International Journal of Future Generation Communication and Networking
Vol.10, No.4 (2017), pp.11-18
http://dx.doi.org/10.14257/ijfgcn.2017.10.4.02

Dynamic Frequency Reuse: A Method for Interference Mitigation in OFDMA Based LTE-A Networks

Asif Reza[1], Khaizuran Bin Abdullah[2], Ahmad Fadzil Bin Ismail[3], Farah Raisa[4], Hudah Adibah Bt. Mohd. Ramli[5] and Wahidah Hashim[6]

[1, 2, 3, 4, 5] Department of Electrical & Computer Engineering, International Islamic University Malaysia, 53100 Kuala Lumpur, Malaysia
[6]College of Computer Science and Info Tech, Universiti Tenaga Nasional Malaysia
[1]asif.a.reza@ieee.org, [2]khaizuran@iium.edu.my, [3]af_ismail@iium.edu.my, [4]f.r.farah@ieee.org, [5]hadibahmr@iium.edu.my, [6]wahidah@uniten.edu.my

Abstract

Spectrum scarcity is one of the most discussed restraining aspects in wireless communication system. To solve this issue Frequency Reuse (FR) concept is introduced. It is a promising development to fulfil the requirement of Long Term Evolution Advanced (LET-A). With the introduction of FR comes the problem of Inter Cell Interference as the neighboring eNodeBs (eNB) which uses the same frequency band that will act as an interference source. In this paper, a Dynamic Frequency Reuse (DFR) method is anticipated. Continuous optimization of resource allocation of each cell is considered in this method. The important focus of the paper is to expand the capacity of the users placed in cell edge areas by reducing out of cell interference. Simulation has been done to prove that the proposed scheme leads to efficient resource management.

***Keywords**: FR, LTE-A, DFR, ICI, capacity*

1. Introduction

High speed, uninterrupted service and reliable connections are the requirement for present day's communication network users. Adding up to that, with the increased number of users, people need something new that will fulfil all their above requirements. Long Term Evolution (LTE) is the cellular standard that can solve all the issues regarding the problems of the network. LTE is considered as the standard for high speed and reduced latency in the service. LTE is also known as the standard of the fourth generation (4G) technology in communication system. Many developed countries are now using this technology to attend to their need of reliable connection. For mobile standard system, the 3rd Generation Partnership Project (3GPP) is currently the main standards development group. Within 3GPP, three multiple access techniques are used: GSM, GPRS and EDGE. They are considered as 2nd Generation system. The 'Third Generation' mainly known as the Universal Mobile Telecommunication System (UMTS) family which has introduced Code Division Multiple Access (CDMA) technology and became known as Wideband CDMA, commonly known as WCDMA. Finally, LTE has taken Orthogonal Frequency Division Multiple Access (OFDMA) technique that is a technology to access, which is dominating the newest mobile technologies.

However, the LTE standard is still evolving every day. To keep pace with the increased number of users, many researchers have proposed different techniques to improve the efficiency and capacity of the system. To meet with the current demand LTE Advanced (LTE-A) has been introduced in the late 2009. It was standardized by the 3GPP. But there was still need of some modification of the system, So, still many researches are still ongoing currently. Limitation of bandwidth is a great problem for more or less every

ISSN: 2233-7857

communication system. So, the use the method of frequency reuse concept, there is a huge possibility to increase the capacity of the system. However, there are some limitations of using frequency reuse. In the system, Inter Cell Interference (ICI) is one of the main restrictive factors. This problem is mainly caused by two sources, the first is the frequency reuse factor equals to ‘1’ in LTE-A system. This means all the neighboring eNodeBs (eNB) use the same frequency channels which will act as an interference source. The rate [1] at which the same frequency can be used in the network is considered to be frequency reuse factor. It can be denoted as 1/K, where K denotes the number of cells which cannot operate in the identical frequency for transmission of data. The second limitation is the heterogeneous positioning of LTE-A networks containing of traditional Macro base stations overlapped with Low Power Nodes (LPN). Often haphazard and unintentional location of these points of access can create severe interference scenario primarily for the users located in cell edge. Figure 1 illustrates the condition of ICI in LTE-A network. For this ICI the efficiency of the system decreases as both the LTE and LTE-A system is planned for frequency reuse factor of ‘1’ to maximize the spectrum capacity. If no accurate planning for the interference management, there is a high probability of call drops and low throughput. Traditional Fractional Frequency Reuse is an effective solution of this problem.

