Interference Mitigation by Dynamic Self-Power Control in Femtocell Scenarios in LTE Networks.

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***Abstract*—Efficient radio resource management and Quality of Service (QoS) guarantee are very important aspects in order to provide a good service in LTE Networks. Although the base station performs a smart scheduling scheme for resource allocation, the expected result could be affected due to interference, specially in femtocell scenarios. This article investigates the problem of interference in femtocell networks in LTE. The proposed method achieves inter-cell interference mitigation though a dynamic power self-control performed at each femtocell. In this paper we use the modulation and coding scheme (MCS) to obtain the optimum power value which assures a trade-off between Signal-to-Interference-plus-Noise-Ratio (SINR) and bit-rate efficiency. The main objective of our work is to optimize the sub-bands in order to decrease the interference and maintain the throughput at the same time. The performance evaluation is conducted in terms of throughput, Packet Loss Ratio (PLR) and SINR.**

***Index Terms*—Wireless networks, quality of service, long term evolution, real time services, interference mitigation, game theory, nash bargaining solution.**

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 (NRT) services. The evolution of actual applications for mobile devices is focused on multimedia services. In order to enhance the capacity of current cellular networks and satisfy the real-time applications services needs Long Term Evolution (LTE) has been proposed and standardized by 3GPP. 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 QoS of 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). 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 low QoS level.

In the LTE specifications [3], a femtocell architecture has been proposed to strongly improve the QoS of next generation wireless technology. Offices, departments or houses could be situated geographically in a position where the macrocell can not assure a good quality of signal. As a solution of this problem operators started to propose femtocell which is a small base station installed at home in order to assure a closeness to the terminal aiming to improve the signal and consequently the QoS. Femtocells in the LTE specifications 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 a better quality of signal to users, the scheduling is susceptible 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, to access control mechanisms, open-access and closed-access are identified. In open-access femtocells, macro-users are allowed to be handed over to the corresponding HeNb. In closed-access the HeNb only grants access to a particular set of authorized users. It is the closed-access system that causes the most harmful interference. Macro-femto interference could be well described 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 due to neighboring issues. 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/her room will experiment strong interference issues in the case in which the neighboring 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.

A. Related Works

There are several notable studies related to interference mitigation. In [12] a coverage and interference analysis based on a realistic OFDMA macro/femto scenario is provided, as well as some guidelines on how the spectrum allocation and interference mitigation problems can be approached in these networks. In [5] 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 [13] 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 use 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 NRT services. Unfortunately, this proposed method might be hard to be adapted to the LTE needs because the core of LTE is focused on RT services such as video and VoIP and this scheme does not satisfy RT services needs. In [18] 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 on only 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 based delay flows are considered for this work, the basic well known constraints of QoS 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.

Power control is a well known method for interference mitigation. Several propositions have been introduced about this topic. In [7] the authors compare interference management solutions across the two main 4G standard: IEEE 802.16m Wimax and 3GPP-LTE. This paper addresses radio resource management schemes for interference mitigation which include power control for macrocell scenarios in downlink and uplink system. In this paper it is well mentioned the importance of SINR and QCI values. Huang et al. in [10] formulate a distributed algorithm for interference mitigation by resorting to a game theory approach. In this paper the transmission power is considered as a continuous variable which is regulated in order to maximize some network utility function. In [16] the authors consider the problem of maximizing the weighted sum-rate of a wireless cellular networks via coordinated scheduling and discrete power control. This work brings out two distributed iterative algorithms which need limited information exchange and data processing at each base station. Although this method seems to work fine for macrocell scenarios, nowadays there is no any power control method proposed to mitigate femtocell interference over LTE in order to satisfy real time (RT) services needs.

B. Contributions

The focus of this work is on introducing a method which carries on an efficient scheme in order to mitigate interference in femtocell scenarios by using a dynamic self power transmission control. Our proposed solution differs from others on the following aspects:

1) Due to interference and throughput are not directly proportional with each other in order to ask for the transmission power level, we propose a method which performs a constant bargain between interference and throughput efficiency in order to find an optimum trade-off which is represented by the femto transmission power value.
2) Our proposed constant bargaining has a low complexity.
3) Since LTE characteristics are focused on RT services, we test our proposed method in a scenario which uses video and VoIP flows.

This paper is organized as follows. Section II describes the system model and the femtocell architecture over LTE. Section III describes the aforementioned proposed interference mitigation method. In section IV the simulation environment scenario is presented, where the traffic model is described and a numerical result analysis is exposed. Section V concludes this paper.

