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Inter-Cell Interference Mitigation Techniques in Long Term Evolution Networks: A Survey

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Abstract

Objectives: This paper gives survey of different techniques and the overview of how the bandwidth is dispensed to the users at the major/edge regions and minor/center regions .It also gives an overview of how the power is dispensed to the users at minor group and major group regions **Methods:** ICIC has one of the schemes which is based on reusing the frequency called as Fractional Frequency Reuse (FFR). There are different techniques of FFR. They are Partial Frequency Reuse (PFR), Soft Frequency Reuse (SFR) and Soft Fractional Frequency Reuse (SFFR). **Findings:** In this survey it is found that, the different techniques of FFR gives different throughput and it is also found that SFFR scheme gives the highest throughput when compared with others. **Applications:** The different techniques of FFR can be used in LTE (Long Term Evolution) based networks. The users will get benefitted based on different power allocations. The real time applications of this technique can be seen in 4G networks.

Keywords: Fractional Frequency Reuse (FFR), Inter-Cell Interference (ICI), Partial Frequency Reuse (PFR), Soft Fractional Frequency Reuse (SFFR), Soft Frequency Reuse (SFR)

1. Introduction

LTE can be evolved from Universal Mobile Telecommunications Service (UMTS) which is defined in 3rd Generation Partnership Project (3GPP) standards or from Evolution Data Optimized (EV-DO) (defined in the 3GPP2 standards) which is illustrated in Figure 1.

LTE has many techniques such as Carrier Aggregation (CA), Multiple Input Multiple Output (MIMO), Co-ordinated Multi-Point (CoMP) and Relay Station to improve transmission performance and extend service coverage of Base Station[1,2]. LTE utilize the Orthogonal Frequency Division Multiplexing (OFDM) which can offer immunity against frequency fading by splitting transmission bandwidth into many number of sub-carriers. Sub-carriers can be Time Division Multiplexing (TDM) and Frequency Division Multiplexing (FDM) among many users which is generally termed as Orthogonal Frequency division Multiple Access (OFDMA)[3]. When OFDMA and Time Division Duplex (TDD) are in usage, the time slot split into OFDM symbols as shown in Figure 2.

The quantity of accessible sub-channels and symbols relies upon the system design and they could fluctuate to help in varying traffic profile[4]. In OFDMA, Binary Phase Shift Keying (BPSK) modulation, which is utilized by the direct transmission, should be exchanged by a Quadrature Phase Shift Keying (QPSK) modulation for the relayed transmission. In addition, QPSK are required for the direct and 16 Quadrature Amplitude Modulation are required for the relayed transmission to utilize the radio resources[5]. OFDMA is adopted in LTE-A to achieve high throughput and spectral efficiency[6]. In the downlink LTE, the scheduler is an important element that assigns Resource Block (RB) allocation for different users in a cell[7]. In LTE, the MAC layer of the eNB is in-charge for scheduling the present dynamic users. This entity plays a vital role in allocating RBs for every Transmission Time Interval (TTI), taking into account of the feedback (Ack/Nack) got from UE in the form of Channel Quality Indicator (CQI), which says about the strength of the signal, send by the UEs to the eNodeB (eNB), to demonstrate the data rate upheld by the downlink chan-

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Figure 1. Evolution of LTE.

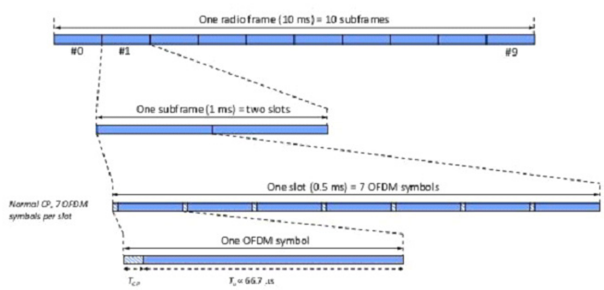

Figure 2. OFDMA.

nel. For scheduling decisions, eNB uses both CA and MIMO. Each Channel Quality Indicator (CQI) has the value in the range of 1 - 15, corresponding to the highest Modulation and Coding Scheme (MCS)[8,9] as delineated in the Table- 1.

