A Hybrid Approach of Time-Frequency Domain Interference Coordination for QoS Guarantee in Macro-Femto Co-channel Deployment

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***Abstract*—Femto is introduced to enhance the indoor coverage and the system capacity in LTE-Advanced system. Some methods, such as time domain interference coordination (TDIC) and frequency domain interference coordination (FDIC), have been discussed to deal with the interference between macro and femto cell when they are deployed in co-channel manner. However, TDIC operates well even though the system load is heavy but it cannot offer enough throughput in certain scenarios. On the contrary, FDIC could offer high throughput under light-load conditions at the cost of much more bandwidth. Combined the advantages of TDIC and FDIC, an approach of hybrid domain interference coordination (HDIC) is proposed and a greedy algorithm is designed in this paper. Moreover, different to the pure TDIC, TDIC used in HDIC is enhanced by allowing the user hopping to a better carrier to cooperate, namely carrier selective TDIC (CS-TDIC). Simulations show that HDIC could improve the average throughput of system in the case of light load and enable more users to meet their QoS demand of services when the load is heavy.**

I. Introduction

It is estimated that 2/3 of voice and over 90% of data traffic originate indoors [1]. Therefore, the indoor, low-mobility and hotspot communication is becoming more and more important in the mobile Internet era. Under this condition, the Third Generation Partnership Project Long Term Evolution (3GPP LTE) introduces some low power nodes [2] to increase the system capacity and resolve the problem of uneven distribution of users.

As one of the low power nodes, femto, namely Home eNB (HeNB), deployed indoors or in offices, is considered as an important candidate to cover the indoor application. The user equipment (UE) served by the same HeNB form a closed subscriber group because only the UEs that have been registered by the owner are admitted to access to. HeNBs are connected to Mobility Management Entity (MME) via wired links as the backhauls [3].

Interference takes place when non-femto/femto users are in close proximity of HeNB in macro-femto co-channel deployment [4]. In this paper, we will study how to deal with the interference when a macro UE (MUE) closes to a HeNB. Concretely, there exist two cases for this interference as shown in Fig. 1, namely downlink and uplink interferences. Both MUE and HeNB UE (HUE) work in downlink transmission for the former case and in uplink transmission for the latter

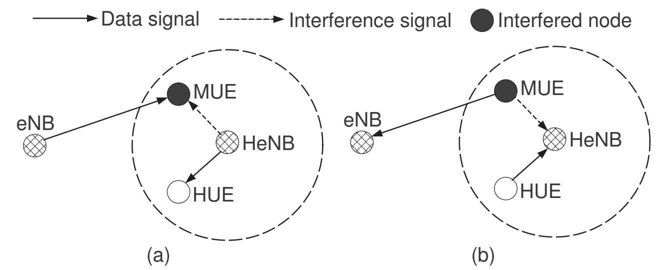

Fig. 1. Two cases of interference when a MUE closes to a femto. (a)Downlink interference; (b)Uplink interference.

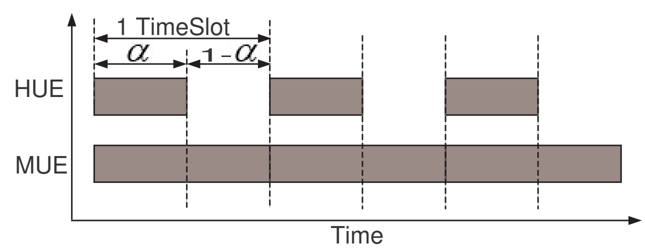

Fig. 2. An illustration of TDIC for scenario shown in Fig.1(a)

case. The cases that MUE and HUE operate in different transmissions can be cancelled by synchronization between eNB and HeNB to prevent too complex interference condition to be treated [5]. In addition, other interference still exists in these two cases, such as the interferences from eNB to HUE in case (a) and from HUE to eNB in case (b). However, these are not the dominating interferences in system because the femtos should not be deployed near the eNB and the reference signal receiving power (RSRP) of HUE is generally far stronger than the interference power from eNB. Besides, power control is adopted for users to avoid too serious interference from user to base station.