II. System Description

Femtocell deployment has been introduced in LTE specifications release beyond 10 in order to help to perform the resource assignation which is the responsibility of the macrocell. 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”. 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 [5]. Users report their instantaneous downlink channel conditions (e.g. 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.

III. Proposed Interference Mitigation Method

A. Network definition and interference computing

When a user ask for resources in a femtocell scenario, it is important to bear in mind several important points.

The well known proposed solutions for interference mitigation in a macrocell scenario could not be used in a femtocell scenario due to an important parameter that is the distance between the user and the base station (macro or femto). In a macro cell scenario users are distributed in large surfaces such as $1000, 2000$, or $3000m$ but in a femtocell scenario the users are distributed in very small surfaces from 25 to 30 m. Note that in a macrocell scenario the interference problem affects to cell-edge users, but in a femtocell scenario due to its small surface there are no cell-edge users, therefore interference affects to all users.

A well known method to reduce interference is by reducing transmission power but it must be taken into account that the transmission power reduction also produces throughput reduction.

Let us explain this point as follows. Let us define an LTE femtocell network as a set of:

- femtocells $F = \{f_1, f_2, ..., f_n\}$
- users per femtocell $U = \{u_1, u_2, ..., u_m\}$
- Subbands $S = \{s_1, s_2, ..., s_l\}$

Consider the 3GPP pathloss model pl between a user u and a femtocell f represented with this formula [5].

$$pl_{u,f} = 127 + (30 * \log(d)) \tag{1}$$

Where d is the distance between the user and the base station.

To perform a total bandwidth distribution among all users it is necessary to divide the total bandwidth into sub-bands. Also the total transmission power TxP must be divided in function of the number of sub-bands in order to get the sub-band transmission power $\delta_{u,f}$

$$\delta_{u,f} = 10\log_{10}\left(\frac{10^{\frac{TxP-30}{10}}}{nsb}\right) \tag{2}$$

Table I
LTE MSC (Modulation and Coding Schemes)

MCS	Modulation	Code Rate	SINR [db]
MCS1	QPSK	1/12	-4.63
MCS2	QPSK	1/9	-2.6
MCS3	QPSK	1/6	-0.12
MCS4	QPSK	1/3	2.26
MCS5	QPSK	1/2	4.73
MCS6	QPSK	3/5	7.53
MCS7	16QAM	1/3	8.67
MCS8	16QAM	1/2	11.32
MCS9	16QAM	3/5	14.24
MCS10	64QAM	1/2	15.21
MCS11	64QAM	1/2	18.63
MCS12	64QAM	3/5	21.32
MCS13	64QAM	3/4	23.47
MCS14	64QAM	5/6	28.49
MCS15	64QAM	11/12	34.6

Where TxP represents the total transmission power and $nsb = |S|$ represents the number of sub-bands.

Using (1) and (2) the interference for user γ_u is computed as follows:

$$\gamma_u = \sum_{f_1}^{f_n} (\delta - pl_{u,f}) \tag{3}$$

In order to obtain the noise-plus-interference firstly we compute the $noise_{db}$ as follows:

$$noise_{db} = nf + np + 10\log_{10}(schb) - 30 = -148.95 \tag{4}$$

Where $nf = 2.5dbm$ is the noise figure, $np = -174dbm$ is the noise power, and $schb = 180kHz$ is the subchannel bandwidth.

In order to compute the measured $SINR$ value $mSinr$.

$$mSinr = \delta - 10\log_{10}(10^{\lambda} + \gamma) \tag{5}$$

Where $\lambda = \frac{noise_{db}}{10}$

$$SINR = \frac{\sum_{s_1}^{s_l} mSinr}{nsb} \tag{6}$$

Now having the $SINR$ value, it is possible to compute the MCS value as shown in Table I and consequently computing the Transport Block Size (TBS) following the 3GPP specification TS 36.213 - Table 7.1.7.2.1-1. Those MCS values are constantly reported to the base station(eNb or HeNb).

B. Analysis

In this work we focus our attention on transmission power control due to its importance on SINR values computed as shown in last section. Due to the coverage surface that femtocells serve (3GPP 5X5 m), the interference level depends closely of the transmission power level. In a case where a femtocell has no femto neighbors a fix transmission power set on the highest level become a privilege for the owner because the quality of signal will be good in a big covered area.

