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Enhancement of Spectral Efficiency in LTE-Advanced Network through Fractional Frequency Reuse

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Abstract: The enhancement of the spectral efficiency of LTE-Advanced network by deploying fractional frequency reuse is one of the major challenges in practical deployment of 4G technology. The FFR can be deployed in LTE network based on the feasibility of cellular network. There are 3 different types of deployment schemes: strict FFR, soft FFR, and FFR-3 schemes for LTE-Advanced network configuration. In the thesis work a variation of the FFR-3 scheme, which is referred to as the dynamic FFR (DFFR) scheme, is proposed. A broad comparison among all these FFR schemes is performed by using Monte Carlo simulations considering performance metrics such as Average throughput in uplink and downlink of LTE network and spectral efficiency. Simulation results show that the average gain in spectral efficiency (b/s/Hz) of the network are significantly higher for the proposed FFR scheme when compared to the conventional FFR scheme in LTE Advanced network.

Keywords: Dynamic Fractional Frequency reuse, Self-optimization network of LTE, Enhanced Spectral efficiency in LTE advanced network, Improvement in FFR, Frequency deployment in 4G Technology

I. INTRODUCTION

LTE-Advanced network uses the multiple access methodology described as "OFDMA" or any multiple access techniques based on OFDM methodology[1]. Key issue with OFDMA is the co-channel interference (CCI) or inter-cell interference; especially terminals located at the cell border largely suffer from the power radiated by the base station of neighbouring cells in their communication band. OFDMA provides the ability for each base station to selectively allocate frequency sub bands, rates and power to the users depending on their location in the cell, according to some predefined frequency reuse pattern which may lead to significant capacity gains for the overall network. There are three major frequency reuse patterns for mitigating inter-cell interference: hard frequency reuse, fractional frequency reuses (FFR) and soft frequency reuse.

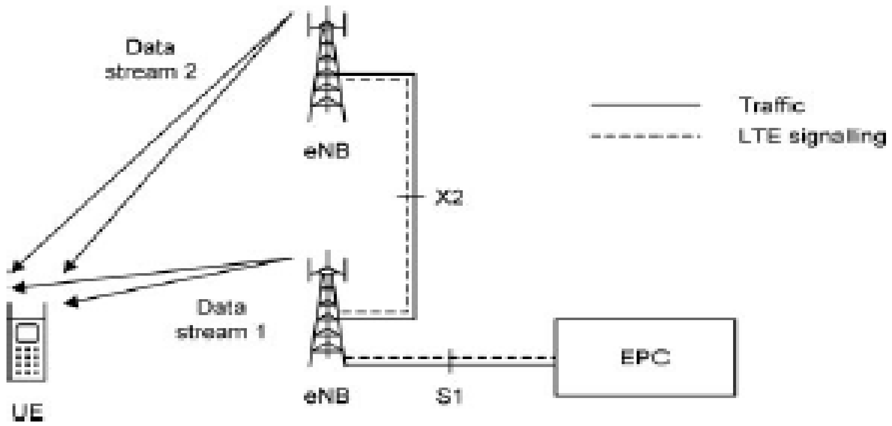

Fig 1: A Sample LTE-A Network

Hard frequency reuse though simple in implementation suffers from quite reduced spectral efficiency. On the other hand, soft frequency reuse has full spectral efficiency and is a strong tool for inter-cell interference mitigation. But as it implies centralized, coordinated resource allocation, such a system can be impractical in realistic network such as LTE or LTE-

Advanced network which involves a large number of base stations, random traffic and realistic path-loss models[2]. FFR is considered as a compromise between hard and soft frequency reuse traditional FFR has higher frequency reuse factor on cell boundaries the proposed FFR ensures maximum of one interference to the targeted cell edge users. Subcarriers and corresponding rates are then allocated to satisfy the required data rates and enable the users to exploit the interference structure in the decoding of desired signals which implies minimization of the transmit power at the base stations. The key idea of the approach is based on the exploitation of lower rate interference stream in the decoding of higher rate desired stream. Proposed approach results in the minimization of the transmit power at the base stations. Important feature of the approach, which makes it feasible and attractive for application, is that little or no coordination, is required between the base stations.