The main method to account for this problem is resource partition [6], including time domain interference coordination (TDIC) and frequency domain interference coordination (FDIC). Taking the downlink interference in Fig. 1(a) for instance, TDIC can be illustrated as shown in Fig. 2, in which the MUE keeps going on all the duration while the HUE is

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TABLE I
COMPARISON BETWEEN TDIC AND FDIC

	Merits	Drawbacks
TDIC	1. *No additional* resource is required 2. *Operates well* when the system load is heavy	1. *Cannot provide enough* throughputs in certain scenarios
FDIC	1. *Offer high* throughputs for light-load condition	1. *Requires more* bandwidth 2. *Cannot work* when the load is much heavy

mute in a fraction of a timeslot [7][8]. Obviously, TDIC does not require additional spectrum resources since it is employed in current carrier. However, it cannot offer enough throughputs when the MUE is far from the base station (eNB) or the QoS demand of MUE is very high. Compared to TDIC, FDIC supports higher throughput because the MUE tries to escape to an idle and conflict-free carrier, namely escape carrier [9]. Thus, the carrier is enjoyed alone by MUE in FDIC instead of communion with HUE in TDIC. However, some spectrum is required to be reserved in FDIC to ensure that MUE can escape successfully, which leads to a waste of resources. As a matter of fact, it is almost impossible to reserve too many frequency resources thanks to the scarcity of spectrum, except that the load of system is light enough. All in all, TDIC cannot offer enough throughputs in certain scenarios but it operates well even though the system load is heavy. Moreover, FDIC could offer high throughputs under light-load conditions at the cost of much more bandwidth.

The results of the analysis are also illustrated in TABLE I, which shows the complementary relationship of performance of TDIC and FDIC. Thus, combined TDIC and FDIC, an approach of hybrid domain interference coordination (HDIC) is proposed in this paper for QoS guarantee in macro-femto co-channel deployment of LTE-Advanced system, expecting that QoS demand can be met for more users and high throughput can be obtained under any load condition. In HDIC, the MUE transfers to a "better" carrier from its original carrier. For example, the MUE could transfer to another carrier in which the HUE is more nearer to the HeNB or has the lower traffic demand than the HUE working in original carrier of MUE. If this "better" carrier is just idle and unused by any HUE under the interfering femto, FDIC is employed. Otherwise, TDIC is applied in this new carrier. Therefore, FDIC and TDIC can be taken as the special case of HDIC when the "better" carrier is idle and conflict-free and when the original carrier of the MUE is just a "better" one, respectively. In this sense, TDIC and FDIC are unified in HDIC. What is the "better" carrier and how to select a "better" carrier will be studied in this paper. Furthermore, we design a greedy algorithm for HDIC to facilitate the employment of HDIC in a realistic system. In this algorithm, the MUE always tries to transfer to the "best" carrier.

The rest of this paper is organized as follows. Section II details the principle of HDIC and proposes a greedy algorithm. In Section III, a system level simulation is given to show that HDIC can obtain better performance in LTE-Advanced system. Finally, we conclude this paper in Section IV.

II. A Hybrid Approach of Time-Frequency Domain Interference Coordination for QoS Guarantee

Interference occurs when a MUE closes with a HeNB. To favor the explanation of our proposed scheme, downlink interference presented in Fig. 1(a) is taken as the example for analysis and evaluation in this paper.

A. Hybrid Domain Interference Coordination

In TDIC presented in Fig. 2, the MUE cooperates with the HUE in the original carrier. However, this may not be the best choice when the QoS demand of MUE cannot be satisfied. In this situation, the MUE should hop to another "better" carrier, in which TDIC could be applied and better performance could be obtained. For example, the MUE could hop to a carrier in which a HUE with low QoS demand or high SINR works.

To avoid influencing the existing active users, the MUE should transfer to a new carrier which has not been used by other MUEs. Then, two probabilities occur in this carrier:

- No HUE works in this carrier.
- A HUE with low QoS demand or high SINR operates in this carrier.

The former is called a blank carrier and the latter is called a cooperating carrier. If the QoS requirement of MUE could be guaranteed in this carrier, it is taken as the "better" one and called a blank efficient-carrier for the former case or a cooperating efficient-carrier for the latter case. We call this scheme hybrid domain interference coordination (HDIC).

