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Simulation of Fractional Frequency Reuse Algorithms in LTE Networks

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ABSTRACT--- LTE (Long Term Evolution)also popular as 4G LTE is the latest mobile technology which uses VOIP technology for communication. There are various limiting factors of wireless cellular technology such as delay, throughput, latency etc, but the most effecting limiting factor is Inter cell Interference (ICI). It can be reduced by using different methods of Frequency reuse techniques. Ns3 supports almost all the popular technologies including LTE, WLAN and Ethernet. LTE module is available to simulate 4G environment by applying different frequency reuse algorithm modules, different handover techniques and much more. In this paper, the different frequency reuse algorithms are presented theoretically for designing 4G LTE topology are discussed and simulated using. The simulation results indicates that the soft frequency reuse algorithm achieves highest system performance in comparison of Soft FFR and Distributed

Keywords—4G, ns3, LTE EPC, HFR, SFR, SFFR, Dynamic FFR

I. INTRODUCTION

ns3 is a network simulator which operates as discrete event network simulator especially developed for research activities and also for educational purposes. All the modules of ns3 are written in C++ with python binding. A complex topology can be created and evaluated by using predefined methods already present in different modules . Fractional- Frequency-Reuse (FFR) is among the most important Radio resource management technology developed for 4G LTE. In 2G and 3G architecture every cell in the network like to use single carrier frequency and only single system bandwidth . Fractional -frequency-reuse is the Inter Cell Interference reduction technique in which the entire cell is divided in outer and inner region to which different frequencies are allotted and also can be reused. Different power level setting can also be utilized for great effienecy. The different performance metric to study frequency reuse includes SINR,Capacity and throughput. Then, depending on physical location, the UEs are allotted to one of these sets of RBs. The LTE standard deploys different FFR algorithms and also some different methods can be modified as per design specifications of vendors. Thus the design of well performing Fractional-Frequency-Reuse (FFR) is an important topic of research for researchers in industry and in academia.

In ns-3 ,the new APIs are added to support the latest FFR algorithms. These can be furthered separately implemented for of uplink and downlink with flexibility in power control. This article is organized by introducing the Architecture of LTE -EPC Module in chapter II, Different fractional frequency reuse algorithms in chapter III, Different frequency reuse algorithms. chapter IV includes the simulation parameters with results obtained using ns3 LTE module followed by conclusion in chapter V.

II. ARCHITECTURE OF LTE EPC MODULE

The following Figure 2.1 shows the architecture of LTE EPC simulation model used in ns3. It mainly consist of two components i.e. LTE model and EPC model [1].

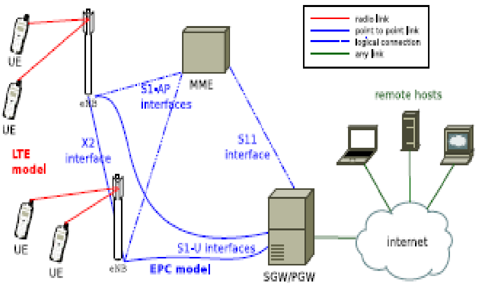

Figure 2.1 Overview of LTE EPC model

LTE Model: LTE module consists of LTE Radio protocol such as, Radio Resource control (RRC), RRC, PDCP(Packet Data Convergence protocol),RLC(Radio link control), MAC(Media Access Control Layer), PHY(Physical layer). These items always resides inside the user equipment node(UE) and the evolved base station node (eNB).

LTE model in ns3 have sufficient classes and functions which will support the designing and evaluating the RRM (Radio Resource Management),Quality of Service(QOS) which helps in scheduling, and accessing the Inter-Symbol-Interference(ISI),and access to the spectrum.

