Coordinated Partial Co-Channel Deployment in Two-Layer Networks

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***Abstract*—Reducing the interference level between the overlapped femtocells and macrocells is one of the main issues facing femtocells deployment. In this paper, a new coordinated scheduling technique based on femtocell-aware frequency planning is proposed. This technique is based on partial co-channel deployment between the macrocell and the femtocell. The main idea of the proposed scheme is to enable the coordination of the spectrum arrangement schemes between the overlapped macrocells and femtocells based on the requested user traffic, taking into consideration the different Quality of Service (QoS) requirements for the different users applications. The macro base station uses the information about the femtocells used frequency band as well as the information about the requested macro user traffic in making the scheduling decisions so that the cross-layer interference between macrocells and femtocells is reduced. Extensive simulations are conducted to demonstrate the performance improvements of the proposed scheme in terms of the macro user blocking probability and the throughput.**

I. Introduction

The deployment of Femtocells is expected to increase in the future to enhance indoor coverage as well as offloading the macrocells traffic. The deployment of femtocells will cause some changes in the topology of traditional macrocellular networks. The new network architecture will consist of two detached layers, namely, the macro-layer and the femto-layer [1]. Cross-layer interference takes place between a macrocell and a femtocell base station when both use the same frequency band and this interference can reduce the overall network performance [2]. Since femtocells are located in the coverage of macrocell, the cross-layer interference is inevitable due to the co-channel transmission. If there is no coordination between the macro BS and femto BS, the inter-cell interference could be severe around the edge of the femtocells and for the edge macro users. In this way, the possibility of having extended femtocell deployment will be diminished or even neglected.

There are several deployment configurations which have been proposed for the spectrum assignment for femtocells [3], [4]. Femtocells could be configured to operate in a separate spectrum or a shared spectrum with the macrocells. Operating in a separate spectrum, "dedicated deployment", means that femto- and macro-layers are not causing any inter-cell interference to each other. The drawback of the dedicated deployment is that the valuable licensed spectrum is inefficiently utilized, as the operator has to reserve a dedicated spectrum for femtocells.

On the other hand, femtocells could share the same spectrum with the macrocells and this is called co-channel deployment. This is regarded as the worst-case co-channel interference deployment and is a risky configuration; in this case, all the cells can cause interference to each other due to sharing the same spectrum bands among all cells. Considering the tradeoff between the spectrum usage efficiency and the co-channel interference, a partial co-channel scheme is proposed in the presented work. In a partial co-channel, the frequencies shared between the femtocell and macrocell are limited to a certain part of available spectrum. The femtocells use only a subset of the macrocells frequencies. How to divide the radio spectrum among the macrocells and femtocells is an important practical issue in the partial co-channel configuration deployment. This is inevitable in order to achieve the benefits of this deployment of enhancing the spectrum usage and limiting the cross-layer interference.

Each of the two deployments discussed above is beneficial for one layer but might be destructive for the other layer. In this paper, a new scheduling technique based on femtocell-aware frequency planning for cross-layer interference reduction between macrocells and femtocells is proposed. This technique is applied to the partial co-channel configuration of the femtocells deployment setting in LTE system [5].

The main idea of the proposal is to enable the coordination of the spectrum arrangement schemes between the overlapped macrocells and femtocells. The macro BS uses the femtocell spectrum information within its coverage, which can impact the scheduling algorithm of the macrocell, so that the co-channel interference at the femtocell could be reduced. We assume that in the two-layer network the users have two distinct applications, Voice-over-IP (VoIP) and File-Transfer Protocol (FTP). Each of this application has different QoS requirements and different constraints. VoIP is a delay sensitive application, while FTP is an error sensitive application. The applications requirements will affect the scheduler decisions. Our proposed coordinated partial co-channel deployment will be compared to the dedicated deployment and uncoordinated partial co-channel deployment presented in [3], [4].

The rest of this paper is organized as follows. Section II illustrates the proposed coordinated scheduling scheme. Section III provides the used system level simulation. In Section IV, the different scheduling functions as well as the simulation scenarios are presented. Section V provides the performance results of the proposed approach using simulation. In Section VI, the conclusions are drawn.

