A Review on Interference Mitigation Scheme in Long Term Evolution Advanced (LTE-A) Heterogeneous Network (HetNet)

O.E. Haruna[1*], S.Magaji[2], I. Mafiana[3], J.O. Ayankale[4], I. Azenabor[5]

[1,3-5]*Centre for Satellite Technology Development (National Space Research and Development Agency), Abuja, Nigeria*
[2]*Computer Engineering Department, Ahmadu Bello University, Zaria, Nigeria*

***Abstract*---Heterogeneous Network (HetNet) is a mixed of small based station such as femto, pico and micro cell within an existing coverage area of macro cell. It has been proposed by the 3rd Generation Partnership Project (3GPP) to provide for the high demand of data by customers. However, one major challenge of HetNet is interference which could lead to low data rate if not mitigated. In this paper we present a review of existing interference mitigation techniques in Long Term Evolution release 10 (LTE rel. 10), and conclude by proposing a new technique to mitigate interference in a femto-macro HetNet.**

***Keywords:* Femtocell, Macrocell, HetNet, Interference, eICIC.**

I. INTRODUCTION

The demand for data is increasing exponentially and expected to grow up to 30.6 ExaByte (EB) per month by the year 2020, this is eight times the total traffic in 2015 [11]. Studies has shown that 70% of the total data traffic and 50% of the total voice traffic are generated indoors [2; 26]. Different schemes has been proposed to meet the demand of customers, one of which is Heterogeneous Network (HetNet). HetNet can be achieved by deploying smaller cell nodes such as pico, micro and femto within the existing coverage area of macro cell [19]. Femto-cell is considered a promising solution for the mobile operators to provide better quality of service (QoS) for indoor users [7]. The advantages of deploying femto-cell is enormous in terms of technical and business point of view [33; 34]:

i. Femto-cell improve coverage and capacity due to short transmit-receive distance [25].
ii. Provides high data rate and call quality to users [5].
iii. Improves macro cell efficiency and reliability by offloading traffic away from macro cell [21].
iv. Deployment of femto-cell is cost effective and self-optimizing, therefore reducing the capital and operational expenditure (CAPEX, OPEX) of the network [8].
v. Femto-cell can easily be deployed by customers without any challenge; because it is a plug-and-play device with self-optimizing capability.
vi. Prolong the battery life of the user equipment since it require less energy to connect to a closer base station [18].

Interference is the major challenge in femto-cell deployment [2;6]. Therefore, to fully utilize the advantages of femto-cell deployment, it is important to mitigate the interference that comes along with it deployment. Frequency Domain (FD), Time Domain (TD) and Power Control (PC) were introduced by the 3rd Generation Partnership Project (3GPP) in it enhanced Inter-Cell Interference Coordination (eICIC) technique to mitigate interference in LTE-A release 10 standards [23; 31]. Several interference mitigation techniques in heterogeneous network has been proposed in the open literature [7; 9; 15; 16; 17; 21; 37].

II. BACKGROUND

A. Long Term Evolution Network

Long Term Evolution marketed as fourth generation (4G) network is a standard wireless communication for high-speed data mobile phones and data terminals. The 3GPP is responsible for developing standards for the LTE network. 3GPP LTE began with the release 8 in 2009 [3; 35] and ever since has undergone several enhancement over the years to release 9/10/11/12/13 [4]. The International Mobile Telecommunication-Advanced (IMT-A) specification required a 1Gbps peak data rate, reduced Latency of less than 10ms and Bandwidth of up to 40MHz for a 4G network, details of this requirement can be found in [22]. However, LTE release 8/9 did not satisfy these requirements but serve as a baseline for further enhancement to fully comply with the IMT-A requirements [35]. Followed by significant improvements and enhancement of release 8/9, release 10 was developed which is known as Long Term Evolution-Advanced (LTE-A). LTE-A was developed with enhanced features such as Carrier Aggregation, advanced Multi-Input-Multi-Output (MIMO) techniques, advanced modulation scheme, coordinated multipoint (COMP), enhanced Inter-Cell Interference Coordination (eICIC) and support for Heterogeneous Network (HetNet) [30]. This features made the LTE-A to exceed the requirement of IMT-A.

Figure 1 shows the architecture of LTE, it was developed based on Orthogonal Frequency Division Multiple Access

(OFDMA) waveform for Down Link (DL) and Single-Carrier Frequency Division Multiple Access (SC-FDMA) waveform for Up Link (UL) communications mainly to improve the user experience for broadband data communications [13]. OFDMA allows data to be directed to multiple users on subcarrier-by-subcarrier basis for a specific number of symbol periods [41].

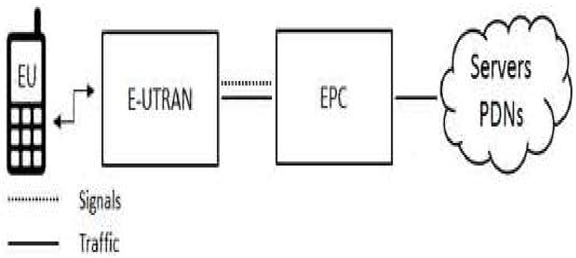

Figure 1: Long Term Evolution Architecture [10].