ICI reduction is one of the remarkable problems of multi-cell OFDMA networks[3]. ICI is considered as a noteworthy issue which is brought about by frequency band intersecting in the contiguous cells. ICI can bring about in extreme performance reduction in the framework, especially for the UEs at the outer regions[10]. It is because of the shortage of radio resources, frequency must be reused

Table 1. CQI and MCS

CQI VALUE	MCS	MODULATION ORDER	CODINGX1024	EFFICIENCY
1	QPSK	2	78	0.1523
2	QPSK	2	78	0.2344
3	QPSK	2	193	0.3770
4	QPSK	2	308	0.6016
5	QPSK	2	449	0.8770
6	QPSK	2	602	1.1758
7	16QAM	4	378	1.4766
8	16QAM	4	490	1.9141
9	16QAM	4	616	2.4063
10	64QAM	6	466	2.7305
11	64QAM	6	567	3.3223
12	64QAM	6	666	3.9023
13	64QAM	6	772	4.534
14	64QAM	6	873	5.1152
15	64QAM	6	948	5.5547

among various cells. The level of Inter-Cell Interference in OFDMA networks depends upon different factors, for example, the topology of the cell frequency reuse scheme, the power assigned for transmission and multiple access techniques[11,12]. Interference reduction schemes in macro BS context are mainly because of interference randomization in interference, control in interference, suppress in interference and interference co-ordination[13]. In order to gain in SINR (Signal- Interference plus Noise Ratio) value, which is reduced due to ICI on system performance, reduction techniques are introduced[14]. In order to solve the issues in interference due to frequency reuse, the FFR concept is presented for hexagonal / regular cells[15]. There are two techniques of FFR. They are referred as FFR - A and FFR- B[16]. In FFR technique, bandwidth is split into two areas cell-center (also called as minor area) and cell-edge (major area)[17]. In this scheme, FFR have RF1 (reuse factor of 1) for minor region users with less power and reuse factor greater than 1 (namely RF3) for major region users[18]. The adjustment made to the power transmission of the entire bandwidth is called as Power control[19]. The cell-edge users will get the priority of high power allocation in order to gain SINR. There are many types of FFR. They are PFR, SFR, Soft Frequency-Time Reuse (SFTR)[20] and SFFR.

2. System Model

The basic model for developing system model is as follows:

1. S = s1... s7: The group of cells in a network.
2. Z = Z1, Z2, Z3…Zi: The group of channels (sub-bands) that creates the spectrum of frequency in each cell.
3. r = r1, r2, r3,… rq: The group of power levels used for transmission.
4. g = g1, g2, g3,.. gs: The group of concentric rings that compose the cell.

3. Frequency Reuse Based Schemes

3.1 Reuse-1

For allocating frequencies in a network, the simplest scheme is to use a Frequency Reuse Function (FRF) of 1[21]. In RF1/FRF1, the total available bandwidth of each cell is reused without posing any constraints on allocating power or usage of frequency reuse[22]. In other words, reuse-1 is a proposition where users in each cell can have access to the entire bandwidth but must deal with interference from out-of-cell users[23] as shown in Figure 3.

The parameters in this approach can be defined as[24]:

Z = Z1, g = g1, r = r1.

All 7 cells in a network are identical, hence expressed as follows:

s1 = s2 = ...= s7 = Z (r1, g1).