Now let us explain the scenario where there exist close femto neighbors asking for resources at the same time as could happen in a metropolis building. If two or more femtocells set their transmission power values to the highest level in a specific case where user (belonging to different femtocells) ask for resources, each femtocell will assign all their subbands to their users. This will cause interference and this interference will avoid an optimal packets transmission performance.

Considering that if femto owners decide to set the transmission power level to the lowest allowed value, logically interference will decrease, but coverage signal quality and MSC values will decrease as well. If MSC values are small TBS values will also be small, therefore throughput gain will not get a high level which is not an optimal solution when transmission packets belong to real-time flows.

Now the key of this game is focused on setting the transmission power value as a dynamic variable which changes depending on the scenario changes. As mentioned in section II, each user computes its SINR estimation and reports its MSC values to the HeNb. Each HeNb will decide the value of transmission power depending on the users position, in order to maintain the power value as low as possible but without affecting the throughput gain. At this level our algorithm proposes a game theory bargain between *SINR* and *throughput* gain as players.

C. 2-person bargaining game

Game theory is nowadays been adapted to some areas such as computing and telecommunications in order to perform optimal and fair algorithms. Non-cooperative games are part of game theory. Non-cooperative games are based on the absence of coalitions in that it is assumed that each participant acts independently without communication or collaboration with any others. In [23] J. Nash presented a two-person zero-sum game concept which aims to find an equilibrium point.

The must important factor of our proposed algorithm is the 2-person game bargaining where players are *Throughput* and *SINR* as early mentioned. Players compete for transmission power value as seen in Fig. 1. In order to increase its level, *SINR* will propose to set the power as low as possible and on the other hand *Throughput* will propose to set the transmission power value as high as possible to increase its level as we can see on the 1st move - Fig. 1. Our algorithm performs a bargaining between those two players at the HeNb in order to find an optimum trade-off between them. The target of this method is focused on avoiding femtocells to transmit with too much power than users need. If femtocells transmit with a high power level even if the user is quite close to the femtocell, the user will get a good QoS level but it must be taken into account that this user could get the same good QoS level if the femto power level transmission is lower. If the femtocell power level transmission is lower it will cause low interference to the neighbors.

D. Proposed Algorithm

All this process is carried on by performing the steps described in Algorithm 1.

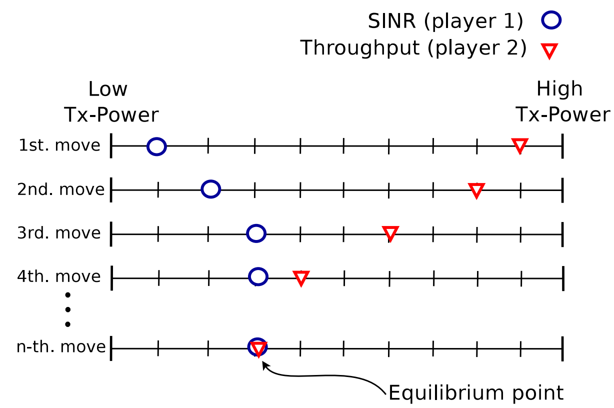

Figure 1. 2-person game for power level control

Algorithm 1 Proposed Algorithm

$tx\_pow_{min} \leftarrow pow_{min}$ {set the HeNb min trans power}
$tx\_pow_{max} \leftarrow pow_{max}$ {set the HeNb max trans power}
$tx\_power \leftarrow tx\_pow_{max}$ {This process will be repeated in a period of 10 TTIs }
$Compute\_Pathloss()$; {According Eq. (1)}
$Compute\_SINR()$; {According Eq. (6)}
$Compute\_MSC()$;
$Compute\_TBS()$;
{Starting bargaining }
$player\_1 \leftarrow SINR$
$player\_2 \leftarrow Throughput$ {Computed at the HeNb using the received TBS in the last period }
$tx\_pow_{com} \leftarrow perform\_Game(player1, player2)$;
if $tx\_pow_{com} < tx\_power$ **then**
  $tx\_power \leftarrow tx\_power - 1$
else
  $tx\_power \leftarrow tx\_power + 1$
end if

IV. Simulation Environment

To perform our resource allocation model, our femtocell scenario is set as follows. The number of femtocells which are neighbors relatively close start from 1 until 10, increasing in one unit in order to increase the interference. There is only one user at each femtocell which utilizes all the femtocell resource blocks. We have tested one scenario where all femtocells serve video flows, and another one focused on VoIP flows. Macrocell interference is not taken into account in this study. Users are constantly moving at speed of 1 $kmph$ in random directions (random walk). LTE-Sim simulator is used to perform this process [11]. LTE-Sim provides a support for radio resource allocation in a time-frequency domain. According to [11], in the time domain, radio resources are distributed every TTI, each one lasting 1 ms. Furthermore, each TTI is composed by two time slot of 0.5 ms, corresponding to 14 OFDM symbols in the default configuration with short cyclic prefix; 10 consecutive TTIs form the LTE Frame (Table II).

