International Journal of Electrical and Computer Engineering (IJECE)
Vol. 8, No. 3, June 2018, pp. 1569~1576
ISSN: 2088-8708, DOI: 10.11591/ijece.v8i3.pp1569-1576

Soft Frequency Reuse (SFR) in LTE-A Heterogeneous Networks based upon Power Ratio Evaluation

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Article Info

Article history:

Received Jan 4, 2018
Revised Apr 20, 2018
Accepted Apr 30, 2018

Keyword:

HetNet
LTE-advanced
Power ratio
SFR

ABSTRACT

As the traffic demand grows and the RF environment changes, the mobile network relies on techniques such as SFR in Heterogeneous Network (HetNet) to overcome capacity and link budget limitation to maintain user experience. Inter-Cell Interference (ICI) strongly affecting Signal-to-Interference plus Noise Ratio (SINR) of active UEs, especially cell-edge users, which leads to a significant degradation in the total throughput. In this paper we evaluate the performance of SFR with HetNet system in order dealing with interferences. Simulation result shows that the power ratio control in SFR HetNet system doesn't have much effect on total achieved capacity for overall cell.

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1. INTRODUCTION

Mobile wireless has enjoyed cellular technology in which the spectrum is reused within service area. Spectrum efficiency is the reason of why we used cellular. In cellular system, handoff is the major feature so that users are able to move between cells [1]. Currently, Long Terms Evolution (LTE) is the most prominent cellular technology that usea new and wider spectrum up to 20 MHz with high data rates and lower latency [2]-[4], offering enhanced user experience with high-bandwith consuming application such as online gaming, video streaming, mobile cloud, and etc. As the traffic demand grows and the RF environment changes, the network relies on cell splitting or additional carriers to overcome capacity and link budget limitations and maintain uniform user experience. A more flexible deployment model is needed for operators to improve broadband user experience in effective way.A heterogeneous cellular network (HetNet) is offering a new deployment of heterogeneous base stations that underlaid in a traditional (macro) cellular network. In HetNet deployments, the overlay macro cell provides a wide area coverage umbrella while the low power nodes (also known as small cells) are deployed in a more targeted manner to alleviate coverage dead zones, and more importantly, traffic with heavy load [5]. HetNet is considered to be an efficient solution to improve resource reuse and spectral efficiency, while offloading user traffic from macro cells toward small ones.

HetNet consists of regular (planned) placement of macro base-stations that typically transmit at high power level, overlaid with several pico, femto, and relay base-stations, which transmit at substantially lower power levels and typically deployed in a relatively unplanned manner [6]. Each mobile terminal is served by the base-stations with the strongest signal strength, while the unwanted signals received from other base-stations are usually treated as interference. Such principles can lead to significantly sub-optimal performanc In HetNet environment Inter-Cell Interference Coordination (ICIC) becomes a central issue since high power and low power nodes are overlaid by each other while sharing the same spectrum [7]. The main idea of ICIC is to divide each cell into two sections, the cell center and the cell edge, and then allocate differentsubcarriers to users in different locations. The basic idea on which the ICIC schemes rely is to divide theusers [8]. ICIC techniques can be classified into Hard Frequency Reuse, Fractional Frequency Reuse (FFR), and Soft Frequency Reuse (SFR) [9]. Soft Frequency Reuse (SFR) is considered as an effective resource allocation technique that improve performance of users, especially for user experiencing poor signal. SFR is considered as the most representative approach due to its effectiveness of inter-cell interference coordination without compromising spectrum efficiency. SFR can achieve better outage conditions than classical reuse schemes and improves the capacity with respect to FFR schemes [10]. Soft Frequency Reuse (SFR) is considered as an effective resource allocation technique that improve performance of users, especially for user experiencing poor signal.

Inter-Cell Interference (ICI) strongly affecting Signal-to-Interference plus Noise Ratio (SINR) of active UEs, especially cell-edge users, which leads to a significant degradation in the total throughput. The combination off different cells with different transmitted power could make the ICI problem is more complicated, since simultaneous transmissions over the same frequency in adjacent cell. The throughput value for users that are far from e-NodeB (eNB) becomes problem since the spectrum efficiency is decreasing, and hence decreasing the quality of system performances. In this paper, we build a system-level simulator to evaluate the performance of SFR with HetNet system in order dealing with interference. In Section 2 the propagation model will be described, while in Section 3 we will be explained the system model and formulation. In Section 4 the simulation setup and the result will be explained while the Section 5 conclude the discussion in this paper.

