Journal of Engineering and Sustainable Development

Vol.24, No. 03, May 2020
ISSN 2520-0917
https://doi.org/10.31272/jeasd.24.3.3

STUDY AND ANALYSIS OF INTRA-CELL INTERFERENCE AND INTER-CELL INTERFERENCE FOR 5G NETWORK

Najim Abdallah. Jazea[1], Dr. Hayam abood Kadim [2] , Dr. Adheed Hasan.Sallomi[3]

1) Phd. student, Electrical Engineering Department, Mustansiriyah University, Baghdad, Iraq.
2) Dr., Advisor at Ministry of Communication, Baghdad, Iraq.
3) Assistant Prof., Electrical Engineering Department, Mustansiriyah University, Baghdad, Iraq.

Received 9 /5/2019 Accepted in revised form 8/9 /2019 Published 1/5/2020

Abstract: In mobile networks, such as fifth generation (5G), the appealing characteristics of the small cells, like easy deployment, affordable, and low power usage, have led to improvement of Heterogeneous Network (HetNet) technique. In HetNet, the restricted resources are usually shared by the small cells, that in turns results in an interference issue challenges. The latter may be regarded as the main barrier for appropriate HetNet performance. In this paper, both Inter Cell Interference and Intra Cell Interference are studied and evaluated for Al-Najaf governorate 5G network. The network performance was investigated before and after interference mitigation. The simulation results are dependent to evaluate the effectiveness of all approaches and schemes that are implemented to cope with both inter and intra cell interference. The simulation of the network is performed by the aid of Integrated Communications System (ICS) telecom software. In Inter-Cell Interference, in term of modulation, it obviously shows that higher modulation occupies only small portion of the covered area due to interference. The modulation scheme 64 Quadrature Amplitude Modulation (QAM) 3/4 occupies 13% from the total covered area with omni profile, while this scheme is being missed with 4-sectors profile due to interference. Intra-cell interference is materialized as Inter Carrier Interference(ICI) and Inter Symbol Interference(ISI), the effect of Cyclic Prefix(CP) on the network performance in terms of ICI is tested based on the simulation of the 3D reflection paths; for the adopted test area, the interfered area equals to 27.06% km^2 according to 5.7µsec guard interval, while the interfered area is reduced to 6.42% km^2 according to 11.4µsec guard interval. The interfered area is reduced by 21% due to ICI when the CP is extended from 5.7µsec to 11.4µsec. CP adopted in this work equals to (1/8), which is the mostly used.

Keywords: *ICI, Spectral Efficiency, 5G, Resource Provision, ISI.*

1. Introduction

Recently HetNets have been introduced in major wireless communication standards like advanced Long Term Evolution (LTE-A) and 5G. HetNet is a

---

Corresponding Author : naabal82@yahoo.com number of small cells (e.g. Pico cell, femto cell….etc) with low power, low cost and easy deployment overlaid the macro cell that adopted to solve the problem of coverage holes [1].

HetNet increases the spectral efficiency per unit area by offloading users from the macro cell through reusing macro cell spectrum due to the scarcity of the resources. However, special care should be given to the resulted interference. Many interference management techniques were proposed to reduce the interference effects and to increase the spectral efficiency during the HetNet operation. The LTE technique is based on Orthogonal Frequency Division Multiplexing Access (OFDMA) in the downlink (DL), where the entire spectrum is divided into blocks called Physical Resource Blocks (PRB). Each PRB is composed of twelve subcarriers corresponding to 180 kHz in frequency domain and six/seven symbols in time domain for normal/extended cyclic prefix. In LTE Rel-8, the Inter-cell Interference Coordination (ICIC) is proposed to manage the PRBs such that inter-cell interference is kept under control by exchanging information via the LTE X2 Interface between Base Stations (BSs) [2]. In LTE Rel-9, the enhanced Inter Cell Interference Coordination (eICIC) implemented through the resources coordination in time domain, where blanked subframes, referred to Almost Blank Subframes (ABSs) were dedicated. This is done in order to serve the small cells' UEs without any data transmission from the macro cell except that for some necessary control signals [3]. LTE-Advance in introduces Further eICIC (FeICIC), which has a proposal scheme to reduce the power of the macro cell during the ABS rather than muting it, to enhance the performance of the macro cell [4].

The resources coordination between cells assists in enhancing the HetNet performance and has attracted much attention within the telecommunication industry [5]. Controlling time, power and frequency allocation between small cells represent a great challenge. This challenge open wide areas changing for the researches to candidate how to manage the HetNet operation by optimally allocating these resources.

The most related researches are worked on one or two of these resources only. For example, [6] presented a self-organization procedure performed in time and frequency domains, while [7] discussed interference minimization by optimally controlling the power of femto cells. Also, [8] introduced optimized joint time and power resources allocations. However, [9] proposed a dynamic spectrum allocation scheme. On the other hand, a fuzzy q-learning approach is introduced to manage the interference[10].

This paper is organized as follows; section (2) introduces the Inter-Cell Interference. Intra-Cell Interference is introduced in section (3). Interference Mitigation Analyses are presented in section (4) and finally the conclusions are introduced in section (5).

2. Inter-Cell Interference

Inter-cell interference occurs at the network system levels as a result to the interaction occurs between neighbor cells. This interaction is either due to operating on the same channel which is referred to as Co-Channel Interference (CCI), or due to the overlapping between adjacent channels which is referred to as Adjacent Channel Interference (ACI) [11].

ACI mainly results due to the receiver equipment, such as non-ideal receiver filters which allow the nearby frequencies to leak within the filter pass band. Preventing the effects of ACI is done by choosing carefully the appropriate filters and proposes a cellular pattern in such a way that reduces using adjacent channels within the same geographical region [12].

The main motivation of using cellular radio system is the frequency reuse principle, where the users in different cells may simultaneously use the same frequency channel due to the limitation of resources. Frequency reuse is considered as a tradeoff between spectral efficiency and CCI. CCI is the critical bad feature of the cellular system and it is hard to be completely eliminated. Many approaches are proposed to mitigate the effects of CCI as shown in Fig.(1) [11].

