Advances in Spectrum Allocation Procedures of 4G LTE

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Abstract—Spectrum allocation is very crucial in realizing high data rates especially in 4G Long Term Evolution (LTE). In this paper we discuss all the current advances in spectrum allocation procedures present in practice. The LTE is targeted for high bit rates with a good cell edge user performance and we found that the Soft Frequency Reuse method is suitable for LTE.

Keywords—*LTE; OFDMA; Inter-cell Interference; SFR; FFR.*

I. INTRODUCTION

Today's telecommunication systems are offering several services to their users. These services include high bandwidth applications so that there is a large requirement of high user data rates. These higher data rates can be supported by using efficient Radio Access Techniques (RATs) and efficient spectrum allocation methods. In developing RATs, so much of evolution has taken place. Now this part is matured to standardize Orthogonal Frequency Division Multiple Access (OFDMA) as RAT and Multiple Access (MA) for emerging new cellular systems. In parallel spectrum allocation also taken much evolution but the spectrum allocation method for cellular is highly dependent upon cellular network's RAT so it cannot be matured to one single method or technique. Recently the 3rd Generation Partnership Project (3GPP) has launched the cellular standard Long Term Evolution (LTE) to fulfill the requirements of International Mobile Telecommunications 2000 (IMT-2000) systems defined by International Telecommunication Union - Radiocommunications sector (ITU-R). This standard adopted OFDMA as the RAT so the spectrum allocation method for LTE, which is not standardized yet, should be designed according to that. This paper will deal with the spectrum allocation method for LTE cellular.

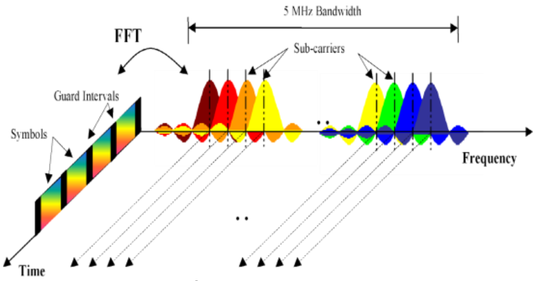
This introductory paper is organized as follows: First we introduce a brief overview of LTE cellular and secondly spectrum allocation problem in LTE is discussed. Then thirdly problem statement and objectives are given.

II. THE LONG TERM EVOLUTION

The Long Term Evolution (LTE) is the standard for Radio Access Network (RAN) part of Evolved-Universal Terrestrial Radio Access (E-UTRA) produced by 3GPP. It uses Orthogonal Frequency Division Multiple Access (OFDMA) as the Multiple Access (MA) technique for downlink and Discrete Fourier Transform (DFT) pre-coded OFDM (Single Carrier Frequency Division Multiple Access, SC-FDMA) as MA for uplink at the air interface. This standard is aimed to provide 10× higher data rates and 2–4× higher spectral efficiency than that is achieved with 3GPP Release6 systems to which Wideband Code Division Multiple Access (WCDMA) is RAT. In [1] it is analyzed that the OFDM performance and WCDMA performance for downlink transmissions and it is shown that OFDM is outperforming the WCDMA for both broadcasting and unicast services. Similarly, for uplink in [2] shown that SC-FDMA is out performing WCDMA for both broadcast and unicast services. In OFDMA, a large bandwidth carrier is divided in to several narrow bandwidth subcarriers. So the frequency selective fading, which is inherently present in wireless transmissions, that could affect large bandwidth transmission is now will be the frequency flat fading on each subcarrier transmission. There by the fading can be equalized with low complexity equalizers. However, in OFDM transmissions the Peak to Average Power Ratio (PAPR) is high as compared to WCDMA. So, it requires high rated power amplifiers. Due to its several advantages, although PAPR problem is present, OFDM is adopted for downlink because transmitter is the base station which usually will have lot of power resources. In uplink, User Equipment (UE) is the transmitter which is driven by some portable batteries so the high rated power amplifiers cannot be there. For this reason SC-FDMA has been chosen for uplink which has less PAPR in comparison to OFDMA.