2. PROPAGATION MODEL

One of most important metric in a cellular network is the Signal to Interference and noise ratio (SINR). Once the SINR distribution is known, the outage and average rate can be easily computed. We could pick an arbitrary set of point processes and fading distributions to plot the SINR distribution using a Monte Carlo simulation. The SINR is formulated in Equation (1), with P_R is the received power by UE, I is total interfering power and N is the noise power [4].

$$SINR = \frac{PR}{I+N} \tag{1}$$

Noise power N in dBm is calculated in Equation (2) with k is Boltzman constant, T is room temperature, BW is system bandwidth, NF is noise figure which is assumed 0 and IL is Implementation Loss which is assumed 0 [11],

$$N = 10\log(kT) + 10\log(BW) + NF + IL \tag{2}$$

In this paper we used Stanford University Interim (SUI) model to describe the characterization of propagation at the largest spatial scale. The benefit of this model is allow us to consider propagation conditions for both longer and closer distance from the eNB [9]. SUI is one of channel model for the frequency bands below 11 GHz, which is developed under the 802.16 IEEE working group that develop the technical standards for fixed wireless access systems [12]. The downlink path loss P_L is defined in two cases, for distance R lower than a reference distance R_0' and for distance higher than R_0'. The downlink path loss is defined as [11],

$$P_L = \begin{cases} \alpha + 10\gamma\log\left(\frac{R}{R_0}\right) + X_f + X_h + s, & if\ R > R_0' \\ 20\log\left(\frac{4\pi R}{\lambda}\right) + s, & if\ R \le R_0' \end{cases} \tag{3}$$

Figure 1 show the HetNet.

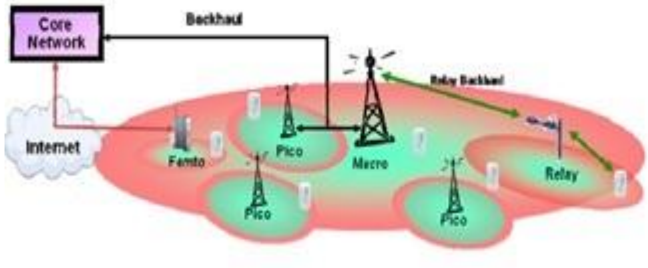

Figure 1. HetNet

R is the distance between eNB and UE in meter, X_f is the correction factor since the frequency used is above 2 GHz which is defined in Equation (4), X_h is the correction factor for the receiver antenna height which is defined in Equation (5), and $s$represents a shadowing term or a 95[th] percentile term in planning margins. The value of $s$is a fixed value, that is equal to 15.8 dB for the intermediate environment [13]. The frequency correction factor can be expressed as [12],

$$X_f = 6 x \log\left(f\,[Mhz]/2000\right) \tag{4}$$

and correction factor for antenna height can be defined as [8],

$$X_h = -d\, x \log\left(h_{UE}/2000\right) \tag{5}$$

where h_{UE} is the receiver antenna height and $d = 10.8$ for terrain types A and B or $d = 20.0$ for terrain type C. The value of α is defined as [12],

$$\alpha = 20 x \log\left(4\pi R_0^{'}/\lambda\right) \tag{6}$$

Reference distance R_0' is defined by [11],

$$R_0^{'} = R_0\, x 10^{-\frac{X_f + X_h}{10\gamma}} \tag{7}$$

The path loss exponent γ depends on the environment, which is defined as [12],

$$\gamma = a - b\, x\, h_{eNB} + \frac{C}{h_{eNB}} \tag{8}$$

where h_{eNB} is the eNB antenna height (in meters). The a, b, and c constants depend on the propagation environment. The value of path loss exponent in the urban area is $\gamma = 2$, for urban area for cellular radio path loss exponent is $\gamma > 2.7$, and for shadowed urban area for cellular radio path loss exponent is between $\gamma > 3$ and $\gamma < 5$. In indoor propagation path loss exponent is over $\gamma > 5$ [13], [14].

