mathbb{R}_+$ represents the benefit and $g = \{g_1, ..., g_n\} \in \mathbb{R}^n_+$ is the vector of claims of the players. In [12] for every bankruptcy problem (N, C, g) an associated bankruptcy game (N, vc_g) is defined.

Considering O'Neill approach, the value of a coalition S is the part of the benefit that remains after paying the aggregated players in $N \backslash S$ all their bandwidth requirements, that is

$$vc_g(S) = \max\left\{C - \sum_{i \in N \backslash S} g_i, 0\right\}$$

$$v(N) = C \tag{1}$$

B. Shapley Value

Shapley value is a Game Theory concept proposed by Lloyd Shapley [14] aiming to propose the fairest allocation of collectively gained profits between the several collaborative players. The basic criterion is to find the relative importance of every player regarding the cooperative activities.

To compute Shapley Value, let us define a function $\phi(v)$ as the worth or value of player i in the game with characteristic function v. The Shapley value is the average payoff to a player if the player enters in the coalition randomly. The formula given by Shapley in [14] is:

$$\phi_i(v) = \sum_{S \subseteq N} \frac{(|S|-1)!(n-|S|)!}{n!}(v(S) - v(S \backslash \{i\})) \quad (2)$$

where $|S|$ indicates the number of players in the coalition, n is the total number of players, $v(S)$ indicates the coalition utility including player i, and $v(S\backslash\{i\})$ indicates the coalition utility excluding player i.

The Shapley Value is a very general method for equitable division. It is defined based on three axioms: symmetry, efficiency and additivity. The condition for efficiency is known as Pareto efficiency, and it gives guarantees that a player cannot obtain a better allocation without making another player allocation worse. Symmetry means that the player's final allocation does not depend on the order the players enter into the game. The symmetry property explains why the Shapley Value is considered as a fairness standard. The additivity axiom specifies how the values of different games must be related to each other. If the allocation is defined for two independent games, so it is also valid for a composite game. In this work we focus on the TU game formalism.

C. Interference mitigation Game Approach

Consider a resource allocation problem where a finite divisible bandwidth capacity C has to be divided among a finite set N of flow classes. For each $i \in N$, each flow of a group of k_i flows claim a bandwidth share $b_i \in \mathbb{R}_+$. Let $g_i \in \mathbb{R}_+$ denotes the total class bandwidth claim. The vector of class resources claim are denoted as $g \equiv (g_i)_{i \in N}$, with $g_i = k_i b_i$. Each class represents a player. The benefit to be divided is the total bandwidth capacity in terms of sub-bands or resource blocks. When several classes share an amount of resource, we interpret them as forming a coalition, and the benefits should be distributed between the members of the coalition.

An arbitrator must divide the benefits among the players of the game efficiently. The arbitrator is the HeNb-Gateway. It makes a fair resource blocks division among classes, no matter what HeNb classes belong to. When already knowing the amount of resources destined to each class, the HeNb-Gateway assigns the corresponding quantity of sub-bands to each HeNb based on the four-coloring method for interference mitigation. A new re-distribution of resources is performed every five TTIs. The inter-class division should be done using some fairness criteria, considering the different flows needs.

We consider a dynamic allocation process in which the number of flows in each class is variable. In a bandwidth allocation game, the classes represent the players who benefit from capacity C. All the classes form a coalition to get the benefit C. Under-loaded classes cooperate with overload classes, giving way unused capacity.

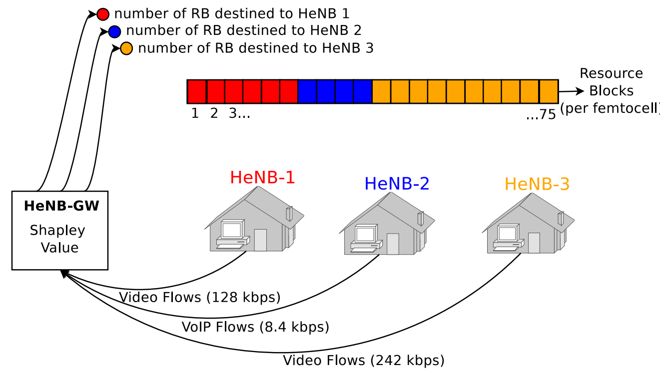

Figure 2. Proposed interference mitigation architecture

IV. Interference Mitigation

Based on a standard bankruptcy game described earlier, we propose a method to improve the four-coloring method for interference mitigation in the downlink system. This process is performed in two steps.