As described earlier, OFDM divides a wide bandwidth carrier in to several narrow bandwidth subcarriers as shown in figure 1. On each subcarrier one modulated data symbol of duration which is reciprocal to subcarrier bandwidth/subcarrier spacing can be transmitted. So, in parallel a number of symbols can be sent on each subcarrier. Then each OFDM symbol is equivalent to number of modulated data symbols (QAM symbols) each mapped to different subcarriers in frequency domain. In time domain OFDM signal is sum of number of complex sinusoidal signal of duration reciprocal to subcarrier spacing. Two consecutive OFDM symbols in time should be separated by some period called guard interval to avoid Inter Symbol Interference (ISI). During the guard interval either null transmission can take place or the last portion of the next OFDM symbol can be prefixed, which is called as Cyclic Prefix (CP), and transmitted. The use of CP is to preserve the orthogonality between subcarriers while avoiding ISI. Further the CP is useful to transform the linear convolution of channel with OFDM symbol to circular convolution and hence the inter carrier interference will be removed at the output of FFT block in receiver. Basically SC-FDMA and OFDMA are same except the fact that in OFDM the data modulated symbols directly map to subcarriers and in SC-FDMA the DFT transformed data modulated symbols will be mapped to subcarriers. So mostly whatever we discuss about OFDM it is also applicable to SC-FDMA.

Figure 1: Time frequency illustration of OFDM [3]



A. Transmission Schemes

In LTE, a radio frame of 10 ms duration consists of 10 subframes of duration 1 ms each. Each subframe consists of two physical slots of 0.5 ms. In each physical slot, 6 or 7 OFDM symbols can be accommodated that depending on the CP length. In LTE standard two CP lengths are defined: one is of 4.7 μs duration and other is 16.7 μs duration. A grid of 12 subcarriers in frequency domain and 7 or 6 OFDM symbols in time domain called Physical Resource Block (PRB) and it is the minimum frequency resource allocation unit for a user in LTE. So, the PRB bandwidth is 12×15 KHz, that is 180 KHz. LTE supports many channel bandwidths from 1.4 MHz to 20 MHz unlike WCDMA standard which supports only one channel bandwidth 5MHz. However, it is useful to measure the transmission bandwidth in terms of number PRBs it can use for transmission rather than in Hzs and the details are listed in table 1 [4]. In each subframe there will be 12 or 14 OFDM symbols in which 3 or 2 OFDM symbols will be used for control signaling purpose and the remaining OFDM symbols will be used to carry user data.

Table 1: Number of PRBs for each channel bandwidth supported by LTE

Channel Bandwidth(MHz)	1.4	3	5	10	15	20
Number of PRBs N_{PRB}	6	15	25	50	75	100

The users' data to be transmitted through air interface will be turbo coded and modulated with one of modulation schemes QPSK, 16-QAM, and 64-QAM. There are 31 combinations of Modulation and Coding Schemes (MCS) are available for data transmission. Since the wireless channels are time-frequency selective fading, and interference coming from neighboring cells is different on each PRB so the channel quality is different from PRB to PRB. According to the channel quality over some PRB, one of MCS schemes available can be chosen for transmission on the PRB. For example, if a user has low (high) channel quality on a given PRB, lower (higher) order modulation scheme can be chosen to meet specified Bit Error Rate (BER) or physical layer Quality of Service (QoS). This technique is called Link Adaptation (LA)/Rate Adaptation (RA). To relate channel quality to MCS selection, channel quality should be measured. Since the selection of MCS is based on targeted BER which is directly related to Signal to Interference plus Noise Ratio (SINR), channel quality will be rated according to SINR. This rated channel quality is called as Channel Quality Indicator (CQI). This CQI can be estimated for a PRB by aggregating the SINRs of each subcarrier in the PRB bandwidth (which has 12 subcarriers). This aggregation can be done through Exponential Effective SNR Mapping (EESM) [5,6] or Capacity Effective SINR Mapping (CESM) or Loga- rithmic Effective Mapping (LESM)[7]. In downlink, users will estimate this CQI over PRBs by measuring SINR on cell's pilot reference signals transmitted symbols. Similarly, in uplink base station will measure CQI from user's uplink sounding reference symbols.

