Non-Cooperative Inter-Cell Interference Coordination Technique for Increasing Throughput Fairness in LTE Networks

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***Abstract*—One major concern for operators of Long Term Evolution (LTE) networks is mitigating inter-cell interference problems. Inter-Cell Interference Coordination (ICIC) techniques are proposed to reduce performance degradation and to maximize system capacity. It is a joint resource allocation and power allocation problem that aims at controlling the trade-off between resource efficiency and user fairness. Traditional interference mitigation techniques are Fractional Frequency Reuse (FFR) and Soft Frequency Reuse (SFR). FFR statically divides the available spectrum into reuse-1 and reuse-3 portions in order to protect cell-edge users, while SFR reduces downlink transmission power allocated for cell-center resources to protect vulnerable users in the neighboring cells. However, these static techniques are not adapted to non-uniform user distribution scenarios, and they do not provide guarantees on throughput fairness between user equipments. In this paper, we introduce a non-cooperative dynamic ICIC technique that dynamically adjusts resource block allocation according to user demands in each zone. We investigate the impact of this technique on throughput distribution and user fairness under non-uniform user distributions, using an LTE downlink system level simulator. Simulation results show that the proposed technique improves system capacity, and increases throughput fairness in comparison with reuse-1 model, FFR and SFR. It does not require any cooperation between base stations of the LTE network.**

***Index Terms*—Long Term Evolution, inter-cell interference, ICIC, FFR, SINR, fairness.**

I. INTRODUCTION

The exponential increase in the number of mobile users, the proliferation of mobile applications and the huge demand for data in mobile networks have led to the introduction of new radio access technologies such as Long Term Evolution (LTE) [1] of Universal Mobile Terrestrial Radio Access System (UMTS). However, wireless communications are characterized by the scarcity of frequency resources required to increase network capacity and to satisfy throughput demands.

3^{rd} Generation Partnership Project (3GPP) LTE chooses frequency reuse-1 model to make maximum use of the available spectrum. Although Orthogonal Frequency Division Multiple Access (OFDMA) technique [2] eliminates intra-cell interference, due to the orthogonality between subcarriers, Inter-Cell Interference (ICI) problems always exist. They have a negative impact on system performance, since they reduce network capacity and User Equipment (UE) throughput, especially for cell-edge UEs located at the border of the cell and receiving high power interfering signals.

Inter-Cell Interference Coordination (ICIC) techniques are required to improve system performance. Some techniques perform ICI mitigation by adjusting resource allocation between cell zones, or between LTE base stations called evolved-NodeBs (eNodeBs). Other ICIC techniques use power allocation strategies to reduce interference in a non-cooperative manner [3], or in a coordinated manner, when eNodeBs cooperate together in order to perform power allocation. ICIC is also seen as a joint resource and power allocation problem, where the objective is to find the optimal resource and power distribution. Fractional Frequency Reuse (FFR) [4] is a static ICIC technique, where restrictions on Resource Blocks (RBs) usage are imposed to protect cell-edge UEs. Another static ICIC technique is Soft Frequency Reuse (SFR); it controls the downlink transmission power allocated for each set of RBs. FFR and SFR are considered as reference state-of-the-art techniques for research on ICI mitigation.

In this paper, we introduce a non-cooperative dynamic ICIC technique that does not require any cooperation between LTE base stations. Our aim is to improve system performance, and to increase cell-edge UEs throughput. Resource and power allocation decisions are made locally by the scheduler of each eNodeB, in order to respond dynamically to throughput demands in each zone. An LTE downlink system level simulator developed by Vienna University of Technology is chosen to simulate our technique, and to compare its performance to that of reuse-1 model, FFR and SFR schemes. Simulation results show that our proposed technique reduces ICI, improves cell-edge UEs performance and increases throughput fairness among all the existing UEs in the network.

The rest of the paper is organized as follows: in section II, we describe the existing ICIC techniques. Section III presents system model. In section IV, we introduce and explain our proposed ICIC technique. Section V gives information about simulation environment, and simulation results are reported in section VI. Concluding remarks are given in section VII.