If the "better" carrier is a blank one, TDIC in this carrier will reduce to FDIC. Likewise, TDIC could be applied in the MUE's original carrier if it is a cooperating efficient-carrier. Otherwise, the MUE will hop to a "better" carrier and cooperate with the HUE in this carrier, which we call carrier selective TDIC (CS-TDIC). Thus, our scheme consists of TDIC, FDIC and CS-TDIC, which is why we call our scheme HDIC.

B. A Greedy Algorithm for HDIC

For the downlink interference presented in Fig. 1(a), the SINRs of MUE and HUE before the interference is treated could be expressed as $\gamma_1 = \frac{P_1}{P_1^I + IN_1}$ and $\gamma_2 = \frac{P_2}{P_2^I + IN_2}$, in which P_1 and P_2 indicate the received data signal power of MUE and HUE, P_1^I and P_2^I the received interference signal power of MUE from HeNB and that of HUE from eNB, IN_1 and IN_2 the sum of the noise and the received interference signal power from other nodes for MUE and HUE. Thus, the throughput of MUE and HUE can be given by

$$\begin{cases} C_M = W \log(1 + \gamma_1) \\ C_H = W \log(1 + \gamma_2) \end{cases} \tag{1}$$

where W is the bandwidth of a user, which is assumed the same for MUE and HUE here.

$\gamma_1^{'} = \frac{P_1}{IN_1}$ indicates the SINR of MUE when the interference from HeNB has been cancelled via TDIC. Thus, the throughput of MUE and HUE after TDIC can be expressed as

$$\begin{cases} C_M^{TD} = \alpha W \log(1+\gamma_1) + (1-\alpha) W \log(1+\gamma_1^{'}) \\ C_H^{TD} = \alpha W \log(1+\gamma_2) \end{cases} \quad (2)$$

Supposing that the data rate demand of MUE and HUE are R_1 and R_2 referring to their services, the throughput of MUE and HUE should be subject to

$$\begin{cases} C_M^{TD} \geq R_1 \\ C_H^{TD} \geq R_2 \end{cases} \Rightarrow \begin{cases} \alpha \leq \dfrac{W\log(1+\gamma_1^{'}) - R_1}{W \log \frac{1+\gamma_1^{'}}{1+\gamma_1}} = Z_1 \\ \alpha \geq \dfrac{R_2}{W\log(1+\gamma_2)} = Z_2 \end{cases} \quad (3)$$

To enable (3) to have solutions, it requires that $Z_1 \geq Z_2$, i.e.

$$\Omega = W\log(1+\gamma_1^{'}) - R_1 - \frac{R_2}{\log(1+\gamma_2)} \log \frac{1+\gamma_1^{'}}{1+\gamma_1} \geq 0 \quad (4)$$

If (4) is satisfied, the parameter α could be chosen from $[Z_2, Z_1]$. In order to ensure that α keeps available as long as possible when UE moves, $\alpha = \frac{Z_1+Z_2}{2}$ is selected in a realistic system.

FDIC could be taken as the special TDIC when $\alpha = 0$. Then, (4) could be reduced to

$$\Omega = W\log(1+\gamma_1^{'}) - R_1 \geq 0 \quad (5)$$

Thus, whether a carrier is "better" for the target MUE could be determined by Ω in (4). The larger Ω is, the "better" this carrier appears. According to the definitions in last subsection, the blank carrier satisfying (5) is called a blank efficient-carrier while the cooperating carrier satisfying (4) is called a cooperating efficient-carrier.

To facilitate the employment of HDIC in a realistic system, a greedy algorithm is designed as shown in Fig. 3.