B. LTE Frame Structure

There are two basic frame types employed in LTE, which are common to both uplink and downlink. Type 1 frames are employed for frequency division duplexing (FDD) full- and half-duplex system, while type 2 frames are reserved for time division duplexing (TDD) operation only. Although the LTE specification describe both FDD and TDD to separate the uplink and downlink traffic in the physical layer, majority of deployed system will employ type 1 FDD frame structure [41]. Figure 2 shows a typical Type 1 FDD frame structure.

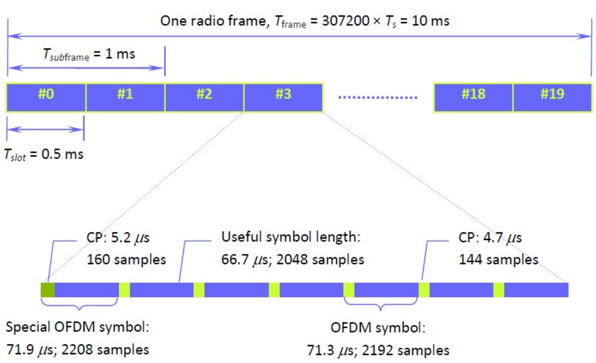

Figure 2: LTE Frequency Division Duplexing (FDD) Frame [32].

ype 1 or FDD frames has a transmission time interval of 10ms and are composed of 20 time slots of 0.5ms each. Two slots are combined to form a sub-frame, which lasts for 1ms. For FDD, 10 sub-frames are available for downlink transmission and 10 for uplink transmission in each 10ms interval. Cyclic Prefix (CP) is used in the time domain to help prevent Multipath Inter-Symbol Interference (ISI) between subcarriers [31]. Each slots last for 0.5ms and contain either 7 or 6 OFDM symbols, depending upon which cyclic prefix (CP) was used whether it is normal or extended cyclic prefix.

The length of a cyclic prefix may vary depending on where that symbol sits within the slots. Within the normal cyclic prefix, symbol 0 in each slot has a CP equal to 5.2μs. While the remaining symbols in the slot have slightly shorter CP of just 4.7μs. When using the extended CP all symbols are prefixed with a CP 16.67μs [31].

C. Heterogeneous network

Heterogeneous Network (HetNet) is a network that consist of a mix of macro cells and low-power nodes (pico, femto and relay nodes), where some may be configured with restricted access and some may lack wired backhaul [13]. The concept of HetNet has attracted a lot of interest to optimize the performance of the radio network. This is due to the fact that the spectral efficiency of current systems like Wide Band Code Division Multiple Access (WCDMA) and LTE is approaching theoretical boundaries [3; 13; 38]. The demand for higher data rates by customers continue to increase exponentially leaving the operators with no choice than to seek for means of bringing the base station closer to the customer. Deployment of femto-cell in macro-cell coverage area to create HetNet is one way of meeting the demand of higher data rate by customers in a cost effective way [20; 33]. Heterogeneous network can be seen in figure 3.

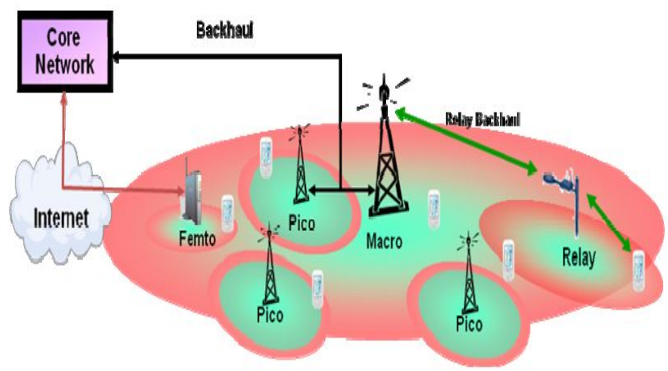

Figure 3: Heterogeneous Network [20].

D. Femto-Cell

Femto-cell are also called Home enhanced Node B (HeNB) [6; 39]. Femto-cell is a low-cost low-power user-deployed wireless access points that offload data traffic using consumers existing broadband Digital Subscriber Line (DSL), cable, or fiber as backhaul to communicate with the mobile operators core network and serving a dozen active users in homes or enterprises [23;33]. Femto-cell operate using licensed spectrum owned by wireless operators and can be deployed with macro cell network in the same frequency or different frequency [39]. However, same frequency deployment is preferred due to scarcity in frequency resources. Femto-cells are deployed in ad-hoc manner without proper planning from the operator or customer [33] and are typically equipped with omnidirectional antennas having transmit power of 100mW which is about -10dB or less [13].

E. Femto-Cell Access Mode

Femto-cell can be classified into three operating modes according to [1; 14]. Figure 2.7 shows different access mode in femto network. Figure 4 is a diagram showing different access mode of femto cell.

