Downlink Interference Coordination and Mitigation for future LTE-Advanced System

Invited paper

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***Abstract*-As the wireless access technology evovles to wider and wider bandwidth, Orthogonal Frequency Division Multiplex (OFDM) becomes the fundamental technology component to provide efficient data transmission. However, compared to Code Division Multplex Access (CDMA), OFDM has no capability to mitigate the intercell interference though it can provide orthogonality among the intracell users. To build a cellular network and guarantee the user experience at the cell edge, some additional technology components, like interference coordination or interference mitigation, are necessary for OFDM based wireless system, where intercell interference is the main contribution to the performance degradation at the cell edge. To deal with the intercell interference, many techniques can be adopted for different perspectives. This paper overviews such technologies based on the LTE framwork, some new interference mitigation technologies are simulated for LTE-Advanced, which can improve the cell edge performance of LTE-advanced effectively.**

I. INTRODUCTION

As the development of the technology and data service market, future cellular system is required to provide higher and higher data access capability to the subscribers with guaranteed quality of service, e.g. extremely high data rate, 1Gbps has been required for IMT-Advanced system [1], which is a further evolution of current 3GPP Long Term Evolution (LTE) [2] or IEEE 802.16e [3] standards. To achieve such target with current technology, up to 100MHz bandwidth is necessary to be supported, where the frequency selective fading will be a challenge, Orthogonal Frequency Division Multiplexing (OFDM) [4] is a promising candidate technique to solve this problem.

By OFDM, a wideband frequency selective mobile channel can be divided into many frequency flat narrow channels, which are fading independently. And thus the adaptive modulation and coding can be adopted in every subcarrier to improve the transmit data rate. By Cyclic Prefix (CP) extension for every OFDM symbol, the Inter Symbol Interference (ISI) can be mitigated or even avoided. Combined with TDMA, CDMA, SDMA or OFDMA, OFDM can also provide many flexible multiple access schemes.

An OFDMA system is defined as one in which a subset of subcarriers are assigned to one user according to his traffic and QoS requirement. For different users occupy different subcarriers, OFDMA provides a natural multiple access method. If signals of different users arrive at the receiver simultaneously, and the length of CP is larger than the maximum delay spread of the channel, no Inter-carrier Interference is produced and the orthogonality among different users' signals is guaranteed. By selecting proper subcarriers for different users according to their the Signal to Interference plus Noise Ratio (SINR) [5], every user can obtain a subset of good subcarriers to meet his QoS requirement because different users have different locations in the cell and their fading is also independent, and thus the multiple user diversity gain is exploited in OFDMA system.

For these advantages, OFDMA has been adopted for LTE downlink and IEEE 802.16e, and it will continue to be the fundamental technique component for future IMT-Advanced.

However, OFDMA itself is only one kind of modulation, which can not mitigate the interference though it can fit to different interference scenarios by adjusting the coding and modulation order according to the signal to interference and noise ratio. To provide seamless handover for the data application and improve the user experience at the cell edge, some techniques to mitigate the inter-cell interference by the frequency reuse in neighboring cells are necessary for an advanced wireless system based on OFDMA.

The techniques o mitigate the inter-cell interference can be classified as several types, including the interference whiten [6], interference avoidance, Interference cancellation and interference nulling. In this paper, the interference mitigation techniques above is overviewed and some advanced technique concepts for IMT-Advanced is discussed and their performance is simulated and compared based on LTE framework.

The organization of this paper is as follows. The interference mitigation techniques of LTE is overviewed in section II, and some advanced concept for inter-cell interference mitigation is introduced and discussed in section III; the simulation parameters and simulation results are presented in section IV; Conclusions are drawn in section V.

II. INTERFERENCE MITIGATION IN LTE

LTE is the next evolution stage for Release 7 of 3GPP standards, which is based on OFDM and MIMO technology. To provide better cell edge performance and seamless handover for data applications, many techniques are proposed to improve the cell edge performance by inter-cell interference mitigation.