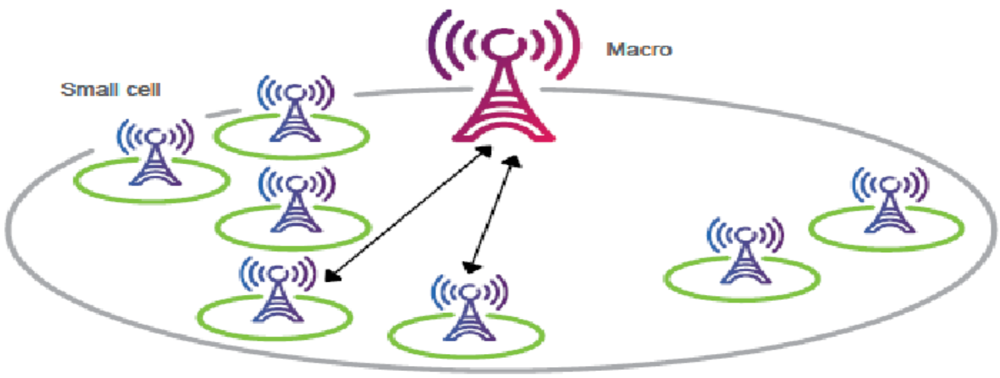

Figure 1. Inter Cell Interference Scenario

Fractional frequency reuse is a combination of reuse-1 and reuse-N model. In this scheme, each cell is alienated into two areas. One is cell centre area and other one is cell edge area. [2] frequency reuse factor of 1 is used for the cell centre area.

Because, in reuse-1 scheme, users situated in each cell can access the whole bandwidth but the problem is, it has to deal with the inter cell interference from the neighbouring cell. On the other hand, the cell edge areas use a higher frequency reuse scheme. In this case the bandwidth gets reduced but the inter cell interference is less. This is a trade-off. Based on these experiments the fractional frequency reuse method is applied. Here, the accessible spectrum is separated into two sub-bands. One of them is utilized in cell centre area and other one is used in cell edge area permanently. Figure 2 is a simple model for the fractional frequency reuse. As they are operating on disjoint spectrum, the capacity of the cell edge area is improved comparing to the universal reuse. This is an important scheme to avoid ICI. In this paper, for the sake of simplicity, a two-cell model has been considered.

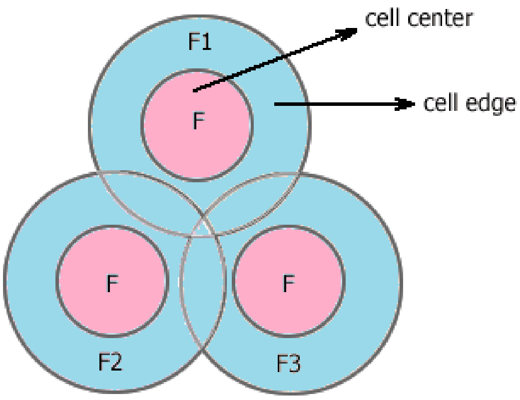

Figure 2. Fractional Frequency Reuse Concept

It is assumed here in the Figure 3, user-1 and user-2 are situated in a distance, l, total power constraint, P, system BW is $2W$, path loss is pl and inter site distance is d. Using the Shanon's capacity theorem the capacity can be modelled as,

$$2W\ \log(1+\frac{\frac{P}{2}pl(d)}{WN+\frac{P}{2}pl(l-d)}) \quad (1)$$

$$W\ log\,(1+\frac{P\ pl(d)}{WN}) \quad (2)$$

Simulation has been used to understand the situation properly. Form the Figure 4, it is clear that, as the distance is increasing reuse-1 start outperforming reuse-2 scheme. In the simulation, here the power is assumed constant for the both cases of frequency reuse. So, implementing reuse-1 and reuse-N scheme together, higher capacity can be obtained.

However, the disadvantages of this scheme are, a portion of the accessible spectrum is remaining unemployed. Also, it cannot deal with changing user traffic. In order to overcome these problems, the method of DFR is proposed. This method is applied under different parametric condition under realistic settings.

The paper is organised as follows, in Section 2 some related works are discussed. Section 3 is about the description of the proposed system model. In Section 4 results and discussions are presented and finally conclusion and future work is added in the Section 5.