II. Proposed Coordinated Scheduling with Partial Co-Channel Deployment

As mentioned in the Introduction section, femtocells can be configured to operate in dedicated part of the licensed spectrum. This dedicated deployment is beneficial for femto-layer, as it will not suffer from macrocells cross-layer interference. On the other hand, the dedicated deployment is detrimental for macro-layer where the operator has to reserve part of the already limited available licensed spectrum for femtocells. Another spectrum configuration is the partial co-channel deployment where the macro-layer accesses its whole licensed band. The femto-layer shares with the macro-layer in limited part of the spectrum. From the spectrum usage point of view, partial co-channel deployment is more efficient than the dedicated assignment but femtocells can suffer from damaging cross-layer interference.

Our proposed coordinated scheduling can be described as follows. The mobile operator configures the spectrum part, shared with the femto-layer. Consequently, macro BS could have knowledge of the shared frequency resource for femtocells within its coverage. Accordingly, the macro BS divides its available spectrum into two disjoint parts, the macro-dedicated spectrum and the femto-shared spectrum. On arrival to a macro BS, a macro user with some traffic (VoIP or FTP) has to be scheduled (assigned resource blocks (RBs)[1]) in the macro-dedicated spectrum part. When this macro-dedicated spectrum is completely occupied, macro BS will begin to schedule users in the femto-shared spectrum, where in this part of the spectrum the femtocells schedule the femto FTP and femto VoIP users.

The macro BS will only schedule macro VoIP users in the femto-shared spectrum. No macro FTP users are going to be scheduled in this part of spectrum. FTP is an error sensitive application, which may suffer from cross-layer interference if scheduled into the femto shared spectrum part. Only macro VoIP users may share femto- spectrum with the femto users.

For femtocells, the advantage of the proposed scheme is that macro VoIP application needs small number of RBs to fulfil its requirements, unlike macro FTP which needs large number of RBs due to the increased data rates. As a result, macro-layer will disturb the femto-layer in a smaller number of RBs compared to the uncoordinated dynamic scheduling. Consequently, femtocells will suffer reduced cross-layer interference.

For macrocells, macro BS in the proposed approach still has the advantage of allocating in the whole spectrum band but with some coordination limitations as described above. This coordination not only does not affect the macro VoIP application but also will enhance its performance. VoIP application is the main, heavily required service from any outdoor cell. VoIP is a delay sensitive application that needs to be quickly scheduled and minimally blocked. The proposed scheme can highly fulfill these requirements as will be shown in the simulations section.

[1]One RB in LTE is 12 contiguous subcarriers for the duration of 1msec and it is the smallest unit that can be assigned to a user.

III. System Model

System level simulation will be performed to analyze the behavior of a network composed of sets of BSs and users [6]. The system level simulation allows the understanding of the evolution of the network as a function of time. The network performance will be evaluated via various measures, such as cell and user throughputs and user blocking probability.

System level simulation will be performed to analyze the behavior of a network composed of sets of BSs and users. The system level simulation allows the understanding of the evolution of the network as a function of time. To capture the end-to-end behavior of a network, the fluctuations of the channel over time and frequency (shadowing/ multipath fading) as well as the nature of the traffic (traffic models) must be simulated. In this way, the behavior of different scheduling techniques can be illustrated. The network performance will be evaluated via various measures, such as cell and user throughputs and user blocking probability.

A. Channel Model

For the channel model, distance dependent path loss and slow fading (shadowing) are considered for all links between base stations and an arriving user. Taking into account the relative position of users with respect to all base stations, the distant dependent path loss can be computed. The shadowing is simulated by adding a log-normal variation of the received power around the predicted median value [6]. The shadow fading corresponds to the value of received power that will be added or removed to the received power, depending on a certain probability. This value and the associated probability depend mainly on both the radio propagation model and the environment. Therefore, in femtocell scenarios the radio links between the base stations and users are divided into outdoor, indoor (the user and femto BS are in the same house), and outdoor-to-indoor (the user and femto BS are in two different houses) links according to the radio environment in order to model the shadow fading.