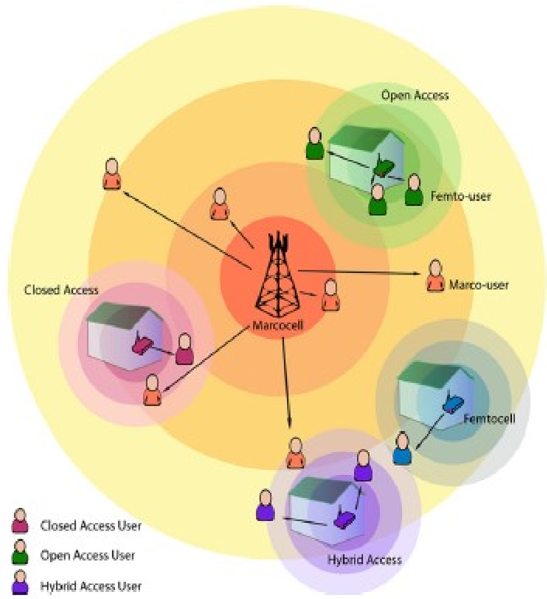

Figure 4: Different Access Mode in Femto Network [1].

In closed access mode, only a set of registered user equipment's belonging to a Closed Subscriber Group (CSG) are allowed to access a femto-cell [34]. This mode is mostly preferred by the femto owners. However, the restricted access of closed femto-cell make them to become a source of interference to non-members around its vicinity [13]. Femtocell operating in open access mode are called Open Subscriber Group (OSG). They have no restriction and allow every user equipment to connect to it [34]. This could mitigate the cross tier interference caused when operating in CSG but increase the number of handovers. The hybrid mode incorporate both closed access and open access mode. All users can connect to the femto cell but lower priority and restriction can be given to users that do not belong to the femto-cell subscriber group [34].

F. Interference in Femto-Macro Network

The deployment of femto-cells in an existing all macro network can introduce cross-tier Inter- Cell Interference (ICI) to the network. The restricted access control associated with femto-cell may lead to strong interference scenario in both uplink and downlink [23; 24]. Femto-cells are not connected directly to the core network of the operator, therefore only limited backhaul signaling for interference coordination is possible. Femto-cell are also deployed in ad-hoc manner without operator supervision [28]. This means that proper operation of femto-cell will highly depend on their self-organizing features, sensing and continuous monitoring of the radio environment in order to adaptively mitigate or avoid interference [12]. When a macro user especially at the boundary of a macro- and femto-cell comes within the strong signal coverage of a femto-cell operating in CSG, the macro base station try to initiate a hand over request to the femto-cell which is definitely going to fail because the user is not a member of the CSG list [39]. The macro user then experience a strong interference in the downlink channel which lead to a decrease in the Signal-to-Interference plus Noise Ratio (SINR) of the user. Interference is therefore the major technical challenge in heterogeneous network [3;6; 23; 34; 40].

G. Inter-Cell Interference Coordination

Inter-Cell Interference Coordination (ICIC) methods specified in release 8/9 of the 3GPP standard do not specifically support Heterogeneous Network (HetNet) [23]. In LTE-A release 10 (rel. 10) enhanced Inter-Cell Interference Coordination (eICIC) techniques was developed. The eICIC techniques support HetNet deployment and can be group under three major categories according to [23]:

i. Time-domain techniques
ii. Frequency domain techniques
iii. Power control techniques

III. REVIEW OF INTERFERENCE SCHEME

Morita et al., [42] proposed an adaptive femto-cell transmit power level setting scheme to mitigate the interference between femto-macro Heterogeneous Network (HetNet). The proposed scheme estimated the path loss between the femto-cell and the neighboring macro-cell user equipment on the basis of the received signal reference power (RSRP) from the macro cell user equipment. The scheme considered penetration losses and adjustable positive factors to estimate the priority of femto-cell power operations. This mitigates the interference to macro user equipment's while maintaining good femto indoor coverage. Simulation carried out to validate the performance of the scheme showed that average user throughput of the macro-cell users within the femto-cell vicinity was increased by 36% greater than that of the fixed power setting scheme. However, the Signal-to-Interference plus Noise Ratio (SINR) of the macro user equipment was not considered in the power control model. This means that the SINR of the victim user equipment can go below the minimum required SINR for LTE.

Zhenwei et al., [39] proposed a novel macro user assisted Home enhanced NodeB (HeNB) power control scheme to keep the increased interference caused by femto-cell. The scheme adjusts the transmit power of the HeNB when receiving interference message from a macro user equipment. Two timers T1 and T2 are used to control the decrease and increase of the transmit power of the HeNB. Timer T1 is used to frequently reduce the transmit power, while timer T2 is used to control the time when the HeNB begin to increase the power transmission. System level simulation results showed that the proposed scheme can not only lower the interference to the victim macro users but also avoid unnecessary performance loss of a femtocell. However, the interference between the femto-cell base stations is not considered in the study. Moreover the victim macro user equipment need to send interference messages to femto-cell, yet there is no direct connection between femto-cell and victim macro user equipment, which implies possible delay and low reliability in transmitting the control information. Femto-cell does not adjust it power setting when it gets a new interference message from a macro user equipment until timer T1 expires, this means that victim macro users can go out of coverage before the femto-cell adjust its power during severe interference.

