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Design of a cell selection mechanism to mitigate interference for cell-edge macro users in femto-macro heterogeneous network

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ABSTRACT

The Femto-Macro heterogeneous network is a promising solution to improve the network capacity and coverage in mobile network. However interference may rise due to femtocell deployment nearby to macro user equipment (MUE) within macrocell network coverage. Femtocell offers main priority in resource allocation to its subscribed femto user equipment (FUE) rather than unsubscribed MUE. MUEs will suffer severe interference when they are placed near or within the femtocell area range especially at the cell edge. This phenomenon occurs due to the distance is far from its serving macro base station (MBS) to receive good signal strength. This paper presents a design of cell selection scheme for cell-edge MUE to select an optimal femto base station (FBS) as its primary serving cell in physical resource block allocation. In this study, the proposed cell selection consists of four main elements: measuring the closest FBS distance, Signal to Interference-plus-Noise-Ratio (SINR), physical resource block (PRB) availability and node density level for the selected base station. The main goal is to ensure cell-edge MUE has priority fairly with FUE in physical resource block allocation per user bandwidth demand to mitigate interference. Hence, the cell-edge MUE has good experienced on receiving an adequate user data rate to improve higher network throughput.

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1. INTRODUCTION

Rapid increase in the network capacity and tremendous user data traffic demand lead to scarcity of available frequency spectrum provided by mobile network provider to satisfy high bandwidth utilization needed by up-to-date network applications [1]. This phenomenon will be hectic if the mobile network providers are not seeking the best strategies to provide an adequate service based on user demands. Recent development of macro-femto heterogeneous network (HetNet) is an attractive solution that enables low power femtocells to operate in high power macro cell to extend service coverage and maximize network capacity. However, it contributes interference among femtocells and macrocell originate from frequency band overlapping and bandwidth sharing. Particularly to cell-edge MUEs, they suffer severe degradation of good signal reception from MBS cell and also downlink interference caused by adjacent FBS.

Femtocell which is also known as home node base station (HNBs) is a very low-range, low-power base station, user-deployed which is provided by a mobile network operator that operates in licensed frequency bands [2]. The deployment of femtocell on the existing macrocell can improve macrocell base station (MBS) reliability where it automatically switches association from the serving macrocell BS to the femtocell when preauthorized mobile station enter the coverage of femtocell [3]. It can bring user equipment (UE) closer to the base station results a higher-quality air interface, which provides better spatial efficiency [4]. A femtocell allows service providers to extend service coverage indoors, especially where access would otherwise be limited or unavailable [5]. However, deployment of femtocell network randomly by users may subsidize an inefficient network strategy to improve the performance of the wireless system caused by inter and intra interference between femtocells and macrocell.

Many existing researches approached various techniques to mitigate of the interference condition, mostly based on radio management techniques, hybrid access femtocells, and power control. The cell selection schemes can play a key point of solution to improve cell spectrum efficiency especially in HetNet that allows UE to have an option in selecting the ideal cell to serve them adequately. Conventional cell selection methods are depending on the highest instantaneous SINR or maximum Reference Signal Received Power (RSRP), but when it implemented in the main LTE traffic channel become inefficient due to shared resources technology and different transmits power levels of nodes such as MBS and FBSs. SINR is become important when the interference is considering in the system evaluation that is measured by UE on Resource Block (RB) basis. While, RSRP is a cell-specific signal strength related metric that is used as an input for cell resection and handover decisions [6].

In contribution [7, 8] the analysis on performance comparison between conventional method based on RSRP and new scheme extended range expansion to allow a UE within range expansions region can attach to the nearest base station (BS) (e.g. Pico cell) without considering available amount of cell capacity for offloading. Other new scheme proposed in [7] based on network coordination uses RSRP to initialize cell selection by taking into account the pico cell load capacity. The proposed algorithm has two steps which considering the selection of serving cell based on received power signal from BS and corresponding achievable capacity with bandwidth.