The SUI model cover three most common terrain categories: a hilly terrain with moderate to heavy tree densities (type A), an intermediate path loss conditions (type B), and a mostly flat terrain with light tree densities (type C). For type B, the terrain type use value $a = 4$, $b = 0.0065$, $c = 17.1$, and $d = 10.8$ [9]. In this paper we considerate the B type terrain.

3. SYSTEM MODEL AND FORMULATION

The system model comprise of macro and micro cells are shown in Figure 2. SFR implementation divide macro cell into cell center with frequency reuse of 1 and cell edge which has frequency reuse pattern with factor $K = 3$ is adopted. Macro cell has radius Rc with distance to the first tier and second tier cell center from measured cell center which is defined as$d_1 = \sqrt{3}Rc$ and $d_2 = \sqrt{3K}Rc$ respectively. Macro cell allocated frequency separately into three segment (F_1, F_2, F_3). Cell center make use of all segments, but cell edge only uses one of the segment differ from its adjacent cell edge segment allocation. This method will reduce the inter cell center interference.

The maximum transmit power of eNB is defined as the power transmitted to the cell edge. Power transmitted for cell center is lower by multiplied with power ratio ω of power transmitted to cell edge is denoted in Equation (9) [11], [15].

$$P_{Te} = \omega_{Tc} \qquad ;0<\omega<1 \tag{9}$$

Interference that occurred in macro cell consist of interference I_c received by cell center UE and interference I_e received by cell edge. UE in cell center interfered by adjacent cells center I_{c1} (6 cells in the first tier and 12 cells in the second tier) and by edge cell I_{c2} (6 cells in the second tier), $I_c = I_{c1} + I_{c2}$ with I_{c1} and I_{c2} in Equations (10) and (13). UE in cell edge interfered by $1/K$ power transmitted from adjacent cell center I_{e1} (6 cells infirst tier and 12 cells in second tier) and adjacent 6 cells edge I_{e2} formulated in (12) and (13). Coefficient φ^* and the probability eNB transmit to the cell edge β defined in [11], [16].

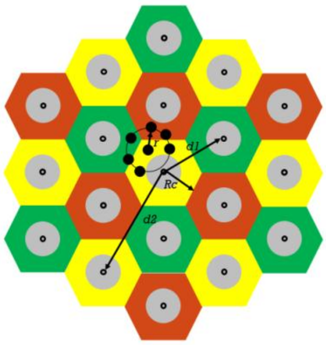

Figure 2. SFR HetNet model with K = 3

$$I_{C1} = \left[6\varphi^* \left(\frac{d_1}{R_c} \right)^{-\gamma} P_{Tc} + 12\varphi^* \left(\frac{d_2}{R_c} \right)^{-\gamma} P_{Tc} \right] \tag{10}$$

$$I_{C2} = \left[6\varphi^* \left(\frac{d_2}{R_c} \right)^{-\gamma} P_{Tc} \right] (1-\beta) \tag{11}$$

$$I_{e1} = \left[6\varphi^* \left(\frac{d_1}{R_c} \right)^{-\gamma} P_{Tc} + 12\varphi^* \left(\frac{d_2}{R_c} \right)^{-\gamma} P_{Tc} \right] \frac{\beta}{K} \tag{12}$$

$$I_{e2} = \left[6\varphi^* \left(\frac{d_1}{R_c} \right)^{-\gamma} P_{Tc} \right] (1-\beta) \tag{13}$$

Micro cell is equipped with low BS transmit power and smaller coverage modelled with frequency reuse of 1. We assume that each micro cell of radius Rc_{mi} is interfered by 6 identic micro cells which is separated by distance $d_{1mi} = \sqrt{3}Rc_{mi}$ each and micro cells is uniformly distributed in a macro cell. The value of interference to the micro cell I_{mi} is [11],

$$I_{mi} = \left[6\varphi^* \left(\frac{r}{R_{c_{mi}}} \right)^{-\gamma} P_{T_{mi}} \right] (1-\beta) \tag{14}$$

where r is the distance of certain UE covered by micro cell from BS. Received power in Equation (15) formulated with considering SUI model, where φ and υ is SUI coefficients explained in [11], [16].