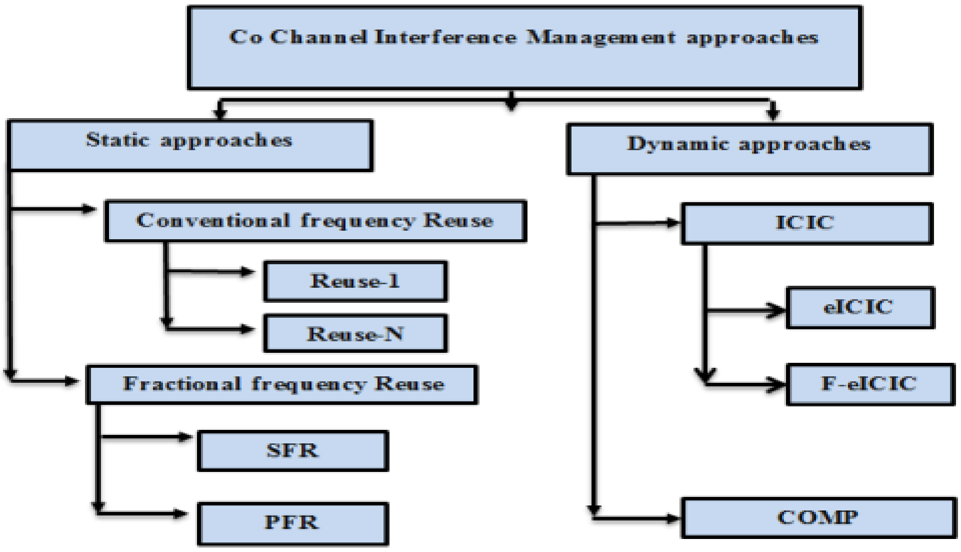


Fig. (1) CCI management approaches [11]

3. Intra-Cell Interference

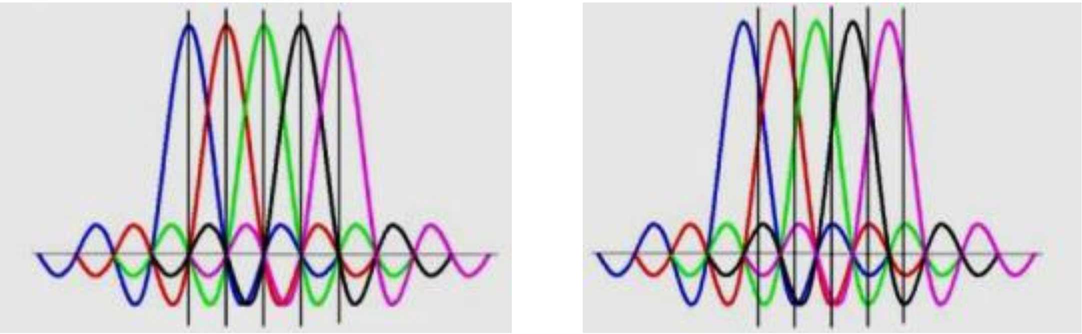
The users in Non Line Of Site (NLOS) environment are exposed to another type of interference due to the multipath phenomena represented by ISI and ICI. The received signals from multipath have different amplitudes and phases, hence the summation of these signals may produce either constructive or destructive field which result in complex envelope refers to as "fading" [7]. The intra-cell interference can be further classified into:-

3. 1 Inter Symbol Interference (ISI)

In a multipath environment and due to the diffraction and scattering, the signal from a direct path reaches faster than the signals from the reflected paths. Accordingly, different signals with different delays are summed at the receiver resulting in signal broadening in time referred to as delay spread phenomena. Delay spread makes successive symbols to overlap with each other, causing ISI [8]. Avoiding ISI requires bulky equalizer at the receiver in a single carrier system, while in an OFDM system the problem of ISI is solved by inserting a sufficient guard interval in time domain between successive symbols [7].

3.2 Inter Carrier Interference (ICI)

In OFDM system as the subcarriers are orthogonal to each other, the system is very sensitive to carrier frequency offset. ICI is introduced when the orthogonally is lost either due to the difference between the transmitter and receiver local oscillator frequencies or due to the Doppler shift in the channel. ICI results in OFDM signal amplitude reduction as shown in Fig.(2) [9]. One solution to eliminate the ICI is by replacing the guard interval with a CP (last part of the symbol is prefixed and followed by the symbol itself). Guarded successive symbols by CP results in convert the linear convolution to circular convolution which ensures orthogonally over the FFT period and simplify the recovery of original signal at the receiver [7].



a) Perfect synchronization, no ICI (b) Synchronization loss, result in ICI

Fig. (2) OFDM spectrum of five carriers

ISI and ICI effect directly modulation and coding schemes distributions over the network area and hence the throughput. As an example table (1) explain the relation between C/(N+I) and the corresponding modulation and coding scheme.

Table (1) AMC and their requirements in terms of C/(N+I) [10]

Modulation &Coding scheme	C/(I+N) (dB)
QPSK ½	6
QPSK ¾	9
16 QAM ½	12
16 QAM ¾	15
64 QAM ½	18
64 QAM $^{2/3}$	20
64 QAM ¾	21

4. Interference Mitigation Analyses

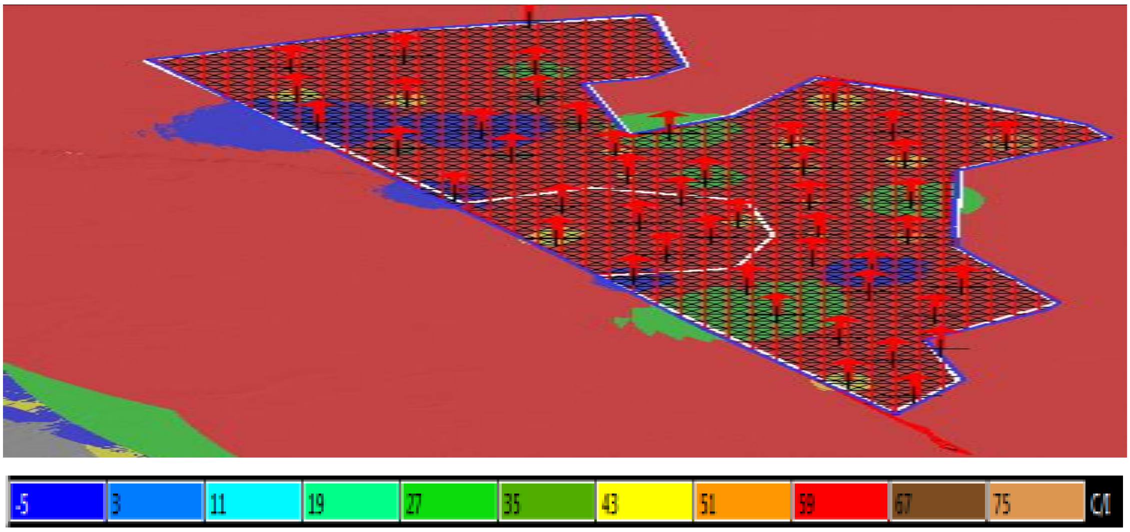
The network performance was investigated before and after interference mitigation. The simulation results are dependent to evaluate the effectiveness of all approaches and schemes that are implemented to cope with both inter and intra cell interference.