B. Scheduling and Resource Allocation

Since PRB is the minimum frequency allocation unit in LTE, for data transmission and reception PRBs can be considered as channels In LTE and all PRBs are shared channels. Which PRB is to allocate to which user is decided by scheduling task that is done by base station. The scheduling task will be done in each subframe that is in every 1 ms which is called as scheduling interval. Scheduling is basically divided into two functional blocks, one is Time Domain Scheduling and other is Frequency Domain Scheduling. In Time domain scheduling, which users should transmit data over the present subframe interval will be decided. It will depend on user priority, user's demanded QoS, and user's retransmission data. Generally, retransmission data will take higher priority than a fresh data.

For the scheduled users through time domain scheduling, which resource blocks to allocate and which MCS to use for user data will be determined from the frequency domain scheduling. It is also called as Resource Allocation. Here the resources for a user are the number of PRBs and MCS scheme they can use. PRB allocation will be done in quantity of two PRBs consecutive in time to a user which may be called as Scheduling Block (SB). A user can get multiple number of SBs but there is a constraint in LTE that all SBs allocated to one user in one scheduling interval will have to use same MCS [8]. After MCS is chosen, schedular will determine the Transport Block Size (TBS) which is the number of bits for which acknowledgement is needed.

C. Duplexing

The mobile communication systems offers two way communication one is from user terminal to base station called uplink (UL) and other communication takes place from base station to user terminal called DownLink (DL). For uplink transmissions and downlink transmissions spectrum should be allocated. If a paired spectrum or two different spectrum is allocated to them, so both transmissions are duplexed on two different spectrum, it is called as Frequency Division Duplex(FDD). Similarly if an unpaired spectrum that is same spectrum is allocated to both downlink and uplink but they share the spectrum in time division fashion then it is called as Time Division Duplex (TDD).

Unlike 3GPP previous release WCDMA, LTE supports both Frequency Division Duplex (FDD) and Time Division Duplex

(TDD) transmissions where the former only supports FDD transmissions. For TDD Time Division Synchronous Code Division Multiple Acces (TD-SCDMA) standard is defined in previous releases. So, the LTE user equipments will be able to operate for both FDD and TDD duplexing. The LTE TDD is also called as TD-LTE. The frame structure is slightly different for FDD and TDD. In FDD for each of downlink and uplink transmissions, one full radio frame will be used and they work in parallel. In LTE TDD (TD-LTE) the radio frame duration is 10 ms and it is shared for uplink and downlink transmissions. As a transient subframe between downlink and uplink transmission called a special subframe will have three fields in it. One field is called downlink pilot symbols (DwPTS), second one is Guard Interval (GI) and third one is uplink pilot symbols (UpPTS). Both TDD and FDD frame structure are given in figure 2 [9].

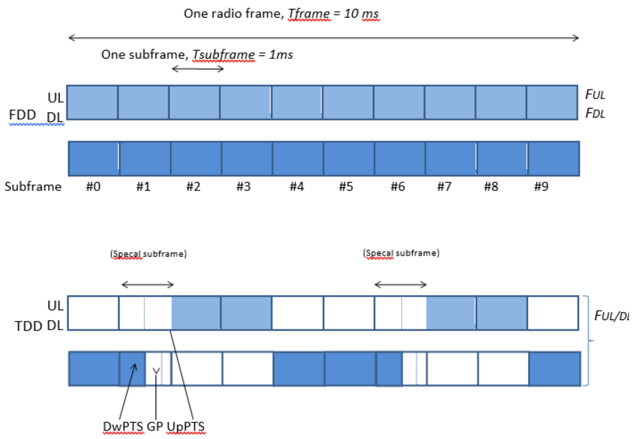


Figure 2: LTE frame structure for both FDD and TDD

In TD-LTE standard, number of subframes with in a radio frame for downlink and uplink can be adapted according to traffic load and the ratios of downlink to uplink number of subframes ranges from 2:3 to 9:1. Two types of downlink and uplink periodicities are provided, those are 5 ms and 10 ms. In 5ms periodicity the special subframe will exist in both half radio frames and in 10 ms periodicity the special subframe exists in only first half of radio frame. When UE turned on first time it doesn't know whether the operating LTE is FDD or TDD so there is some thing should be common for TD-LTE and LTE FDD frame structure. In a radio frame of both FDD and TDD LTE every 0th subframe and 5th subframe are dedicated to downlink and it will contain the system information such as whether it is operating in FDD mode or TDD mode, cell IDs, and synchronization signals etc.