$$P_R = \varphi\left(\frac{R}{R_{c_{mi}}}\right)^{-\upsilon} P_T \tag{16}$$

The received power level in dBm can be expressed as [11],

$$P_R = P_T + G_T + G_R - L_T - L_R - P_L \tag{17}$$

where G_T, G_R, L_T, and L_R are transmitter antenna gains, receiver antenna gains, transmitter losses, and receiver losses. Average throughput of a UE R_{UE} in bit/s is defined [17].

$$RUE = 12\,x\,7\,x\,\eta_i\,x\frac{PRB_u}{TTI} \tag{18}$$

where PRB_u is the number of PRB allocated for certain UE on Transmission Time Interval (TTI) of 1 ms given in Table 1.Efficiency η_i in bit/resource element defined in,

$$\eta_i = r_i \log_2\left(M_i\right) \tag{19}$$

Code rate $r_i$and modulation size M_i given in Table 2 [18].

Table 1. Number of PRBs Allocated per TTI

Bandwith (MHz)	Number of PRBs per TTI, N_{PRB}
1.5	12
2.5	24
5	50
10	100
15	150
20	200

Table 2. Overview of different CQI

CQI Index	Modulation Type	M_i	Code Rate, r_i	Efficiency, η_i
0	No Transmission			
1	QPSK	4	78/1024	0.1523
2	QPSK	4	12/1024	0.2344
3	QPSK	4	193/1024	0.3770
4	QPSK	4	308/1024	0.6016
5	QPSK	4	449/1024	0.8770
6	QPSK	4	602/1024	1.1758
7	16QAM	16	378/1024	1.4766
8	16QAM	16	490/1024	1.9141
9	16QAM	16	616/1024	2.4063
10	64QAM	64	466/1024	2.7305
11	64QAM	64	567/1024	3.3223
12	64QAM	64	666/1024	3.9023
13	64QAM	64	772/1024	4.5234
14	64QAM	64	873/1024	5.1152
15	64QAM	64	948/1024	5.5547

4. SIMULATION RESULT AND ANALYSIS

4.1. Simulation setup

In our simulation, we aim to evaluate the power ratio variations by inspecting achieved capacity of the cell. Percentage of UEs covered buy micro cells also become an interesting parameter to evaluate. Total number of UEs served is 100. Simulation parameters listed on Table 3.

Table 3. Simulation Parameters

Parameter	Value
Number of macro cell per cluster	7
Number of micro cell per macro cell	10
Bandwidth of macro cell	15 MHz
Bandwidth of micro cell	5 MHz
Macro-cell radius	1644 m
Micro-cell radius	50 m
Number of total RBs macro cell	150 PRBs
Number of total RBs microcell	50 PRBs
Frequency spacing of each RB	180 kHz
Thermal noise	-174 dBm/Hz
Total eNB macro cell transmit power per cell	37 dBm
Total BS microcell transmit power per cell	25 dBm
Path loss Model	SUI

4.2. Simulation result

We represent achieved cell capacity as the power ratio of cell center and edge of macro cell in Figure 3. The capacity for AWGN channel and Rayleigh channel is evaluated. For AWGN channel, the total achieved capacity is around 110 Mbps, while for Rayleigh Channel is around 63 Mbps. For both schemes we can conclude that power ratio doesn't have much effect on total achieved capacity for cell. This result quite contradicts the common belief that adding non macro cell will decrease performance since adding interference level. Since the desiredsignal also increasing as fast as interference level increasing, so the overall SNR will have a stable value. We can conclude that complex power control it is not needed for achieve high capacity in HetNet. In Figure 4 we represent the user association with micro-cell variation corresponding to total achieved capacity. It is shown that the highest capacity is achieved when 20% of users are associated with micro-cell, while the rest are associated with macro-cell. So for the rest simulation, we use 80% users in macro-cell while 20% users are in micro-cell. We represent the distribution of UEs covered by macro-cell corresponding to eNB position in Figure 5. With 10 micro-cells distributed uniformly in a macro-cell, we show UEs position covered in micro-cell in Figure 6. Total number of UE covered in a micro-cell is total of UE in micro-cell divided by number of micro-cell.For the rest simulation, we use fixed power ratio and fixed percentage of user covered by micro-cells in AWGN channel, as described in Table 4.