Table II
LTE DOWNLINK SIMULATION PARAMETERS

Parameters	Values
Simulation duration	60 s
Frame structure	FDD
Apartement size	100 m^2
Bandwidth	10 MHz
Slot duration	0.5 ms
Scheduling time (TTI)	1 ms
Scheduler	EXP-RULE
Number of RBs	50
Max delay	0.1 s
video bit-rate	128 $kbps$
Number of femtocells	$1, 2, 3, ..., 10$
Multipath	Ped-A
PenetrationLoss	0 dB
Shadowing	log-normal distribution (mean = 0dB, standard deviation = 8dB)

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 [3]. For VoIP flows, G.729 voice flows are generated by the VoIP application. Particularly, the voice flow works with an *ON/OFF* model where the *ON* period is exponentially distributed with mean value 3 s, and the *OFF* period has a truncated exponential probability density function with an upper limit of 6.9 s and an average value of 3 s [11]. During the *ON* period, the source sends 20 bytes sized packets every 20 ms (i.e., the source data rate is 8.4 $kbps$), while during the *OFF* period the rate is zero because the presence of a Voice Activity Detector is assumed. We set the EXP-RULE as scheduler based on our previous work [17].

The 3GPP LTE propagation loss model consists of 4 different models (shadowing, multipath, penetration loss and path loss)[1]

B. Simulation Results

We prove the efficiency of our algorithm by presenting the simulation results. Figures present two curves, the red curve represents the scenario where the transmission power value is fixed to 23dbm. The blue curve represents our proposed method which we call Dynamic Self-Power Control (DS-PC) where power is dynamically changing depending on our algorithm results.

Fig. 2 and Fig. 4 show the average throughput per video and VoIP flows respectively. There is not an significant decrease of throughput when using DS-PC method compared to the fixed power (23 dbm). As we can appreciate 23 dbm causes a hight interference which makes decrease the throughput avoiding a good QoS level even when 2 femtocells transmit at the same time. On the other hand when using DS-PC method we reach to maintain the throughput up to 2 femtocells assigning resources for video flows at the same time. For VoIP flows DS-PC method maintains the desirable throughput up to four femtocells transmitting at the same time.

Figures 3 and 5 show the PLR of video and VoIP flows respectively. Both figures show a decrease of PLR. Although the PLR decreases considerably in both cases it is important to highlight that the PLR value is grater than 3% (which is the supported percentage for VoIP flows), and the 1% (which is the supported percentage for Video flows).

Figure 6 represents the interference level by SINR values against throughput gain for video flows. As we can see the interference decreases when using our method compared to the static power.