A. *Automatic Neighbor Relations*

During the configuration process, there is no need for a base station to find out anything about its neighboring cells and no need for it to set up a neighbor list. Instead, a mobile can identify a neighboring cell by itself and can tell the base station about it later on using the RRC measurement reports. The base station can then establish communications with its neighbor using the automatic neighbor relation procedure. The procedure is triggered when the base station receives a measurement report containing a physical cell identity that it was not previously aware of. The base station cannot contact the new cell right away, so it sends the mobile a second measurement configuration to ask for more information. In response, the mobile reads the neighbouring cell's system information and returns its global cell identity, tracking area code and PLMN list in a second measurement report. The base station now has enough information to initiate an S1 based handover to the new cell. To support X2 based handovers, the base station sends the global cell ID to the MME and asks it to return an IP address that the neighbouring base station is using for communications over X2. The MME is already communicating with the neighbouring base station over S1, so it can send the request onwards and can return the neighbour's reply. The two base stations can now establish communications across the X2 interface, using a procedure known as X2 setup. During this procedure, the base stations exchange information about all the cells they are controlling, including their global cell identities, physical cell identities and carrier frequencies.

B. *Interference Coordination*

The X2-AP Load Indication procedure [7] helps a network to minimize the interference between neighboring base stations and to implement the fractional frequency re-use schemes. To use the procedure, a base station sends an X2-AP Load Information message to one of its neighbours. In the message, it can include three information elements for each cell that it is controlling. The first describes the transmitted power in every downlink resource block. The neighbor can use this information in its scheduling procedure, by avoiding downlink transmissions to distant mobiles in resource blocks that are subject to high levels of downlink interference. The second information element describes the interference that the base station is receiving in every uplink resource block [5]. The neighbor can use this in a similar way, so that it does not schedule uplink transmissions from distant mobiles in resource blocks that are subject to high uplink interference[9]. The third is a list of uplink resource blocks in which the base station intends to schedule distant mobiles. Here, the second base station is expected to avoid scheduling uplink transmissions from distant mobiles in those resource blocks, so that it does not return high levels of uplink interference to the first.

C. *Mobility Load Balancing*

Mobility load balancing [4] or resource status reporting is a procedure, using this procedure, nearby base stations can cooperate to even out the load in the radio access network and to maximize the total capacity of the system. Using an X2-AP Resource Status Request, a base station can ask one of its neighbours to report three items of information. The first is the percentage of resource blocks that the neighbor is using in each of its cells, for both GBR and non GBR traffic. The second is the load on the S1 interface, while the third is the hardware load. The neighbor returns an acknowledgement and then reports each item periodically for both the uplink and downlink, using an X2-AP Resource Status Update. As a result of this information, a congested base station can hand over a mobile to a neighboring cell that has enough spare capacity and can even out the load in the radio access network.

II. METHODLOGY

The dynamic fraction frequency reuse for LTE advanced network has been designed so that a network operator can set up a new base station with minimal knowledge of the outside world, which might include the domain name of the network management system, and the domain names of its MMEs and serving gateways. The base station can acquire the other information it needs by a process of self configuration. During this process, the base station contacts the management system and downloads the software it will require for its operation. It also downloads a set of configuration parameters,

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such as a tracking area code, a list of PLMN identities, and the global cell identity and maximum transmit power of each cell. In the configuration parameters, the management system can explicitly assign a physical cell identity to each of the base station's cells.

A. In the modeling process a sample LTE advanced network has been designed with minimum number base stations for an urban area using RF planning tool. Initially the network deployed conventional FFR scheme and performed the Monte Carlo simulations for the collection of relevant statistical data for calculating the spectrally efficiency. Further a variation of the FFR , that is the proposed dynamic fractional frequency reuse is deployed in the same network and then performed the relevant Monte Carlo simulations for the collection of statistical data in order to calculate the spectrally efficiency under the new network parameters. Finally the data from the two different network conditions has been processed and the performance parameters such as average throughput in uplink and downlink of LTE network, Performance Matrices of LTE-A Hetnet Base Station, aggregate application throughput for comparison with Low Powered Node (LPN) Hetnet base station has been calculated and estimated for determine the maximum spectral efficiency under different network parameters of an LTE advanced network.

III. RESULTS AND DISCUSSION

The fractional frequency reuse for LTE advanced network is achieved by the analysis of LTE network with various dynamic traffic conditions and by varying the configuration parameters of the wireless network. In order to perform the simulation work a small area is selected, such that the quantum of the work can be better utilized for the derivation of the proposed algorithm. In order to achieve the desired result a dynamic traffic condition the network. Initially the traffic simulation of the LTE advanced network has been performed.