Interference whitening. The scrambling [6] is one kind of such technique, which can whiten the intercell interference and make it perform like the Additional White Gaussian Noise (AWGN), and thus average and stablize the interference in time domain. The rational of the scrambling

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in time domain is to scramble the signal from different cells with different codes which have low correlation each other. Thus, by descrambling at the receiver with different codes, the inter-cell interference with different scrambling code can be randomize and average in time domain, and make the receiver work in stable status.

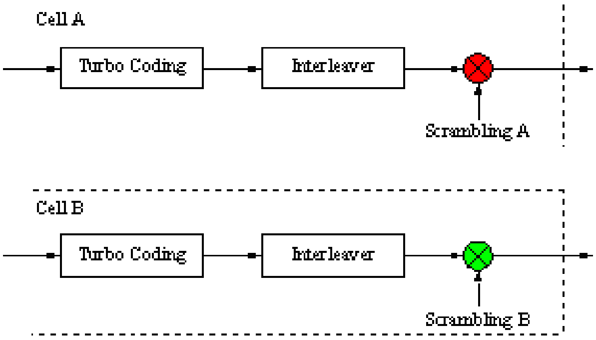

Figure 1 Rational of scrambling

Inter-cell Interference Coordination (ICIC): The second type of such techniques is the ICIC [7]. According to the resource allocation restriction principle, the ICIC methods can be classified into soft frequency reuse (SFR), fractional frequency reuse (FFR), and full frequency reuse, respectively. In SFR, every cell can use the whole frequency band. Two SFR schemes can be defined based on a certain frequency reuse factor according to different power isolation methods:

1) Forward power isolation (SFR1): full power transmission is adopted in a certain frequency subset, while the power is reduced in all the other frequency subsets, as shown in Figure 2;

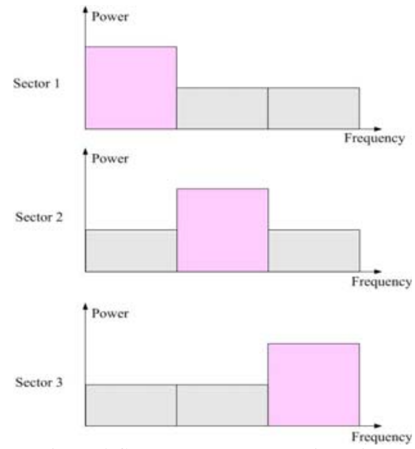

Figure 2 SFR: Forward Power isolation

2) Reverse power isolation (SFR2): the power is reduced in a certain frequency subset, while full power transmission is adopted in all the other frequency subsets, as shown in Figure 3.

For SFR scheme 1, increasing the frequency reuse factor will result in the power on more fraction of the frequency band being suppressed, while the opposite is true for SFR scheme 2. For example, assume that the reuse factor is 7, the power on 6/7 and 1/7 of the frequency band will be suppressed in SFR scheme 1 and 2, respectively.