EPCmodel: This module contains core network interfaces, entities and protocols. These protocols and entities resides inside the Serving gateway(SGW), PGW & MME nodes, and also partially inside the eNB node. EPC model helps to provide end to end IP connectivity and simulation of the required topology. It also supports multiple user equipments (UEs) to the internet by means of RAN (radio access network) having multiple eNBs (evolved base station nodes) connected to the single SGW/PGW node .It supports IPV4 type of Packet Data Network. The functions of Serving Gate Way (SGW) and (Packet Data Network Gateway(PGW) are implemented within a single node

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III. FREQUENCY- REUSE ALGORITHMS

The ns3 LTE Module supports seven different Fractional-frequency-reuse algorithms. They are No operation-frequency algorithm (NOOPFR), Hard- frequency Algorithm (Hard FR), Strict-frequency Algorithm(Strict FR), Soft-fractional-frequency Algorithm (Soft FFR),Enhanced-fractional-frequency Algorithm(Enhanced FFR) and Distributed-fractional -frequency Algorithm(Distributed FFR).

It produces very high throughput in cell center. Due to high interferences from adjacent cells the through put is very less at cell edges. Fractional Frequency Reuse scheme divides the allotted bandwidth to number of sub band frequencies with different FRF and with distinct transmitting power [6].

The classes for Frequency reuse algorithms in ns3 are represented by[2]

- `ns3::LteFrNoOpAlgorithm`
- `ns3::LteFrHardAlgorithm`
- `ns3::LteFrStrictAlgorithm`
- `ns3::LteFrSoftAlgorithm`
- `ns3::LteFfrSoftAlgorithm`
- `ns3::LteFfrEnhancedAlgorithm`
- `ns3::LteFfrDistributedAlgorithm`

3.1) No-frequency reuse Scheme

It is similar to Full-frequency reuse scheme, i.e. there is no partition between the eNBs of same core network. |It has the frequency reuse factor of one. All the eNBs make use of entire system bandwidth and the signals are transmitted with uniform power over all Radio Base Stations. This technique help in achieving very high peak data rate but due to huge level of interference from nearby or neighboring cells, edge cell users performance is highly limited. It is the simplest of all other algorithms and by default is installed on eNBs.

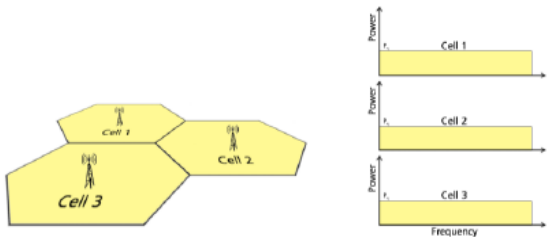

Fig 3.1 No-frequency reuse scheme

3.2 Hard-Frequency reuse Scheme

This Reuse scheme or algorithm improves the reduction in interference from neighboring cell and reduces ICI. The entire system bandwidth is divided into few number of disjoint sub bands typically 3,4 or 7. All the ENBs of these cells are allotted with different sub-band of frequencies. The frequency reuse factors will be equal to the number of sub bands. It improves the cell users performance by reducing ICI at cell edge. the disadvantage with this scheme is that the peak-data- rate level which can also be limiting factor.

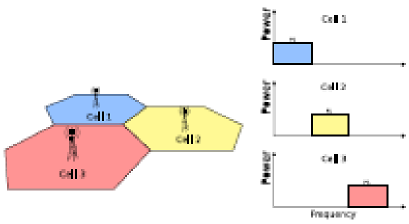

Fig 3.2 Hard-frequency reuse scheme

3.3 Strict Frequency Reuse Scheme

This Frequency-reuse-scheme or algorithm combines both Full and Hard-Frequency-Reuse schemes.

The full system bandwidth is splited into two parts with different frequency reuse factors.

A single sub band frequency of the system bandwidth is allotted to each interior of the cell having frequency reuse factor 1 and the remaining bandwidth is distributed between the nearby eNbs similar as we have in Hard-frequency reuse (having reuse factor N),which creates one sub band providing very low level of ICI within every sector. User Equipments (UEs) inside the center region are acknowledged the fully reused frequencies, where the edge cell UEs are acknowledged with orthogonal frequencies [7]. It means that interior UEs will not have spectrum interference with edge UEs from neighboring cell. This will reduce the interference for both.