4.1 Inter-Cell Interference Analyses

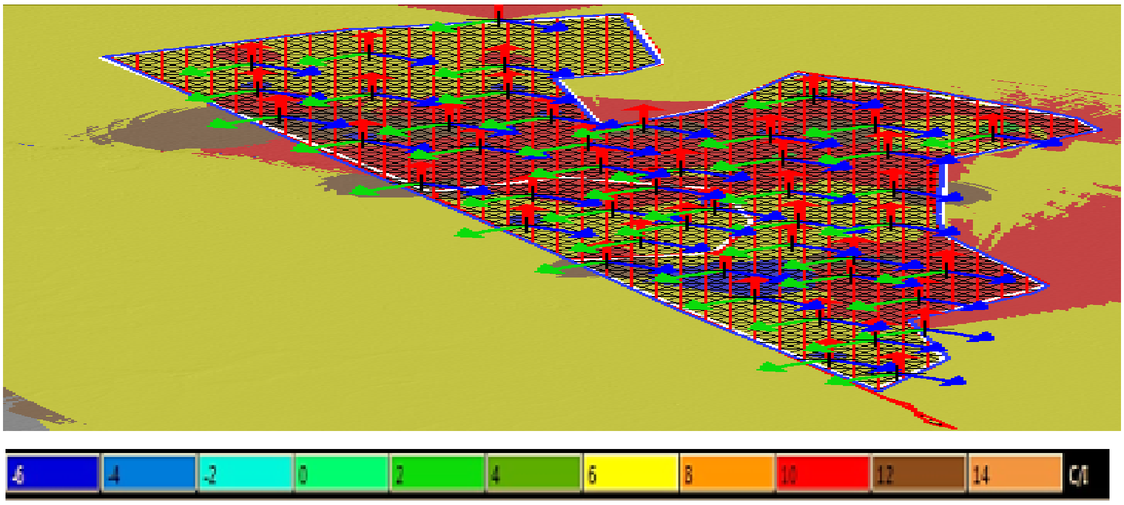
After simulating the network performance by the aid of ICS telecom software, many analyses are dependent to quantify the effect of inter-cell interference as below:

The pictorial representation of interference maps simulation is depicted in Fig.(3). Then the simulation results are translated into numerical results as shown in Fig.(4) which represents the percentage area (km^2) in terms of C/I ratios , where (I) is the summation of all interferers signals.

Omni



3-sectors



4-sectors

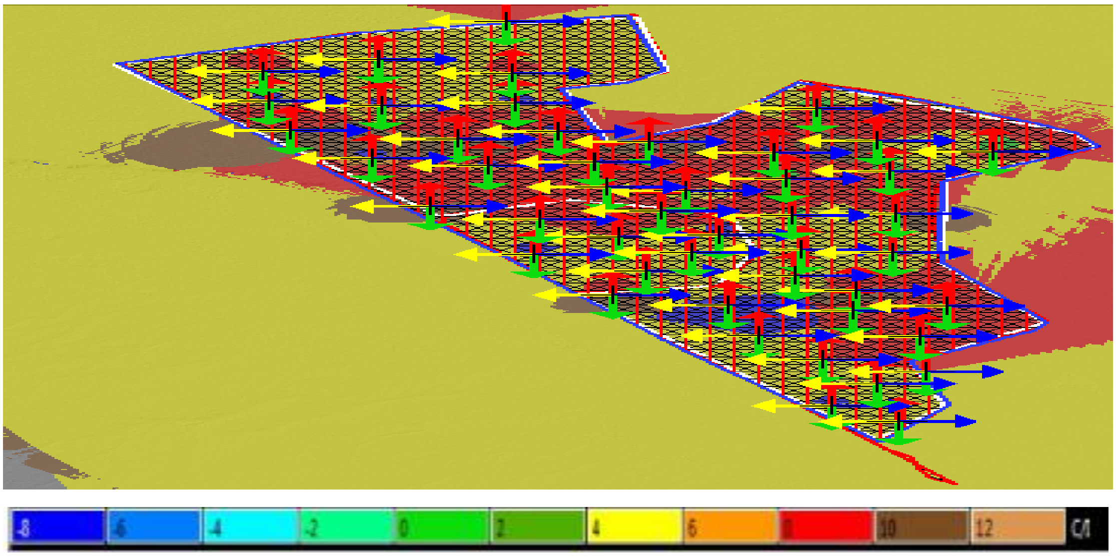


Fig. (3) Interference map

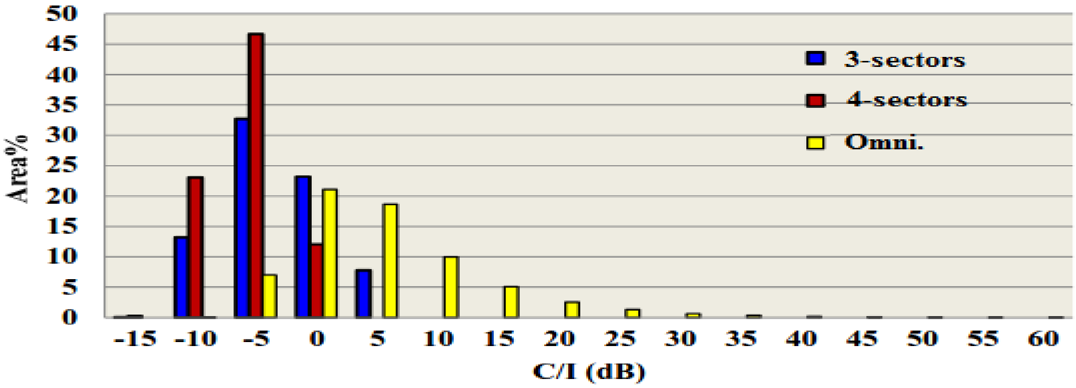


Fig. (4) Interfered area vs. C/I for various cell profiles.