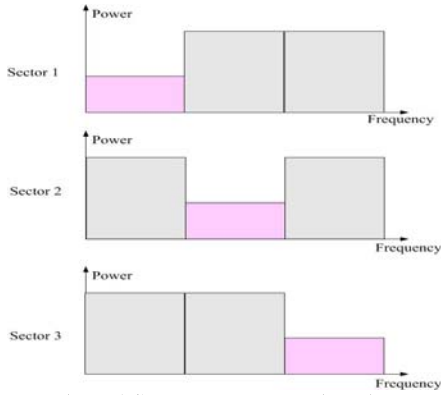

Figure 3 SFR: Reverse Power isolation

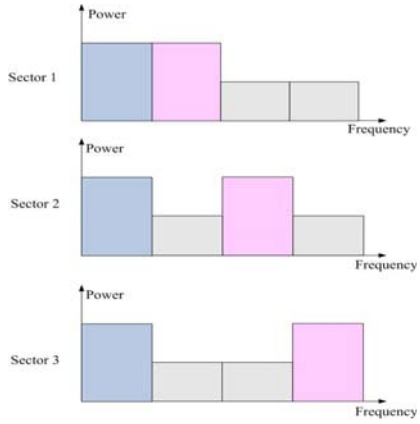

Figure 4 FFR1: Partial Power isolation

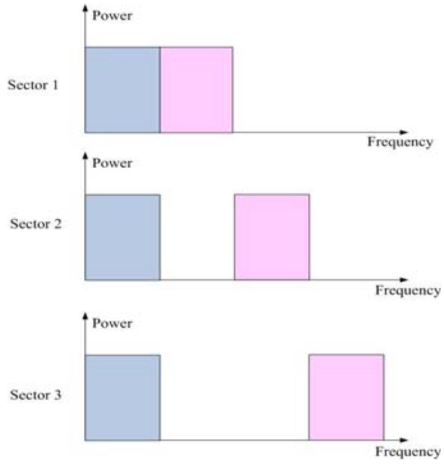

Figure 5 FFR2: Full Power isolation

(a) Full power isolation

(b) Partial power isolation

In FFR, there is one frequency subset that is used by all the cells with reuse factor 1. The rest of the frequency band have reuse factor larger than 1. The FFR schemes can be further divided into two categories depending on whether hard frequency reuse or soft frequency reuse is adopted in the rest of the frequency band:

1) Full power isolation (FFR1): hard frequency reuse is Adopted in the rest of the frequency band, i.e., N ¡1=N of the rest of the frequency band is muted with a frequency reuse factor N, as shown in Figure 4;

2) Partial power isolation (FFR2): soft frequency reuse is adopted in the rest of the frequency band, i.e., the power on N¡1=N of the rest of the frequency band is reduced with a frequency reuse factor N, as shown in Figure 5.

Note that in SFR and FFR, the SINR in some frequency subsets are improved by power reduction or usage restriction on the same frequency subsets in the adjacent cells. These frequency subsets are referred to as cell-edge bands in the rest of the paper.

Beamforming [8]: With multiple antennas at the eNB, transmitter can focus the transmitter power in the destination direction in some degree and thus reduce the interference to users served in the neighboring sectors by the digital processing at the transmitter. Traditionally, this is also named as smart antenna. The effect of beamforming on interference can be illustrated as below:

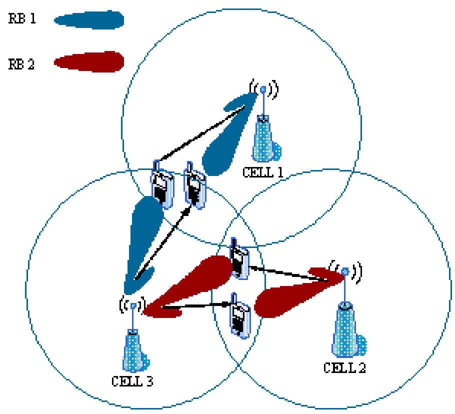

Figure 6 Effect of Beamforming for interference Nulling

Assume the channel response matrix of user k on subcarrier n can be expressed as:

$$\mathbf{H}_n = \begin{bmatrix} h_{11} & \dots & h_{1N} \\ \dots & \dots & \dots \\ h_{M1} & \dots & h_{MN} \end{bmatrix} \tag{1}$$

Where M and N are the UE number and eNB transmitter antenna number. Then weight matrix for ZFB is [9]:

$$\mathbf{B}_n = \mathbf{H}_n^\dagger \left(\mathbf{H}_n \mathbf{H}_n^\dagger\right)^{-1} \mathbf{D}_n \tag{2}$$