B. Traffic Modeling

Traffic models are used in system level simulation in order to simulate the behavior of a given application or service, for example, VoIP, video conference or FTP. This behavior is considered at different levels, including the session generation process and the data generation within each session. For the session generation process, the arrival rate of the users and their system service times must be modeled to capture the dynamics of the users. In macrocell, the Poisson process has been widely used to model the traffic load of the network over time. For the simulation in this paper, this process is used to model the arriving traffic load. Modeling the user service time depends on the type of application used. For data generation process, two different traffic models are considered here, VoIP and FTP [7], [8], similar to the data traffic models used in the LTE-advanced standard [9].

C. Interference Model

In downlink (DL), where the interference is suffered from at the users, it can be said that a certain user, U_x, whose serving cell is C_i, suffers from interference from cell C_j if C_i and C_j are using the same RB for downlink transmission in the same LTE subframe. The interference suffered in DL by U_x at RB $RB_{i,k,t}$ will be the sum of the interference coming from all neighbour cells. The interference level at the U_x user on the k-th RB at the t-th symbol, $I_{x,k,t}$, is given by [10]

$$I_{x,k,t} = \sum_{j=0,j\neq i}^{N-1} P_{j,k} Lp_{j,x} \phi_{j,k,t}, \tag{1}$$

where i is the index of the serving cell, C_i, j's are the indices of the interfering cells, C_j's, $P_{j,k}$ is the power transmitted by C_j on the k-th RB and $Lp_{j,x}$ is the distant dependent path loss between C_j and U_x including the shadowing effect. Finally, is a binary variable $\phi_{j,k,t}$ that equals 1 if cell C_j is using $RB_{i,k,t}$ and zero otherwise.

The signal-to-interference plus noise ratio (SINR) for any RB, $RB_{i,k,t}$, can be computed as

$$SINR = \frac{C}{I + \sigma^2}, \tag{2}$$

where C is the desired signal strength and I is interference level and σ^2 is the background thermal noise power. The interference signal power I can be derived from interference model presented above in (1). While the desired signal power C can be similarly estimated as

$$C = P_{i,k} Lp_{i,x}. \tag{3}$$

Based on the above model the state of each user can be obtained. The possible states of the users are: Blocked, if the cell does not have sufficient RBs to satisfy the minimum requested service throughput or if the SINR reported by the Channel Quality Information (CQI) is smaller than the required SINR for the minimum user profile (minimum modulation and coding scheme required), or Successful, if the user is transmitting and has achieved the minimum requested service throughput.

IV. Scheduling Functions and Simulation Scenarios

To study the effectiveness of the proposed downlink coordinated scheduling, an LTE system level simulation has been developed. The simulation system scenarios consist of number of macro BSs and femto BSs. The transmission power of macro BSs is set to be 2 watt. Background noise is added such that the received signal-to-noise ratio (SNR) at the macrocell edge is 3 dB. The femto BS transmit power is set such that the SNR at the femtocell edge is 10 dB. The macro BSs are located at fixed position with one or more femtocells randomly placed inside each macrocell.

Macro BS always has higher VoIP load than femto BS as the macro BS is a large outdoor cell serving large number of voice users. For VoIP application, to simulate different service densities within a given scenario, different values for the cell load can be defined per service with constant mean call time. Any cell VoIP load, measured in Erlang, represents the call mean service time divided by user mean inter-arrival time. Furthermore, for the FTP application, the number of FTP users in macrocell is higher than the number of users attached to a femtocell as explained above. In our simulations, we will exploit the network evolution as a function of time or events. There are two main events; the first event is a user arriving to the network. In this event, RBs are allocated to the user to satisfy his requested service QoS requirements. The second event is a user departure from the network.

A. User Arrival Event

This event captures a user arriving to a BS. The locations for the users arriving to a certain cell are randomly generated; users are uniformly distributed in the cell. The serving BS first checks the user requested service (VoIP or FTP). The type of requested service affects the users scheduling procedures. FTP and VoIP applications are defined based on certain QoS requirements and throughputs. These service requirements are used to decide on which resources should be allocated to each user as well as to determine the user state (Successful or Blocked). The scheduler allocation is affected by the type of the BS, macro or femto, and by the spectrum deployment technique, i.e. dedicated deployment, partial co-channel, or coordinated partial co-channel deployment (our proposed scheme). In general, there will be different scheduling functions depending on the application. These scheduling functions can be described as follows.