Wang and Pedersen [36] investigated interference management methods based on femto-cell power reduction and time domain (TDM) muting in heterogeneous networks. They considered a co-channel deployment of macro-cells and femto-cell operating in the Closed Subscriber Group (CSG) mode. They authors evaluated the trade-off offered by femto-cell power settings and time domain muting in the downlink transmission of an LTE-Advanced system. Simulation results showed that some interference is still generated due to the fact that signals like Common Reference Signals (CRS) are transmitted during almost blank sub-frame (ABS). Time domain muting between the macro-cell and femto-cell can achieve a better trade-off on condition that the interference from Almost Blank Sub-frame (ABS) due to CRS is significantly reduced as compared to non-ABS sub-frames. Otherwise in a realistic femto-cell interference on ABS where no offset account for the interference due to transmission of CRS, the best trade-off is achieved with only power reduction. Therefore in order for TDM muting to be beneficial a further reduction of the femto-cell interference on ABS is needed. Results obtain also show that it is recommended not to use TDM muting with muting ratio beyond 50% of the total sub-frame. However, power reduction setting and time domain techniques combine together and careful determination of the muting ratio and power offset for CRS interference will perform better than using only one technique.

Pang et al., [29] proposed a distributive technique to determine victim user equipment protection from interference by almost blank sub-frame. In the work it was assume that all pico user equipment are scheduled during almost blank sub-frame while the number of almost blank sub-frame to be created is determined using the rule of thumb i.e. the number of almost blank sub-frame should be approximately proportional to the number of user equipment schedule for almost blank sub-frame. The unique feature of the proposed solution is that only limited information exchange via backhaul is required. An optimized time domain resource partitioning was carried out to obtain Almost Blank Sub-frame (ABS) density and configuration. However, the capacity of the aggressor eNodeB will be reduced since zero ABS was used. During almost blank sub-frame no data is sent but only Control Reference Signals (CRS) are sent. This implies that the capacity of the aggressor eNodeB will be reduced since it is not sending data in all of its sub-frame.

Kshatriya et al., [43] proposed an Orthogonal Almost Blank Sub-frame (OABS) scheme. The proposed scheme determines the number and location of sub-frames that are to be blanked at each aggressor node. The number of Almost Blank Sub-frame (ABS) to be blanked was dependent on the number of victim users and normal users who are not interfered by the aggressor node. In the work a Heterogeneous Network (HetNet) comprising of macro, pico and femto cell was considered. The Macro enhanced NodeB is an aggressor to the pico users within the macro cell coverage and femto eNodeB is an aggressor to the macro users within the femto-cell coverage. The scheme ensures that the ABS pattern in all aggressor eNBs are orthogonal to each other. This means that the same sub-frame cannot be used as ABS in all the aggressors. Results obtain showed that throughput and spectral efficiency of the victim user equipment can be significantly increased. The OABS scheme improves the performance of the victim user equipment when compared to without ABS and random ABS selection scheme. However, the capacity of the aggressor eNBs will be reduced since traditional zero ABS was used where no data is sent during ABS except for common reference signals only. The coordination between femto and macro eNodeB was not considered in the work. In LTE-A rel. 10, there is no direct X2 interface between the femto and macro eNodeB. This means that ABS coordination can be slow and cause victim users to go out of coverage because of the delay in coordination.

Deb et al., [44] developed a novel algorithm to solve the coupled problems of: (i) determining the amount of radio resources that macro cells should offer to pico-cells and (ii) determining the association rules that decide which user equipment should associate with pico-cell. Cell Selection Biasing (CSB) was used to determine user association, while the amount of radio resources that macro station should offer to pico-cells was determined using traditional zero Almost Blank Sub-frame (ABS) where no data is transmitted during the sub-frame . The two solutions were implemented in a joint manner using the notion of ABS and CSB proposed by LTE standards. Results obtain demonstrate that capacity can be enhance using such a joint optimization. However, the capacity of the aggressor macro base station will be reduced at the expense of increasing pico-cell capacity since the macro base station will not transmit any data during almost blank sub-frame. This will lead to a reduction in the overall system capacity.

Pal et al., [27] proposed a simple resource allocation strategies along with power coordination scheme for two-tier Macro/Femto heterogeneous network. The strategy allows femto-cell to coordinate and allocate more frequency resources by using fractional frequency approach. In Fractional Frequency Reuse [8] the users near a base station or cell center are allocated with the wider bandwidths while users at the cell edge are able to use only a small fraction of the total bandwidth. Two most conventional approach in FFR was considered: the strict fractional frequency reuse and soft frequency reuse. In strict fractional frequency reuse the bandwidth is divided in such a way that each cell allocate a common frequency at the center and the rest of the band is divided across the cell edge with a reuse factor of three. While in soft fractional frequency reuse (SFFR) instead of using one common sub-band in the cell center, the band of the neighboring cell edge bandwidth is used. Simulated results showed that using soft fractional frequency reuse the signal-to-interference plus noise ratio of the cell edge users will be better compared to FFR and no FFR. Final results showed that there was an improvement of about 16% in the signal to interference plus noise ratio of the cell edge users. However, the use of fractional frequency reuse will lead to waste of valuable spectrum and limit network capacity,licensed spectrum is a scarce and valuable resource to operators. With this knowledge LTE was design to operate with a frequency reuse of one and to also support co-channel deployment.