SINR for UE covered by macro cell represented in Figure 7 and its capacity represented in Figure 8. The capacity relation with SINR further described in [17]. We expect that the SINR value will have linear relation with user position, that is the nearest one from eNB will have highest SINR and capacity, and for the farthest one from eNB will have lowest SINR and capacity. But the results show that the users that areSINR for UE covered by micro cell represented in Figure 9 and its capacity represented in Figure 10. For overall, the SINR and capacity are highest when the user's distance is the nearest one, and lowest when the user's distance is the farthest one, since the farther user from eNB, the lower power will be transmitted due to path loss and interference. But as shown in those graphics, starts from user with 37 m distance from eNB, the SINR value is increasing a bit until 2 dB. It is caused due the users are receiving lower interference from another micro-cells. The number of micro-cell used is 10, while each of cell separated by $d_{1mi} = \sqrt{3} \times 50\ m$, which is uniformly distributed in a macro cell.

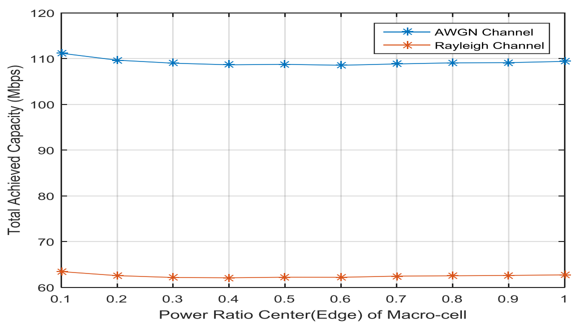

Figure 3. Power Ratio Variations

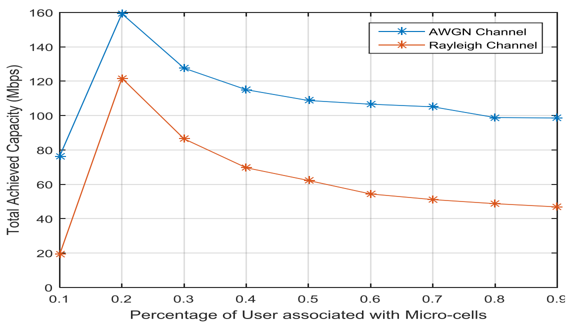

Figure 4. Users Association Variation

Table 4. Simulation Parameters

Cell Parameteres	Value
Number of Macro-cells	1
Number of Micro-cells	10
Number of UEs covered by a Macro-cell	50
Number of UEs covered by a Micro-cell	5
Total UEs Measured	100
Power Ratio	50%
User Coverage by all Micro-Cells	50%
Channel	AWGN