Interference coordination is triggered when the MUE is under its QoS demand due to the downlink interference mainly cost by the nearby femto, namely

$$C_M < R_1 \quad (6)$$

where C_M is defined in (1). Firstly, the MUE tries to find the "best" blank efficient-carrier, which is defined as the blank efficient-carrier with the maximal Ω in definition (5), and then FIDC is employed. If no blank efficient-carrier exists in the system, the MUE will check whether there are cooperating efficient-carriers. If an affirmative answer is given, the MUE will choose the "best" one, which is similarly defined as the cooperating efficient-carrier with the maximal Ω in definition (4). Here, TDIC is considered as a special case of CS-TDIC. If there is no any idle carrier satisfying (4), the MUE will come back to its original carrier and then it go on without any interference treatment. This suggests that no action will be taken if there is no enough resource to support interference coordination. As a matter of fact, other measures, such as the allocation of more bandwidth, could be adopted in this case. However, it is not what we focus on in this paper.

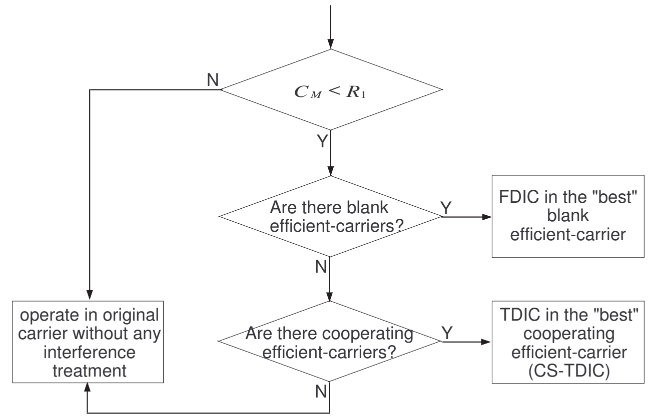

Fig. 3. A greedy algorithm for HDIC

In a word, FDIC is given the highest priority to obtain higher throughput for MUEs. Then, CS-TDIC is taken as the complement to enable more MUEs to meet their QoS demand.

III. Simulation and Evaluation

In this section, TDIC and FDIC will be taken as the comparisons. Without loss of generality, the scheme without any interference coordination (no-IC) is chosen as the baseline.

A. Simulation assumptions

Only downlink transmissions are considered in our simulation, as shown in Fig. 1(a). The simulation parameters are configured referring to [10][11], as presented in TABLE II. Inter-station distance (ISD) indicates the distance between any two neighboring eNBs. The cell radius of femtocell is defined as the distance between HeNB and the point, which locates on the linking line between HeNB and eNB. A user locating at this point could achieve the same received power from eNB and HeNB. Power control is adopted for HeNBs to ensure the cell radius anywhere while there is no power control for eNBs. 19 eNBs are considered in our simulation.

One resource block (RB) per UE is assumed. This implies that each femetocell could admit a maximum of 25 UEs to access while it will reach to 100 for a macrocell. N UEs distribute in a macrocell. 90% of the N UEs are indoor users, 50% of which are HUEs. Therefore, the macrocell with 4 HeNBs can accommodate up to 200 UEs, in which 10%, 40% and 50% are outdoor MUEs, indoor MUEs, HUEs, respectively.

Actually, it is not true that only one RB is allowed to be used by each UE in realistic system. Radio resource management will allocate more bandwidth to users with poor channel quality and high traffic demand. Thus, a MUE with small bandwidth and a HUE with large bandwidth may interfere with each other in their overlapping spectrum. The cooperation carrier in this paper can be considered as the overlapping spectrum in practical system. On the other hand, we study interference coordination instead of bandwidth allocation in

TABLE II
SIMULATION PARAMETERS

Parameters	Macrocell	Femtocell
Carrier frequency	2GHz	2GHz
System bandwidth	20MHz (100RBs)	5MHz (25RBs)
Cell layout	Hexagonal Grid, Omni-directional antenna, 19 eNBs	Circular cell, 4 HeNBs per Macro
Cell size	ISD=500 m	radius=10 m
Antenna gain	14 dBi	5 dBi
Pathloss (dB)	$15.3 + 37.6 \log_{10} d$	$37.0 + 30 \log_{10} d$
penetration loss	20 dB	20 dB
Lognormal shadowing standard deviation	4 dB for link between HeNB and indoor UE, 8 dB for other links	
Max. transmit power	43 dBm	20 dBm
Thermal noise level	-174 dBm/Hz	-174 dBm/Hz
Min. distance between UE and BS	35 m	3 m
Min. distance between eNB and HeNB	75 m	

this paper. Hence, the assumption that each user uses one RB is rational and feasible in simulation.