1) VoIP user scheduling function:: A typical VoIP call can normally be divided into two states: active and inactive. In the active state, the user needs to be assigned RBs to transmit his voice packets. During the active state, packets of fixed size are generated. The model is updated at a regular frame interval. The size of packet and the rate at which the packets is sent depends on the corresponding voice codec. In this paper, vocodec G.729 [7], [10] is used. G.729 transfers a voice packet of 20 bytes at a regular frame interval of 20 ms. which represents a bit rate of 8 kbps. While in inactive state no packet is sent because we assumed the presence of a voice activity detector.

The used voice activity factor is 50%. For VoIP packet of 20 bytes and 8 kbps, the scheduler selects the QPSK constellation with code rate 1/2 as the suitable modulation and code rate for VoIP transmission. The BS allocates 2 RBs for the VoIP transmission every 2 frames (in LTE 1 frame is 10 ms).

The scheduling decision is assumed to be updated at regular frame interval of 20 ms. After the scheduler decides RBs range of the serving BS, it searches for 2 empty RBs that can fulfill the SINR requirement for QPSK modulation with code rate 1/2 as given in Table I [10]. The SINR for each RB is calculated using (2). The VoIP user is blocked if the cell does not have sufficient RBs to fulfill the VoIP requirement or if the SINR reported by the CQI is less than the SINR required to get the minimum user profile (QPSK modulation with code rate 1/2). If the required RBs are found and allocated to the voice user, these RBs service time has to be updated. The service time is updated using exponential distribution with a mean equals the

Table I: Carried bytes per RB and SINR requirements for the different modulation schemes and coding rates

Modulation	Code rate	Efficiency (bits/symbol)	SINR threshold (dB)	Carried Bytes/RB
QPSK	1/2	1	2	15
16QAM	1/2	2	7.9	30
16QAM	3/4	3	12.2	47
64QAM	3/4	4.5	17.5	70

call time mean. Also, the serving BS next arrival is generated with inter arrival time drawn from an exponential distribution.

2) FTP user scheduling function:: In this function, the FTP file size to be transferred is generated using a log-normal distribution of mean 2 MByte and standard deviation 0.72 MByte. The size of file must not exceed 5 MByte [7], [8]. The BS has a maximum number of RBs to be assigned to the FTP file and a minimum value determined by minimum average FTP throughput requirement (128 kbps).

In LTE, 1 RB has 126 resource elements (RE) for data transmission where the pilots REs are subtracted[2]. Each of these 126 REs can carry 1 information symbol. The numbers of carried Bytes per a RB for the different used modulation and coding schemes are illustrated in Table I. The scheduling decision is updated at a regular frame interval of 20 ms as the VoIP scheduling, i.e., semi-persistent scheduling is assumed which is configured by a 20 ms periodicity. In our scheduling, these RBs must be idle (not assigned to any other user in this BS) and their SINR must, at least, fulfill the SINR requirement of the minimum user profile.

The FTP users are blocked if the assigned RBs cannot fulfill the minimum average throughput required (128kbps). If the RBs have higher SINR than the minimum profile (QPSK-1/2), this will lead to a higher modulation and coding scheme. As a result, more bytes are carried per one RB. The used modulation and coding scheme is determined according to the average SINR. The user is assigned number of RBs to transfer his FTP file. The number of RBs assigned to an FTP file depends on the bytes carried by each RB. The service time for FTP assigned RBs is updated to indicate the duration for which the FTP application will use these RBs. The FTP user is blocked if the cell does not have sufficient resources to satisfy the FTP minimum requested throughput. Before the end of this function, the user next FTP request is randomly updated using an exponential distribution with a mean that equals the FTP reading time.

B. The User Departure Event

When a user arrives to a base station, the BS schedules the user in some RBs to fulfill his application requirements. A service time is generated to indicate for how long this user will use these assigned RBs. When this time elapses, i.e., the user session is finished, the BS has to vacate these RBs and reset their service time.