On the first step a fair resource distribution among classes using Shapley value method is performed. HeNb-GW receives as information the number of flows to serve (and the bit-rate that each flow needs) from each HeNb. On the second step, having the proportion of resource destined to each class (video, VoIP, CBR, etc) a sub-band distribution is performed by the HeNb-Gateway among Femtocell neighbors following the four-coloring method.

For instance, as it is illustrated by Fig. 2 the HeNb-GW receives as information from HeNB-1, HeNB-2 and HeNB-3 their flow bitrates 128 Kbps, 8.4 kbps and 242 Kbps respectively as the number of flows that each HeNB belongs. With this information a femto-bargain is performed at the HeNB-GW using the Shapley Value having as result the number of sub-bands or resource blocks that each femtocell is allowed to assign to users.

A. Step One: Fair resource distribution among flow classes by using Shapley value

At this level a TU game is carried on, taking into account the parameters shown in Table I.

Based on section III where resource allocation game approach was described, let us consider the following scenario to explain with an example our proposed interference mitigation model.

Let us define three classes $A = video_1$, $B = VoIP$ and $D = video_2$ as players in our scenario $N = \{A, B, D\}$. Consider $C = 48Mbps$ (75 Resource Blocks per TTI). The amount of bandwidth required by a single flow of each class is $b = (128, 8.4, 242)kbps$. The allocation is dynamic and depends on simultaneous flows quantity $K = (k_A, k_B, k_D)$. Thus, our bandwidth game is modeled as $(N; vc_g)$ where $|N| = 3$ and $vc_g(S) = max\{C - \sum_{i \in N \backslash S} g_i, 0\}$, with $v(N) = C$. Developing the characteristic functions in order to explain how our game works we have:

$$
\begin{aligned}
vc_g(1) &= max\{48000 - (8.4k_B + 242k_D), 0\} \\
vc_g(2) &= max\{48000 - (128k_A + 242k_D), 0\} \\
vc_g(3) &= max\{48000 - (128k_A + 8.4k_B), 0\} \\
vc_g(1,2) &= max\{48000 - 242k_D, 0\} \\
vc_g(1,3) &= max\{48000 - 8k_B, 0\} \\
vc_g(2,3) &= max\{48000 - 128k_A, 0\} \\
vc_g(1,2,3) &= 48000
\end{aligned}
$$

Thus, we go through to Shapley value (2) to compute the resources related to each class depending on K.

B. Step two: Sub-band assignment according to four-coloring method

Mitigating interference by using graph coloring algorithms is a well known method used in wireless networks. This method works by coloring the nodes of a graph with minimum number of colors, such that no two connected nodes (neighbors nodes) have the same color. By assuming each color as a different sub-band, this method facilitates the sub-band assignment where neighbor base stations must not use the same sub-band. As we can see, Fig. 3 represents the worst neighboring scenario where every femtocell has active users asking for resources at the same time. Each color represents a set of sub-bands assigned to femtocells. Neighbors must not use the same set of sub-bands. This means that according to the classical algorithm, each femtocell is assigned only 1/4 of the total bandwidth according regardless of the number of neighbors.

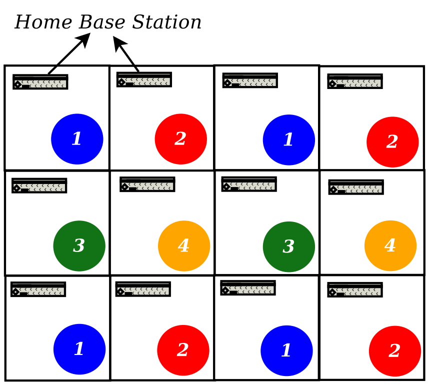

Figure 3. Four-coloring method for interference mitigation

In order to improve resource assignment, flexibility in the number of assigned sub-bands per femtocell is therefore desired. Now assuming that it is possible to have the desired flexibility related to the number of sub-bands to be assigned, it is important to find the answer to the following questions. Who does take this decision? and What is this decision based on? In our proposed solution it is the HeNb-gateway who makes the decision based on the Shapley value early explained. In this way the number of sub-bands destined to be allocated are chosen bearing in mind the type of services that femto users need.

C. Scheduling Algorithm

Must of previous works have focused their research specifically on interference mitigation without bearing in mind QoS parameters such as PLR, throughput, delay per service. Although total throughput has been analyzed in several results as seen in Section I-A, the type of flows have not been specified. Also, the most common chosen algorithm is PF (Proportional Fair). It is important to highlight that the scheduling algorithm is a serious choice to make when performing quality of service in wireless systems specially for real-time services such as video and VoIP. In [10] we have tested the performance of some well known algorithms such as PF, MLWDF (Modified-Large Weighted Delay First) and the EXP-RULE (Exponential Rule) over LTE systems. It has been shown by simulations that the better performance is experimented by EXP-RULE. Therefore, we chose the EXP-RULE [15] [10]. as the scheduling algorithm in this work.