A. Inclusion of Femto access points

To improve the spectral efficiency [6] and so maximizing the network capacity and specifies the allocation of frequency resources to the base station. The methodology can be achieved by the intensive use of femto access points to reduce the co-channel interference. Also the maximum achievable data rate for the user and the base station can be achieved. The proposed algorithm hence expected to not only maximize total throughput, but also improve the fairness between Femto access points (FAP)[3]. Since the installation and management of Femto access points are performed by user it is essential to have a self-organized mechanism for resource allocation to improve spectral efficiency and mitigate interference issue simultaneously. In the proposed algorithm a learning automata method have to be used.

B. Comparison using Traffic simulation

In the experiment initially after the traffic simulation network performance has been carried out without using fractional frequency reuse (FFR) and then by utilization of FFR schemes. The result shows further improvement under the utilization of FFR schemes. Further a heterogeneous LTE advanced network performance has been evaluated and again the result shows a further enhancement in the aggregate throughput. Finally before deploying learning automata scheme for a dynamic traffic load condition FFR comparison has been carried out for LTE- A network and for a LTE-A Hetnet. As the FFR can perform better in a heterogeneous network scenario the result showcase the same.

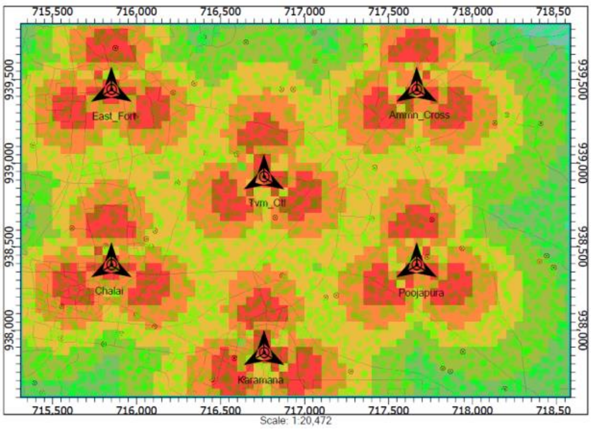

Fig 2: Traffic Simulation of LTE-A Network

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The traffic simulation of the LTE-Advanced network where the network simulated with six base stations and each base station comprises of six sectors. The traffic output can be obtained with cell statistics and user statistics. The output that can be obtained includes uplink throughput, downlink throughput and spectral efficiency of the network. The traffic report obtained from the RF planning tool comprises of the data specific to the radio link and the corresponding data throughputs. A comparison study can be performed in the different throughputs obtained in LTE network with fractional frequency reuse and without fractional frequency reuse. The statistical data rates can be compared and analyzed using the RF planning tool. Furthermore analysis of the fractional frequency reuse has to be performed in order to carry out the evaluation of proposed dynamic FFR system which enhances the effective utilization of the spectrum.

Fig 3: Traffic Simulation of LTE-A Network

Figure shows the Traffic simulation of the LTE-Advanced network where the network simulated with six base stations and each base station comprises of six sectors. The traffic output can be obtained with cell statistics and user statistics. The output that can be obtained includes uplink throughput, downlink throughput and spectral efficiency of the network. The traffic report obtained from the RF planning tool comprises of the data specific to the radio link and the corresponding data throughputs. A comparison study can be performed in the different throughputs obtained in LTE network with fractional frequency reuse and without fractional frequency reuse. The statistical data rates can be compared and analyzed using the RF planning tool . Furthermore analysis of the fractional frequency reuse has to be performed in order to carry out the evaluation of proposed dynamic FFR system which enhances the effective utilization of the spectrum.