3.2 Reuse-3

In Reuse-1, ICI becomes a problem when the same frequency band is used for adjacent cells[25]. Each macro-cell is split into three different cells and each cell is provided by a different antenna. The whole frequency bandwidth is split into three identical and orthogonal sub-channels, assigned to cells so that neighboring cells always uses varying frequencies[21]. The three sectors are assigned the three different sub-bands such that the interference is only limited to the sector that operates on the same sub-bands in neighboring macro-cells[26]. As each cell is using 1/3 of total available bandwidth, there is a large capacity loss[22] which in turn reduces throughput[25]. The power level for transmission for every cell is set to be 3*p in which p is referred to as the power of conventional scheme[27,28]. The Reuse-3 scheme can be represented in the Figure 4.

The parameters in this approach can be defined as[24]:

Z=Z1, Z2, g=g1, r=r1.

The 7 cells in a network can be expressed as follows:

s1=Z1 (r1, g1), Z2 (0, 0), Z3 (0, 0)

s2=s4=s6=Z1 (0, 0), Z2 (r1, g1), Z3 (0, 0)

s3=s5=s7=Z1 (0, 0), Z2 (0, 0), Z3 (r1, g1)

3.3 Fractional Frequency Reuse (FFR)

FFR scheme is instinctive and best for the hexagonal shaped cell pattern[29]. FFR scheme is also called as FFR-A[30]. It limits on RB allocation between the different users in each cell[31]. Downlink FFR, typically supports links with higher rate requirements with limited interference and we can avoid power control by allocating identical power in down-links[32]. The basic idea on which the FFR schemes depend is to divide the entire bandwidth into two subsets: majority group and minority group[33]. Majority group is used to provide the users in outer regions means the users are provided with a fraction of the total bandwidth while minority group is used to surround the users in the inner regions[21]. FFR is one of the ways in improving the cell-edge SINR and it also maintains a better spectral efficiency by using an RF more than one for the outer regions/ major region and an FRF of one for the inner regions/minor region[34,35]. Cell-center throughput

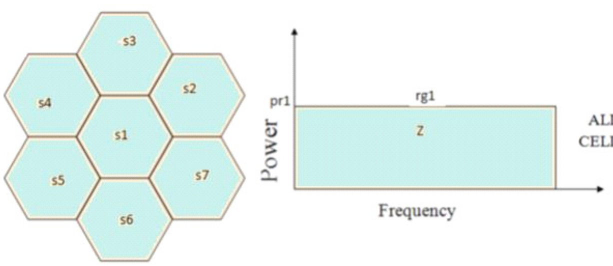

Figure 3. Reuse-1.

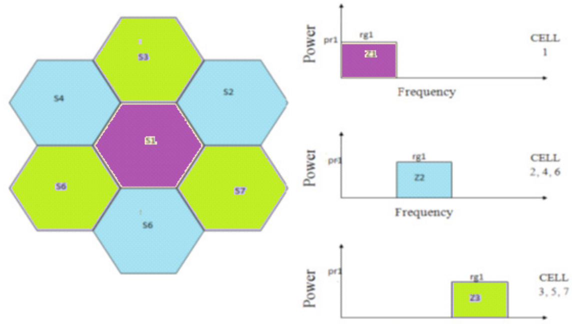

Figure 4. Reuse-3.

decreases when compared to the reuse-1, cell-edge user yields high throughput[36]. There is a balance between the spectral efficiency of users in the cell- edge region and entire throughput of the system[37]. In[38], four FFR schemes improving cell-edge UE's throughput are derived. In[39] fixed SINR threshold is used to separate the outer and inner regions. In[40], impact of SINR threshold for real time traffic is shown. The formula which is used to calculate the number of bands allocated for outer and inner regions are given below

Number of Center Regions (NCR) = beta FR* Number of Physical Resource Blocks (NPRBs)

$$NER = (NPRBs - NCR) = 3^{33} \qquad (1)$$

The FFR scheme can be represented in the Figure 5.

The parameters in this approach can be defined as[24]: Z= (Z1, Z2, Z3, Z4); g=g1, g2; r=r1.