Strict-frequency reuse scheme needs total N + 1 sub bands, also helps to manage frequency reuse factor in the range of 1 and 3.

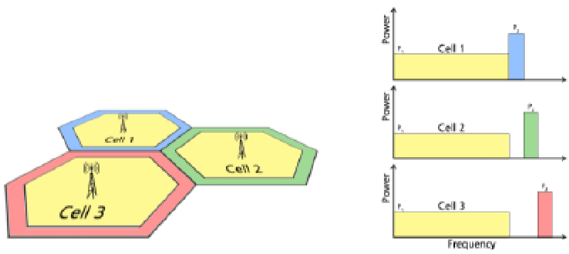

Fig 3.3 Strict-frequency reuse Scheme with N=3

Figure 3.3 above represents how the power and frequencies are planned with cell edge reuse factor of N=3

3.4 Soft-frequency reuse Scheme

In Soft-frequency reuse scheme or algorithm each eNb utilizes entire system bandwidth for transmission. Inside the cell, there will be two sub band frequencies within UEs which are supplied with different power level[1]. The UEs of at the cell center shares the entire bandwidth with the neighboring cells and by transmitting less power at center than the edge cell user. Soft- Frequency- Bandwidth scheme is higher bandwidth efficient compared to Strict-Frequency-Reuse as it make use of full system bandwidth. The drawback of this scheme is that it produces much more interference with edge users as well as cell interior.

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There are 2 different available versions of **Soft-frequency reuse Scheme**

1. In this first version, the available sub band of small frequency is given over to the cell edge UEs can be awed for center UEs residing in the cell but only with lower power level provided they are not engaged by the edge cell UEs[9] . The sub band allotted to cell center is accessible only for users equipments (UE) at the centre .

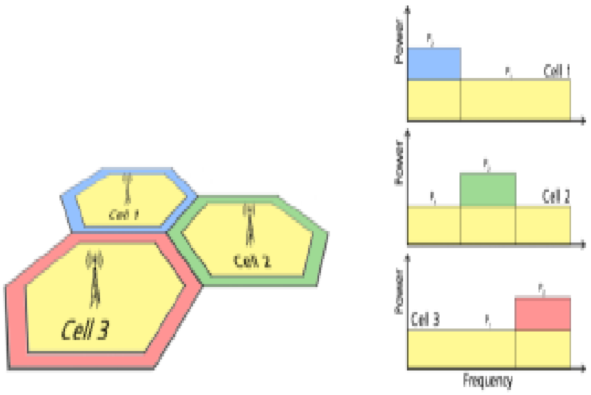

Fig 3.4a. Soft-frequency reuse Scheme (SFR) version1

2. In this second version, the small frequency band which was given over to cell center UE cannot be awed for cell edge UE. Hence, all the cells can make a use of full system bandwidth along with reduced neighboring cell interference[1].

Lower level of ICI for the cell edge can be acquired at the expense of lesser utilization of the spectrum.

Fig 3.4 b below shows the power and frequency plans for SFR version2. As shown Soft-Frequency-Reuse algorithm manages two maps as shown.

To determine about the level of transmission power, the user equipment should also provide the SFR algorithm which helps in handling the measurements related to user equipment, after which those are compared with the threshold value. The quality of Signal threshold obtained for inner as well as outer area can be configured by system attributes.