C. Performance of the LTE Advanced Network with FFR

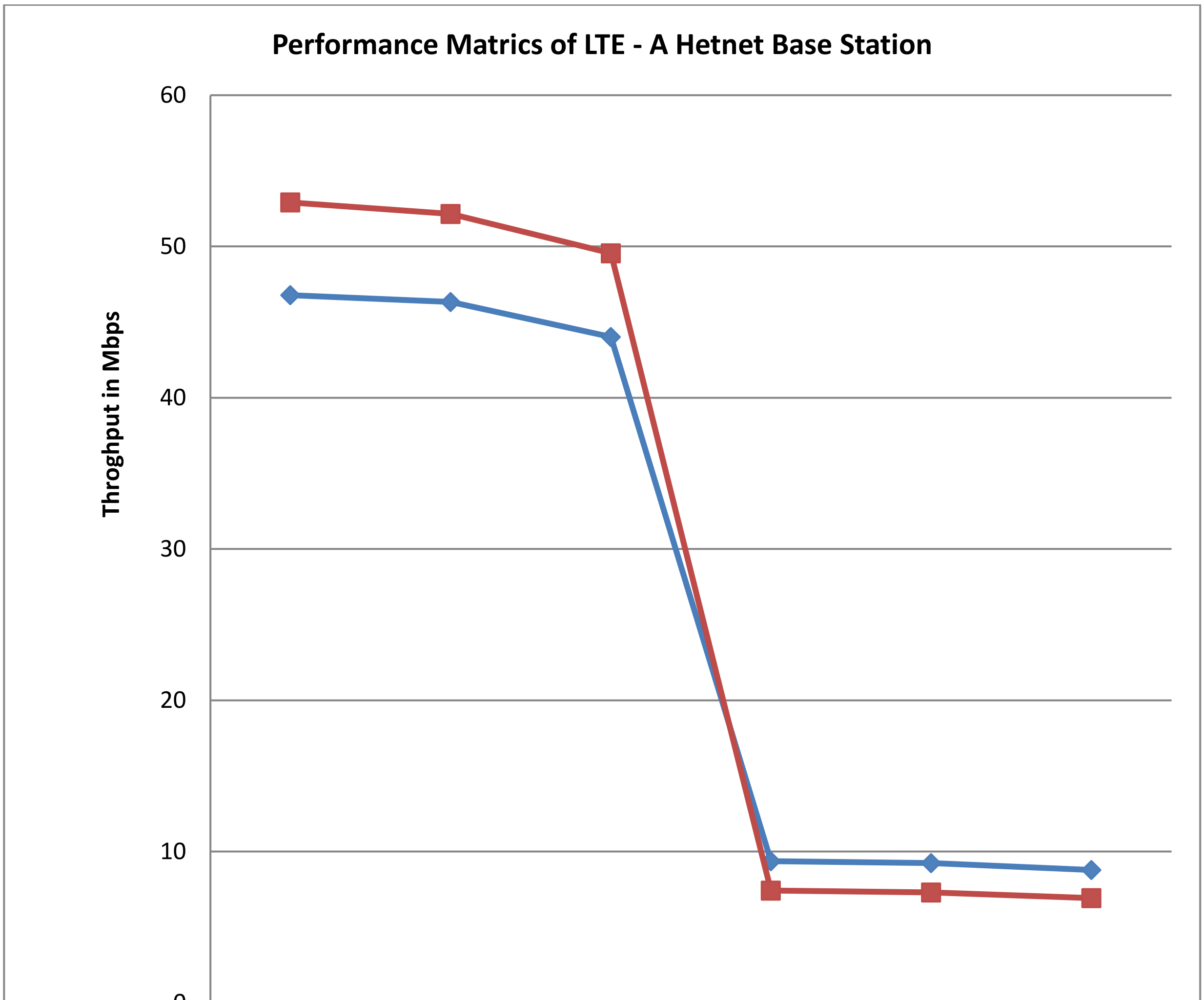
TABLE I : Comparison of LTE –Advanced network throughput (without FFR Vs FFR)

Throughput Particulars		Without FFR	With FFR	Improvement
Connected	Users	4,357	4,514	3.60%
Active	Downlink:	2,688	2,732	1.64%
	Uplink:	1,389	1,497	7.78%
	Downlink + Uplink:	227	235	3.52%
	Inactive:	53	50	-5.66%
DL:	(In Mbps)			
	Peak RLC Aggregate	866.09	876.25	1.17%
	Effective RLC Aggregate	861.84	871.45	1.12%
	Aggregate Application	818.75	827.88	1.12%
UL:	(In Mbps)			
	Peak RLC Aggregate	143.44	153.78	7.21%
	Effective RLC Aggregate	142.23	152.56	7.26%
	Aggregate Application	135.12	144.93	7.26%

The table shows a comparison between two LTE-Advanced networks, where as one network with FFR and other network without FFR. It can be observed that throughput is enhanced in LTE-Advanced network with fractional frequency reuse, an increase of 7.26% is obtained in uplink data rates and an increase of 1.12% is increased in the downlink data rates. Further more study has to be performed based on the statistical analysis of LTE-Advanced network.