Bartoli et al., [45] proposed a simple approach to determine adaptively the most suitable value of the muting ratio as a function of the network traffic load based on suitable threshold values. A macro-femto Heterogeneous Network (HetNet) was considered, the femto cell was deployed in the Open Subscriber Grouped (OSG) mode. Cell Range Expansion (CRE) was implemented at the OSG femto cell to ensure that more users are offloaded from the macro to the femto-cell. Almost blank sub-frame was used to mitigate interference experienced by user equipment in the CRE region. A simple method was proposed which choose adaptively the Almost Blank Sub-frame (ABS) period that needs only the knowledge of the load required by the users in the CRE area of each cell. This was achieved by deriving suitable threshold values on the network traffic load that allow the selection of the ABS period among a finite set of values. However, the use of open access femto cell is a limitation to the work. Most commercial femto-cells available are closed-access; they only allow the subscribed users to be connected, and the non-subscribers are connected to the macro base station. This is essential because the femto-cell is a lightweight device and thus does not have the capacity for more users.

Nasri et al., [46] developed a novel technique which combine interference cancellation and interference avoidance to mitigate downlink interference in a femto-macro HetNet. This was achieved by mitigating interference both at the receiver and transmitter side. At the receiver side, a downlink interference cancelation scheme was developed to reduce interference impact on users by optimizing their received Signal-to-Interference plus Noise Ratio (SINR). Interference avoidance techniques based on sub-frame blanking was used to mitigate interference at the aggressor cell. The proposed Low Power Almost Blank Sub-frame (LP-ABS) which minimizes the effect of downlink interference by transmitting data at low power during ABS instead of muting completely the sub-frame i.e. zero ABS. Simulation results obtained suggest that global network performance and user experience in terms of total throughput and Signal-to-Interference plus Noise Ratio (SINR) where significantly enhanced. While Low Power Almost Blank Sub-frame (LP-ABS) optimally utilized the available bandwidth. The limitation to the work is that the downlink interference cancellation at the receiver will increased computational burden and lead to excessive drainage of battery, also some level of interference can still be present due to cell reference signal and data sent during low power almost blank sub-frame.

Koutlia et al., [47] proposed a scheme based on Almost Blank Sub-frame (ABS) to protect the small cell user equipment from interference in a Heterogeneous Network. Since zero ABS is done at the expense of macro cell user capacity, the proposed scheme exploits jointly the advantages of frequency domain technique, time domain technique and power control in order to balance the trade-off between interference mitigation and capacity degradation at the aggressor cell. This was achieved by reserving a number of resources in the frequency domain devoted to the victim user equipment and allowing macro cell transmission in the ABS sub-frames with restricted transmit power. Simulation result showed that the proposed scheme improved the overall user capacity by about 26%. However, the number of ABS that should be muted in each frame of the aggressor base station was not determined in this work, this means that sub-frames randomly muted can lead to wastage of resources and reduce the capacity of the aggressor cell.

Kurda et al., [48] proposed a femto power control strategy for mitigating the interference experience by macro cell users while preventing femto-cell throughput degradation. The proposed power control schemes make use of femto and macro user’s context information in terms of positioning for setting the appropriate prioritization weights among the victim macro users and still maintained a high performance for femto cell users when compared to a conventional power control scheme. Two context-based adjustment schemes namely Global Power Adjustment (GPA) and Selective Power Adjustment (SPA) were considered in the work. The common objectives of both scheme is to mitigate the interference on the victim macro users while implementing two different degrees of awareness of femto user throughput degradation. The main advantages of the work is based on power adjustment parameters which values are dynamically adapted to the interference impact of each femto-cell on the global interference situations. However, the signal-to-interference plus noise ratio (SINR) of the macro user equipment was not considered in the work. This means that the SNIR of the victim macro user equipment can go below the minimum required SINR and lead to poor performance and quality of service.

Magaji et al., [49] developed an adaptive hybrid technique to mitigate cross-tier interference in a femto-macro Heterogeneous Network. The algorithm mitigate interference depending on the position of the victim macro user, the technique used a hybrid power control or Zero-power Almost Blank Sub-frame (ABS) based time domain technique to mitigate the effect of interference. A target Signal-to-Interference plus-Noise Ratio (SINRtar) and a threshold distance Dmin was set for all users. For macro users at the cell edge, meaning users that were at distances greater than Dmin, the scheme implemented power control technique by adaptively changing the transmit power of the femto base station. The scheme implemented Zero-power ABS time domain technique for macro users at distances less than Dmin. Simulation results showed that the hybrid scheme performed better in terms of SINR and throughput when compared to implementing only power control or time domain technique. The limitations of this work was that time domain technique using zero power ABS limited the capacity of the femtocell which in turn degraded the throughput of the femtocell users and also led to spectrum underutilization.