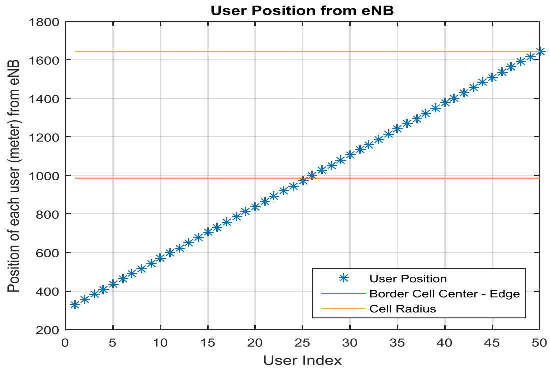

Figure 5. UE Distribution in Macro-cell

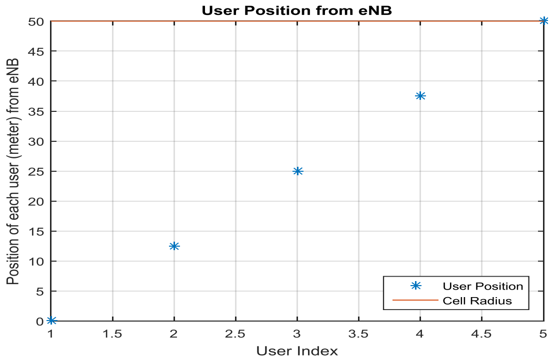

Figure 6. UE Distribution in a Micro-cell

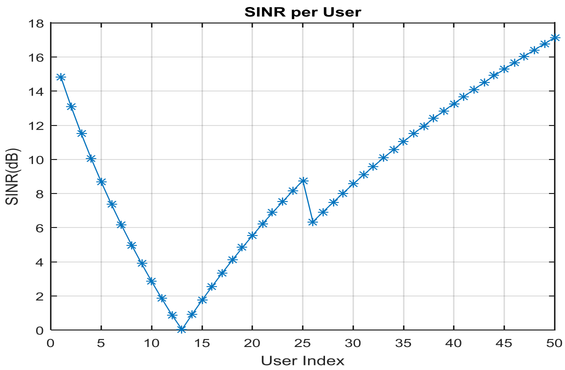

Figure 7. UE SINR Covered by Macro-Cell

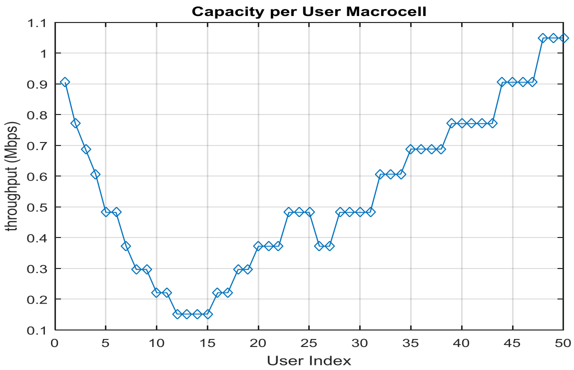

Figure 8. Capacity per UE in Macro-cell

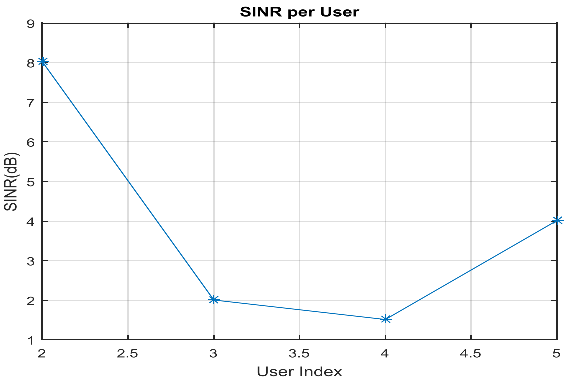

Figure 9. UE SINR Covered by a Micro-Cell

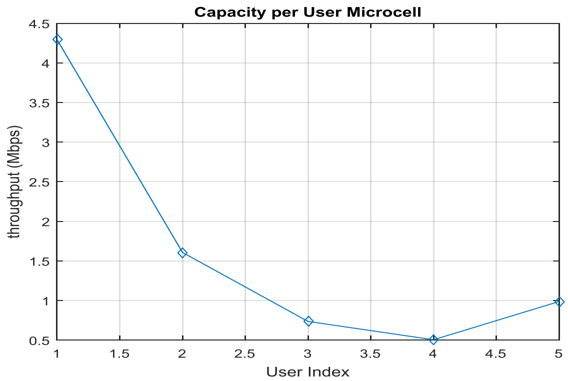

Figure 10. Capacity per UE in a Micro-cell

5. CONCLUSION

In this paper we investigate the dynamics of power ratio in AWGN and Rayleigh channels for HetNet system. The system model comprises of SFR implementation divide macro cell into cell center with frequency reuse of 1 and cell edge which has frequency reuse pattern with factor K=3. The inter cell center interference is reduced by cell center make use of all segments, but cell edge only uses one of the segment differ from its adjacent cell edge segment allocation.

The result shows that changing power ratio in HetNet system doesn't have much effect on total achieved capacity both for AWGN and Rayleigh conditions, which is contradict the common belief that adding the micro-cell will be increasing the interference. It is caused due the desired signal also increasing as fast as interference level increasing, so the overall SNR and capacity will not change much. So for achieving high capacity in HetNet, it doesn't need more complex power control.