D. Performance Matrices of LTE-A Hetnet Base Station

In the Heterogeneous network planning the large and small cells in the service area are separated through the use of different frequencies[8]. However, LTE-A networks mainly use a frequency reuse of one to maximize utilization of the licensed bandwidth. In heterogeneous networks the cells of different sizes are referred to as macro-, micro-, pico- and femto-cells; listed in order of decreasing base station power. The actual cell size depends not only on the eNB power but also on antenna position, as well as the location environment; e.g. rural or city, indoor or outdoor[7]. The HeNB (Home eNB) is a low power eNB which is mainly used to provide indoor coverage, femto-cells, for Closed Subscriber Groups (CSG), for example, in office premises. Specific to HeNBs, is that they are privately owned and deployed without coordination with the macro-network. If the frequency used in the femto-cell is the same as the frequency used in the macro-cells, and the femto-cell is only used for CSG, then there is a risk of interference between the femto-cell and the surrounding network[4]. The Relay Node (RN) is another type of low-power base station which is connected to a Donor eNB (DeNB) via the Un radio interface, which is based on the LTE Uu interface. When the frequencies used on Uu and Un for the RN are the same, there is a risk of self interference in the RN. From the UE perspective the RN will act as an eNB, and from the DeNB's view the RN will be seen as a UE. As the part of the work heterogeneous base station has been simulated and its performance has been compared with the actual LTE network which will not use the heterogeneous platform.



	Peak RLC Aggregate Throughput (DL):(In Mbps)	Effective RLC Aggregate Throughput (DL): (In Mbps)	Aggregate Application Throughput (DL): (In Mbps)	Peak RLC Aggregate Throughput (UL): (In Mbps)	Effective RLC Aggregate Throughput (UL): (In Mbps)	Aggregate Application Throughput (UL): (In Mbps)
Conventional Scheme	46.78	46.33	44.02	9.36	9.24	8.78
Proposed Scheme	52.91	52.16	49.56	7.43	7.29	6.92

Fig 4: Performance Matrices of LTE-A Hetnet Base Station

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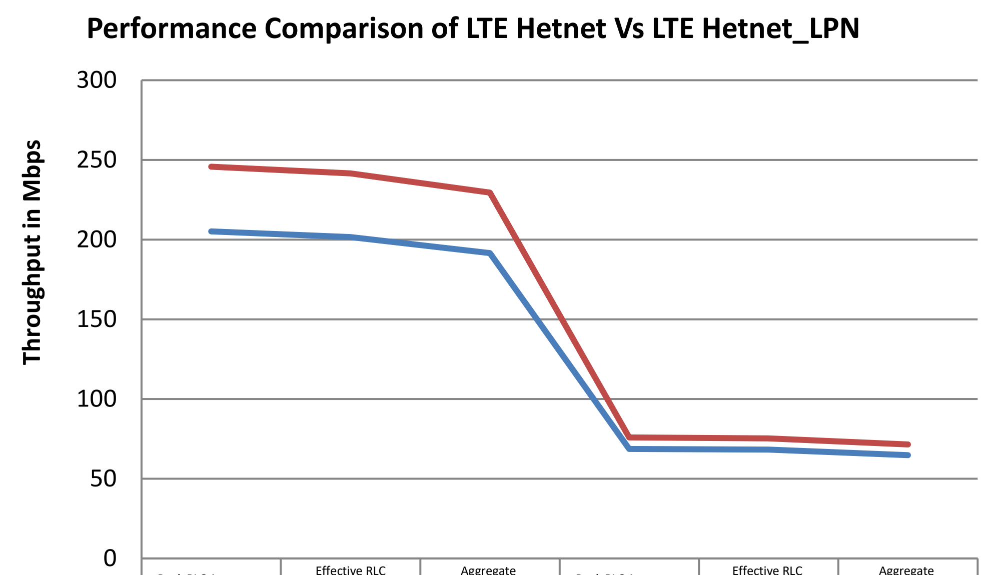