II. RELATED WORK

The scarcity of radio resources is becoming more severe with the huge increase in data demands, and with the proliferation of mobile applications. LTE network operators are committed to reduce ICI, and to improve cell-edge users performance, while keeping spectral efficiency at an acceptable level. Another concern that we particularly address in this paper is increasing throughput fairness among all the existing users. Interference mitigation in Global System for Mobile communications (GSM) networks is achieved through the cellular concept [5] as well as frequency planning [6]. Within a cluster of N cells, reuse-N model specifies the number of frequency resources to be used in each cell. However, network capacity and spectral efficiency are reduced.

Classic ICIC techniques for LTE networks divide each cell into two zones: a cell-center zone containing UEs close to the serving eNodeB, and a cell-edge zone containing UEs located at the edge of the cell. FFR and SFR are frequency reuse-based static ICIC techniques. FFR [7] reduces ICI by creating restrictions on RB usage within each cell. The cell-center zone is allowed to use half of the available spectrum according to reuse-1 model. However, reuse-N model is used to allocate the remaining bandwidth among adjacent cell-edge zones. UEs having low Signal-to-Interference and Noise Ratio (SINR) are protected, since they do not receive interfering signals from their neighboring cells. For SFR [8], ICIC is seen as a joint RB and power allocation problem. Reuse-1 model is maintained; however, cell-edge zones in adjacent cells are allocated disjoint portions of the available spectrum to avoid ICI. In addition, the remaining bandwidth allocated for cell-center zones is used at a lower transmission power. The basic principles for FFR and SFR techniques are illustrated in Fig. 1a and Fig. 1b respectively.

LTE architecture does not include a centralized entity that controls the entire network. However, neighboring base stations exchange information about RB usage over X2 interface. Coordinated ICIC techniques make use of the cooperation between adjacent eNodeBs to adjust RB distribution, power allocation, or both according to radio conditions, user demands, or network load. For instance, power allocation is dynamically adjusted according to SINR for each RB in [9]. Note that this cooperation creates an additional signaling traffic that is exchanged between adjacent eNodeBs, and it increases computational complexity in comparison with non-cooperative techniques.

The introduction of LTE-Advanced (LTE-A) architecture and Coordinated Multi-Point (CoMP) transmission and reception techniques [10] gave birth to a new category of ICIC techniques. These techniques are qualified as centralized, since there is a central entity that sets restrictions on RB usage within multiple network cells. A centralized downlink ICIC technique is introduced in [11] where each cell defines RB restrictions for each of its dominant interferer neighbors. A restriction list is sent to the central entity, that makes RB restriction decisions and sends them to network schedulers. The different classes of ICIC techniques are summarized in Table I.

TABLE I: ICIC Techniques Classification

ICIC Class	Description	Example
Frequency reuse	Static RB and power allocation	FFR, SFR
Non-cooperative	RB and power allocation without cooperation	Techniques in [12, 13]
Coordinated	Cooperation between neighboring eNodeBs	Using X2 interface
Centralized	Central control entity	LTE-A architecture

III. System Model

OFDMA is the multiple access technique chosen for the downlink of the radio interface in LTE. The spectrum is divided into several channels, where each channel consists of a number of consecutive orthogonal subcarriers. One RB consists of 12 consecutive subcarriers in the frequency domain, and 7 OFDM symbols (respectively 6) in the case of normal cyclic prefix (respectively extended cyclic prefix) in the time domain. The scheduling period in LTE networks is called Transmit Time Interval (TTI = 1 ms), and the smallest scheduling unit is the RB.