In [9] introduced cell selection scheme uses specific subframe named almost blank subframe (ABS) based on expected user data rate as a function of the ABS ratio. The users enable to select their serving cells by comparing the expected data rate of target cells that can provide higher data rate regardless of the bias value. A new prediction algorithm [10] is proposed to enable new user can select best serving cell to provide an effective achievable data rate by predicting the Proportional Fair (PF) scheduling algorithm to estimate the expected number of resource block (RB) that will be assigned to a new user. The output shows that the new proposed scheme improved performance of user located in FBS and MBS coverage unlike the conventional cell selection scheme achieves better SINR value for user located only in MBS coverage area. In common, the new coming users (e.g. cell-edge user) that are located at non-serving cell have been ignored to receive achievable data rate from the nearest cell (e.g. femtocell) as a result of interference to maintain its throughput and improve network performance.

The interference behaviour in [11] presents the average throughput of cell-edge MUEs located nearby femtocells area range is decreased due to weak signal received and higher inter-cell interference. Implementing frequency reuse technic can mitigate interference for MUE and FUE situated at the cell-edge region using two types of Fractional frequency reuse (FFR) schemes: FFR-3 and FFR-6 [12] where the frequency band is divided into various sub-bands and they are allocated at the inner and outer region differently. Intra-cell and inter-cell interference can be reduced by properly providing efficient spectrum. The combination of both coordinated multipoint (CoMP) and load balance including coordinated beamforming (BF) and joint transmission (JT) abe to eliminate interference in non-orthogonal multiple access (NOMA) heterogeneous network. Another solution for interference mitigation scheme is applying a self-organizing as proposed in [13] which is combined with power control mechanism to adjust the femtocell’s transmission power at femtocell downlink to reduce the interference between femtocells for Long Term Evolution (LTE) femtocell network.

This paper presents the design of cell selection mechanism to mitigate interference for cell-edge macro users dispersed randomly in femto-macro heterogeneous network. In this study, a new technique is approached with less complexity of mathematical formulations and algorithms to elect the optimal femtocell as a main serving cell to the cell-edge MUE for an effective deployment in heterogeneous network (HetNet). It enables FBS can be applied as a primary resource provider to serve proximate non-authorised MUEs to rise their throughput. The base station selection is based on the measurement of the closest distance of FBS and

MUEs, SINR of cell-edge MUEs, PRB availability and node density level of selected cell (e.g. femtocell). This mechanism is designed to increase network throughput at outer region (cell-edge) for MUE served by an adequate FBS to support ongoing services. The rest of this paper is structured as follows: the system model is discussed in section 2. Section 3 proposed cell selection mechanism is explained and followed by the discussion and future work in section 4.

2. SYSTEM MODEL

In this section, we suggest the concept of the proposed cell selection mechanism as depicted in Figure 1. It consists of four sub-process are: (1) measuring the closest distance between base station (FBS and MBS) and MUE, (2) an average SINR, (3) calculate the availability of PRB can be served by FBS and (4) determine the level of node density. At the initial stage the distance and SINR are calculated between MUEs and FBS and the output is compared with the benchmark value between MUE and its MBS. Then, it will proceed to measure the PRB amount to ensure an efficient achievable PBR that can be assigned to UEs based on bandwidth demand and the node density level must be at low percentage which indicates the condition of network congestion.