V. Simulation Environment

To perform our resource allocation model, we define our scenario as follows. We use a single cell with several femtocells distributed in a building. Each femtocell serves two users, the first one receives VoIP flows and the second one receives video flows. Users are constantly moving at speed of $1kmph$ in random directions (random walk) in their office or home. The 3GPP 5x5 standard for femtocell is used to model the indoor scenario [5]. This work is focused only on femto-femto interference mitigation therefore macrocell interference is not taken into account in our scenario. LTE-Sim simulator is used to perform this process [6]. LTE-Sim provides a support for radio resource allocation in a time-frequency domain. According to [6], resource allocation is performed at each TTI, each one lasting 1 ms. One TTI is composed by two time slot of $0.5ms$, corresponding to 14 OFDM symbols in the default configuration with short cyclic prefix; 10 consecutive TTIs form the LTE Frame (Table II).

A. Traffic Model

A video service with 128 kbps source video data rate is used in the simulation, this traffic is a trace based application that sends packets based on realistic video trace files which are available on [7]. For VoIP flows, G.729 voice flows are generated by the VoIP application. The voice flow has been modeled with an *ON/OFF* method, where the *ON* period is exponentially distributed with a mean value of $3s$, and the *OFF* period has a truncated exponential probability density function with an upper limit of $6.9s$ and an average value of $3s$ [11]. During the *ON* period, the source sends 20 bytes sized packets every $20ms$ (i.e., the source data rate is $8.4kbps$), while during the *OFF* period the rate is zero because the presence of a Voice Activity Detector is assumed. The LTE propagation loss model for femtocell is specified in [5] [1].

B. Numerical Results

It is helpful here to better appreciate the behavior of our proposed solution, to compare it to other scenarios. Therefore we defined our curves as:

- *Femto*: This curve represents the femtocell simulation scenario where interference problem is not mitigated.

Table I
NOTATION AND DESCRIPTION OF VARIABLES FOR BANKRUPTCY GAME AND ITS ADAPTATION TO LTE SCENARIO

Variable	Bankruptcy Game	Bandwidth Allocation
n	total number of players	total number of flow classes
C	total benefit	total bandwidth capacity
g_i	player's benefit claim	flow class bandwidth claim

Table II
LTE DOWNLINK SIMULATION PARAMETERS

Parameters	Values
Simulation duration	100 s
Frame structure	FDD
Femto BS Tx power	15 dBm
Bandwidth	15 MHz
Slot duration	0.5 ms
Scheduling time (TTI)	1 ms
Number of RBs per femtocell	75
Maximum delay	0.1 s
Video bitrate	128 $kbps$
VoIp bitrate	8.4 $kbps$
Number of users per femtocell	2
Scheduling Algorithm	EXP-RULE
Pathloss	$PL = 127 + 30\log(d)$ d = distance UE - HeNb.
Multipath	Ped-A
PenetrationLoss	0 dB
Shadowing	log-normal distribution (mean = 0dB, standard deviation = 8dB)

- *Femto-4Color*: This curve represents the performance of the classical four-coloring algorithm in order to mitigate interference.
- *Femto-SH*: This curve represents our proposed method using Shapley Value to improve the four-coloring method.

1) Throughput: Figure 4 represents the average throughput per video flow. In this figure, we can realize that *Femto-4Color* curve experiments a decrease compared to the *Femto* curve. This can only be adequately explained by the fact that the four-coloring algorithm assigns only one quarter of bandwidth to each femtocell, but the throughput is not reduced to one quarter of it because the four-coloring method is not affected by interferences. On the other hand our proposed method, the *Femto-SH* curve shows a sharp rise compared to the four-coloring curve, even its performance is close to the *Femto* level curve. By adopting the view that Shapley value assigns resources based on parameters such as number of flows and bitrate, we can explain this important improvement due to the video flow bitrate is much higher than VoIP bitrate. According to those results, only two users are able to use the video services at the same time without experiencing losses due to interference.

In Fig. 7 we can appreciate the throughput for VoIP flows. As we can see in *Femto* curve, the VoIP flows performance is reduced due to neighbor interference. It is important to underline the fact that VoIP bitrate is $8.4Kbps$. This is a contributory factor to support the great improve of VoIP performance when using both methods, *Femto-4Color* and *Femto-SH*. The great capacity of bandwidth that LTE technology grants is clearly enough to serve VoIP needs, even if the femtocell uses only a quarter of its capacity (in the worst case). This explains why the performance of those two curves is almost the same that in a non-interference scenario. According to all PLR curves there is no issue related to throughput when using our proposed method or the four-coloring method when resources are shared to femtocell neighbors.