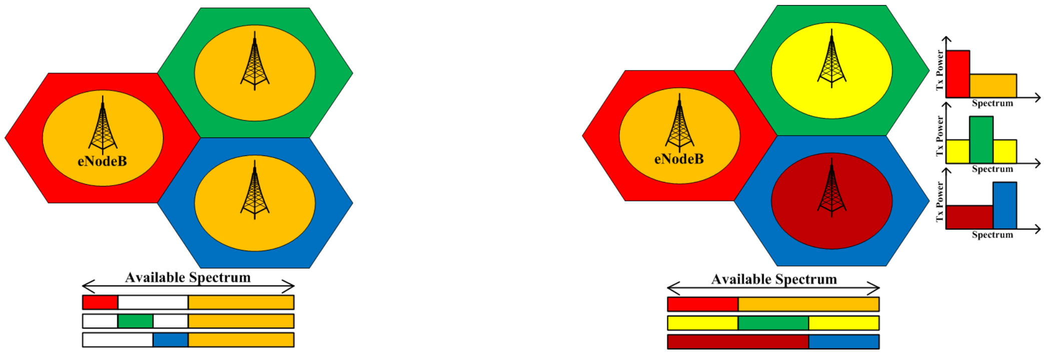
The geographical partitioning of each cell into cell-center and cell-edge zones assumes that cell-center UEs are characterized by high SINR values due to their proximity to the transmitting antennas, and that cell-edge UEs have lower SINR levels since they are far from the serving base station. However, we might have cell-center UEs suffering from interference problems, as well as cell-edge UEs with good radio conditions due to fast fading and other propagation issues. This approach also requires the knowledge of the exact position of each active UE. For these reasons, we perform UE classification according to mean wideband SINR values. An SINR threshold ($SINR_{th}$) is defined to classify UEs: when mean SINR of a UE is higher than the predefined $SINR_{th}$, it is considered as a Good Radio (GR) conditions UE; otherwise, it is considered as a Bad Radio (BR) conditions UE. GR UEs are commonly taken for as cell-center UEs, and BR UEs as cell-edge UEs. Our classification is more accurate than the traditional approach, and it does not require any localization information. SINR of a UE k attached to cell i and allocated RB n is given by:

$$SINR_{k,n}^{i} = \frac{P_n^i \cdot G_{k,n}^i}{\sum\limits_{j \neq i} P_n^j \cdot G_{k,n}^j + P_{TN}} \tag{1}$$

Where P_n^i is the downlink transmission power allocated by cell i for the RB n, $G_{k,n}^i$ is channel gain for UE k served by eNodeB i on RB n, and P_{TN} is the thermal noise power on the considered RB. Indexes i and j refer to useful and interfering signals respectively.

IV. Non-Cooperative ICIC Technique

The main disadvantage of FFR, SFR and other state-of-the-art techniques is that the available spectrum is statically allocated for cell-center and cell-edge zones. These resource allocation policies are not adapted for non-uniform UE distributions between cell zones. We might improve BR UEs throughput, while causing system performance degradation. We introduce a non-cooperative dynamic ICIC technique for multiuser OFDMA networks such as LTE. Originally, RB and power allocation for GR and BR zones are performed according to the SFR scheme. Periodic interventions are made by the scheduler of each eNodeB in a distributed manner to find out whether



(a) FFR technique (b) SFR technique

Fig. 1: FFR and SFR schemes

Algorithm 1 Non-cooperative dynamic ICIC

Allocate RBs and power according to SFR
All UEs send CQI feedbacks to the base station
for each $RB \in RB\_pool$ **do**
  $\overline{\text{CQI}_n}(\text{t}) = \frac{\sum_{k=1}^{K} \text{CQI}_n^k(\text{t})}{K}$
  $\overline{\text{CQI}_n}(\text{t}) = \gamma \times \overline{\text{CQI}_n}(\text{t-1}) + (1-\gamma) \times \text{CQI}_n(\text{t})$
end for
Every 25 TTIs:
if $(\overline{R_{GR}} - \overline{R_{BR}} > \Delta_{th})$ **then**
  Borrow best RB from GR to BR zone
else if $(\overline{R_{BR}} - \overline{R_{GR}} > \Delta_{th})$ **then**
  Borrow worst RB from BR to GR zone
else
  Keep the same RB distribution
end if