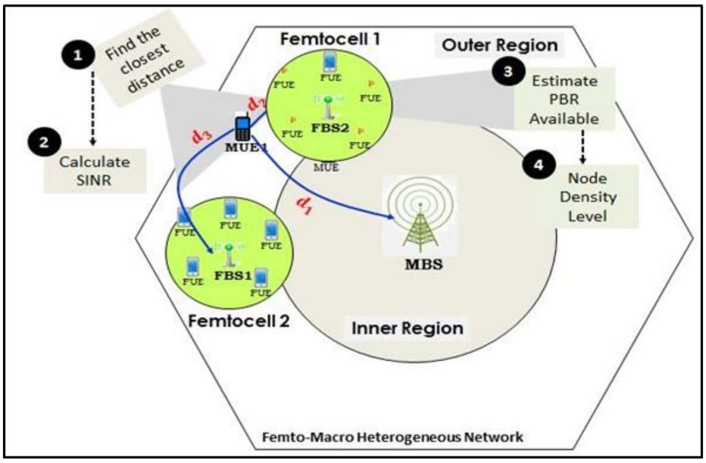

Figure 1. Concept model for the proposed cell selection mechanism

2.1. Network scenario

LTE Femto-macrocell heterogeneous network consisting of a MBS located in the middle of the cell and 7 femtocells are located randomly overlaid in macrocell area range is considered in a MATLAB simulator. LTE-downlink with 20MHz QAM system bandwidth and a total of 100 PRBs per cell is assumed; which is all FUEs and MUEs are assigned with a different PRB requirement based on application type bandwidth demand setting as depicted in Table 1. There are two main network scenarios will be selected: 1) co-channel operation without network partitioning and 2) with network partitioning based on ICIC mechanism into two regions: inner and outer region whereas the allocation of the frequency sub-bands into macrocell and femtocell using FFR and SFR. If a femtocell is positioned in the outer region of a macrocell, the sub-band used for the inner region can be recycled to allocate for the FUEs. On the contrary, a femtocell dropped in the inner region cannot reuse the sub-band which was assigned to the cell edge users of the macrocell. The reason is the transmit power of the BS in each case. Inner cell users are closer to the BS, which means that lower transmit power is required. Instead, the BS should transmit in maximum power in order to satisfy cell edge users.

Three scenarios have determined based on ICIC mechanism [11] to experiment the proposed cell selection as the following:

Scenario 1. Co-channel operation. This circumstance describes the worst case of inter interference between femtocells and macrocells where no frequency partition is required. The used of spectrum for both femto-macrocells are equal.

Scenario 2. FFR aware. The frequency band dedicated to the cell centre users is commonly reuse factor 1. Then, femtocell can use sub-band that allocated to neighbouring macrocell based on factor of 3 since only one macrocell is employed.

Scenario 3. SFR aware. SFR utilizes frequency band similarly to FFR but allows inner of the cell to share sub-bands of edge users at adjacent cells.

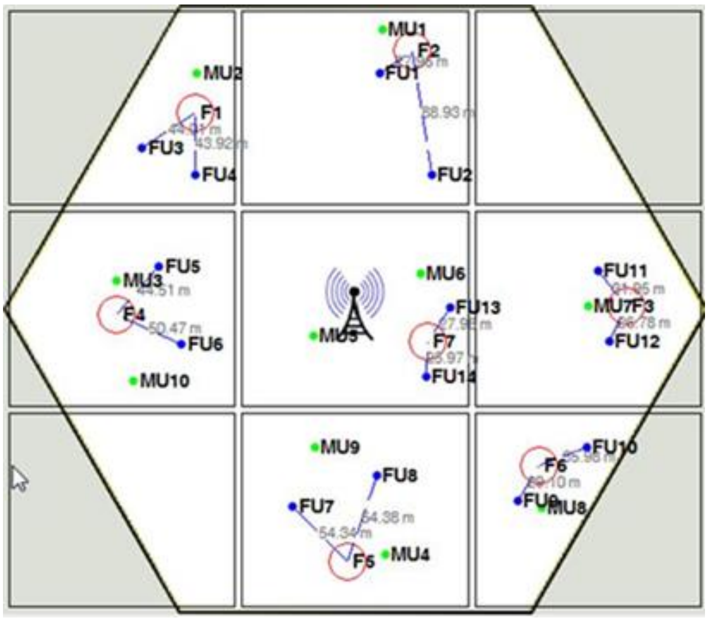

Figure 2. Simulation model for femto-macro heterogeneous network environment

In this study, we suggest a simulation model of femto-macro network in Figure 2 adaptation from [11] as a basis network model. The number of network entities including femtocell base station (FBS), femto user equipment (FUE) and macro user equipment (MUE) randomly dispersed in hexagonal cell of two-tier femto-macro network environment. The deployment of femtocell randomly contributes interference between macrocell and femtocell including its neighbouring. The consequence is decreasing the network throughput specifically for the cell-edge MUEs. The default values of simulation parameter are summarized in Table 1. A few input values were determined to ensure realistic parameter and acceptable result.

