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AN IMPROVED CROSS-TIER INTERFERENCE MITIGATION SCHEME IN A FEMTO-MACRO HETEROGENEOUS NETWORK

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ABSTRACT

The deployment of femtocells presents an attractive solution for the improvement of mobile network services, providing better data rates and coverage to indoor users. Since the deployment of femtocells results to a heterogeneous network, where two layers utilize the available spectrum, issues of interference arise. The interference mitigation in literature made use of a single or hybrid enhanced inter-cell interference coordination techniques to reduce interference in heterogeneous networks. These techniques mitigate interference at the expense of reduced capacity or coverage of the interfering cell as well as the network as whole and also cause underutilization of the spectrum resources. A method used in this research to address this challenge investigated the positions of the user equipment and the installed femto base stations. The developed improved adaptive hybrid technique that combined Time domain technique using reduced power ABS and Power control technique was then used to mitigate the cross-tier interference between the femto base station and the macro-user in the vicinity of the femtocell. This was done in order to achieve optimal and fair overall performance of the network.

1. INTRODUCTION

Heterogeneous Networks (HetNets) promises to address the technical challenges of high demand for mobile data traffic on cellular networks in terms of data throughput and network capacity [1]. There are unprecedented trends in the growth of mobile data traffic in recent years and that will continue globally for years to come. According to [2], voice traffic was surpassed by mobile data traffic in 2009 and it is anticipated to continue consistently. It is anticipated that there will be annual growth in mobile video traffic by 45 percent through 2023 which will account for 73 percent of all mobile data traffic. Also, it is anticipated over the next 6 years that data traffic from social networking applications will grow steadily by 31 percent annually [3].

To accommodate this exponential growth in demand for high mobile data, the telecommunications industry is faced with the urgent needs of expanding the mobile access network capacity by 1000 times. Today, customers want to communicate with one another anytime, anywhere, and through any available media, including instant messages, video conferencing, email, voice, and video calls [4]. The growth in mobile data traffic is driven by the increasing number of smartphone subscriptions and increasing average data volume per subscription, primarily propelled by more viewing of video content at higher resolutions [3].

This makes it vital for the network operators to devise new means of enhancing the indoor coverage by reducing transmit-receive distance by bringing the transmitter and receiver closer to each other. The users' expectations on demand for mobile broadband services is met by improving the overall performance at hotspots and cell edges. In order to achieve this, efficient use of the available resources is required as well as new techniques of securing, deploying, utilizing, managing, and optimizing these resources. Telecommunications services providers make use of various methods to meet customers' expectations which includes: improving the coverage and capacity of the existing network by densifying the current macrocells through the addition of small cells [5].

The concept of heterogeneity and dense deployment of small cells as a paradigm shift in cellular networks has become an attractive solution recently in meeting future demands for high data rates, reduced latency, and enhanced coverage [6][7]. HetNets can be defined as a collection of low power Base Stations (BS) distributed across a macrocellular network in order to improve the capacity and enhance the coverage of the network. These low power BS includes femtocells, microcells, relays, picocells, and remote radio heads, which are deployed at hotspots, enterprise environment, homes, and low geometry locations [8].

Femtocells provide high spectral efficiency, low cost of both deployment and maintenance which made it to gain enormous attention in the wireless industry [9]. Studies have shown that 50 percent of the total voice traffic and 70 percent of the total data traffic are generated indoors and for the mobile operators to provide better Quality of Service (QoS) to these indoor users, femtocells deployment is considered a promising solution [10]. The deployed femtocell makes use of the same or different carrier frequencies with the existing macrocell network. Using different carrier frequencies prevents inter-cell interference between macrocell and femtocell, but requires more radio resources. From the fact that licensed spectrum is scarce and expensive, network operators make use of the same carrier frequency (co-channel) in order to reduce large spectrum requirement [11]. Although, the same carrier frequency deployment ensures efficient spectrum utilization and larger bandwidth for both macrocell and femtocell, but also results to cross-tier interference, which may prevent the macro users within the vicinity of the femto eNodeB from having good Signal-to-Interference-Plus-Noise Ratio (SINR) [12]. Typically, femtocells are deployed in a closed access mode, where the network is only accessed by users enlisted in the Closed Subscriber Group (CSG). In the downlink transmission, femtocells operating in CSG mode tend to subject macro users in its vicinity to severe cross-tier interference [13].

2. RELATED WORKS

[14] proposed a new algorithm that integrated interference avoidance and interference cancellation to mitigate the effect of interference in the downlink channel of a macro-femto HetNet. The scheme implemented interference avoidance at the transmitter and interference cancellation at the receiver. At the transmitter, Low Power Almost Blank Subframe (LP-ABS) was used to minimize the effect of interference by transmitting signals with low power during the ABS instead of muting the frames completely. The downlink interference cancellation scheme reduced the effect of interference on users by optimizing their received Signal-to-Interference plus Noise Ratio (SINR) at the receiver. System level simulation results showed an enhancement in network performance and user experience in terms of total throughput and received SINR. There was high computational burden at the receiver due to optimization processes. There is still room for improvement on the capacity of the network by using suitable adaptive LP-ABS such that the interfering cell can transmit on both the normal and ABS.