TABLE II: Simulation Parameters

Parameter	Value	Description
Inter-eNodeB distance	500 m	Urban area
Operating bandwidth	5 MHz	—
Number of RBs (N)	25	In the 5 MHz bandwidth
TTI	1 ms	Transmit Time Interval
Pathloss model	TS 25.814	Same as in HSDPA
Feedback delay	3 ms	3 TTIs
Scheduler	Round Robin	—
Traffic model	Full buffer	—
eNodeB max. power (P)	20 W	43 dBm
Max. RB power (P_{RB})	0.8 W	$\frac{P}{N}$
SINR threshold	3	UE classification
SFR power ratio (α)	0.25	$P_{GR} = \frac{P_{RB}}{4}$
Δ_{th}	512 kbit/s	UE satisfaction

GR or BR UEs are unsatisfied. Intervention period is 25 ms, so that the scheduler has enough time to receive UE feedbacks, and to calculate mean throughput for each zone. The proposed technique is illustrated in Fig. 2.

In LTE, Channel Quality Indication (CQI) feedbacks [14] sent from UE to eNodeB reflect the level of SINR for a certain frequency band. We use narrowband CQI reports to classify RBs in each zone: the higher the mean received CQI value is, the better the RB is. CQI_n^k denotes CQI feedback sent by UE k for RB n, and $\overline{\text{CQI}_n}$ is the mean CQI value for RB n over all UEs. In addition, we define a throughput threshold value Δ_{th} to decide when UEs of a cell zone are unsatisfied. Algorithm 1 shows how our ICIC technique operates at each scheduler.

Our objective is to increase throughput fairness among all the existing UEs. When mean throughput per GR UE ($\overline{R_{GR}}$) exceeds by Δ_{th} the mean BR throughput ($\overline{R_{BR}}$), the BR zone selects the best RB from GR zone and borrows it to improve BR UEs performance. Reciprocally, when $\overline{R_{BR}}$ exceeds by Δ_{th} the mean GR throughput, the worst BR RB (having the lowest mean CQI value) is borrowed by the GR zone. Power allocation mask is kept the same, so that we do not create additional ICI problems when modifying RB allocation. Δ_{th} is used to specify the tolerated throughput difference between cell zones. It is a tuning parameter that could be adjusted by network operator according to quality of service requirements. Our technique operates locally independently of the scheduler type, and it does not require any additional signaling messages to be exchanged between eNodeBs.

V. Simulation Parameters

A MATLAB-based LTE downlink system level simulator [15] developed by Vienna University of Technology is chosen as the simulation platform. It allows to investigate several system-level issues such as resource allocation and ICI mitigation. We consider an LTE network of several adjacent hexagonal cells. Each cell is equipped with 120° directional transmit antennas with an azimuth offset of 30°. The original version of the simulator includes frequency reuse-1 model as well as FFR technique. However, homogeneous power allocation is considered.

We integrated SFR scheme within the simulator, and we adjusted the power allocation scheme so that the power mask can be modified. Finally, we integrated our proposed distributed ICIC technique. The simulated network includes several adjacent hexagonal LTE cells, with a 5 MHz operating bandwidth. Since the total bandwidth per RB equals 180 kHz, we have 25 RBs available in each cell. SINR threshold is used to classify active UEs into GR and BR UEs. Its value is chosen in order to have indirect control of the percentage of GR UEs when UE positions are generated. Traffic model is full buffer; thus,