Table 1. Simulation parameters

SINR Value	Throughput
Cellular layout	Single macrocell
Number of macro BS	1
Macrocell radius	250m
Macro BS TX Power	46 dBm
Carrier frequency	2 GHz
Femto BS default TX power	11 dBm
Exterior walls loss (low)	15 dB
Interior walls loss (low)	7 dB
Bandwidth (MHz)	20
Modulation type	64QAM
Subcarrier spacing	15 KHz
White noise power density	-17dBm/Hz

2.2. User traffic model

The user traffic is modeled by taking into account the current bandwidth requirement by application based on user demands in the market. Referring to LTE FDD frame, a resource block is 180 kHz wide in frequency and 1 slot (0.5ms) long in time. In frequency, resource blocks are either 12 x 15 kHz or 24 x 7.5 kHz subcarrier wide. Most of the application bandwidth requirement is in bit rate (bps) measurement, so that the conversion from bps to hertz (Hz) is acquired to be used in frequency domain. In this study, the 64QAM modulation scheme is used which required 6 bits for each symbol. The outcome of estimated bandwidth in Hz based on application bandwidth requirements as tabulated in Table 2.

Table 2. User traffic model

Application Type	Bandwidth Requirement (bps)	Estimate Bandwidth Requirement (Hz)	Minimum No. of RB Requirement	Subcarrier Downlink
Standard Definition (SD) Video	3 Mbps	600 KHz	3	37
High Definition (HD) Video	5-8 Mbps	1-1.6 MHz	5-8	60-97
Ultra-High Definition (UHD) Video	25 Mbps	5 MHz	25	301
Video Streaming (e.g.Skype)	4 Mbps	800 KHz	4	48
Audio Streaming	300 Kbps	100 KHz	0.6	7
Social Network (e.g. Facebook)	200 Kbps	40 KHz	0.2	3

Each MUEs and FUEs will be assigning multiple applications with its bandwidth requirement randomly. This is intended to determine the amount of PRB needed by each user for allocating efficient PRB by its serving cell based on user demands.

3. CELL SELECTION MECHANISM

In this section, we proposed cell selection mechanism comprises of four sub-processes including calculation of the closest distance between MUE and FBS, SINR, available PBR to allocate to MUEs based on user bandwidth demand and the level of node density as shown in Figure 3.

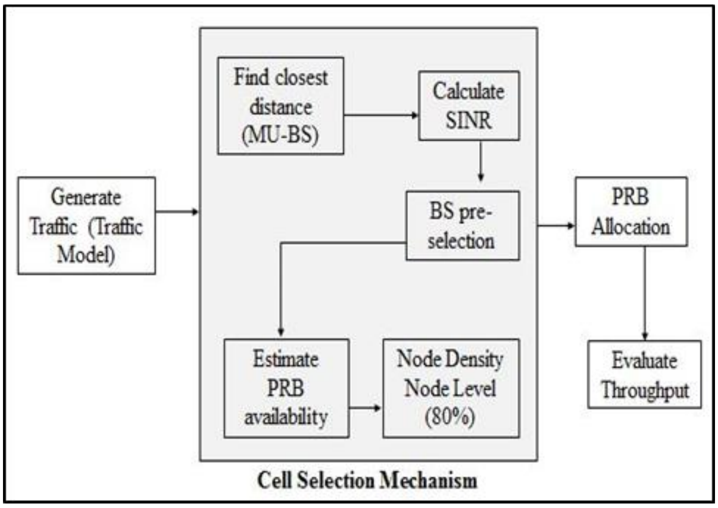

Figure 3. Block diagram of cell selection process

3.1. Measuring the closest distance of BS

In mobile network, mobile UE continuously sense the signal strength from their nearest base station to associate the strongest base station even though it is under another BS servicing cell. Therefore, the BS with the strongest signal is assumed to be the one closest to mobile UE and preferred as a primary candidate in allocating resources to UE. In common, MBS is a main serving cell to MUE and become a primary resource allocator, but when MUE placed at the cell edge its position with MBS is farther than adjacent FBSs. It may reduce signal strength received from MBS whereas it has been interfered from neighbouring FBS signal propagations. In this scenario, MUE is better to be served by its adjacent FBS to enhance its throughput and smooth service continuity.mBoth distance between MUE-FBS and MUE-MBS is measured using basic mathematical formulation:

$$D = \sqrt{(x\_dist)^2 + (y\_dist)^2} \quad (1)$$

where D is the distance, x_dist and y_dist is the distance at x axis and y axis respectively.
The steps of the closest distance measurement can be summarized as follows:
Step 1: Find distance from MUE to MBS.
Step 2: Set as minimum distance (min_dist).
Step 3: Find distance between MUE and the nearest FBS.

Step 4: If dist_MUE-FBS < dist_MUE-MBS, update as min_dist.
Step 5: Iteration process min_dist with other FBS

3.2. SINR estimation

The measurement of SINR is used to estimate the signal quality whereas it better computes the relationship between radio frequency (RF) conditions and throughput. UEs typically use SINR to calculate the channel quality indicator (CQI) that indicate suitable transmission data rate to the network. Referring to the proposed network scheme, the measurement of SINR value includes the path loss and propagation models. The inter-cell interference between macrocell and femtocell is considered in estimation as well as intercell interference among femtocells with adjacent cells. The received SINR for a macro user, m on a subcarrier, sc can be expressed as [14, 15]:

$$SINR_{m,sc} = \frac{P_{M,sc}\, G_{i,M,sc}}{N_0\, \Delta f + \sum_F P_{F,sc}\, G_{m,F,n}} \tag{2}$$

where, PM, sc is transmit power of serving macrocell M on subcarrier sc. While, Gm, M, sc is channel gain between macro user m, and serving macrocell M on subcarrier sc. Transmit power of neighbouring femtocell F on subcarrier sc is denoted by PF, sc and Gm, F, sc represents channel gain between macro user m, and neighboring femtocell F on subcarrier sc. Finally, N0 represents white noise power spectral density and Δf is subcarrier spacing. In case of a femto user f, the received SINR on a subcarrier sc can be similarly given by [14, 15]:

$$SINR_{f,sc} = \frac{P_{F,sc}\, G_{m,F,sc}}{N_0\, \Delta f + \sum_M P_{M,n}\, G_{m,M,sc} + \sum_{F`} P_{F`,sc}\, G_{m,F`,sc}} \tag{3}$$

where F` is the set of interfering neighbouring femtocell. The channel gain G is dominantly affected by path loss, which is different for macro users and femto users. The path loss between a macro BS and a User Equipment (UE) is for outdoor user is modelled as [16]:

$$PL_{outdoor} = 15.3 + 37.6 \log_{10} R \tag{4}$$

whereas, the model for the case of indoor user is given as:

$$PL_{indoor} = 15.3 + 37.6\, f_0 \log_{10} R + L_{wall} \tag{5}$$

where R is the distance between a base station and user in meters and L_wall is the penetration loss of an outdoor wall. The path loss between a femto BS and a UE in a same housed is elaborated as following [15, 16]:

$$PL_{indoor} = 38.5 + 20 \log_{10}(d) dB \tag{6}$$

where $L_{\_wall}$ is 7, 10 and 15 dB for light internal, internal and external walls, respectively. Hence, the channel gain G can be expressed as:

$$G = 10^{-PL/10} \tag{7}$$

Referring to the calculation, the closest distance from MUE and BS and the higher SINR will be elected as the finest value for BS (either M BS or FBS) in pre-selection stage before proceeding to the BS determination process.