III. Inter-cell interference

Spectrum allocation is main concern in Frequency Division Multiplexing (FDM) based cellular. It distributes the available spectrum for cellular system among the adjacent cells so that their transmissions will not be interfered. The interference will occur when the same frequency spectrum/channel is used in multiple cells, this is called as frequency reuse, and the amount of the interference depends upon the distance between the cells. The number of adjacent cells whose allocated frequencies are different is called as cluster size and it depends upon the frequency reuse distance which is the distance between two cells to which same frequency is allocated. Since OFDM signal is generated by Fast Fourier Transform, each base station will process the entire bandwidth allocated to LTE system for the transmission or reception. Frequency reuse can be adopted in LTE by nullifying some subcarriers' power by giving zero signals at the same indexed inputs of IFFT block. frequency reuse can be quantified in form of cluster size, for example, if cluster size is 3 for a cellular coverage area means frequency reuse three. Frequency reuse factor is reciprocal of frequency reuse.

A. Inter-Cell Interference

By using same frequency channel in multiple cells, one cell's transmission will interfere other cell transmission at the receiver. The receiver receives the signal which is destined to it and also from other co-channel cells which use the same frequency. The latter part of the received signal interferers in decoding of the former which is required and its results interference. This interference is called as Co-Channel Interference (CCI) or Inter-Cell Interference[2] (ICI). However the effect of ICI will be considered in terms of Signal to Interference Ratio (SIR). It is the ratio of received power of Signal Of Interest (SOI) from own base station (own cell user) at the user position (base station) and the total received interference power from other cells as given in Equation 1.

$$SIR_i = \frac{S_i}{\sum_{cell \neq i} S_{cell}} \quad (1)$$

Where SIR_i is SIR in cell i at a user position, S_{cell} is the received signal power from the co-channel base station cell.

The received signal power from a cell base station j, S_j, can be calculated by subtracting the propagation loss from the transmitted power from base station j. Propagation loss will occur from distant dependent path loss (PL), shadowing (S), and multipath fading(H_k). The distance dependent path loss is proportional to the distance between user equipment and base station power path loss exponent (PLE). Equation 2 [10] shows the received power in dBm at a user terminal located at distance d from the base station when propagation loss is subjected to distance dependent path loss alone.

$$P_r(d) = P_r(d_o) - 10n \times log_{10}\left(\frac{d}{d_0}\right) \quad (2)$$

where $P_r(d_0)$ is the received power at a reference point near to base station at a distance of d_0, d is the distance from base station to user equipment, and n is path loss exponent.

Shadowing is the effect on propagating signal when the user is in Non Line of Sight (NLOS) regions. For example, behind the buildings and walls etc. from base station. This shadowing/shadow fading can be modeled as log normally distributed random variable. And the multipath fading occurs when user receives multiple copies of base station transmitted signal with different delays and attenuation factors/coeficients. So, in frequency domain this effect will vary on frequency to frequency. These coefficients also vary in time and the correlation between the same path coefficients in time depends on the user speed. These coefficients can be modeled by using Rayleigh distribution or Rician distribution. However, since this shadow fading and multipath fading are random in nature, so if we average the multiple received signal powers both in time and frequency, the effect of these will be ruled out and the received signal power depends on the simple distance dependent path loss.

As we increase the frequency reuse, the number of interfering cells will be reduced thereby higher SIR can be achieved. Therefore, the greater we adopt frequency reuse, the bigger will be the cluster size and the distance between co-channel cells will be increased whereby the received power from co-channel base stations is decreased and hence the interference is mitigated. The main requirement in communication systems is capacity (bits/s) and it is related to SINR and transmission bandwidth as given in Equation 3, which tells how much data rate a cell can provide.

$$C = BW \times log_2(1 + SIR) \quad (3)$$

Where BW is total transmission bandwidth and SIR is signal to interference ratio as given in Equation 1.