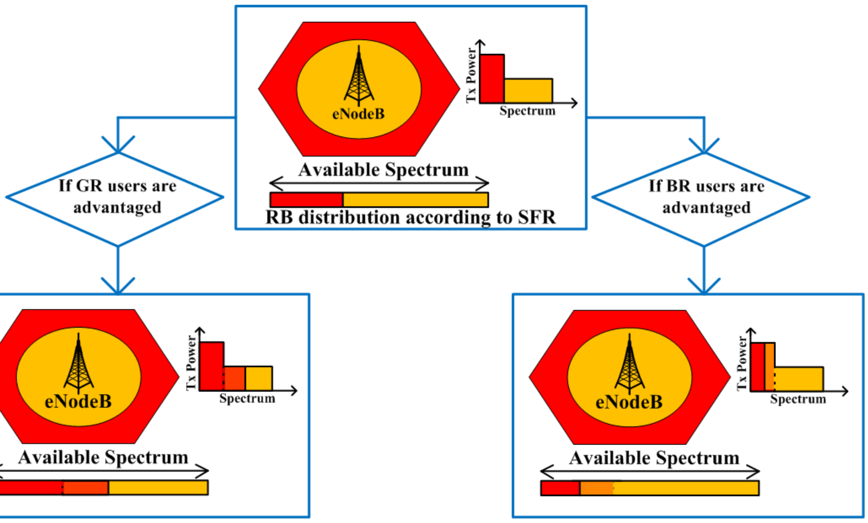


Fig. 2: Distributed ICIC technique

the available spectrum is permanently used to serve UEs once they exist in the network. Simulation parameters are given in Table II. We use Jain's fairness index [16] to measure throughput fairness among all UEs existing in the network. It is given by:

$$J(x_1, x_2, ..., x_n) = \frac{(\sum_{i=1}^{n} x_i)^2}{n \cdot \sum_{i=1}^{n} x_i^2} \quad (2)$$

Where J rates the fairness of a set of throughput values; n is the number of UEs, and x_i is the throughput of UE i. Jain's fairness index ranges from $\frac{1}{n}$ (worst case) to 1 (best case). It reaches its maximum value when all UEs receive the same throughput.

VI. Simulation Results

A. Impact on system throughput

First, we study the impact of our ICIC technique on GR and BR throughputs. We simulate a network of seven LTE cells with 10 UEs randomly placed in each cell. The throughput difference used to decide whether to borrow RBs or not equals 512 kbit/s. Simulation time equals 1000 TTIs, and interventions occur every 25 TTIs to adjust RB allocation between cell zones. Mean throughput for GR and BR zones as well as throughput difference are reported in Fig. 3.

During the first 100 TTIs of simulation time, throughput difference between GR and BR zones exceeds the predefined threshold (512 kbit/s). ICIC algorithm implemented at the scheduler decides to borrow RBs characterized by the highest CQI feedback values from GR to BR zone. Throughput difference is therefore reduced, and we improve quality of service for BR UEs. Our algorithm succeeds in increasing throughput fairness among all UEs existing in the network. Δ_{th} value allows to define the tolerated throughput difference between GR and BR zones.

B. Throughput cumulative distribution function

The simulated network consists of seven adjacent LTE cells with 10 UEs randomly placed in each cell. Simulation

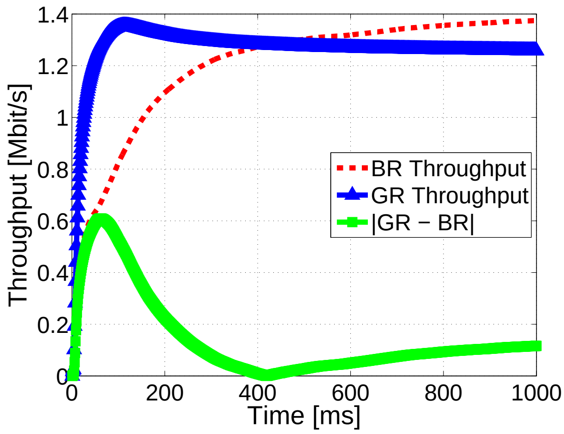


Fig. 3: GR and BR throughputs with time

time is 1000 TTIs, and it is repeated 100 times. The objective is to show how our distributed ICIC technique modifies throughput Cumulative Distribution Function (CDF). The obtained results are shown in Fig. 4.