Let γ_i indicate the received SINR of a user i. Constrained by achievable modulation and coding scheme in practical system, the capacity of a link cannot reach the Shannon limit $C = W \log(1 + \gamma_i)$. Therefore, another formula to calculate throughput of user i is introduced (kbps) [10][12]

$$X_i = \begin{cases} 5.4W & \gamma_i \geq 32\text{dB} \\ 0.56 \log(1 + \frac{\gamma_i}{2}) & \text{-10dB} \leq \gamma_i < 32\text{dB} \\ 0 & \gamma_i < -10\text{dB} \end{cases} \quad (7)$$

where W=200kHz due to the assumption that each user uses one RB.

Due to the definition of throughput in (7), we get

$$\begin{cases} W \log(1 + \gamma_1) = X_1 \\ W \log(1 + \gamma_1^{'}) = X_1^{'} \\ W \log(1 + \gamma_2) = X_2 \end{cases} \quad (8)$$

Thus, the corresponding expressions in ($1 \sim 5$) should be rewritten based on (8) when they are used in simulation.

Two types of services are considered here. 128kbps for high quality streaming audio and 384kbps for videophone are required in order to guarantee a quality user experience [13]. It is assumed that 70% of the users use high quality streaming audio and the remainder use videophone here.

This simulation is completed in MATLAB.

B. Simulation results

There are 4 HeNBs in each macrocell. Taking the eNB as origin to establish Cartesian coordinate system, the positions of 4 HeNBs could be given by (80,0), (0,130), (-180,0) and (0,-230). Why these HeNBs locate with different distances from the eNB is because that femtos are unplanned nodes and could be deployed by users themselves. So, a femto could lie anywhere independent of the position of eNB. Meanwhile, the 4 femtos disperse in the cell to ignore the interference among femtos, which is not what we concern about here.

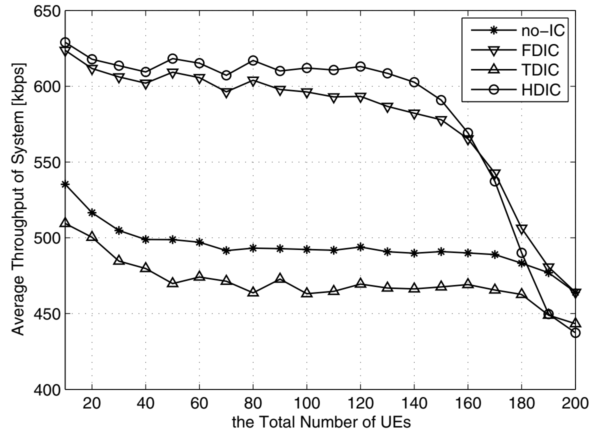

Fig. 4. Average throughput of UE

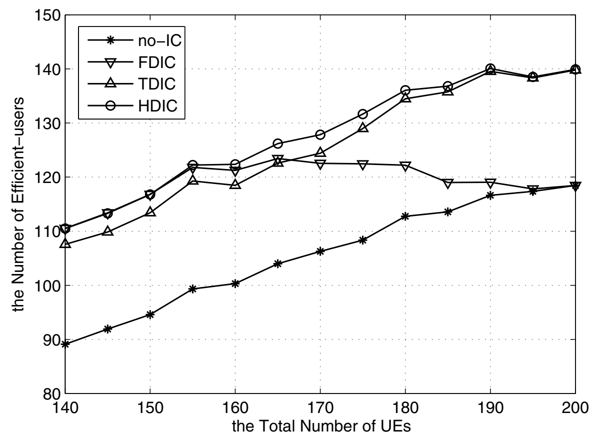

Fig. 5. Efficient-users

When N is small, the resources are so sufficient that every UE could be served well. In this case, we should further improve the throughput to provide higher quality of experience (QoE) for users via interference coordination. This aim could be reached in HDIC, as shown in Fig. 4. When $N < 165$, the highest throughput could be achieved in HDIC. On the other hand, we observe that TDIC performs poorer than no-IC on average throughput. Actually, whether the average throughput of TDIC goes up relative to that of no-IC is determined by

$$C_M^{TD} + C_H^{TD} > C_M + C_H \quad (9)$$

Based on (1) and (2), it can be written as

$$\log_2(1 + \gamma_1^{'}) > \log_2(1 + \gamma_1) + \log_2(1 + \gamma_2) \quad (10)$$

Limited by the definition (8), it should be transferred as

$$X_1^{'} > X_1 + X_2 \quad (11)$$

Obviously, TDIC performs poorer than no-IC because (11) is not satisfied.