Fig.(5) depicts the modulation distribution , it obviously shows that higher modulation occupies only small portion of the covered area due to interference. The modulation scheme (64 QAM 3/4) occupies 13% from the total covered area with omni profile, while this scheme is being missed with 4-sectors profile due to interference.

The previous analyses show that, 4sectors profile represents the worst case interference scenario. Due to its wide coverage area, 73% of the covered area is jammed by interferer, where 46% from its area scores C/I equals to (0) dB. This yields in scarifying the higher modulations schemes and this certainly degrades the performance in terms of throughput. To verify an accurate decision about the suitable profile, further analyses will be performed after implementing some of interference mitigation approaches.

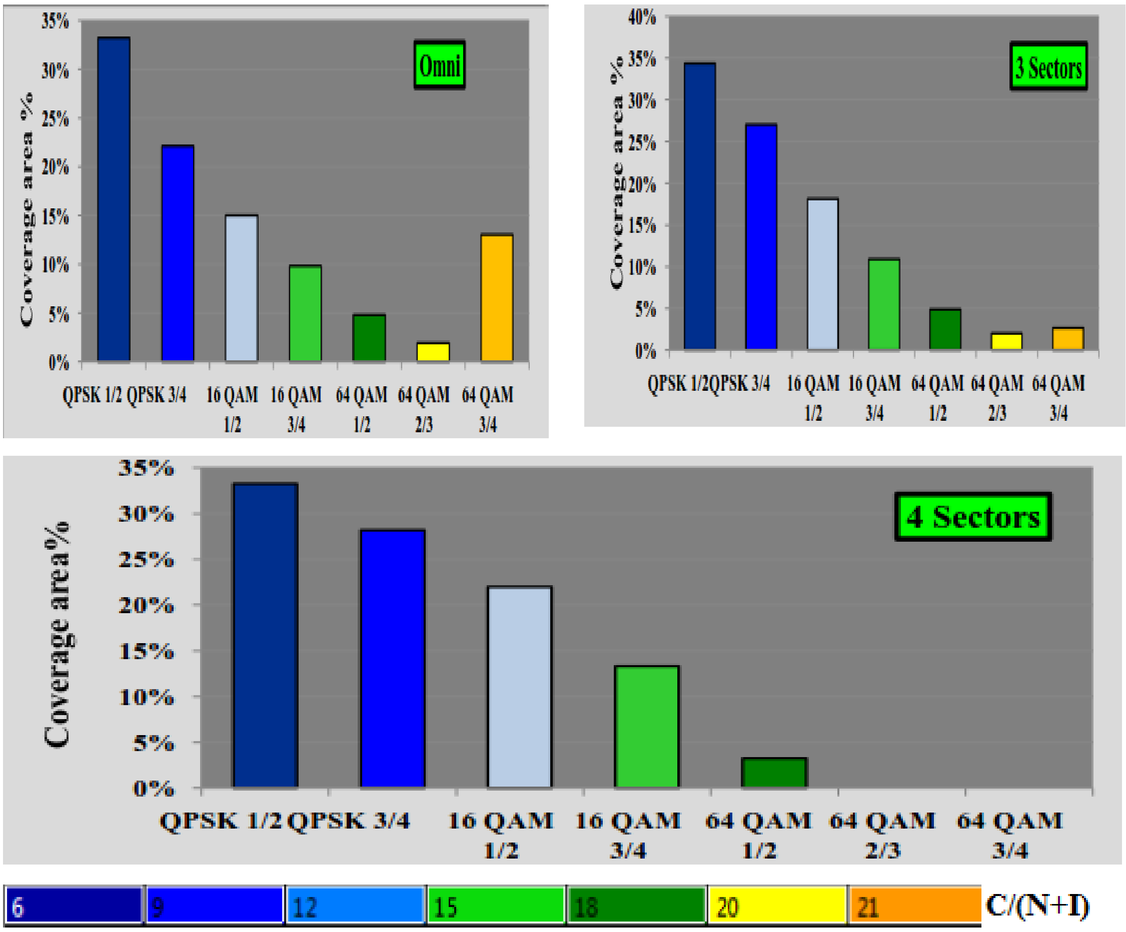


Fig. (5) AMC (Adaptive Modulation and Code) distribution on the network for different profiles.

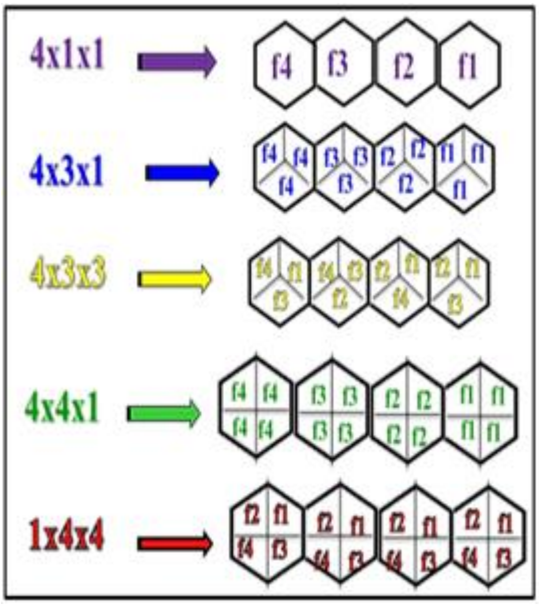
4.2 Inter Cell Interference Mitigation Simulation Results

Based on the previous analyses, it was obvious that interference effects are materialized by decreasing the served Subscribers (SSs) due to the degradation of signal quality. Accordingly, the designed network performance is to be enhanced by investigating number of various interference mitigation approaches:

A. *Frequency Reuse:*

In order to achieve 100% B.W usage, four frequency patterns are suggested in this work as shown in Fig.(6).The effect of each one of the frequency reused patterns on interference mitigation is investigated separately based on SSs average C/(I+N) and the interference map. The obtained results are shown in Figs.(7) and (8).