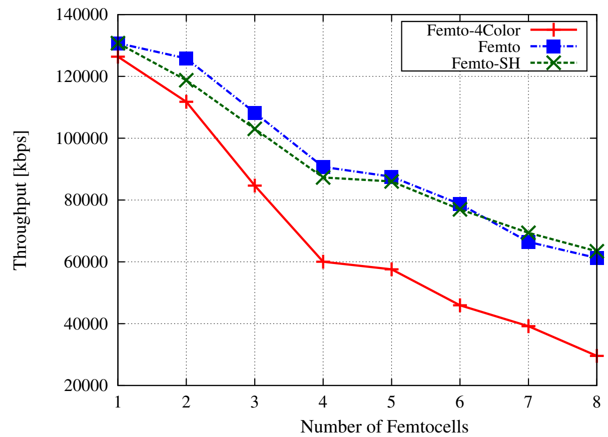

Figure 4. Average throughput per video flow

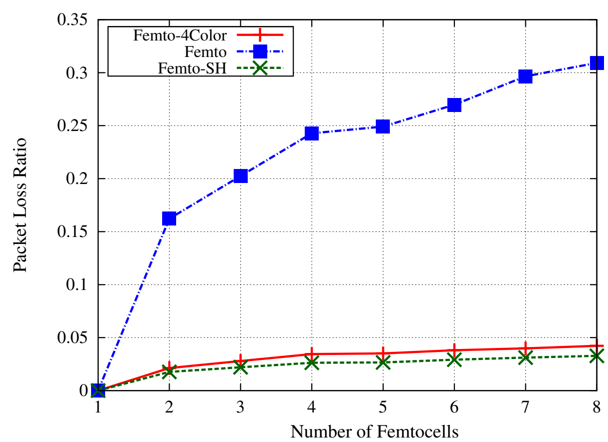

Figure 5. Packet loss ratio for video flows

2) Packet Loss Ratio: PLR for video flows is illustrated in Fig. 5. To complement the throughput performance shown and explained in the previous paragraph by the *Femto* curve, the loss of packets plays an important role in the QoS. The accepted PLR for video flows is 1%, unfortunately the level of PLR shown by *Femto* curve presents a PLR higher than 15% when there are two neighbors transmitting at the same time. This high quantity of PLR is fed by interference losses and buffer losses. On the other hand, *Femto-SH* curve shows an important decrease of PLR. This decrease is explained by the fact that there is no neighboring femtocells asking for the same subchannels. According to this concept if there is no interference there should be no PLR which is not the case as we can see in our curves. To explain this, it is important to bear in mind that there is a maximal delay for video and VoIP flows set in our scenario as we can see in Table II. It