	Peak RLC Aggregate Throughput (DL):	Effective RLC Aggregate Throughput (DL):	Aggregate Application Throughput (DL):	Peak RLC Aggregate Throughput (UL):	Effective RLC Aggregate Throughput (UL):	Aggregate Application Throughput (UL):
LTE Hetnet	205.17	201.58	191.5	68.74	68.19	64.78
LTEHetnet_LPN	245.76	241.55	229.48	75.85	75.27	71.51

Figure 5: Performance Matrices of LTE-A Hetnet Base Station with LPN

E. Performance Comparison of FFR Vs Hetnet FFR

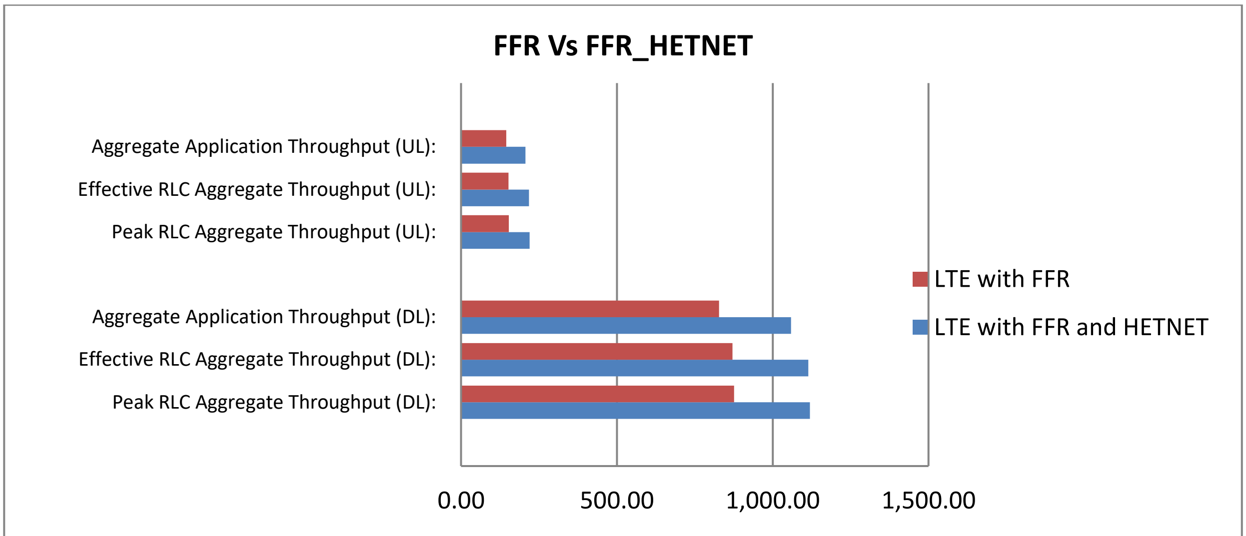

Figure6: Performance Comparison of FFR Vs Hetnet FFR.

The principle of fractional frequency reuse is to divide the overlapping area of neighboring cells into different frequency bands in order to reduce intercell interference[6]. This method no longer works in a HetNet. eICIC (evolved Intercell Interference coordinator) redefines an additional time dimension, which allows signals in different cells to be orthogonal in the time domain. Compared with ICIC, eICIC can reduce intercell interference not only on traffic channels but also on control channels. In other words, ICIC coordinates intercell interference on traffic channels in the frequency and power domains, and eICIC coordinates intercell interference on traffic and control channels in both the frequency, time and power domains also. With the help the RF planning software FFR is deployed in a conventional LTE network and further the same work has been carried out in a heterogeneous network. The result shows the heterogeneous network LTE-A performs better than LTE-A network in the FFR scenario.

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F. Performance of LTE-A with Load Balancing