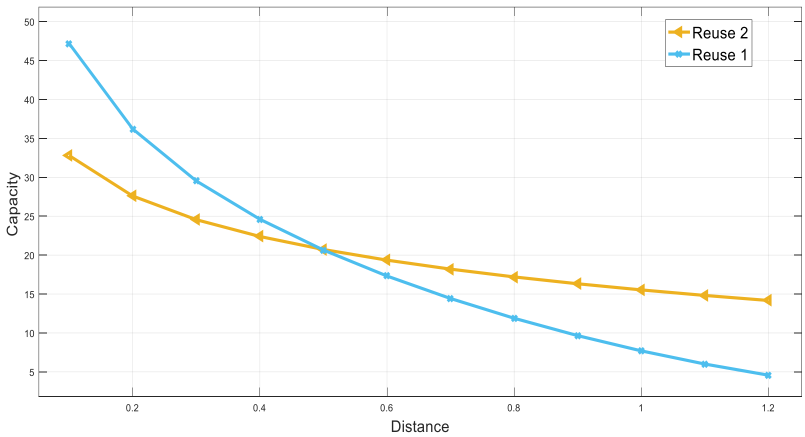

Figure 3. Performance of Reuse 1 vs Reuse N (=2)

2. Related Work

Application of fractional frequency reuse in the LTE-A system has been a highly-discussed topic in communication society. Adaptive partial frequency reuse has been proposed in [3] can improve the system capacity. However different transmit power and positions has been assumed. In another paper [4], contention based FFR is proposed but the algorithm is applicable for certain conditions only. In [5], congestion management in intellectual transportation system is proposed. Soft Frequency Reuse (SFR) is proposed in [6-8]. However, most of the paper of them do not consider the effect of inter cell interference. Dynamic allocation of frequency is considered in [9-10]. However, none of these considered multiple base stations with each serving randomly placed users.

As the ICI mitigation technique has become one of the major concerning issues in the communication sector, there are many researchers working on this topic to improve the condition. Some of the leading techniques that are being discussed are pointed out in the next section.

2.1. Comparison of Different Approaches

Table 1. Comparison Table of Different Approaches

Name (Year)	Approach	Strength	Weakness
Saquib, (2013) [11]	Fractional Frequency Reuse	1. Able to reduce the interference 2. Significant improvement in throughput comparing to the other FFR scheme	1. Proposal is made for static condition only. 2. Under dynamic traffic condition, blocking probability may increase.
Sun, (2015) [3]	Adaptive Partial Frequency Reuse	1. Simple algorithm. 2. Can improve the capacity of the system.	1. Different RN transmit power and positions has been assumed. 2. Modification of algorithm is required for deployment in practical scenario.
Zhan, (2016) [4]	Contention based FFR	1. Improvement in the capacity.	1. Algorithm is only applicable in certain conditions.
Elfadil, (2015) [12]	Modified Fractional Frequency Reuse	1. Improve the capacity in cell edge areas.	1. Decrease the capacity in cell center area.
Ali, (2015) [5]	Hybrid frequency reuse method	1. Congestion management in intelligent transportation system is introduced. 2. Reduction in ICI. 3. Improvement in packet loss is 49.4%. 4. 25% more new sub carriers are produced.	1. The maximum vehicular speed is considered 60 KM/Hr. 2. The method is applicable in urban areas, still rooms for modifications. 3. Assumption is made that the BS distributed over the area for full coverage.

Yu, (2010) [6]	Soft frequency reuse	1. ICI mitigated comparing to traditional frequency reuse scheme.	1. Trade-off of throughput between cell edge users and cell centre users. 2. Average cell throughput is poor.
M. Rahman, (2015) [9]	Dynamic Fractional Frequency Reuse	1. Provides better throughput.	1. Load balancing is overlooked. 2. Algorithm is only applicable in static condition.
Bojović, (2016) [13]	Machine learning based Dynamic Frequency Reuse	1. 33% improvement in capacity.	1. Some parameters are predicted. 2. In practical field, the improvement is not cost efficient.
Chung (2015) [10]	Dynamic Frequency Reuse based on traffic load ratio	1. Improvement in throughput.	1. Leads to computational complexity.
Qian, (2015) [7]	Adaptive soft frequency reuse scheme for wireless cellular network	1. This inter cell resource allocation algorithm can optimize the sub carriers and power allocation. 2. Capacity is increased.	1. Complex algorithm. 2. Breaking the resources into small pieces is not desirable.
Huang, (2016) [14]	Coordinated soft frequency reuse	1. 97.4% users are satisfied with the service. 2. Average cell edge user throughput is increased.	1. Leads to computational complexity. 2. Not cost efficient.