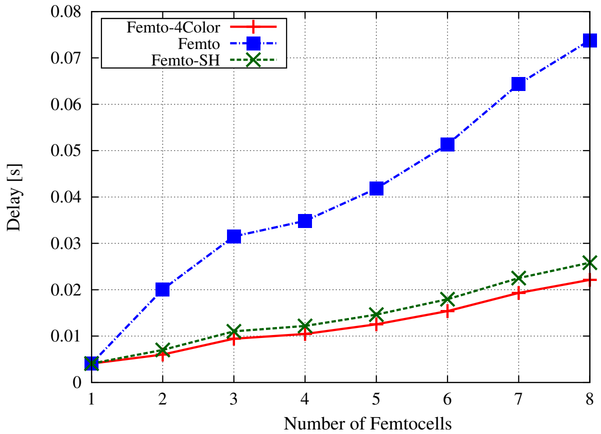

Figure 6. Delay for video flows

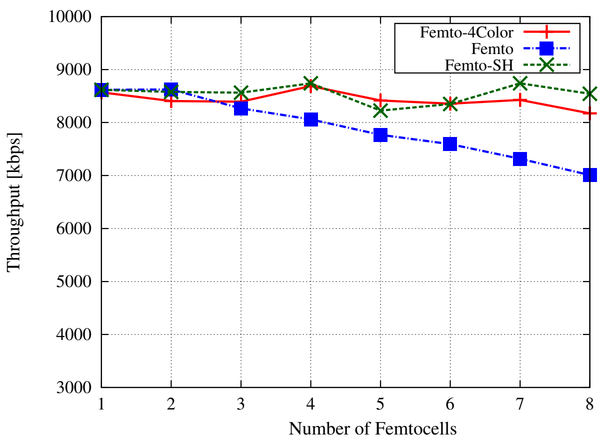

Figure 7. Average throughput per VoIP flow

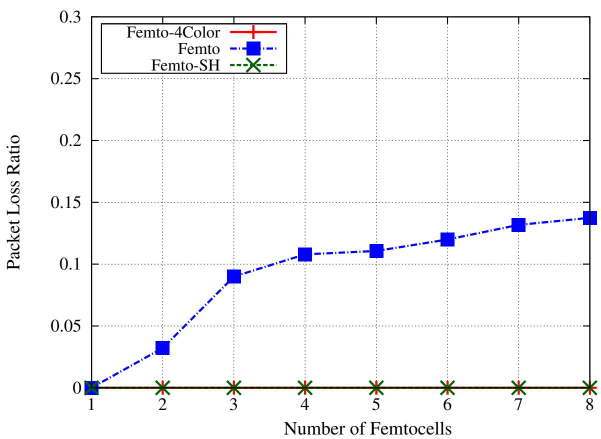

Figure 8. Packet loss ratio for VoIP flows

means that if a packet exceeds this limit of time, this packet is removed from the queue.

Figure 8 illustrates the PLR of VoIP flows. Here we can appreciate how the *Femto* curve complements the throughput behavior for VoIP flows (Fig. 7). Due to LTE-Sim VoIP model works using *ON/OFF* periods we can explain the picks and falls that all curve experience. *Femto-SH* and *Femto-4Color*

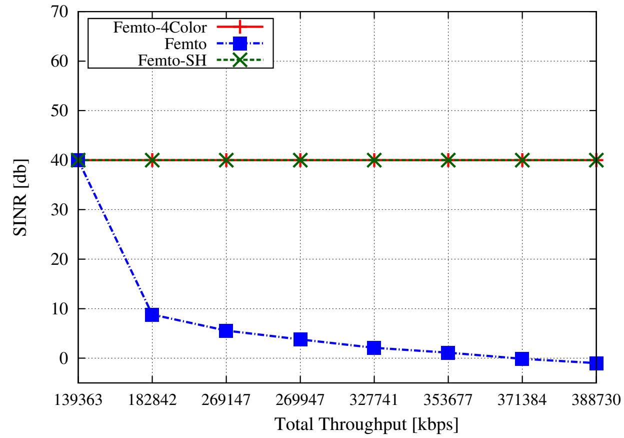

Figure 9. Average received SINR

perform a PLR almost null which is logically explained by the sub-band distribution among femto-neighbors. Unlike video flows suffer losses due to the video packets in the queue exceed the maximum delay as early mentioned, VoIP flows are not affected by this issue because of the number of VoIP packets in the queue is relatively small compared to video packets. When performing the resource block distribution among the different type of flows helped by the Shapley value method before performing the scheduling, our method assure resource assignation to all classes of flows, therefore VoIP packets has its own queue considerably shorter than the video packets queue. By those results we can assume that to improve the performance of QoS, this maximal delay parameter is an important factor to control the PLR in video flows which should be tested under different scenarios.

3) Delay: Figure 6 represents the delay for video flows. Both curves *Femto-4Color* and *Femto-SH* show shorter delays than *Femto* femto curve. We can judge this behavior as normal because of the fact that avoiding interference we reduce losses therefore the retransmissions rate is reduced as well. Also with this curve we can complement and support our explanations previously presented about throughput increase in Fig. 4 and why the reduction of PLR in video flows Fig. 5.

4) Interference: Figure 9 represents the interference mitigation when using our method. As we can see, the value of SINR increases up to 40 which is the limit set in our scenario when using sub-band distribution. Here we can appreciate the important reduction of interference and this information complements the other metrics early analyzed and discussed.

VI. Conclusions

This study paper has focused attention on interference mitigation in femtocell scenario in LTE downlink system. We defined four performance metrics namely, throughput, PLR, delay and SINR. With respect to these measures we can conclude that interference issues can not be neglected in a scenario where users utilize real-time services. Although femtocell architecture propose an interesting alternative to improve the QoS, simulation results have shown the impact that interference causes in their performance regarding a considerable degradation of capacity. We proposed a method based on game theory that improves the well known four-coloring algorithm for interference mitigation. We introduced an intelligent alternative to mitigate interference without decreasing the throughput and decreasing the PLR which is extremely important in order to get a desirable QoS when performing real-time services. The proposed scheme allows a low complexity implementation, which is suitable for practical wireless systems. Our work is limited to perform indoor scenarios. Future work could be focused on including the eNb to our scenario, which could be another source of interference to mitigate when using our method.

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