The 7 cells in a network can be expressed as follows: s 1=Z1(r1,g1),Z2(r1,g2),Z3(0,0),Z4(0,0)

s2=s4=s6=Z1(r1,g1),Z2(0,0),Z3(r1,g2),Z4(0,0)

s3=s5=s7=Z1(r1,g1),Z2(0,0),Z3(0,0),Z4(r1,g2)

3.4 Partial Frequency Reuse (PFR)

The PFR is also called as FFR with full isolation (FFR-FI), as UEs at outer regions are completely separated with higher power from neighboring cells interference[34]. Inner region UEs do not share any resources with outer region users, which results in reduction of interference in both inner region users and outer region users[41]. The system is divided into B0 and B1 which are outer zone (cell-edge) and inner zone (cell-center) respectively. B is total available bandwidth.

$$B = (B1 + (B0/3))\ 21 \qquad (2)$$

The PFR scheme can be represented in the Figure 6.

The parameters in PFR approach can be defined as[24]:

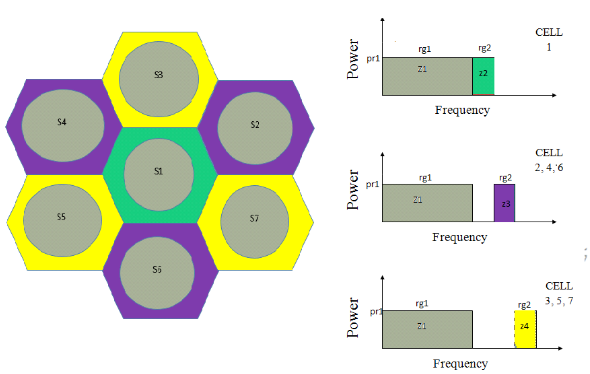

Figure 5. FFR.

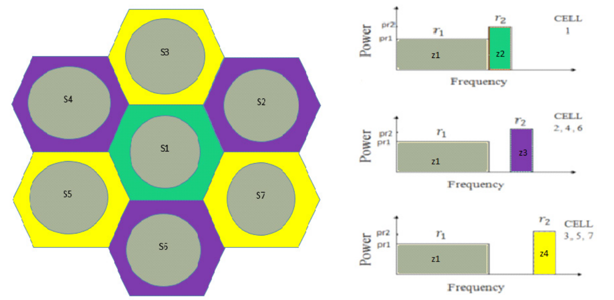

Figure 6. PFR.

Z=Z1, Z2, Z3, Z4; g=g1, g2; r=r1, r2.

The 7 cells in a network can be expressed as follows:

s1=Z1(r1,g1),Z2(r2,g2),Z3(0,0),Z4(0,0)

s2=s4=s6=Z1(r1,g1),Z2(0,0),Z3(r2,g2),Z4(0,0)

s3=s5=s7=Z1(r1,g1),Z2(0,0),Z3(0,0),Z4(r2,g2)

3.5 Soft Frequency Reuse (SFR)

SFR is more bandwidth effective when it is related with PFR[42]. Basic idea of SFR is that it uses FRF-1 for inner region users and FRF-3 for outer region users[43,44]. Soft reuse means that efficient reuse of the scheme can be attained by splitting the powers between frequencies utilized in major and minor bands[45]. The cells are separated into majority/cell-edge and minority/cell-center users. The cell edge user uses 1/3 of the bandwidth. The cell-center user uses remaining bandwidth[46-50]. Edge users should be scheduled first[39]. There are two power levels user for CEU or CCU according to the mobile user location[51]. The lower transmission power for the inner region is used to avoid the interference to outer region of neighboring cells[52]. Edge zone is also referred as center-edge zone/cell-center zone[53]. The formulas for calculating bandwidth for Centre and edge users are given below. There are two ways for calculating NER[54].