3. Overview of the Proposed Model

The proposal of initial dynamic frequency reuse includes two steps of initialization. The first is implementation of an empirical, circulated algorithm for ideal resource allocation in LTE-A system. When there is no chance of communication with other Base stations (BS), each BS can dynamically assign resource for each of its users. But assigning resources allocation to improve the capacity leads to [15] Non-Deterministic Polynomial Time Hard (NP-Hard) problem. A problem is considered NP-hard, if an algorithm for simplifying it can be interpreted into one for explaining any NP problem. So, NP-Hard means it is as hard as ay NP problem even though it can be even tougher. Due to this problem, computational complexity arises. In order to avoid this, a proposal has been made in this paper called Dynamic Frequency Reuse scheme. The total power allocated is minimized with a constant data rate for each of the user by resources allocated by BS. The idea is to grouping the subcarriers into sub-bands. In telecommunication system, the subcarriers are signal carrier which is passed on top of an additional carrier. As a result, two signals can be carried at the same time. In the receiver side, the main carrier and the subcarrier signals are demodulated distinctly. On the other hand, the sub-band is the sub-division of a frequency band and sub-band coding, typically done by Fast

Frequency Transformation (FFT) breaks the signal into different frequency bands. In other word, it is simply the set of subcarriers. For a user to be placed in an exact sub-band meaning his virtual channel will contain the frequencies that are portion of the sub-band.

The following assumptions were made, the OFDMA in LTE-A system is consisted of inter-cell interference but there is no inter-carrier interference. There is a constant data rate, R for users. They only require this rate, R for maintain the services. Channel quality information is fed back for each sub-band and user.

If the channel quality information is denoted as, i and the calculated subcarrier is m_{ij} and total required power is p_{ij}, then the user requires the CDR, R if user i is located in the sub-band of j. Let's consider a binary random variable z_{ij} which indicates, when the user i is allotted to the sub-band j. Then, the following constrained integer programming problem shown in equation (3,4,5) will be solved in each BS,

$$min_{z_{ij}} \sum p_{ij} z_{ij} \tag{3}$$

$$\sum p_{ij} z_{ij} \leq p \tag{4}$$

$$\sum_i m_{ij} z_{ij} \leq c \, \forall_j \tag{5}$$

Here, c is sub-band capacity and p is total power constraint. This equation can be further relaxed by letting the z_{ij} to consider real in the time interval [0,1] and $\sum_j z_{ij} = 1, \forall_i, z_{ij} \geq 0 \, \forall_{i,j}$ in z_{ij}'s has a tendency to be 0 or 1.

Here, A two cell scenarios is considered. When cell edge consumers placed in cell 1 are assigned to sub-band which is 1, the cell 2 users will face huge interference on sub-band 1 and it will automatically be pressed towards 2^{nd} sub-band. Cell center consumers are not as much exaggerated by ICI as the cell edge users. So, it will choose the sub-band with best condition. In this case, sequential order is maintained for the users. The user's COST is maintained by the base station. COST is a function of the fee to be payed for essential power on sub-band. In other word, it can be said that COST is a function of power. Cost minimized means the low power sub-band but that can maintain the desired service of the user without any interruption. State variable of the base station monitors the available power and the sub-band in the base station. This data is taken and updated after that next user is taken in account. When the sharing period ends, the state variables are reduced to signify the work orders.

4. Results and Discussion

For analyzing the results, following assumptions are made;

Table 2. Parameters in the Simulation

Parameters	Value
Path loss model	COST 231-Walfisch Ikagami model $42.64 + 26\ log10(d) + 20\log(f)$
Inter site distance	2.5 Km
Band Width	20 MHz
Constant data rate	9.6 Kbps
No. of subcarriers	48
Subcarriers allocated for each user	1
Fading condition	Rayleigh fading
Thermal Noise Power	$P = KTB$, Here K = Botlzman Constant

Considering the above-mentioned parameters, simulations has been done using Matlab. In the previous section, the capacity of reuse-1 and reuse-N has been discussed. The combination of these to reuse factors give the capacity of the FFR scheme. The capacity of the FFR scheme is shown in Figure 5, the capacity of FFR scheme can be seen at different power levels. When the power level is increasing the capacity also increasing with the distance. In this paper, the cell edge users are given more priorities as they are mainly affected by the ICI scenario.