Mohamed et al., [50]carried out a performance review on femto-cell network interference management technique. The authors discuss in details two categories of co-tier and cross tier interference mitigation scheme in femto-cell networks. Two major techniques such as power management schemes and spectrum management schemes where discuss in each of the category, the author stated that spectrum management schemes seem to be more preferable over power management schemes in- terms of decreased complexity levels and cost efficiency. And also, has relatively improved levels of throughput. The authors further discuss Fractional Frequency Reuse Schemes (FFR), which is a technique that partition the bandwidth to reduce interference by allocating distinctive frequency portions to cell zones and further improve edge user's performance. The author's stated that FFR can effectively mitigate both cross-tier and co-tier interference at the same time. However, the authors have not reviewed hybrid scheme techniques with expected to perform better.

Tekanyi et al., [51]carried out performance evaluation of a reduced-power ABS and Zero-Power ABS time domain interference mitigation technique in femto-macro heterogeneous network. The authors developed a hybrid interference mitigation technique using reduced power ABS and time domain technique. Depending on the position of victim users the technique uses power control or reduced power ABS to mitigate the effect of interference. A target Signal-to-Interference plus-Noise Ratio (SINRtar) and a threshold distance Dmin was set for all users. For macro users at the cell edge, meaning users that are at distances greater than Dmin, the scheme implemented power control technique by adaptively changing the transmit power of the femto base station. The scheme implemented low power ABS time domain technique for macro users at distances lose to the femto cell, meaning distances less than Dmin Simulated results showed that the hybrid scheme when low power ABS was used performed better than zero-power ABS. However, there is a tradeoff, as implementation of low power ABS introduce some little interference into the system.

IV. CONCLUSION

It is evident from literature reviewed so far that interference management has been the major challenge in Heterogeneous Network (HetNet), and meaningful research attention is been given to mitigate the effect of interference through various eICIC techniques. Most work done on interference management has been on eICIC by either power control of femto-cell, frequency domain or time domain through the use of Almost Blank Sub-frame (ABS). However, the use of a single eICIC technique, mitigate interference at the expense of reduced aggressor cell capacity. Power control in femto-cell mitigate the interference on victim users at the cell boundary of femto-cell by reducing its power but is limited when the victim user is very close to the femto-cell because some of the femto users can go out of coverage when the power is reduced. Time domain technique can effectively mitigate the interference of victim user closer to the femto-cell by creating blank sub-frames but decreases the throughput of the aggressor cell because data is not transmitted during almost blank sub-frame. Therefore an adaptive Hybrid Power-control and Time-domain technique (aHPTT) is proposed to mitigate the cross-tier interference in heterogeneous femto-macro network. The technique will mitigate the interference of victim users both at the edge and close to the femto-cell with insignificant reduction in the aggressor capacity.

REFERENCES

[1]. Afaz, U. A., Mohammad, T. I., & Mahamod, I. (2014). Dynamic resource allocation in hybrid access femtocell network. Paper presented at the *Scientific World Journal*, 539-720. doi: 10.1155/2014/539720

[2]. Afroz, F., Sandrasegaran, K., & Al Kim, H. (2015). Interference Management In Lte Downlink Networks. *International Journal of Wireless & Mobile Networks, 7*(1), 91.

[3]. Ali, M. S. (2015). An Overview on Interference Management in 3GPP LTE-Advanced Heterogeneous Networks. *International Journal of Future Generation Communication and Networking, 8*(1), 55-68. doi: dx.doi.org/10.14257/ijfgcn.2015.8.1.07

[4]. Astely, D., Dahlman, E., Fodor, G., Parkvall, S., & Sachs, J. (2013). LTE release 12 and beyond *IEEE Communications magazine, 51*(7), 154-160.

[5]. Bouras, C., Diles, G., Kokkinos, V., Kontodimas, K., & Papazois, A. (2014). A simulation framework for evaluating interference mitigation techniques in heterogeneous cellular environments.

Wireless Personal Communications, 77(2), 1213-1237. doi: 10.1007/s11277-013-1562-5

[6]. Bouras, C., Kokkinos, V., Kontodimas, K., & Papazois, A. (2012). A simulation framework for LTE-A systems with femtocell overlays. *Proceedings of the 7th ACM workshop on Performance monitoring and measurement of heterogeneous wireless and wired networks*, 85-90.

[7]. Cao, F., & Fan, Z. (2013). Downlink power control for femtocell networks. Paper presented at the *IEEE 77th Vehicular Technology Conference (VTC Spring), 2013*, 1-5.

[8]. Chandrasekhar, V., Andrews, J. G., & Gatherer, A. (2008). Femtocell networks: a survey. *IEEE Communications Magazine., 46*(9), 59-67.

[9]. Cho, K.-T., Kim, J., Jeon, G., Ryu, B. H., & Park, N. (2011). Femtocell power control by discrimination of indoor and outdoor users. Paper presented at the *Wireless Telecommunications Symposium (WTS), 2011*, 1-6.

[10]. Chor, A. L., Dai, W. E., & Zhang, C. C. (2015). Performance analysis of voip over lte network. Retrieved from www.sfu.ca/~lcicor/Ensc%20427/427Website.