The transmission bandwidth of a cell is equal to the total available bandwidth divided by frequency reuse. So, if we increase the frequency reuse the transmission bandwidth for cell will be reduced. However, with the greater frequency reuse we achieve good amount of SIR in return cost paying in terms of bandwidth. But the capacity is linearly related to bandwidth where SIR is related in logarithmic so the gain in capacity achieved by frequency reuse through SIR improvement cannot compensate the capacity loss by transmission bandwidth reduction.

For reuse one scheme the capacity is

$$C = BW \times log_2(1 + SIR)$$

For reuse 3 scheme

$$C = \frac{BW}{3} \times log_2(1 + SIR)$$

IV. ADVANCED SPECTRUM ALLOCATION PROCEDURES

LTE is targeted to support higher cell throughput, 100 Mbps and 50 Mbps in downlink and uplink respectively, for that frequency reuse one is proposed as spectrum allocation scheme. GSM like systems which require minimum SINR 9 dB[11] to have proper connection between user and base station, but here in LTE with proper link adaptation a user whose SINR is close to −10 dB can also be served. So with frequency reuse one LTE can be operated and it will achieve higher cell throughput as desired but if we see the per user performance wise, it will be worsen for user at the cell edge1.

To increase the area spectral efficiency [11], in bits/sec/Hz/unit area, cell sectoring is used in which a number of directed antennas will be installed for cells base station. Essentially each directed antenna at a cell's base station, called sectoral antenna, will act itself as a base station. So, each sector can use same bandwidth, in the case of frequency reuse one, and works in parallel to support the users which are falling in its directed beam foot print. Thereby the number of users served per sector or area spectral efficiency can be increased.

As discussed, to achieve targeted bit rates in LTE, frequency reuse one is suitable, where frequency reuse three cannot achieve required performance at any SINR, but the drawback of it is the cell edge user performance degradation. To handle this several techniques came in literature. One is called Reuse Partitioning [11] in which the total available bandwidth to the system will be divided in to number of disjoint parts and each part can be used at different frequency reuse and since for different reuse schemes achieves different SINRs so on each part user will get different SINRs. Then based on the user location (near or far from the base station) and required SINR, spectrum can be allocated from the part which suits well to that user. In LTE main issue is cell edge user performance so according to Reuse Partitioning the available bandwidth can be divided into two disjoint parts and one can be used at reuse one and other can be used at reuse 3. Since cell edge users experience high ICI, reuse 3 spectrum can be allocated whereby the main dominant interference coming from the near two base stations will be removed.

In this reuse partitioning scheme, the size of this disjoint parts can be chosen according to edge user traffic load. Let us denote B_{reuse1} be the size of the bandwidth part which is used at reuse one, B_{reuse3} be the band width part which is used at reuse 3, and B be the total available bandwidth for LTE system then

$$B = B_{reuse1} + B_{reuse3} \quad (4)$$

If B_{reuse1} is represented as pB where 'p' is the fraction of B then B_{reuse3} will be (1 − p) B. [11] defines an effective frequency reuse r_{eff} :

$$r_{eff} = \frac{B}{B_{cell}} \quad (5)$$

Where B_{cell} is the available transmission bandwidth for a cell and is:

$$B_{cell} = B_{reuse1} + \frac{B_{reuse3}}{3} = \left(p + \frac{1-p}{3}\right) B \quad (6)$$

Hence, from equation 5 the effective frequency reuse will be in relation to p
is:

$$r_{eff} = \frac{3}{2p+1} \quad (7)$$

Therefore B_{reuse1} and B_{reuse3} can be represented in terms of r_{eff} as:

$$B_{reuse1} = B.\frac{3-r_{eff}}{2r_{eff}} \quad (8)$$

$$B_{reuse1} = 3B.\frac{r_{eff}-1}{2r_{eff}} \quad (9)$$

According to traffic load r_{eff} can be set and it can be determined from the equation (7). However, r_{eff} need to be fixed same for each cell in the service area.