[2]A resource element is one OFDM subcarrier in a certain OFDM symbol. The number of REs per RB calculated here is calculated assuming that the first two OFDM symbols in the subframce (14 symbols/subframe assuming Normal Cyclic Prefix) are used for control and neglecting the other control information overheads (such as Primary Synchronization Signal (PSS), Secondary Synchronization Signal (SSS), etc.)

Table II: Simulation Parameters

Parameter	Value	Parameter	Value
System BW (MHz)	5	Simulation Time (hours)	100
RBs/BW	25	Femtocells RBs/ frames	200
Frame time (ms)	10	Max. FTP assigned RBs/2frames	40

Propagation Model	Parameter Value
Path loss exponent	3.5
Outdoor shadowing	8dB
Indoor shadowing (femto BS-user in same home)	4dB
Indoor shadowing (femto BS-user in 2 adjacent homes)	6dB
Macro BS parameters	
Number macro BS	3
Macro Tx power (watt)	2
Macro SNR at cell edge (dB)	3
Macro Radius (m)	500
Macro load (Erlang)	40
Macro VoIP mean call time(s)	180
Number macro FTP users	20
Femto BS parameters	
Number femto BSs	4
femto SNR at cell edge (dB)	10
femto Radius (m)	20
femto load (erlang)	15
Macro mean call time(s)	180
Femto-Macro distance	100m
Number femto FTP users	5

V. Simulation Results

In this section, performance simulations for the scenarios presented before are carried out. The aim of this study is to evaluate the performance of the different deployments and the performance gains provided by the proposed coordinated scheduling technique. The performance of the network is evaluated via different measures such as the users blocking probabilities and the cells throughputs. Table II summarizes the simulation parameters used. The parameters in this table are used as the default parameters if nothing else is mentioned.

Fig. 1 shows the users blocking probability (FTP users or VoIP users) for different values of femtocell allocated RBs. The user is blocked if no empty RBs are found in the serving BS or if the RBs' SINR is less than the minimum user profile requirement. As shown in Fig. 1, in all deployments the femtocell user average blocking probability, whether FTP users or VoIP users, decreases with increasing the number of femtocell allocated RBs. The FTP users blocking probability is always higher than VoIP, as FTP requires more RBs and higher modulation and coding scheme to fulfill the minimum throughput requirement (128 kbps).

In partial co-channel deployment, the femtocell users blocking probability is higher than the dedicated deployment blocking probability. The reason for this is the presence of macrocell cross-layer interference in the shared spectrum band. The proposed scheme, although is based on partial co-channel deployment, gives better performance for femtocells. The explanation for this is that in the coordinated partial co-channel deployment, only macro VoIP users that are not served in the macro separate spectrum are scheduled in the femto spectrum part. Therefore, lower numbers of macro users interfere with the femtocells transmissions. Consequently, cross-layer interference suffered by the femto-layer is minimized and femto users blocking probability decreases significantly.