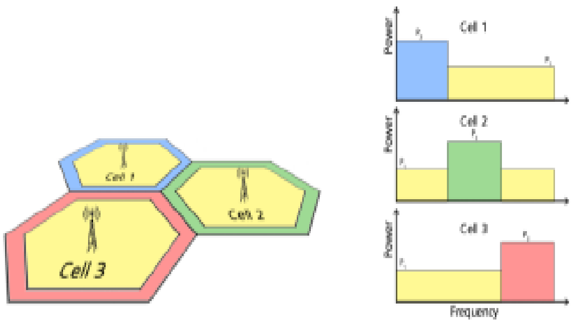

Fig 3.4b. Soft-frequency reuse Scheme (SFR) version2

3.5 Soft-fractional frequency reuse Scheme

Soft-fractional frequency Reuse (SFFR) scheme is composite of strict-frequency reuse and Soft-frequency reuse scheme[6]. Strict-frequency reuse (SFR) makes use of different sub band for outer region in neighboring cell. The inner cell transmitting power use soft FFR with less transmitting power. Thus, under these circumstances SFFR use the sub band with the greater as well as lower transmitting power level same as SFR.

The Soft FFR makes helps in increasing the throughput of the inner cell UEs.

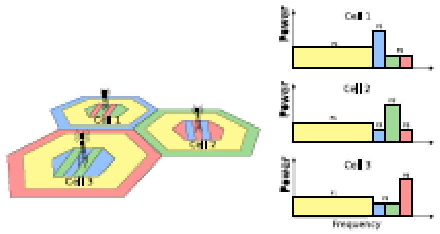

Fig 3.5 Soft-fractional frequency reuse Scheme

3.6 Enhanced-fractional frequency reuse Scheme

Enhanced-fractional frequency reuse(EFFR) describes three cell types to the direct adjacent cells in the given cellular system. This reserves for each cell type which is built in part of the entire band of frequency and tagged as Primary Segment. This will be one of different type cells and also they must be orthogonal among themselves. Hence the reuse on the Secondary Segment by each cell have to follow 2 rules:

1. monitor the segment use in advance
2. resource the reuse depends on SINR evaluation.

Every cell takes notice on each secondary sub- channel every time. Also it makes SINR estimation before choosing the secondary sub channel reported by the gathered channel quality information (CQI) . Accordingly it will chose the best estimated values for reuse.

The scheduling process contains 3 steps and 2 scheduling polices.

During ns3 implementation, reuse with factor 1 sub channels can only be used with users present at cell center. Reuse with factor 3 sub channels can also be used by the users residing at the cell edges but only on the condition with no edge user. The transmission for the users present in cell center will be provided by reuse 3 sub channels.

Figure3.6 shows Enhanced-fractional frequency reuse(EFFR) scheme representing Power and frequency plan.

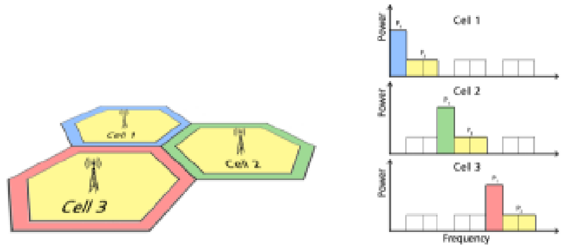

Fig 3.6 Enhanced-fractional frequency reuse Scheme

3.7 Distributed-fractional frequency reuse Scheme

This Distributed-fractional frequency reuse Algorithm (DFFR) accordingly improves which focus especially in the distribution of received power levels. The DFFR algorithm adaptively selects RBs for cell edge sub band based on

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coordination information from adjacent cells. This will be notified at the base stations which belongs to the adjacent cells that, which RBs is preferred to use in edge sub band. Each cell base station make use of the information received The basic equation use for calculation of cell edge band metric A_k for each radio base station RB is given by.

$$A_k = \sum_{j \in J} w_j X_{j,k}$$

where J -→ neighbor cell set

$X_{j,k} = \{0 , 1\}$ -→ RNTP from the j^{th} neighboring cell.

It is set to 1, when the k^{th} RB in the j^{th} neighboring cell

w_j → weight with respect to neighboring cell j,

If the value of received power is much high it means that the i^{th} cell experience very high interference from the j^{th} cell.

If the RB is less ,it means ith cell has less interference levels from the another neighboring cell. The serving cell have to select a number of eRBs as cell edge sub band is configured in ascending order of A_k. At last, those RBs are chosen in which less number of edge cell user equipments receives large level of interference due to neighboring cells. Updated value of RNTP is directed to all adjacent cells [7].