Where $\mathbf{D}_n = diag\left(d_1, \dots d_k, \dots, d_M\right)$ is the diagonal matrix which keeps the transmit power unchanged after beamforming, and $\dagger$ means the hermit transpose. M is the UE Number, which is also the independent data stream number for the eNB transmission.

$$d_k = 1 \Big/ \sqrt{\left[\left(\mathbf{H}_n \mathbf{H}_n^\dagger\right)^{-1}\right]_{k,k}} \tag{3}$$

If M data stream are transmitted and $\mathbf{S} \in \mathbb{C}^{M\times 1}$ is the modulated symbol vector, the element s_k is the transmitted data symbol on the data stream k, the transmitted signal after beamforming is:

$$\mathbf{x}_n = \mathbf{B}_n \mathbf{S}_n \tag{4}$$

At the UE, the received signal can be expressed as:

$$\mathbf{r}_n = \mathbf{H}_n \mathbf{x}_n + \mathbf{n} = \mathbf{H}_n \mathbf{B}_n \mathbf{S}_n + \mathbf{n} = \mathbf{D}_n \mathbf{S}_n + \mathbf{n} \tag{5}$$

Because $\mathbf{D}_n$ is a diagonal matrix, the MIMO channel is decomposed into M SISO channels with channel gain d_k respectively on subcarrier n.

III. NEW CONCEPT FOR LTE-ADVANCED

For LTE-Advanced, more challenging requirements have been defined in 3GPP TR 36.913[9]. To improve the cell edge performance and cell spectrum efficiency further, some new concepts have been discussed for LTE-Advanced, e.g. Coordinated Multiple Point (CoMP) transmission [10] was proposed. In multi-cell scenario, since the inter-cell interference should be taken into account for the subcarrier and power allocation, multi-cell coordination by some centralized or distributed strategy will lead to higher efficiency for resource utilization though it may introduce more complex system architecture and heavy signaling overhead. The rational of CoMP can be demonstrated as **Figure 7**, where each eNB site works as a Remote Radio Unit (RRU) and perform as the RF front, and the baseband signals are connected to the central unit for joint processing by CoMP algorithm.

Although CoMP naturally increases system complexity, it has potentially significant capacity and coverage benefits, making it worth a more detailed consideration.

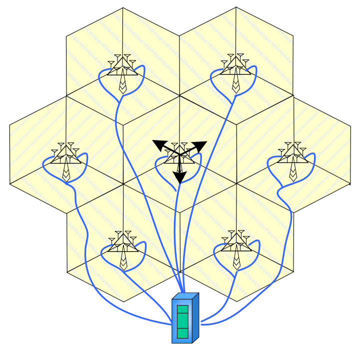

Figure 7 CoMP system with different sites cooperation

By the processing strategy, the CoMP can be classified as two types: one is full Channel State Information (CSI) based algorithm, where the full CSI can be obtained by channel sounding or CSI feedback, e.g. uplink sounding in TDD system; the other one is partial CSI based algorithm, where partial CSI is feedback from the terminals, e.g. Preocding Matrix Index (PMI) feedback based global precoding.

In this paper, the power of each eNB is distributed uniformly on every spatial sub-channel of every subcarrier and thus the problem is simplified as multiuser subcarrier allocation and multiuser antenna selection.

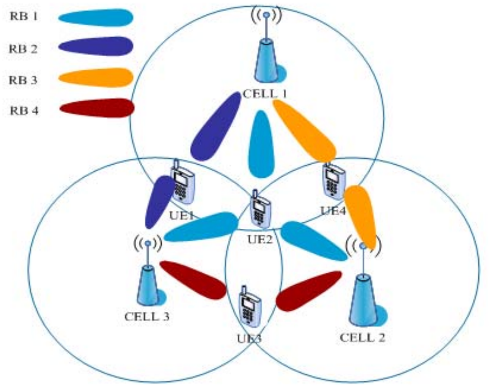

Figure 8 Effect of global beamforming

In this paper, the three types of CoMP algorithms are investigated and simulated.