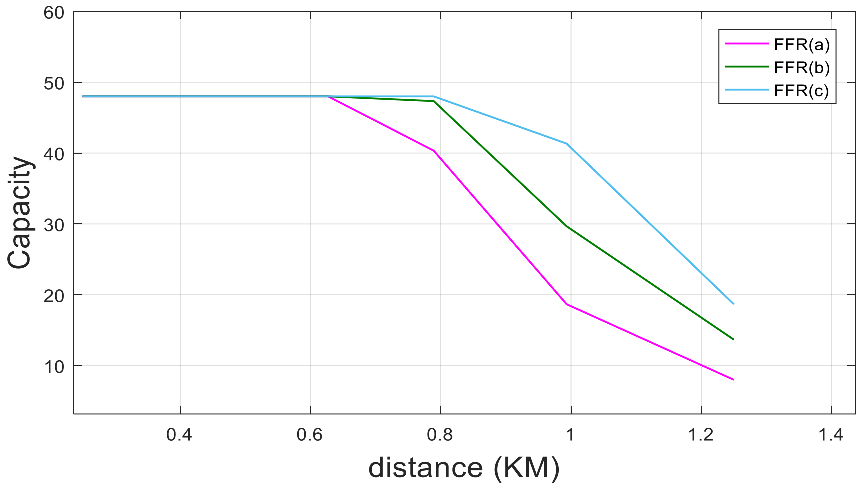

Figure 4. Performance of FFR at different Power Levels

In the simulation for our proposed model, a limit has been considered for the users to be assigned in the sub-bands and power consumption. The simulation will stop when there is lack of subcarriers or power. User's placement and fading has been considered multiple times. Then the data are analyzed and stored for the use of simulation and take care of randomness. Like, shown in Figure 4, here also two cell model is considered. New users are added from the different locations. Figure 6 shows the system capacity based on the number of users supported using DFR comparing to the FFR. From the simulation results, it is clear that DFR outperforms the FFR in terms of increasing the system capacity.

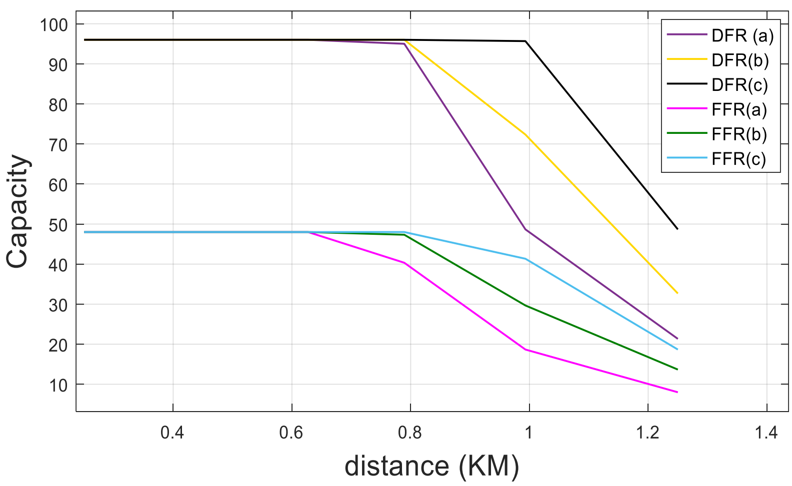

Figure 6. Performance Comparison of DFR vs FFR

5. Conclusion and Future Work

Inter cell interference avoidance in LTE-A system through Dynamic Frequency Reuse has been discussed in this paper. The proposed scheme compare the available sub-bands and then chooses the best sub-band for the users. Simulations results also indicates that this scheme outperforms the traditional FFR scheme. At the cell edge area and also the cell center area, the capacity is almost double comparing to FFR. Simulation has been used to justify the proposed method. Adding up to that, in the simulation, the environment is considered with the realistic parameters. Further studies regarding this matter may lead to efficient radio resource management.

While this scheme increase the capacity of the system through interference avoidance, there are some parameters which are assumed. To take care of the randomness some of the parameters are considered constant which is need to be taken care of in future researches. Different data rates, path loss models may also be considered for the future research.