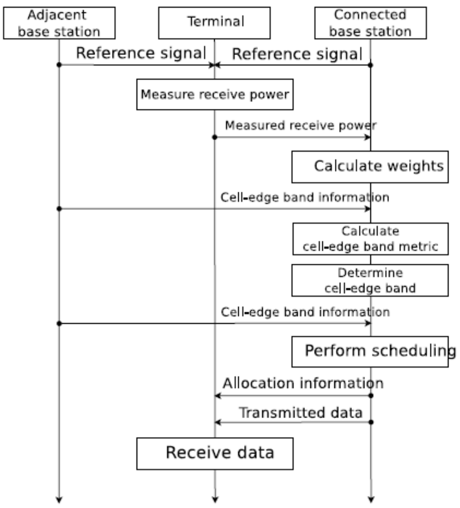

Figure 3.7 Sequence diagram of Distributed Fractional Frequency Reuse (DFFR)Scheme

IV. SIMULATION PARAMETERS AND RESULTS

Simulation parameters	Value
Simulation Time (Seconds)	50
Bandwidth	25
Number of eNb nodes	3
Number of Center Ue nodes	3
Number of Edge Ue nodes	3
Generate REM	True
RemRbId	20

Simulation Results:

The Simulation Results generates (Radio Environment Map) REM file which shows the SINR (Signal to Interference Noise Ratio)in decibels at all the co-ordinates with intensity parameter specified during programming. Hard Fr uses entire band and has highest SINR strongest at center. Soft Frequency reuse and Soft Fractional frequency reuse is found to have decrease in transmitting power at center area which will be less and not sufficient to combat fading as well as ICI. Enhanced Fractional frequecny reuse REM also shows the good uniform SNIR as shown in figures below.