Global Precoding: the fundamental idea of this scheme is try to reuse the design of LTE release 8, where precoding based on PMI and rank indicator feedback has been specified. Since LTE release 4 has only defined the codebook for not more than 8 antennas, this scheme has to be limited to few sites coordination, e.g. 2 sites with 2 antennas. In this case, the 4 antennas from 2 sites are regarded as the virtual antennas of the coordinated eNB set and serve one user simultaneously from two sites on the same radio resource. By such mechanism, the users located at the cell edge may be served better by two neighboring cells. However, since the radio resource of two cells has to be transmitted with the same data, which may provide some diversity gain by sacrificing the system efficiency.

Global beamforming: similar as the global precoding, the antennas from the different eNB sites which have been involved in the coordination, are grouped together and regarded as the virtual antennas for the processing unit of the CoMP. Based on the full CSI at the central processing unit, eNB or the network can decide the beamforming weight vector for all the eNBs which has been involved in the coordination. However, for global beamforming, only one user can be served with one data stream among the coordinated eNB set. However, similar disadvantage as global precoding on the system efficiency can be observed. The beamforming algorithm and demodulation reference signal can reuse the design of LTE release 8.

MU-MIMO: similar as the above two schemes, the antennas from the different eNB sites which have been involved in the coordination, are grouped together and regarded as the virtual antennas for the processing unit of the CoMP or the coordinated eNB set. Based on the full CSI at the central processing unit, multiple users from the coordinated eNB set can be selected to be served with one or two data streams adaptively and the signal can be transmitted simultaneously from all the eNBs of the coordination set. The BD SVD [10] algorithms can be adopted. By multi-user spatial multiplexing on the same radio resource of the coordinated eNB set, the system efficiency can be improved, however the cell edge performance may not be improved as much as the two schemes above.

IV. EVALUATION METHODOLOGY AND RESUTLS

To investigate the gain of different schemes mentioned above for Interference coordination and mitigation, TD-LTE based frame structure and evaluation framework has been adopted. The frame structure of TD-LTE [11] (also named as LTE TDD in 3GPP) is as Figure 9.

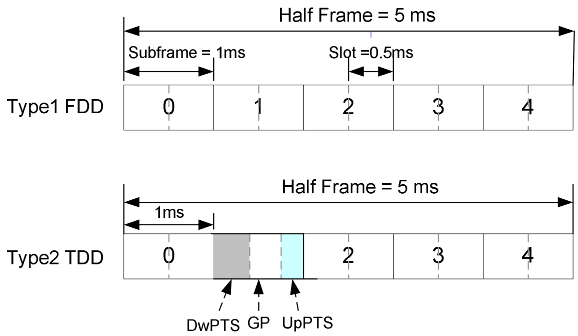

Figure 9 Frame structure of LTE TDD

The other system simulation parameters are as Table 1.

Table 1 system simulation assumptions

Parameter		Assumption
Carrier Frequency		2GHz
Band width		10MHz
Sample Frequency		15.36 MHz
Sub-carrier spacing		15 kHz
CP length(μs/samples)		7.29/14
FFT Size		1024
Occupied Subcarriers number		601
Subcarrier Group number		75
Inter-site distance		2Km
Cell number		27 (9 clusters)
Distance-dependent path loss		L=128.1 + 37.6log10(R)
Shadowing standard deviation		8 dB
Correlation distance of Shadowing		50 m
Shadowing correlation	Between cells	0.5
	Between sectors	1.0
Penetration Loss		20dB
Channel model		SCM
Total eNB TX power		43dBm
Minimum distance between UE and cell		>= 35 meters
User data rate		2Mbps
H-ARQ		Chase combining

For SFR and FFR comparison, 2x1 MISO is configured for the downlink simulation. For beamforming comparison, 2x2 and 8x2 MIMO are configured as the baseline and enhanced case respectively. For CoMP simulation, 2x2 and 4x2 MIMO is configured.