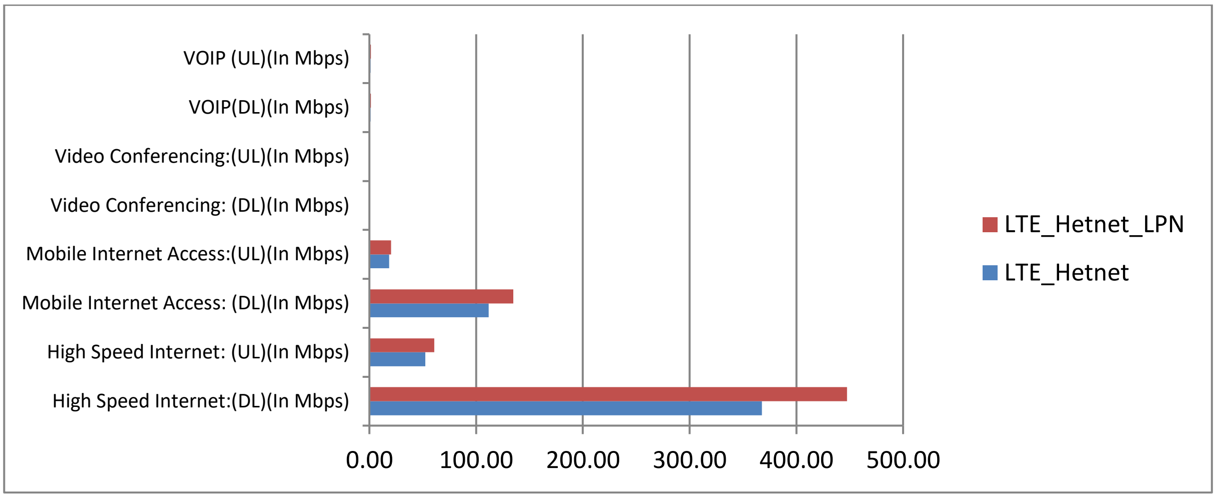

Figure 7: Performance of LTE-A with Load Balancing

The principle of load balancing offers better spectral efficiency in LTE-A network which can be realized from the above shown graph. The introduction of Home- e-Node B resulted in increasing the spectral efficiency to a higher level. The existing FFR methods have certain shortcomings which limits it's direct application in LTE- Advanced network[11]. The modification in existing LTE-Advanced network has been done with the help of low power nodes which suits for real time applications. The proposed FFR scheme can be used for the optimal design of Self Organizing Network. The optimal design with cell range extension and cell load coupling satisfies the requirements of Self Planning and Self organizing feature of LTE-A network.

IV. CONCLUSION

FFR is a simple and effective mechanism for interference management in OFDMA-based LTE-Advanced Network. Initially a broad comparison of LTE-Advanced network with fractional frequency reuse and without fractional frequency reuse is performed. Simulation results show that the FFR scheme offers superior performance than LTE-Advanced system without FFR schemes. The FFR static allocations may not be optimal under dynamic traffic load variation (e.g., due to the mobility of UE) and may increase the blocking probability. Note that an open access mode can reduce this blocking probability resulting from static resource partitioning. Optimal FFR schemes in the presence of mass deployment of HeNBs that satisfy the data rates for UE as well as the target blocking probabilities need to be developed. In this context, self-organizing and autonomous FFR frameworks will be desirable from the scalability point of view. In addition, dynamic power control methods can be developed to use in conjunction with FFR schemes to improve the capacity of HetNets. Such a hybrid scheme based on resource partitioning through FFR as well as power control is currently being considered for LTE-Advanced systems.

V. FUTURE WORK

Even though the traditional and proposed FFR scheme comparison can be used for the estimation of spectral efficiencies of an Advanced LTE-A network, the power required to achieve the desired spectral efficiency has not yet evaluated in this scheme which may have significant effect on the performance of a communication network[10]. The date rate estimation on this network has been performed without power estimation. In order to deliver exact spectral response we have to obtain the power required to achieve desired FER without interference.

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BIOGRAPHY

An Electronics and Communication engineering graduate from Rajiv Gandhi Institute of Technology, Kottayam. Soon after graduation joined in Tata Elxsi Limited, Trivandrum as Design and development Engineer. After that joined in Bharath Sanchar Nigam Limited as Junior Telecom Officer and carried out the design and development of different training programmes for Mobile communication as per the requirement of the various Central and State Departments /Organisations and Corporates. The major area of interest includes LTE, Self-Optimizing Networks and RF planning of NGN wireless networks. Currently working as a Lecturer in Electronics Engineering under Department of Technical Education, Kerala.

An Electronics and Communication engineering graduate from College of Engineering, Trivandrum. After graduation joined as Assistant Professor in Electronics and Communication Engineering under Department of Technical Education, Kerala. The major area of interest includes latest trends in communication engineering. After completing Post Graduation in Biomedical engineering from IIT, Bombay currently working as Associate Professor in Electronics and Communication engineering under Department of Technical Education, Kerala.