3.3. BS pre-selection

The FBS is pre-elected based on the minimum distance and SINR value. The closest distance between MUE and FBS is determined based on the minimum distance obtained by comparing the distance value among MUE and its surrounding FBS. Basically, the cell-edge MUE distance is farther from its serving MBS than nearer FBS.

The SINR value gain will be compared with the standard SINR value respect to throughput as shown in Table 3. An appropriate candidate of BS to be a primary serving cell will be elected based on the highest value of SINR and the minimum distance between MUE and FBS.

Table 3. SINR value reference

SINR Value	*Throughput*
>10	Excellent
6-10	Good
0-5	Fair
<0	Poor

3.4. Physical Resource Block (PRB) availability

For 20MHz 64QAM modulation scheme, the number of physical resource block (PRB) is assumed to be allocated for each cell is 100RB. The available RB is estimated after allocating the needed RB required by its serving FUE and can be depicted as:

$$\mathrm{RB_{avail}} = \sum_i \mathrm{RB_F} - \sum_\mathrm{i} \mathrm{RB_f} \tag{8}$$

where RB_avail is the available resource block of FBS, $\sum_i \mathrm{RB_F}$ is total RB allocated to each FBS and $\sum_\mathrm{i} \mathrm{RB_f}$ is total RB requested from FUEs.

3.5. Node density level

Node density is estimated regarding to portion of the potential connection in a network that are actual connection. The potential connection is referred as a connection that could potentially exist between FUEs and FBS. Potential connection can be described as:

$$PC = \frac{n\,(n-1)}{2} \tag{9}$$

where n represents the number of node or in this situation refers to FUE in femtocell network.

In general, the node is considering in a high density level when the number of transactions through the node approaches the maximum processes handling capacity of the node itself [17]. If the node utilization exceeds 80 percent, it considers the network in the critical node congestion level. When the node is clogged, the process of allocating RB to users is interrupted caused by traffic queue delay.

3.6. Throughput evaluation

Based on the simulation model, in this section we calculate the throughput for MUE (served by the MBS and FBS). Beforehand, the capacity of MUE, *m* on subcarrier, *sc* can be calculated using the following equation [18]:

$$C_{m,sc} = \Delta f.\log_2\left(1 + SINR_{m,sc}\right) \tag{10}$$

where, Δf denotes to the available bandwidth for each subcarrier divided by the number of users that share the specific subcarrier. Moreover, the overall throughput serving macrocell *M* can be conveyed as:

$$T_M = \sum_m \sum_{sc} \beta_{m,sc}\, C_{m,sc} \tag{11}$$

where $\beta_{m,sc}$ represents the subcarrier assignment for macro users. When $\beta_{m,sc} = 1$, the sub-carrier, *sc* is allocated to macro user, *m* otherwise, $\beta_{m,sc} = 0$. Similar expression for overall throughput serving femtocell (FBS) F to MUE is possible but T_M=T_F.

4. CONCLUSION AND FUTURE WORK

In this paper, a cell selection mechanism is designed to mitigate interference in LTE femto-macrocell heterogeneous network. The proposed mechanism enables cell-edge MUE to select the optimal FBS as its primary serving cell instead of MBS based on the measurement of the nearest distance, SINR value, amount of PBR available and node density. The outcome should be balanced the system load and increased network throughput of MUE in the cell edge region. The future work will be focus on the development of the cell selection mechanism in MATLAB simulation tool to evaluate the simulation result by comparing user data rate and overall network throughput which is generated in three ICIC network scenarios.

REFERENCES

[1] M. N. T. Mohd Faisal Ibrahim, Masita Jamal, Saadiah Yahya, "Available Bandwidth Estimation in Network-Aware Applications for Wireless Campues e-Learning System," *J. Comput. Networks Commun*., vol. 2012, pp. 1–9, 2012.

[2] ETSI TR 136 921 V10.0.0 (2011-05), "FDD Home eNode B (HeNB) Radio Frequency (RF) requirements analysis," 2011.

[3] M. Al Haddad and M. Bayoumi, "Evaluation of Femtocell Technology Challenges and Its Power Control Methodologies for Green Heterogeneous Networks WHY SMALL CELLS AND," in SMARTGREENS 2014 - 3rd International Conference on Smart Grids and Green IT Systems, 2014, pp. 247–255.