Table 2 performance of ICIC

	Avg. spectral efficiency [bps/Hz/cell] and gain		**Cell-edge (5% CDF)user spectral efficiency [bps/Hz/cell] and gain**	
No ICIC	1.42	0%	0.045	0%
FFR1	1.22	-16.5%	0.056	+23%
FFR2	1.42	+0.11%	0.051	+12.7%
SFR1	1.44	+1.7%	0.047	+4%
SFR2	1.45	+2.1%	0.047	+3.7%

Note:

Spectrum efficiency=Throughput*(38/42)*(5/3)/10MHz

The simulation results of ICIC for LTE is presented as Table 1. FFR1 can improve the cell edge user spectrum efficiency about 23% by sacrificing 16.5% cell average spectrum efficiency. With FFR2, the cell average spectrum efficiency is almost kept the same but the cell edge spectrum efficiency can be improved 12.7%. By SFR, the spectrum efficiency can be improved about 2% while the cell edge performance improvement is about 4%.

Table 3 Performance of CoMP schemes

Algorithms		Avg. spectral efficiency [bps/Hz/cell] and gain		Cell-edge (5% CDF)user spectral efficiency [bps/Hz/cell] and gain	
LTE Release 8	precoding 2x2	1.56	-	0.047	-
	precoding 4x2	1.67	+7.1%	0.05	+6.4%
	Beamforming 8x2	1.92	+23%	0.077	+63.8%
CoMP	Global Precoding 2x2	1.52	-2.6%	0.069	+46.8%
	Global Beamforming 2x2	1.54	-1.3%	0.071	+51.1%
	MU-MIMO 2x2	1.62	+3.8%	0.05	+6.4%
	MU-MIMO 4x2	2.24	+43.6 %	0.069	+46.8%

Table 3 shows the spectrum efficiency and cell edge spectrum efficiency of Release 8 LTE and CoMP for LTE-A. Comparing the performance of Precoding and beamforming of LTE release 8, we can see that the performance can be improved much by beamforming, where 23% spectrum efficiency gain and 63.8% cell edge spectrum efficiency gain has been observed with ideal channel estimation. The reason for the degradation on the cell spectrum efficiency and the improvement on the cell edge performance has been explained as above

Comparing the different algorithms for CoMP, we can see that the global precoding and global beamforming have obtained much better cell edge spectrum efficiency by sacrificing little bit cell spectrum efficiency. With 2x2 antenna configuration, the performance gain of MU-MIMO is marginal compared to the LTE release 8 with 2x2 precoding. However, with 4x2 antenna configuration, the gain of MU-MIMO is improved much, e.g. 44% cell spectrum efficiency gain and 47% cell edge spectrum efficiency gain is observed.

Summarily, beamforming is very efficient to improve the system performance, especially on the cell edge spectrum efficiency. CoMP is also a efficient solution to improve the system performance, which performs well with 4 antennas at each eNB by coordination among neighboring sites.

V. CONCLUSION

Since OFDMA can not mitigate the interference, to provide seamless handover and guaranteed QoS at the cell edge, some other techniques, e.g. multiple antennas and ICIC, have to be adopted. In this paper, the techniques for inter-cell interference cancellation or coordination for LTE are overviewed, and their performance is compared under the framework of LTE and its evolution. From the simulation results, we can draw the conclusion that FFR with proper optimization can improve the cell edge performance by sacrificing some cell average spectrum efficiency, while the gain of SFR is marginal. Beamforming is very efficient to improve the system performance, both cell edge and cell average performance. Compared different CoMP schemes, global precoding and global beamforming has much gain on cell edge performance, but some sacrifice on the cell average performance. CoMP MU-MIMO with more than 2 antennas at eNB is very effective to improve the system performance.

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