$$NER = NPRBs/3 \qquad (3)$$

$$NCR = NPRBs - NER \qquad (4)$$

This equation can also be written as[55] Reserve 2/3 of the bandwidth for center users

$$NCR = 2/3(NPRBs) \qquad (5)$$

$$NER = NPRBs - NCR \qquad (6)$$

The formula for calculating power for center and edge users[56]

$$Pccu = S*P= (a -1) T + S \quad (7)$$

$$Pccu = 3P=a + 2Pccu - \text{Power for cell center users} \quad (8)$$

$$Pceu = a *PccuPceu - \text{power for cell edge users} \quad (9)$$

S-Total number of sub-channels in a system

T-Available sub channels for the CEUs

a-denotes the ratio of power of the sub-channel used by the edge user to the center user. Higher power level is given for edge a user which is triple the power of center users[57]. The SFR scheme can be represented in the Figure 7.

The parameters in SFR approach can be defined as:

Z= Z1, Z2, Z3; g=g1, g2; r=r1, r2.

The 7 cells in a network can be expressed as follows:

s1= Z1 (r1, g1), Z2 (r1, g1), Z3 (r2, g2)

s2=s4=s6= Z1 (r1, g1), Z2 (r2, g2), Z3 (r1, g1)

s3=s5=s7= Z1 (r2, g2), Z2 (r1, g1), Z3 (r1, g1)

3.6 Soft Fractional Frequency Reuse (SFFR)

The PFR scheme will not use the entire bandwidth and due to that it has a less throughput in cells as compared to conventional schemes of reuse-1 scheme[21]. SFR can utilize the entire available frequency and thus there is an increase in the overall system throughput when compared it with PFR; anyhow, the entire system throughput of SFR may be lower when compared it with reuse one scheme[21]. SFFR scheme had been introduced with the idea to improve the overall system throughput of FFR[21,22,58]. The soft FFR's effect on bandwidth effectiveness is estimated based on the schemes of transmitted power and the total number of sub-bands[59]. The only contrast between the PFR and SFFR scheme is that the unused bands left after allocation of minor region and major region users is accessed by center users. SFFR is not like the PFR scheme, it can have access to all the unused sub-channels except the one used for edge users of that cell[27]. The power assigned to common sub-bands in macro-BS is reduced. The ratio of the power level for transmission over major region sub-channels to the power level for transmission over the 2 additional sub-channels of the center region is assigned to (10:1)[37]. The SFFR scheme can be represented in the Figure 8.

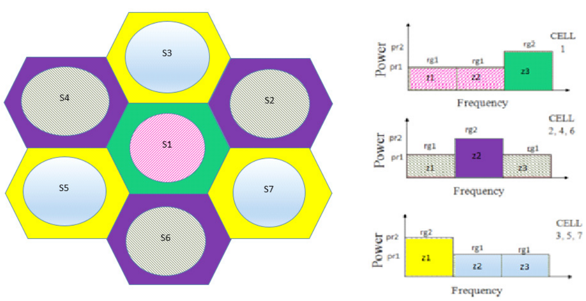

Figure 7. SFR.

The parameters in SFFR approach can be defined as[24]:

Z=Z1, Z2, Z3, Z4; g=g1, g2; r=r1, r2.

The 7 cells in a network can be expressed as follows:

s1=Z1(r1,g1),Z2(r1,g1),Z3(r1,g1),Z4(r2,g2)

s2=s4=s6=Z1(r1,g1),Z2(r1,g1),Z3(r2,g2),Z4(r1,g1)

s3=s5=s7=Z1(r1,g1),Z2(r2,g2),Z3(r1,g1),Z4(r1,g1)

4. Results

In this paper, the simulation is carried out using an LTE down-link system-level simulator [60] which was introduced by Vienna University of Technology. The simulation parameters that are used here are illustrated in Table- 2

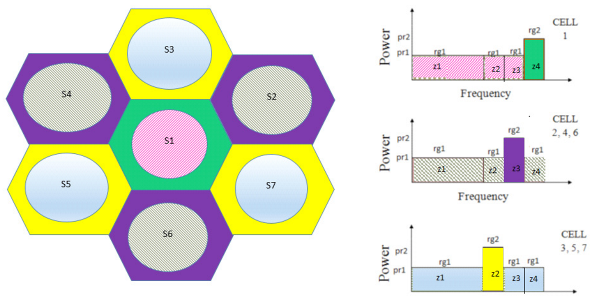

Figure 8. SFFR.