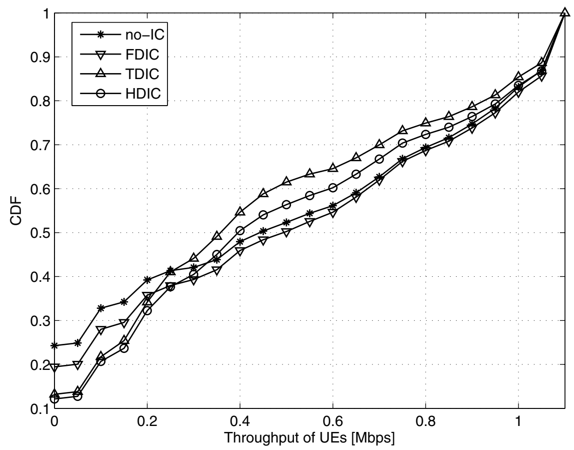

Fig. 6. The cumulative distribution functions (CDF) of UE throughput when N=180

When N is large, interference between eNB and HeNBs is so severe that lots of users cannot satisfy their QoS demands. In this case, we should enable as many users as possible to meet the requirements of date rate. The user satisfying its QoS demand is defined as an efficient-user. As presented in Fig. 5, the number of efficient-users in HDIC is the largest among all schemes and it improves significantly when $N > 150$. This implies that HDIC can support more users to satisfy their QoS demands than any other scheme when the load is heavy. On the other hand, with the increase of the number of users, there are not enough resources to support FDIC while TDIC operates well. Therefore, TDIC exceeds FDIC in the number of the efficient-users when $N > 165$, as shown in Fig. 5.

Why are the gains obtained in HDIC? When the load of system is light, FDIC dominates in HDIC. Compare to the pure FDIC, user always tries to find the best blank carrier to further improve its throughput. So, HDIC has the highest performance on throughput than the pure FDIC. When the system load is heavy, TDIC dominates in HDIC. Different to the pure TDIC, however, user could hop to another better carrier to cooperate in HDIC, namely CS-TDIC. Then, the users which cannot meet the QoS demands in their original carrier may be satisfied when they works in the better carriers. Thus, the number of efficient-users increases. In addition, the increase of efficient-users is at the expense of the decrease of the throughput of certain users. As presented in Fig. 6, HDIC achieves the best performance for UEs with low rate but performs worse than no-IC and FDIC on the performance of UEs with high rate. This is because the throughput of MUEs with low rate is improved at the expense of degradation of performance of HUEs with high rate.

IV. Conclusion

In this paper, a hybrid approach of time-frequency domain interference coordination (HDIC) is proposed to reduce the interference between macrocell and femtocell in macro-femto co-channel deployment for LTE-Advanced system. To favor the explanation of the proposed scheme, the downlink interference presented in Fig. 1(a) is taken as the example in this paper. In HDIC, a MUE transfers to a "better" carrier, and then FDIC for blank efficient-carrier or TDIC for cooperating efficient-carrier is applied. The criterion to determine whether a carrier is "better" is studied and then a greedy algorithm for HDIC is designed, in which MUE always tries to seek the "best"carrier. The system level simulations show that HDIC could improve the average throughput of system in the case of light load and enable more users to meet their QoS demand of services when the load is heavy. On the other hand, we must note that these gains are obtained at the expense of processing overhead caused by hopping frequency and computing cost induced by seeking the "best" carrier. Finally, we emphasize that the application of HDIC can be extended to other interference scenarios with little modification, such the case of uplink interference as shown in Fig. 1(b).

Acknowledgment

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