The obtained results show that the same profile that scores the worst case interference scenario (4sectors) overcomes other profiles after adopting (1x4x4) frequency reused pattern in terms of interference and capacity. A peak coverage area (43%) is scored at C/I equals to 10-20 dB, besides achieving highest users' average C/(N+I) especially near the BS. Accordingly, this pattern is adopted for the further evaluations and tests, where additional mitigation approaches will be implemented to this profile for achieving more enhancements.



Fig(6) Frequency reuse patterns

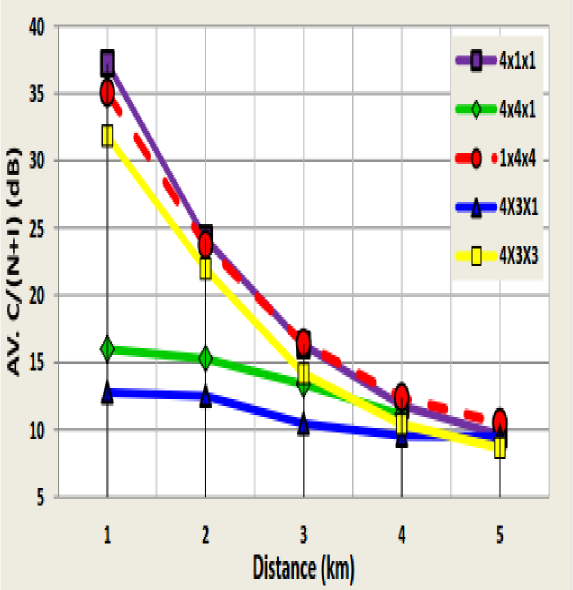


Fig. (7) Frequency reuse pattern effect on interference.

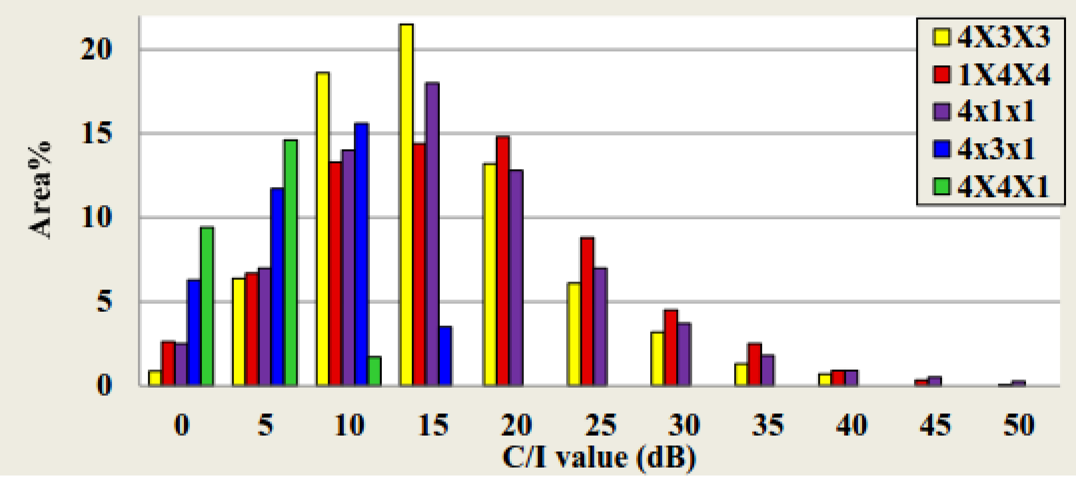


Fig. (8) Interfered area vs. C/I for various frequency reuse patterns.

B. Power Management:

The effect of MIMO scheme on reducing the power while conserving the coverage is simulated. The results show the network performance in terms of global interference is presented in the table (2).

Table (2) Results of performing MIMO approach

MIMO scheme	1X1	2X1	4X1	6X1
Power	7 w	3.5 w	1.75 w	1.16w
Antenna gain	14dBi	17dBi	20dBi	21.78dBi
Coverage% km	75.29	75.29	75.29	75.29
Interfered area% due to global interference	40.14	31.59	20.45	16.54

It is clearly that as the number of antenna increased, the interference decreased due to the reduction of the interferer power. Implementing array with 6 antennas leads to 23.6% reduction in the interfered area keeping on the same coverage.

C. Antennas tilt angle:

It is possible to orient antennas of the interferer BS in such a way that the energy radiated towards the horizon is reduced. This will have the effect of maintaining the signal power within the wanted area but reducing interference outside of it. In this work, BSs tilt angle was adjusted (based on ICS telecom software optimization ability) in such a way that the tilt angle of the BS antenna is calculated and assigned according to the average tilt angles between the BS and its' associated SSs as shown in Fig.(9).

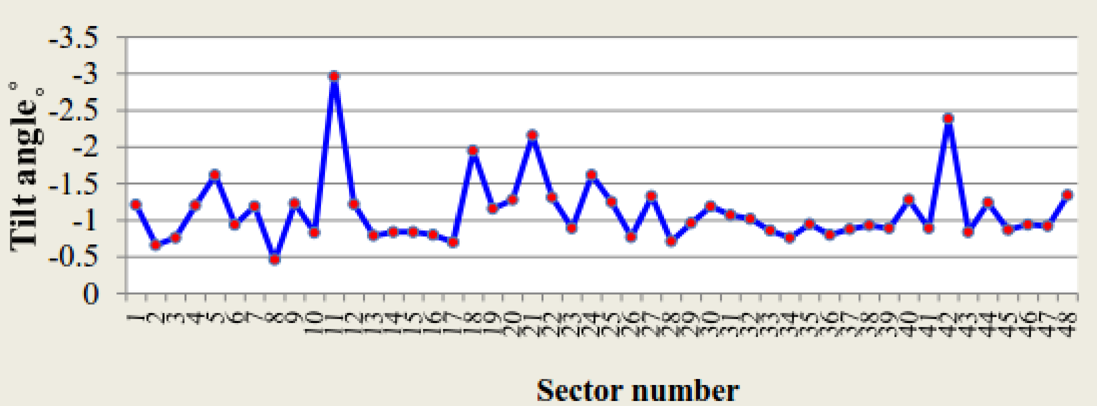


Fig. (9) BS antennas assigned tilt.