The results also show that the highest capacity is achieved when we use 80% users in macro-cell while 20% users are in micro-cell. For users in macro-cell, the users that are located in cell edge have better SINR and capacity rather than users located in cell center, since every segment has been allocated the fix number of RB. For users in micro-cell, the SINR and capacity are highest when the user's distance is the nearest one, and lowest when the user's distance is the farthest one, since the farther user from eNB, the lower power will be transmitted due to path loss and interference.

REFERENCES

[1] S. Neeraja, G. Sasibhushana Rao, "A Comparative study on Handoff Algorithms for GSM and CDMA Cellular Networks", *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 7, no. 3, June 2017, ISSN: 2088-8708.
[2] Iskandar, I. Setyawan, and H. Nuraini, "Inter-cell Interference Management Technique for Multi-Cell LTE-A Network", *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 7, no. 5, October 2017, ISSN: 2088-8708.
[3] Adeeb Salh, Lukman Audah, Nor Shahida Mohd Shah, Shipun Anuar Hamzah, "Adaptive Antenna Selection and Power Allocation in Downlink Massive MIMO Systems", *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 7, no. 6, December 2017, ISSN: 2088-8708.
[4] Iskandar and D. Hidayat, "SC-FDMA LTE Performance Through High Altitude Platforms Communications (HAPS) Channel", *TELKOMNIKA (Telecommunication, Computing, Electronics, and Control)*, vol. 14, no. 2, June 2016, pp. 119-128.
[5] Aubida, A. Jasim, and S. A. Mawjoud, "LTE Heterogenous Network: A Case Study", *International Journal of Computer Applications (0975-8887)*, vol. 61, no. 8, January 2013.
[6] A. Ghosh, et all, "Heterogenous Cellular Network: From Theory to Practice", *IEEE Communications Mag,* pp. 54-64, June 2012.
[7] G. Giambene, V.A. Le, T. Bourgeau, H. Chaouchi, *"Soft Frequency Reuse Schemes for Heterogenous LTE Systems"*, IEEE ICC 2015 - Mobile and Wireless Networking Symposium, pp. 3161-3166, 2015.
[8] E.R. Martinez, "Inter Cell Interference Coordination Techniques in HETNET: Almost Blank Sub-Frames Approach," 2013.
[9] M. Yassin, et al, "Survey of ICIC Techniques in LTE Networks under Various Mobile Environment Parameters", December 2015.
[10] R. Patil, R.D. Patane, "Inter-cell Interference Mitigation Reduction in LTE Using Frequency Reuse Scheme", *International Journal of Scientific and Reseach Publications,* vol. 5, no. 8, August 2015.
[11] G. Giambene and T.A. Yahiya, "LTE Planning for Soft Frequency Reuse", 2013.
[12] V. Erceg, K.V.S. Hari, et al., "Channel models for fixed wireless applications", tech. rep., IEEE 802.16 Broadband Wireless Access Working Group, January 2001.
[13] W. Afric, N. Matosic and D. Vakante, *"WiMAX on 3.5 GHz Cell Size Calculation"*, Proceedings ELMAR 2006, Zadar, 2006, pp. 195-198.
[14] Ramjee Prasad; "Universal Wireless Personal Communications", Artech House, Boston, London, 1998, pp. 350-353.
[15] G. Giambene and V.A. Le, *"Performance evaluation of different fractional frequency reuse schemes for LTE"*, 2014 Euro Med Telco Conference (EMTC), Naples, 2014, pp. 1-6.
[16] V. Erceg *et al.*, "An Empirically Based Path Loss Model for Wireless Channels in Suburban Environments", vol. 17, no. 7, pp. 1205-1211, 1999.
[17] G. Giambene, V.A. Le, T. Bourgeau, and H. Chaouchi, *"Soft frequency reuse schemes for heterogeneous LTE systems"*, in IEEE International Conference on Communications, 2015, vol. 2015–Septe, no. Icic, pp. 3161-3166.
[18] V. Erceg, L.J. Greenstein, S.Y. Tjandra, S.R. Parkoff, A. Gupta, B.nKulic, A.A. Julius, R. Bianchi, "An Empirically based Path Loss Model for Wireless Channels in Suburban Environments", *IEEE JSAC*, vol. 17, no. 7, pp. 1205-1211, July 1999.