[4] "White Paper: Optimizing Small Cells and the Heterogeneous Network (HetNet)," JDSU Website, 2013. [Online]. Available: http://www.jdsu.com/ProductLiterature/smallcellhetnet_wp_nsd_tm_ae.pdf. [Accessed: 01-Jun-2015].

[5] V. Chandrasekhar, J. G. Andrews and A. Gatherer, "Femtocell networks: a survey," in *IEEE Communications Magazine*, vol. 46, no. 9, pp. 59-67, September 2008.

[6] F. Afroz, R. Subramanian, R. Heidary, and S. Ahmed, "SINR, RSRP, RSSI and RSRQ Measurements In Long Term," *Int. J. Wirel. Mob. Networks*, vol. 7, no. 4, pp. 113–123, 2015.

[7] A. Kamal and V. Mathai, "A novel cell selection method for LTE HetNet," *2014 International Conference on Communication and Signal Processing*, Melmaruvathur, 2014, pp. 738-742.

[8] Tongwei Qu, Dengkun Xiao, Dongkai Yang, Wei Jin and Yuan He, "Cell selection analysis in outdoor heterogeneous networks," *2010 3rd International Conference on Advanced Computer Theory and Engineering (ICACTE)*, Chengdu, 2010, pp. V5-554-V5-557.

[9] J. Oh and Y. Han, "Cell selection for range expansion with almost blank subframe in heterogeneous networks," *2012 IEEE 23rd International Symposium on Personal, Indoor and Mobile Radio Communications - (PIMRC)*, Sydney, NSW, 2012, pp. 653-657.

[10] M. A. AboulHassan, E. A. Sourour and S. E. Shaaban, "Novel cell selection algorithm for improving average user's effective data rate in LTE HetNets," *2014 IEEE Symposium on Computers and Communications (ISCC)*, Funchal, 2014, pp. 1-6.

[11] C. Bouras, G. Diles, V. Kokkinos and A. Papazois, "Evaluation of femtocells interference mitigation techniques over ICIC coordinated LTE-a networks," *2013 IFIP Wireless Days (WD)*, Valencia, 2013, pp. 1-3.

[12] M. O. Mohamed, B. Abdelhamid and S. El Ramly, "Interference mitigation in heterogeneous networks using Fractional Frequency Reuse," *2016 International Conference on Wireless Networks and Mobile Communications (WINCOM)*, Fez, 2016, pp. 154-159.

[13] S. G. A. Ali et al., "*An interference mitigation scheme for LTE based femtocell networks*," AIP Conf. Proc., vol. 1774, 2016.

[14] A. P. Christos Bouras, Georgios Kavourgias, Vasileios Kokkinos, "*Interference management in LTE femtocell systems using fractional frequency reuse*," in Wireless Telecommunications Symposium (WTS), 2012, 2012, pp. 1–7.

[15] P. Lee, T. Lee, J. Jeong, and J. Shin, "*Interference management in LTE femtocell systems using fractional frequency reuse*," in Advanced Communication Technology (ICACT), 2010 The 12th International Conference on (Volume:2), 2010, pp. 1047–1051.

[16] 3GPP TR 36.814 V9.0.0, "Evolved Universal Terrestrial Radio Access (E-UTRA); Further advancements for E-UTRA physical layer aspects (Release 9)," 2010.

[17] K. SuhazlanSuhaimi, "*The Impact of The Number Of Nodes, Speed Of Nodes, Speed Of Network and The Network Space To The Number Of Nodes Keeps Alive*," in International Conference on Global Trends in Academic Research, 2014, pp. 416–421.

[18] D. Bilios, C. Bouras, V. Kokkinos, A. Papazois and G. Tseliou, "Optimization of fractional frequency reuse in long term evolution networks," *2012 IEEE Wireless Communications and Networking Conference (WCNC)*, Shanghai, 2012, pp. 1853-1857.