[11]. Cisco. (2016). Global Mobile Data Traffic Forecast Update, 2015–2020. Paper presented at the *Cisco Visual Networking Index*, 1-39.

[12]. Claussen, H., Ho, L. T., & Samuel, L. G. (2008). An overview of the femtocell concept. *Bell Labs Technical Journal, 13*(1), 221-245.

[13]. Damnjanovic, A., Montojo, J., Wei, Y., Ji, T., Luo, T., Vajapeyam, M., Yoo, T., Song, O., & Malladi, D. (2011). A survey on 3GPP heterogeneous networks. *IEEE Wireless Communications, 18*(3), 10-21.

[14]. Frank, H. (2016). Interference Mitigation for Femto Deployment in Next Generation Mobile Networks. Paper presented at the *Proceedings of the International Multi Conference of Engineers and Computer Scientists*, 1-5.

[15]. Gadam, M., Maryam, A., Nordin, N. K., Sali, A., & Hisyam, F. (2015). Decentralized time domain muting for interference mitigation in LTE-advanced heterogeneous networks. Paper presented at the *2015 IEEE Conference on Sustainable Utilization And Development In Engineering and Technology (CSUDET)*, 1-6. doi: 10.1109/CSUDET.2015.7446219.

[16]. Hsiu-Lang, W., & Kao, S.-J. (2012). An efficient femtocell deployment scheme for mitigating interference in two-tier networks. Paper presented at the *IEEE International Conference on Communication, Networks and Satellite (ComNetSat), 2012*, 79-83.

[17]. Jin, M. S., Chae, S. A., & Kim, D. I. (2011). Per cluster based opportunistic power control for heterogeneous networks. Paper presented at the *IEEE 73rd Vehicular Technology Conference (VTC Spring)*, 1-5.

[18]. Kanak, R. C., & Rachna, A. (2013). Comparison of SINR in FemtoCell and MacroCell Network in MacroCell Environment. *International Journal of Engineering and computer Science (IJECS), 2*(8), 2476-2480.

[19]. Khalid, W., & Kwak, K. S. (2013). Handover optimization in femtocell networks. Paper presented at the *2013 International Conference on ICT Convergence (ICTC)*, Jeju, South Koera, 122-127.

[20]. Khandekar, A., Bhushan, N., Tingfang, J., & Vanghi, V. (2010). LTE-advanced: Heterogeneous networks. Paper presented at the *European Wireless Conference (EW), 2010.*, 978-982.

[21]. Kim, S. (2013). Femtocell network power control scheme based on the weighted voting game. *EURASIP Journal on Wireless Communications and Networking, 2013*(1), 1-9.

[22]. Kumar, S., & Marchetti, N. (2009). IMT-Advanced: Technological requirements and solution components. Paper presented at the *Second International Workshop on Cognitive Radio and Advanced Spectrum Management, 2009*, 1-5.

[23]. Lopez-Perez, D., Güvenç, S., De la Roche, G., Kountouris, M., Quek, T. Q., & Zhang, J. (2011). Enhanced intercell interference coordination challenges in heterogeneous networks. *IEEE Wireless Communications, 18*(3), 22-30.

[24]. López-Pérez, D., Valcarce, A., De La Roche, G., & Zhang, J. (2009). OFDMA femtocells: a roadmap on interference avoidance. *IEEE Communications magazine, 47*(9), 41-48.

[25]. Lu, P.-C., Tsao, K.-J., Huang, C.-R., & Hou, T.-C. (2010). A suburban femtocell model for evaluating signal quality improvement in WiMAX networks with femtocell base stations. Paper presented at the *Wireless Communications and Networking Conference (WCNC), 2010*, 1-6.

[26]. Mach, P., & Becvar, Z. (2010). Dynamic power control mechanism for femtocells based on the frame utilization. Paper presented at the *2010 6th International Conference on Wireless and Mobile Communications (ICWMC)*, 498-503.

[27]. Pal, S. K., Nugraha, T. A., Shams, S., & Rahman, A. (2014). Resource Allocation Strategy using optimal power control for mitigating two-tier interference in heterogeneous networks. Paper presented at the *IEEE Wireless Communications and Networking Conference Workshops (WCNCW), 2014.*, 104-109.

[28]. Palanisamy, P., & Nirmala, S. (2013). Downlink interference management in femtocell networks-a comprehensive study and survey. Paper presented at the *2013 International Conference on Information Communication and Embedded Systems (ICICES)*, 747-754.

[29]. Pang, J., Wang, J., Wang, D., Shen, G., Jiang, Q., & Liu, J. (2012). Optimized time-domain resource partitioning for enhanced inter-cell interference coordination in heterogeneous networks. Paper presented at the *IEEE Wireless Communications and Networking Conference (WCNC), 2012*, 1613-1617.

[30]. Parkvall, S., Furuskär, A., & Dahlman, E. (2011). Evolution of LTE toward IMT-advanced. *IEEE Communications Magazine., 49*(2), 84-91.

[31]. Rathi, S., Malik, N., Chahal, N., & Malik, S. (2014). Throughput for TDD and FDD 4 G LTE Systems. *International Journal of Innovative Technology and Exploring Engineering (IJITEE), 3*(12), 73-77.