Fractional Frequency Reuse (FFR) is another scheme which is recently proposed and it is almost similar to the reuse partitioning scheme except the power ratio of transmit power over frequency reuse one subband and transmit power over frequency reuse 3 subband is less than one, where in latter scheme it is equal to one. So, the special case of FFR for which the power ratio is equal to one is the reuse partitioning scheme.
We know that in frequency reuse 3 scheme each cell will get one third of total available bandwidth of system and a cluster of cells share the available bandwidth. Then the remaining part of the bandwidth in each cell is not used for transmissions. Soft Frequency Reuse (SFR) scheme first introduced in [14], which follows reuse three scheme, in this scheme each cell will get one third of available bandwidth over high transmit power can be transmitted, then the remaining bandwidth in each cell will be used at low transmit power. Therefore in each cluster of three cells each cell will use orthogonal or disjoint subband at high transmit power. Since, the users nearer to base station, called cell center users (CCUs), will get high SINR as compared to edge users, so these low transmit power subband can be used to allocate for the transmissions of CCUs. Then the cell edge users (CEUs) can be allocated to high transmit power subband which is being used at reuse three. In this scheme each cell will use entire bandwidth with varying power levels where FFR or reuse partitioning only 2p+1 fraction of available bandwidth is used.

In these above given reuse schemes, how to differentiate a user is a cell edge or cell center user is an issue. However, it can be done on the basis of the user distance from base station but it will not be a good metric to differentiate them because the propagation loss from a base station to user (or vice versa) is not only depend on distant dependent path loss but also depend on the shadowing or multipath fading. It may happen that geographically user is close to a base station but due to shadowing or multipath fading the user may receive low signal strength form the base station further and receive high signal strength from the neighboring base stations. Since the main idea of these scheme is to increase user performance which is being affected by ICI so there should be a method so that the frequency subband on which interference is less should be allocated to such a user. One can use Geometry factor (G) which is defined as for a particular user the ratio of total received power from the base station to which it is associated and total interference power that is the total received power from other base stations.

V. SIMULATIONS AND RESULTS

To test different spectrum allocation procedures a 19 cell two tier system with wraparound technique is simulated in MATLAB with the following simulation parameters.

Table 2: Simulation parameters

Parameter	value
Carrier frequency	2000 MHz
Cellular layout	Two tier (19 cells), 3 sectors per cell, Total 57 sectors
Inter-site distance	1.732 Km
System bandwidth	5 MHz, 24 PRBs considered
Distance-dependent path loss	$128.1 + 37.6 \log_{10}(R)$, R in kilometers
Lognormal Shadowing	Log Normal Fading with 0 mean, 8dB standard deviation
Base station transmit power	43 dBm
User equipment Noise Figure	7 dB
Tx antennas (eNB)	1
Rx antennas (UE)	1
Traffic model	Full buffer
Minimum UE distance from eNB	$35m$
Scheduling	Round Robin
Bandwidth per PRB	180 kHz
Number of major PRBs	8
Number of minor PRBS	16
Reuse 3 spectrum size in FFR	12 PRBs
SFR power ratio	0.4
FFR power ratio	0.3
Geometry factor threshold	3 dB
White noise power density	−174 dBm/Hz
Minimum Coupling Loss (MCL)	70 dB

Firstly, to compare the reuse 1 and 3 schemes we have obtained capacity versus user SINR plot and user SINR versus distance from base station and plots are given in figures 3 and 4.