Table 2. Simulation Parameters

Parameter	Values
Transmission Time Intervals (TTI) simulation length	500 TTIs
Bandwidth	3 MHz
Number of Resource Blocks	15
Number of sub-carriers in the up-link	180
Number of sub-carriers in the down-link	181
Sub-carrier spacing	15 KHz
Slot duration	0.5 ms
TTI	1 ms
Number of OFDM symbols per slot	7
Simulation Type	Tri-sector-tilted
User Equipment (UE)s per eNodeB	20
Number of UEs	180
betaFR	0.4
Scheduler	Round Robin

When the bandwidth is 3 MHz, 5 MHz, 10 MHz, 15 MHz, and 20 MHz then the available Resource Blocks will be 15, 25, 50, 75, and 100 respectively. The scheduler used here is the Round Robin Scheduler which is fair to all the users. The Fairness Index is calculated by using Jain's Fairness Index[61] and Average UE throughput, Edge UE throughput and Peak UE throughput are calculated as defined in[62] and for scheduling decisions, eNB uses both CA and MIMO[63] which is used for tackling fading and interference[64]. Cell statistics of all the schedulers are illustrated in the Table-3, Table-4, Table-5 and Table-6.

Table 3. Cell Statistics of Fractional Frequency Reuse

Cell statistics	Values
Fairness Index	0.235542
Peak/Average/Edge UE throughput(Mb/s)	0.02/0.00/0.00
Average cell throughput(Mb/s)	0.08

Table 4. Cell Statistics of Partial Frequency Reuse

Cell statistics	Values
Fairness Index	0.189908
Peak/ Average /Edge UE throughput(Mb/s)	0.03/0.00/0.00
Average cell throughput(Mb/s)	0.08

Table 5. Cell Statistics of Soft Frequency Reuse

Cell statistics	Values
Fairness Index	0.246001
Peak/ Average /Edge UE throughput(Mb/s)	0.03/0.00/0.00
Average cell throughput(Mb/s)	0.14

Table 6. Cell Statistics of Soft Fractional Frequency Reuse

Cell statistics	Values
Fairness Index	0.163532
Peak/ Average /Edge UE throughput(Mb/s)	0.07/0.01/0.00
Average cell throughput(Mb/s)	0.18

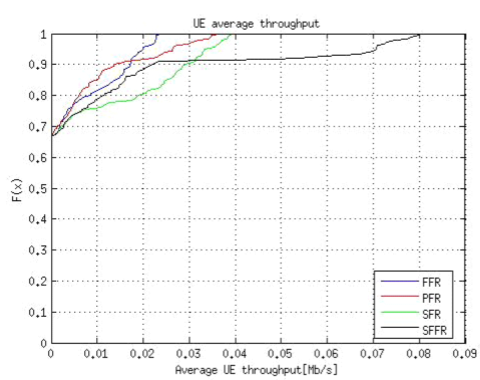

Figure 9. Comparison of all schedulers.

The throughput of all the schedulers is compared in the Figure 9

5. Conclusions

In this survey, the ICI avoidance techniques are stated. The types of FFR schedulers and how the bandwidth and power are allocated are discussed. It is found that there is increased throughput in SFFR when compared with other reused based techniques. In future, other FFR techniques such as EFFR (Enhanced Fractional Frequency Reuse) and DFFR (Distributed Fractional Frequency Reuse) may also be implemented and the throughput of overall FFR techniques may also be compared.

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