D. Aggregated all Above Approaches:

Combining the previous approaches will cumulative their effects on the interference mitigation which can be sensed from the simulation results shown in figures (10-12). Fig.(10) shows the interference map numerical results, represented by the coverage area in terms of C/I. It is obviously showed that 34% of the covered area has C/I ratios from 20-30 dB, which is a great enhancement comparing to the initial network where no positive C/I ratio is recovered all over the network area.

Other verifications are done based on the analyses represented by Fig.s (11) and (12) in terms of SSs average C/(N+I) ratio and global interference respectively.

The obtained results showed that each approach has some effect on the interference mitigation, where the users' average C/(N+I) near the BS is enhanced by 5 dB, 16 dB and 24 dB compared to frequency reuse, MIMO and antenna tilt approach respectively. At the cell edge and for the same comparison, the users' average C/(N+I) is enhanced by 3.5dB, 0.4dB and 4.4dB. These results show that the frequency reuse has the major effects between all approaches at the cell center, while MIMO scheme is the dominate approach in mitigating interference at the cell edge. Also by implementing all the previous approaches, the interfered area% is reduced by 56%.

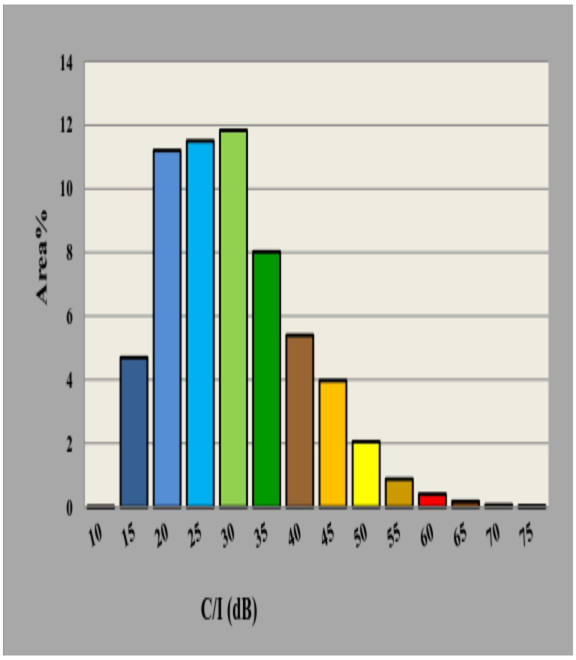


Fig. (10) Interference map numerical results after implementing all mitigation approaches.

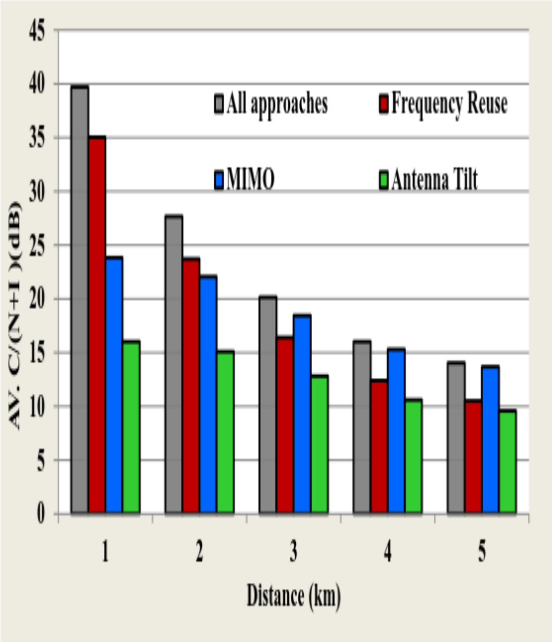


Fig. (11) Comparison of inter-cell interference mitigation approaches vs. distance.

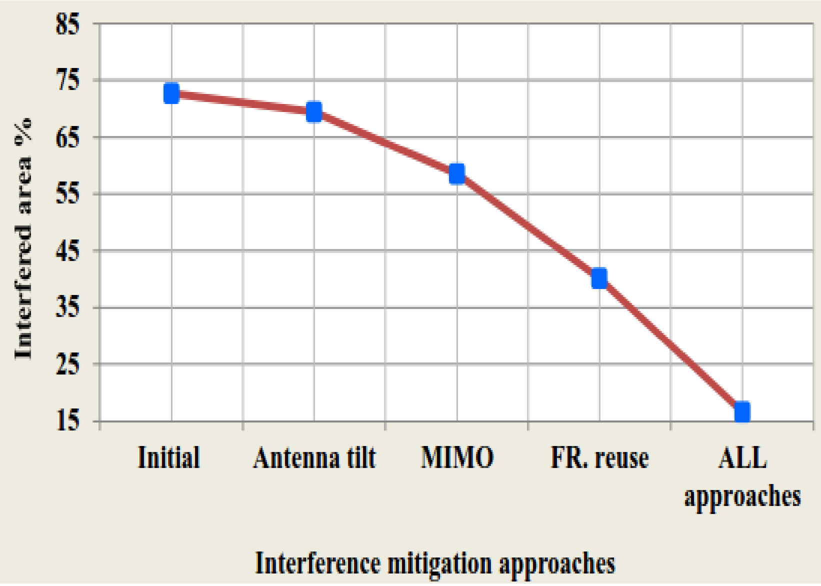


Fig. (12) Effect of inter-cell interference mitigation approaches on interfered area.

The higher C/I ratios recovered by the previous figure can be materialized also by good enhancement in modulation distribution as depicted in Fig.(13). It is worthy to notice that implementing interference mitigation approaches result in increasing the network throughput. This result is obvious from increasing the percentage of higher modulation (64 QAM 3/4) to 20%, while this modulation scheme was missing at the initial network area.