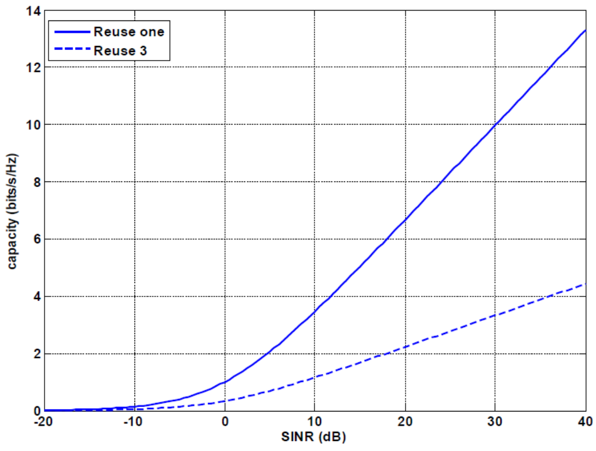


Figure 3: Capacity vs. SINR for frequency reuse one and 3

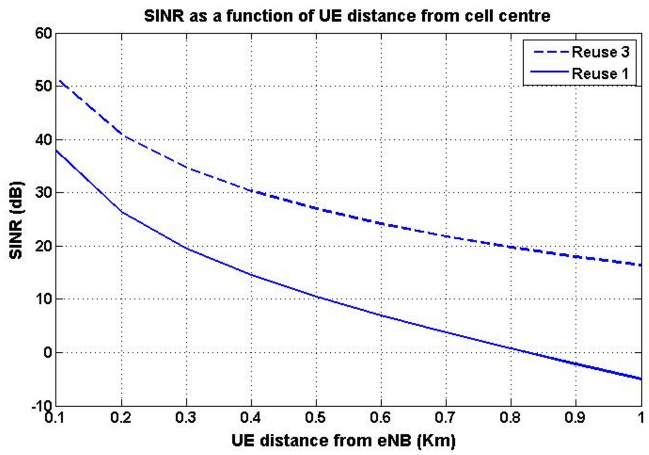


Figure 4: SINR versus UE distance from base station

Figure 3 shows that the capacity that is achieved with frequency reuse one (where full bandwidth is available) at a particular SINR equal to the capacity achieved by frequency reuse 3 (where one third of bandwidth is available) at greater SINR. It is seen that the reuse 3 scheme need to improve SINR by 10 dB, at low SINR region of the figure 3, to provide same capacity as frequency reuse one provides.

The figure 4 shows the comparison between frequency reuse one SINR and frequency reuse 3 SINR versus user distance. We observe that in cell edge region the SINR difference is more as compared to cell center region and hence reuse 3 must be used for the users located far away from base station.

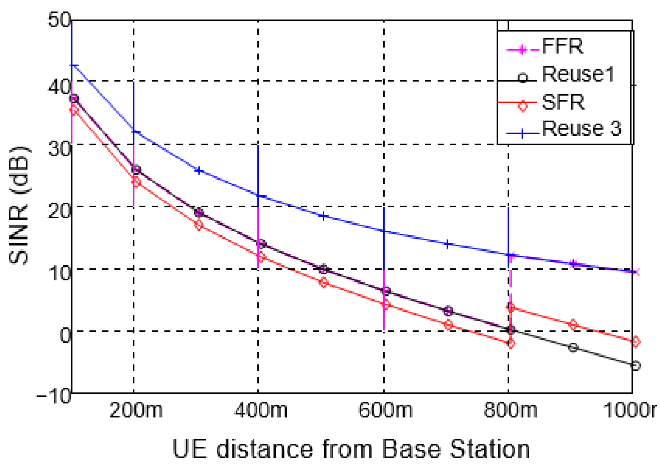


Figure 5: SINR vs.UE distance from eNB for SFR and FFR

Figure 5 shows that with the FFR scheme the SINR in the cell-center region is same as reuse one scheme, because the cell-centered users are allocated PRBs from reuse one spectrum. With the FFR scheme For the users beyond the cell-center cell-edge boundary (800m from base station) SINR performance is as same as reuse 3 scheme. This is because the users in this zone are considered as cell-edge users and are allocated PRBs from the spectrum reused at 3.

For SFR scheme it is seen that the SINR performance for the users with in the distance $800m$ is less than that of frequency reuse one scheme. This is because, in SFR scheme the PRBs allocated to cell-centered users are using at high transmit power(at 40% higher, for power ratio $\gamma = 0.4$) in the adjacent cells. It is also observed that SINR performance for edge users is lower than reuse 3 (and higher than reuse one scheme). This is because in latter scheme, the PRBs which are allocated to users are used at zero power (not used) in the adjacent cells where in the former case edge user allocated PRBs are used at low transmit power. Therefore the interference level is increased in SFR scheme.

I. CONCLUSIONS

Because of the link adaptation techniques are present in the LTE, with low SINRs also data can be transmitted. So we can decrease the reuse factor and increase the spectral efficiency even when SINR is compromised. However with low SINR, cell edge user performance is drastically reduced and to improve this FFR and SFR advanced spectrum allocation is proposed. We found that SFR is better than FFR as it provides the entire bandwidth to cell with improved cell edge user performance.

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