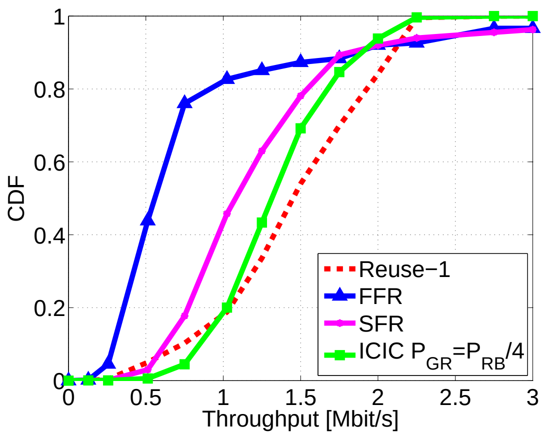


Fig. 4: Throughput cumulative distribution function

For a given throughput value, CDF represents the probability to find a UE served with a low throughput. The lower the CDF is, the better the quality of service is. We notice that our proposed ICIC technique shows a lower CDF for throughput values less than 2 Mbit/s, when compared to FFR and SFR schemes. It also shows the lowest CDF for throughput values less than 1 Mbit/s in comparison with reuse-1 model. Consequently, the number of UEs suffering of bad quality of service is reduced. For throughputs higher than 2 Mbit/s, FFR and SFR are slightly better than the distributed ICIC technique. In fact, our objective is to increase throughput fairness among all UEs by reducing the number of RBs allocated for UEs having relatively high throughputs, in order to improve quality of service for vulnerable UEs.

C. Jain's fairness index

We simulate the same scenario as in the previous subsection. The scheduler used for GR and BR zones is round robin, and ICIC algorithm interventions occur periodically (every 25 TTIs). We generate UEs with uniform and non-uniform distributions between GR and BR zones. For each user distribution, simulations are repeated 30 times, and results are shown in Fig. 5.

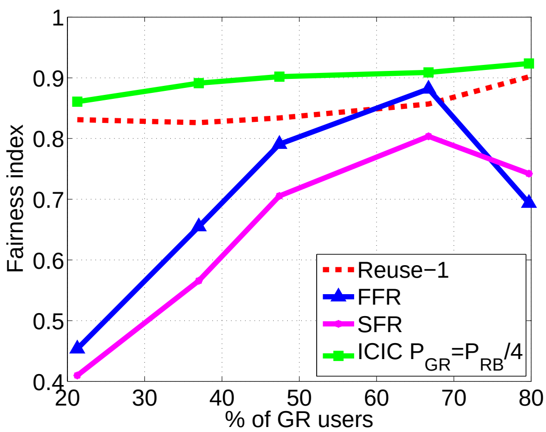


Fig. 5: Fairness index with percentage of GR users

Simulation results reported in Fig. 5 show that FFR and SFR techniques have a lower fairness index in comparison with frequency reuse-1 model, especially for non-uniform user distributions between cell zones. In fact, static RB classification is not adapted for situations where the majority of UEs served by an eNodeB are located in only one of the two zones. FFR improves throughput fairness in comparison with reuse-1 model only when RB classification between GR and BR zones matches UE demands in these zones. SFR's fairness index is lower than that of FFR, since RBs used in the BR zone are permanently used by GR UEs of the neighboring cells. However, it becomes better when the majority of UEs are GR UEs, since FFR provides less RBs for GR UEs. Our proposed non-cooperative dynamic ICIC technique adjusts RB allocation according to UE demands, without any cooperation between eNodeBs. Therefore, it shows the highest Jain's fairness index compared to SFR, FFR and frequency reuse-1 model.

VII. Conclusion

Due to the scarcity of frequency resources required to increase network capacity and to satisfy throughput demands, frequency reuse-1 model is proposed for LTE networks. However, inter-cell interference problems have a negative impact on UE throughput and system performance. Several ICIC techniques are introduced to reduce interference, and to improve quality of service for BR UEs. For instance, FFR adjusts RB distribution between cell zones, while SFR considers ICIC as a joint RB and power allocation problem.

In this paper, we introduced a non-cooperative ICIC technique that dynamically adjusts RB allocation according to UE demands in each zone. It operates locally independently of the scheduler type, and it does not require any cooperation between network base stations. Simulation results show that the proposed ICIC technique reduces throughput difference between cell zones, and improves quality of service for vulnerable UEs. It increases throughput fairness among all UEs existing in the network under uniform and non-uniform user distributions.

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