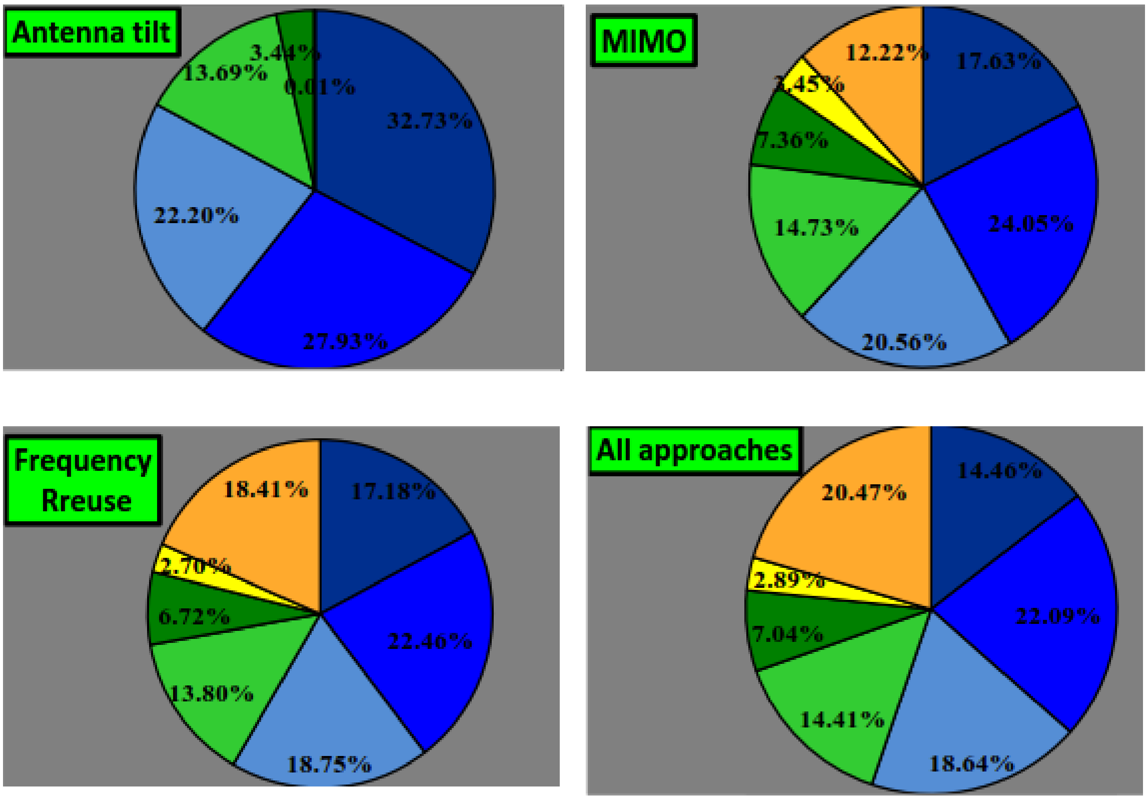


Fig. (13) AMC distribution on the network for various interference mitigation approaches.

4.3 Intra-Cell Interference Analyses

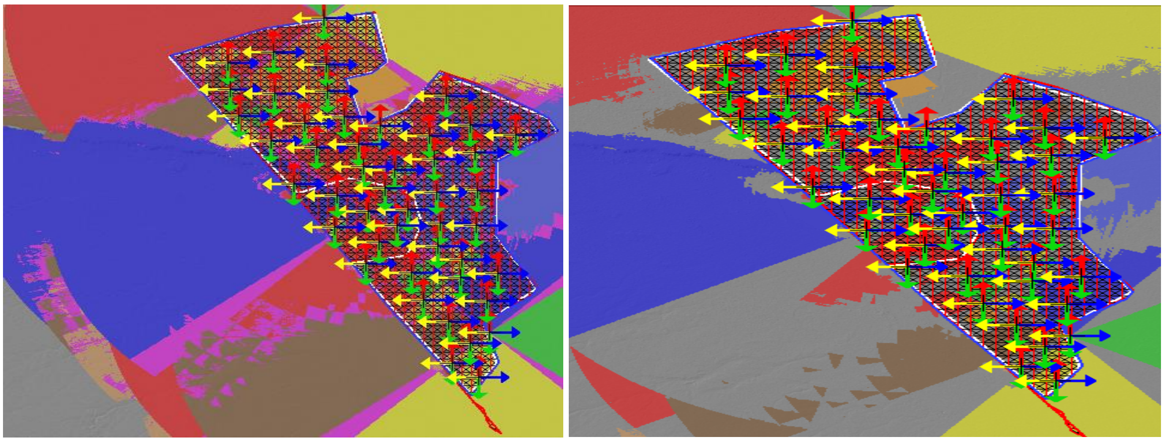
Intra-cell interference is materialized as ICI and . ICS telecom software is used to analyze ICI and ISI and simulates their effects as below:

4.3.1 ICI Analysis

The effect of CP on the network performance in terms of ICI is tested based on the simulation of the 3D reflection paths as shown in Fig.(14), where interfered area represented by pink color equals to 27.06% km2 according to 5.7µsec guard interval as shown in Fig.(14a), while the interfered area is reduced to 6.42% km2 according to 11.4µsec guard interval as shown in Fig.(14b).

4.3.2 ISI Analysis

The ISI can be modeled by simulating the network performance in terms of TOA, where each point is analyzed by the time difference between the direct and longest reflected path as shown in Fig.(15). The results obtained by this analysis are summarized in table (3). The first column represents the SSs percentage suffering from different propagation delay values that given in the second column, while the third and fourth columns represent the appropriate CP and the corresponding guard time that must be chosen to reconfigure that region of the network such that the guard interval between two successive symbols will overcome this delay.