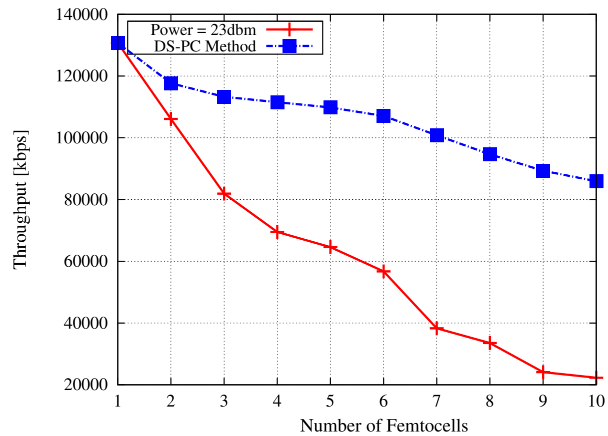

Figure 2. Throughput average per video flow

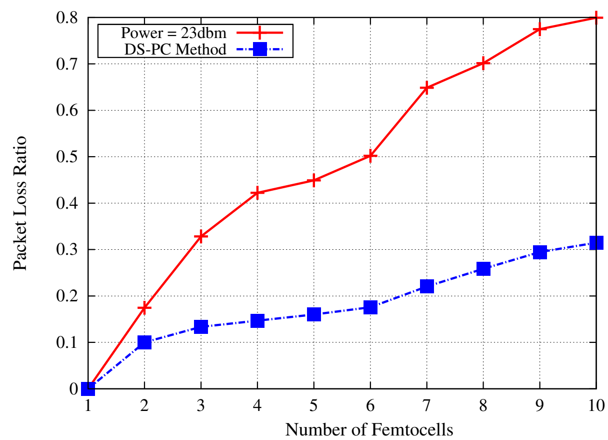

Figure 3. packet Loss ratio for video flows

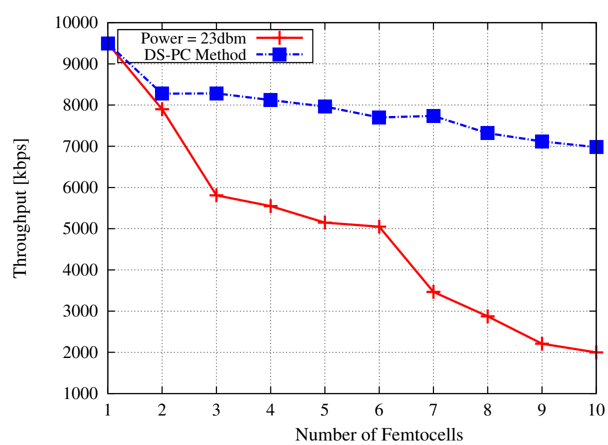

Figure 4. Throughput average per VoIP flow

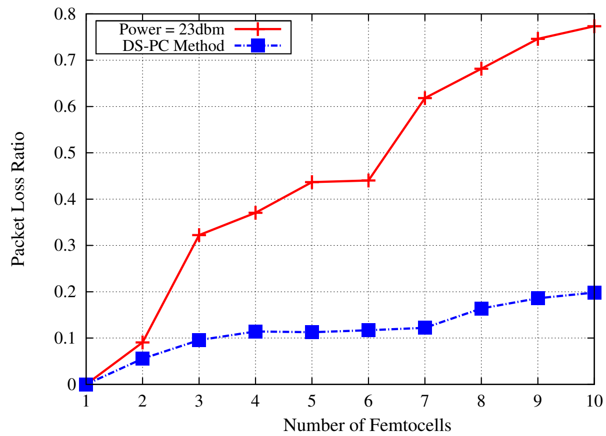

Figure 5. packet loss ratio for VoIP flows

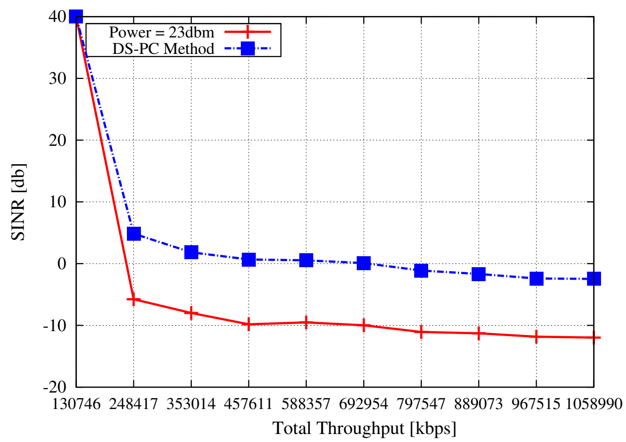

Figure 6. Interference in video flows scenario

V. Conclusions

This paper has focused attention on interference mitigation in femtocell scenario in LTE downlink system. We defined three performance metrics namely, throughput, PLR, and SINR. With respect to these measures we can conclude that interference issues can not be neglected in a scenario where users utilize RT services. Although femtocell architecture proposes an interesting alternative to improve the QoS. By simulation we have shown the impact that interference causes in their performance regarding a degradation of capacity if the transmission power value is not set to an optimum level specially in femtocell scenarios where signal coverage surfaces are small. In order to solve this problem we proposed a method based on controlling the transmission power value that changes dynamically this value depending on the interference level. We introduced this smart alternative to find an optimum trade-off between throughput and interference in order to mitigate interference without decreasing the throughput which is extremely important to get a desirable QoS when performing RT services. In this work we can conclude that the power level value plays an important role in performing a good QoS. Also it is important to remark that a neglecting control of this value, it could be an important cause to perform a degradation of throughput. The proposed scheme allows a low complexity implementation, which is suitable for practical wireless systems. Our work is limited to perform indoor scenarios therefore future work could be focused on finding out a way to include the macrocell into this scenario, which can not be neglected in real transmission systems scenarios.

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