Fig. 2 shows the effect of changing the number of macro

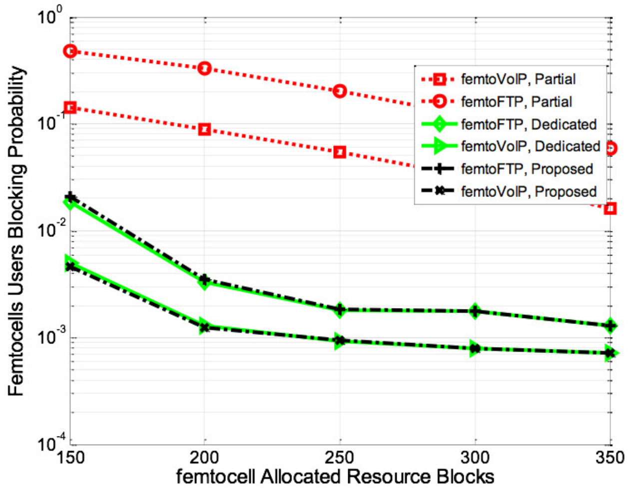

Figure 1: Femtocells Blocking Probability versus femtocell allocated RBs

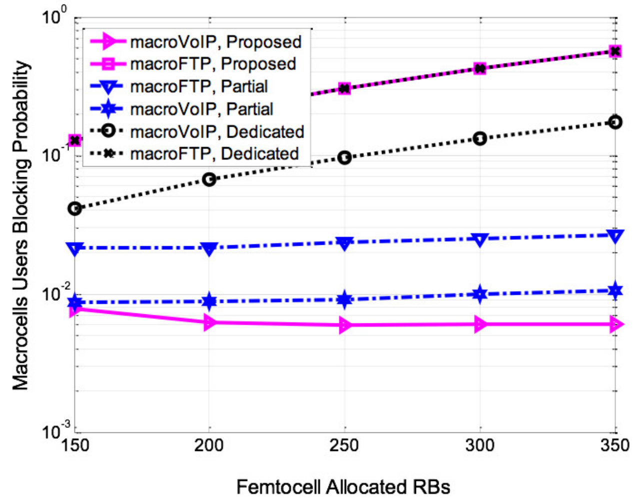

Figure 3: Macrocells Blocking Probability versus femtocell allocated RBs

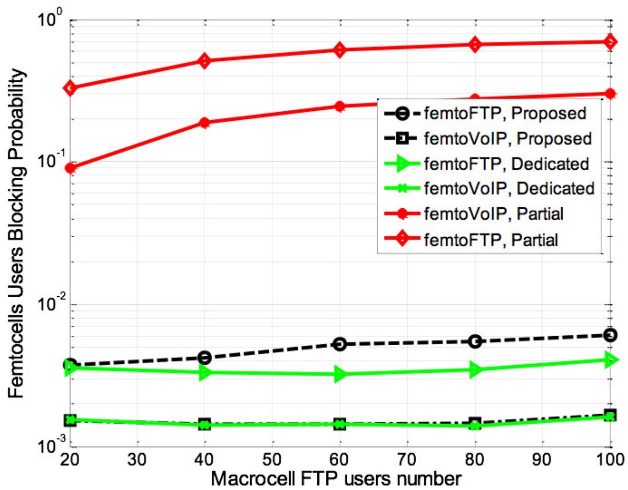

Figure 2: Femtocells Blocking Probability versus macrocell FTP users

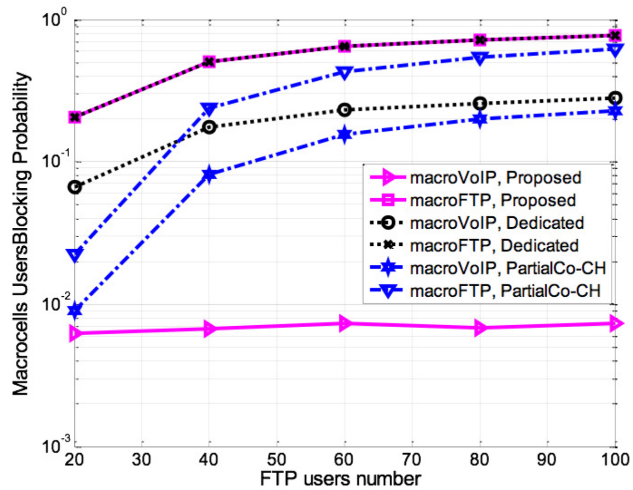

Figure 4: Macrocells Blocking Probability versus macrocell FTP users

FTP users on the femto-layer in the different deployments. The number of femtocell FTP users is assumed to be 5 users (worst case scenario). Fig. 2 illustrates how uncoordinated partial co-channel deployment can highly degrade the femtocell performance for large number of macro FTP users. This is because of the high cross-layer interference that is present in the shared spectrum part, where large number of RBs in this part is allocated to the macro FTP users to fulfill their service requirements. Consequently, in a large number of femtocells RBs suffer from high cross-layer interference.

From Fig. 2 it is clear that the proposed scheme has elevated performance for femto-layer (almost similar to the femtocell preferable dedicated deployment). This is due to detaching the femto users from the macro FTP users that are more in number and voracious for RBs. As a result, the inter-cell interference is minimal and femtocells almost operate separately as in the dedicated deployment case.