(a) Tg =5.7µsec , CP=1/16 (b) Tg=11.4µsec, CP=1/8

Fig. (14) Effect of CP on ICI

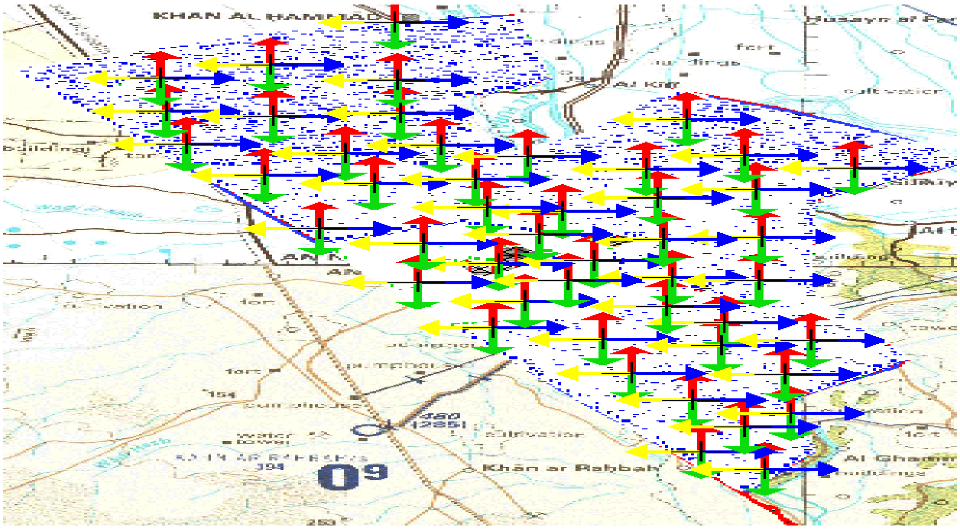


Fig. (15) The network performance analysis in terms of TOA

Table (3) Analysis results for TOA

SSs%	Delay(µsec)	Appropriate G	Tg (µsec)
19.4	Less than 3	1/32	2.9
12.8	3-6	1/16	5.7
11	6-11	1/8	11.43
41.5	11-22	1/4	22.8
21.3	More than 22	1/4	

The previous results show the role of CP in reducing the effects of ICI. In figures (15), the interfered area is reduced by 21% due to ICI when the CP is extended from 5.7µsec to 11.4µsec. CP adopted in this work equals to (1/8), which is mostly used. Accordingly, the results obtained from Fig.(15), show that only 11% of the SSs are located at positions which are appropriate to the network guard interval (11.4µsec), 32% of them can be guarded with less than the network guard interval, the rest SSs need longer guard interval and 42% of them can be guarded safely by 22.8µsec.

5. Conclusions

Because of the explosion in the cellular data traffic, it is truly important to create the best utilize of the spectrum resources to improve the spectral performance. The frequency reuse idea can be an effective solution to this issue. However, if the similar subcarriers are occupied by different users among the near cells, the Inter Cell Interference (ICI) challenge may occur in particular for the customers at the cell edges. Convenient Inter Cell Interference

Coordination (ICIC) techniques should be applied to reduce the interference and improve the system capacity. In this paper, both Inter Cell Interference and Intra Cell Interference are studied and evaluated for Al-Najaf governorate 5G network. The simulation of the network is performed by the aid of ICS telecom software. In Inter-Cell Interference, in term of modulation, it obviously shows that higher modulation occupies only small portion of the covered area due to interference. The modulation scheme (64 QAM 3/4) occupies 13% from the total covered area with omni profile, while this scheme is being missed with 4-sectors profile due to interference. Intra-cell interference is materialized as Inter Carrier Interference(ICI) and Inter Symbol Interference(ISI), the effect of Cyclic Prefix(CP) on the network performance in terms of ICI is tested based on the simulation of the 3D reflection paths; for the adopted test area, the interfered area equals to 27.06% km^2 according to 5.7µsec guard interval, while the interfered area is reduced to 6.42% km2 according to 11.4µsec guard interval. the interfered area is reduced by 21% due to ICI when the CP is extended from 5.7µsec to 11.4µsec.

6. References

1. Z. Bharucha, E. Calvanese, J. Chen, (2015). "*Small Cell Deployments: Recent Advances and Research Challenges*", in Proc. 5th International Workshop on Femtocells , King's College London.
2. A. TRIKI and L. NUAYMI. (2016). “*InterCell Interference Coordination Algorithms in OFDMA wireless systems*”, in Proc. Vehicular Technology Conference (VTC Spring), pp. 1-6.
3. H. Du, L. TIan, L. Li1 and Z.(2018). "*An Interference-aware Resource Allocation Scheme for Self-Organizing Heterogeneous Network*", in Proc. IEEE Wireless Communication and Network Conference (WCNC).
4. T. Garand, LTE-Advanced. (2017). “*A Practical Systems Approach to Understanding 3GPP LTE*” Releases 10 and 11 Radio Access Technologies,CHP14., Elsevier’s Science & Technology, UK.1029-1068.
5. H. Zhang, W. Zheng, X. Chu, X. Wen, M. Tao, A. Nallanathan and D. Lopez-Perez.(2016). “*Joint subchannel and power allocation in interference-limited OFDMA femtocells with heterogeneous QoS guarantee*”, in Proc. IEEE Global Communications Conference (GLOBECOM).
6. M. Simseki, M. Bennis and A. Czylwiki.(2017). " *Dynamic Inter-Cell Interference Coordination in HetNets: A Reinforcement LearningApproach*", in Proc.Globecom - Wireless Networking Symposium.
7. D. Lopez-Perez, X. Chu, A. V. Vasilakos, and H. Claussen. (2018*)." Power Minimization Based Resource Allocation for Interference Mitigation in OFDMA Femtocell Networks*", IEEE JOURNAL ON SELECTED AREAS IN COMMUNICATIONS, vol. 32, no. 2, February.

8. N. Trabelsi, L. Roullet and A. Feki. (2018). *" A Generic Framework for Dynamic eICIC Optimization in LTE Heterogeneous Networks*", in Proc. IEEE 80th Vehicular Technology Conference.
9. T. Peng , T. Hui, G. Li-qi, Z. Jun and W. Meng. (2016). " *Dynamic spectrum allocation for cell range extension in tiered Macro-Pico heterogeneous networks*", The Journal of China Universities of Posts and Telecommunications, p.p: 66–72.
10. A. Daeinabi.(2019). " *Intercell Interference Mitigation in Long Term Evolution (LTE) and LTE-Advanced*", Ph.D. thesis. University of Technology, Sydney.
11. A. AL-Samarrie, H. Alyasiri and A. AL-Nakkash. (2018). " *Proposed Multi-Stage PSO Scheme for LTE Network Planning and Operation*", submitted for publication, Karbala International Journal of Modern Science/ ELSEVIER. August.
12. D. Lopez-Perez, G. de la Roche, A. Valcarce, A. J¨uttner and J. Zhang. (2017). " *Interference Avoidance and Dynamic Frequency Planning for WiMAX Femtocells Networks*", Proc. in 11th IEEE Singapore International Conference on Communication Systems, ICCS.