[32]. Rayal, F. (2010). LTE in Nutshell: The Physical Layer. *Telesystem Innovations*, 1-18.

[33]. Saad, S. A., Ismail, M., & Nordin, R. (2013). A Survey on Power Control Techniques in Femtocell Networks. *Journal of Communications, 8*(12), 845-854.

[34]. Saquib, N., Hossain, E., Le, L. B., & Kim, D. I. (2012). Interference management in OFDMA femtocell networks: issues and approaches. *IEEE Wireless Communications, 19*(3), 86-95.

[35]. Scheme, B. T. (2009). LTE: the evolution of mobile broadband. *IEEE Communications magazine*, 45.

[36]. Wang, Y., & Pedersen, K. I. (2011). Time and power domain interference management for LTE networks with macro-cells and HeNBs. Paper presented at the *IEEE Vehicular Technology Conference (VTC Fall), 2011*, 1-6.

[37]. Yeh, S.-p., Talwar, S., Himayat, N., & Johnsson, K. (2010). Power control based interference mitigation in multi-tier networks. Paper presented at the *IEEE GLOBECOM Workshops (GC Wkshps), 2010*, 701-705.

[38]. Zeng, M., Chen, X., Zhang, X., Sang, L., & Yang, D. (2013). A Novel Dynamic Interference Coordination Scheme in Macrocell-Picocell Heterogeneous Networks. Paper presented at the *IEEE 77th Vehicular Technology Conference (VTC Spring), 2013*, 1-5.

[39]. Zhenwei, W., Xiong, W., Dong, C., Wang, J., & Li, S. (2011). A novel downlink power control scheme in LTE heterogeneous network. Paper presented at the *2011 International Conference on Computational Problem-Solving (ICCP)*, 241-245.

[40]. Zhou, H., Ji, Y., Wang, X., & Zhao, B. (2015). ADMM based algorithm for eICIC configuration in heterogeneous cellular networks. Paper presented at the *2015 IEEE Conference on Computer Communications (INFOCOM)*, 343-351.

[41]. Zyren, J., & McCoy, W. (2007). Overview of the 3GPP long term evolution physical layer. Paper presented at the *Freescale Semiconductor Inc.*, 1-27.

[42]. Morita, M., Matsunaga, Y., & Hamabe, K. (2010). Adaptive power level setting of femtocell base stations for mitigating interference with macrocells. Paper presented at the *IEEE 72nd Vehicular Technology Conference Fall (VTC 2010-Fall), 2010*, 1-5.

[43]. Kshatriya, S. N. S., Kaimalettu, S., Yerrapareddy, S. R., Milleth, K., & Akhtar, N. (2013). On interference management based on subframe blanking in heterogeneous LTE networks. Paper presented at the *Fifth International Conference on Communication Systems and Networks (COMSNETS), 2013*, 1-7.

[44]. Deb, S., Monogioudis, P., Miernik, J., & Seymour, J. P. (2014). Algorithms for enhanced inter-cell interference coordination (eICIC) in LTE HetNets. *IEEE/ACM Transactions on Networking (TON), 22*(1), 137-150.

[45]. Bartoli, G., Fantacci, R., Marabissi, D., & Pucci, M. (2014). Adaptive muting ratio in enhanced Inter-Cell Interference Coordination for LTE-A systems. Paper presented at the International Wireless Communications and Mobile Computing Conference (IWCMC), 2014, 990-995.

[46]. Nasri, R., Affes, S., & Stephene, A. (2015). Combined Interference Cancellation and Avoidance over the Downlink of Spectrum-Sharing LTE HetNet. Paper presented at the IEEE International Conference on Ubiquitous Wireless Broadband (ICUWB), 2015, 1-6.

[47]. Koutlia, K., Perez-Romero, J., & Agusti, R. (2015). On Enhancing Almost Blank Subframes Management for Efficient eICIC in HetNets. Paper presented at the IEEE 81st Vehicular Technology Conference (VTC Spring), 2015, 1-5.

[48]. Kurda, R., Boukhatem, L., & Kaneko, M. (2015). Femtocell power control methods based on users' context information in two-tier heterogeneous networks. EURASIP Journal on Wireless Communications and Networking, 2015(1), 1-17. doi: 10.1186/s13638-015-0328-z

[49]. Suleiman, M., Sani, S. M., & Tekanyi, A. M. S. (2017). Development of an Adaptive Hybrid Technique to Mitigate Cross-Tier Interference in a Femto-Macro Heterogeneous Network. International Journal of Computer Applications, 168(12).

[50]. Mohamed, K. S., Alias, M. Y., & Roslee, (2018) M. Review on Femto-cell Networks Interference Management Techniques, 1-7.

[51]. Tekanyi, A. M. S., Kassim, A. Y., Sani, S. M., Usman, A. D., Abdulkareem, H. A., & Muhammad, Z. Z. (2019). Performance Evaluation of Reduced-Power ABS and Zero-Power ABS Time Domain Interference Mitigation Technique in Femto-Macro Heterogeneous Network. ATBU Journal of Science, Technology and Education, 7(3), 32-41.