Figs. 3 and 4 show the performance of macrocells under the use of the three different deployments for different values of femtocell allocated RBs and different numbers of macro FTP users. These figures illustrate the advantage of partial co-channel deployment for macrocells. In this deployment, macrocell has the authority to use the whole available licensed frequency band. As a consequence, the macrocell users blocking probability is clearly reduced in partial deployment. On the other hand, the dedicated deployment degrades the macrocell performance due to reserving part of macrocell's licensed spectrum for femtocells usage. This reservation reduces the macrocells already limited resources and lead to higher user blocking probability.

As clear from Figs. 3 and 4, the proposed partial co-channel with macrocell coordinated scheduling gives the best performance for macro VoIP application. The proposed scheme has a better performance than the dedicated deployment.

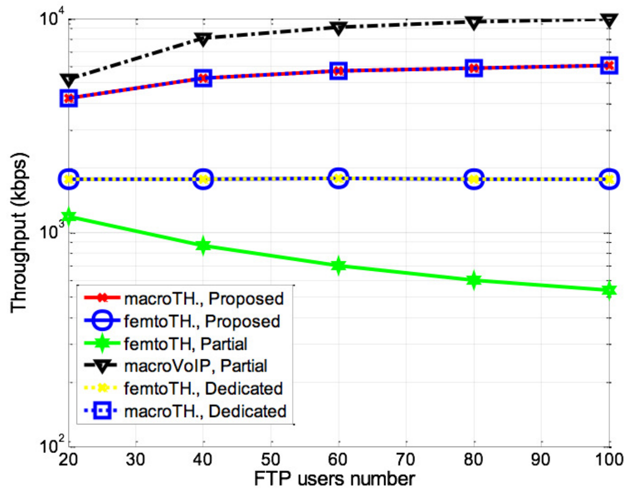

Figure 5: Femto and macro accumulated throughput versus macro FTP users.

Furthermore, the proposed coordinated approach has better performance than uncoordinated partial co-channel. The explanation for this is that in the uncoordinated deployment the macro VoIP application competes with the macro FTP application over the available RBs for the whole used BW. FTP is a RBs greedy application that requires a large number of RBs to fulfill its requirements. As a result, little number of RBs is available for macro VoIP application.

On the other hand, in our proposed scheme, the macro VoIP application has two disjoint spectrum parts; in one part, the macro dedicated part, macro VoIP is struggling for the RBs with the FTP application; while in the other part, the femto-shared part, macro VoIP almost operates with a small number of other macrocells VoIP users. In the femto-shared part, the serving macrocell serves only macro VoIP, thus the blocking probability for macro VoIP users greatly decreases. Furthermore, the femto cross-layer interference on macro-layer is confined as the femtocells transmit power is small compared to the macrocells power.

Fig. 5 shows the throughput for the three different deployments for both layers for different numbers of macro FTP users. In uncoordinated partial co-channel deployment, the femtocells accumulated throughput is much less than the dedicated deployment. The explanation for this is the presence of great cross-layer interference in this deployment. On contrast, the proposed coordinated partial co-channel has superior femtocells throughput (similar to the femtocell preferable dedicated deployment). This is due to the reduced interference level in the proposed coordinated deployment, where macro FTP users are scheduled in separate spectrum segment.

For the macro-layer, the macrocells accumulated throughput in the dedicated deployment is lower than the partial co-channel deployment. On contrast, in partial co-channel deployment, macrocell can use the whole valuable licensed band. Consequently, the macrocells' accumulated throughput is much higher. For the proposed scheme, Fig. 5 shows that although the proposed coordinated partial co-channel is beneficial for femto-layer applications and improves macro VoIP application in macro-layer, it has no advantage for macro FTP application.

VI. Conclusions

The paper presents a proposal for the coordination and spectrum sharing among macro and femto base stations. Part of the band is dedicated for macro base stations while the rest of the band is shared. In the shared band macro base stations can assign VoIP, while femto base stations can assign VoIP or FTP users. Other traffic will be studied in future research. The following conclusions can be drawn. Femto base stations are minimally affected by interference from macro base stations., while femto base stations considerably increase the system throughput. Also, sharing part of the band among the macro and femto base stations in which the macro base stations allocate only VoIP users proves to be the best sharing scenario. With the appropriate choice of the ratio of the band to be shared the FTP traffic increases in both types of base stations.

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