References

[1] S.-E. Elayoubi, O. Ben Haddada and B. Fourestie, “Performance evaluation of frequency planning schemes in OFDMA-based networks”, IEEE Transactions on Wireless Communications, vol. 7, no. 5, **(2008)**, pp. 1623-1633.

[2] M. A. AboulHassan, M. Yassin, S. Lahoud, M. Ibrahim, D. Mezher, B. Cousin and E. A. Sourour, “Classification and comparative analysis of inter-cell interference coordination techniques in LTE networks”, In 2015 7th International Conference on New Technologies, Mobility and Security (NTMS), IEEE, **(2015)**, pp. 1-6.

[3] C. Sun, J. Shu, W. Zheng, Z. Yang and X. Wang, “Adaptive partial frequency reuse in LTE-Advanced relay networks”, In 2015 IEEE 34th International Performance Computing and Communications Conference (IPCCC), IEEE, **(2015)**, pp. 1-8.

[4] H.-Y Zhan, B.-J. Hu, Z.-H. Wei, W.-J. Liu, B. Li and X. Liu, “Contention-based fractional frequency reuse scheme in LTE/LTE-A network”, In Information Technology, Networking, Electronic and Automation Control Conference, IEEE, **(2016)**, pp. 663-666.

[5] N. A. Ali, M. A. El-Dakroury, M. El-Soudani, H. M. ElSayed, R. M. Daoud and H. H. Amer, “New hybrid frequency reuse method for packet loss minimization in LTE network”, Journal of advanced research, vol. 6, no. 6, **(2015)**, pp. 949-955.

[6] Y. Yu, E. Dutkiewicz, X. Huang, M. Mueck and G. Fang, “Performance analysis of soft frequency reuse for inter-cell interference coordination in LTE networks”, In Communications and Information Technologies (ISCIT), 2010 International Symposium on IEEE, **(2010)**, pp. 504-509.

[7] M. Qian, W. Hardjawana, Y. Li, B. Vucetic, X. Yang and J. Shi, “Adaptive soft frequency reuse scheme for wireless cellular networks”, IEEE Transactions on Vehicular Technology, vol. 64, no. 1, **(2015)**, pp. 118-131.

[8] J. Huang, J. Li, L. Zhao and S. Huang, “CoSFR: coordinated soft frequency reuse for OFDMA-based multi-cell networks with non-uniform user distribution”, Wireless Networks, **(2016)**, pp. 1-14.

[9] Md T. Rahman, Md D. Alam and M. Zaman Chowdhury, “Interference mitigation and capacity enhancement based on dynamic frequency reuse for femtocell networks”, In 2015 IEEE International Conference on Telecommunications and Photonics (ICTP), IEEE, **(2015)**, pp. 1-5.

[10] S. Chung, “Dynamic Frequency Reuse Scheme Based on Traffic Load Ratio for Heterogeneous Cellular Networks”, The Journal of Korean Institute of Communications and Information Sciences, vol. 40, no. 12, **(2015)**, pp. 2539-2548.

[11] N. Saquib, E. Hossain and D. In Kim, “Fractional frequency reuse for interference management in LTE-advanced hetnets”, IEEE Wireless Communications, vol. 20, no. 2, **(2013)**, pp. 113-122.

[12] H. Eldin Elmutasim Osman Mohamed Elfadil, M. Adil Ibrahim Ali and M. Abas, “Fractional frequency reuse in LTE networks”, In Web Applications and Networking (WSWAN), 2015 2nd World Symposium on IEEE, **(2015)**, pp. 1-6.

[13] B. Bojović, E. Meshkova, N. Baldo, J. Riihijärvi and M. Petrova, “Machine learning-based dynamic frequency and bandwidth allocation in self-organized LTE dense small cell deployments”, EURASIP Journal on Wireless Communications and Networking, no. 1, **(2016)**, pp. 183.

[14] J. Huang, J. Li, L. Zhao and S. Huang, “CoSFR: coordinated soft frequency reuse for OFDMA-based multi-cell networks with non-uniform user distribution”, Wireless Networks, **(2016)**, pp. 1-14.

[15] Q. Ye, B. Rong, Y. Chen, M. Al-Shalash, C. Caramanis and J. G. Andrews, “User association for load balancing in heterogeneous cellular networks”, IEEE Transactions on Wireless Communications, vol. 12, no. 6, **(2013)**, pp. 2706-2716.