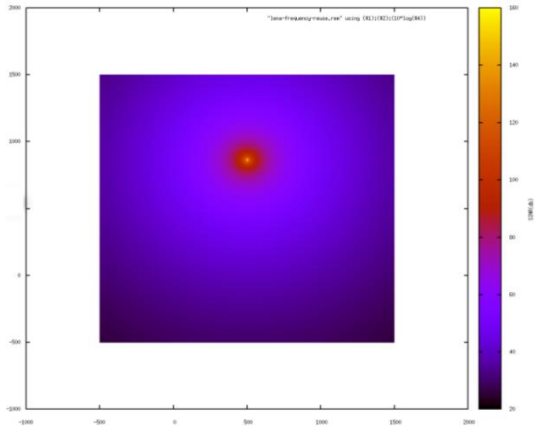

Fig 4.1 REM obtained from Simulation with implementation of Hard FR Algorithm

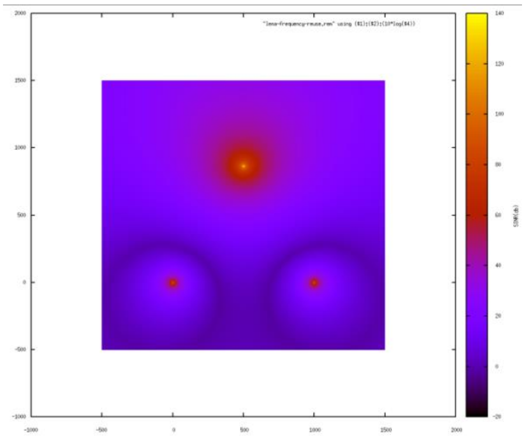

Fig 4.2 REM obtained from Simulation with Soft FR Algorithm enabled

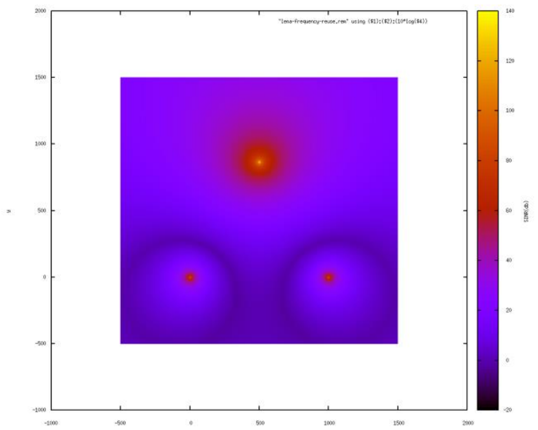

Fig 4.3 REM obtained from Simulation with Soft FfR Algorithm enabled

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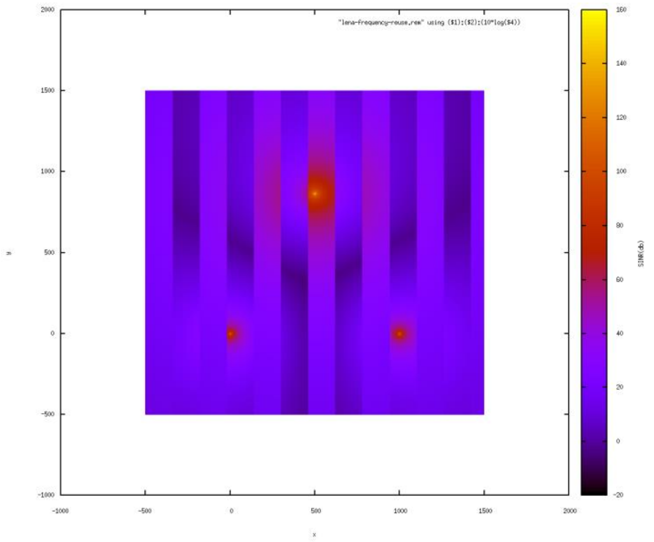

Fig 4.4 REM obtained from Simulation with Enhanced FfR Algorithm enabled

	Hard Fr Algorithm	Soft Fr Algorithm	Soft Ffr Algorithm	Enhanced Ffr Algorithm
Downlink (Dl) Average Throughput Kbps	171	384	214	194
Uplink (Ul) Average Throughput Kbps	165	215	161	71

Fig 4.5 Downlink and Uplink Throughput Calculations using Frequency Reuse Algorithms

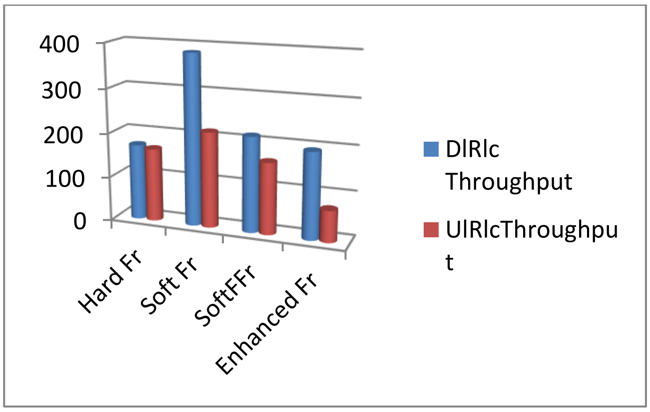

Fig 4.5 Downlink and Uplink Throughput Calculations using Frequency Reuse Algorithms

V. CONCLUSION

This paper gives the introduction to different types of Frequency reuse and Fractional Frequency reuse schemes available in LTE module of ns3. The simulation of topology described by the parameters given in table shows the Radio Environment maps of various Ffr algorithms.. Hard Fr uses entire band and has highest SINR strongest at center. Radio Environment map Shows the SINR at all the coordinates with the default intensity values. The downlink and uplink Throughput are calculated using DlRlc and UlRlc trace files.

The graph shows the increase in throughput in downlink with soft Fr highest and more in Soft Ffr and Enhanced Ffr Algorithms. These Fractional frequency reuse algorithms are complex to implement and proposes new ideas for improvement of System Performance

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