[15] studied a new enhanced Inter-Cell Interference Coordination (eICIC) technique for managing ABS subframes. The algorithm exploited jointly power, frequency and time dimensions in order to balance the tradeoff between capacity degradation of macro users and interference mitigation in small cells. This is aimed at providing efficient utilization of the available spectrum resources. Simulation results presented higher capacity gains without subjecting the victim users to severe interference. Limitation of the work was that interference experienced by small cell users that were not in the CRE region was not mitigated.

[16] developed an adaptive hybrid technique to mitigate cross-tier interference in a femto-macro HetNet. Depending on the position of the victim macro user, the technique uses power control or Zero-power ABS based time domain techniques to mitigate the effect of interference simultaneously. A target Signal-to-Interference-plus-Noise Ratio ($SINR_{tar}$) and a threshold distance D_{min} was set for all users. Macro users at the cell edge, meaning users that were at distances greater than $D_{min,}$ 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 D_{min}. 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 is that time domain technique using zero power ABS limits the capacity of the femtocell which in turn degrades the throughput of the femtocell users and also leads to spectrum underutilization. This left room for modification or enhancement in the ABS scheme in order to provide better SINR, higher throughput and enhanced spectral efficiency.

3. MATERIALS AND METHOD

3.1 SYSTEM MODEL

The femtocells deployed in a macrocell network introduce cross-tier Interference to the network. Severe interference scenario could be caused in both downlink and uplink of nearby macro UE due to the operation of femtocell in closed access mode [17]. It is difficult for the operators to supervise, manage and optimize the network due to the ad hoc deployment of femtocells [18]. The femtocells proper operations strongly depend on their sensing, self-optimizing features, and continuous monitoring of the radio environment in order to mitigate interference adaptively [19].

For macro users at the edge of a femtocell operating in a CSG, the macro eNodeB tries to initiate a handover request which fails due to the fact that it is not in the CSG list [20]. This makes the macro UE to experience a severe cross-tier interference in the downlink, which results to a decrease in the SINR of the user and this interference is a major technical challenge in HetNet. Figure 1 shows the cross-tier interference scenario in a femto-macro HetNet.

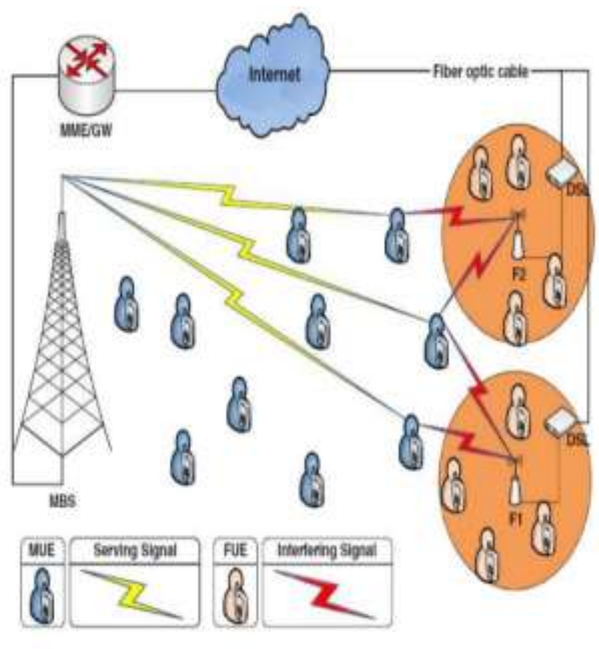

Figure 1: Cross-Tier Interference Scenario in a Femto-Macro HetNet [12]

3.1.1 Path Loss Model

The path loss heavily depends on the technology used and environment in which the network is deployed. The path loss between the UE and their corresponding macrocell or femtocell is determined in the following ways [21]:

The path loss between a femto UE and a femtocell in the same apartment is given by [21]

$$\mathrm{PL(dB)} = 38.46 + 20\log_{10}\mathrm{R} + 0.7\mathrm{d}_{2\mathrm{D\,indoor}} + 18.3\mathrm{n}\left(\frac{(\mathrm{n}+2)}{(\mathrm{n}+1)-0.46}\right) + \mathrm{q} * \mathrm{L}_{\mathrm{iw}} \quad (1.1)$$

Considering the case of a femto user associated to a femtocell but not in the same apartment. When outdoor loss is also considered in this case, the path loss between the user and the femtocell is given [22] as:

$$\mathrm{PL(dB)} = \max\left(15.3 + 37.6\log_{10}\mathrm{R}, 38.46 + 20\log_{10}\mathrm{R}\right) + 0.7\mathrm{d}_{2\mathrm{D\,indoor}} + 18.3\mathrm{n}\left(\frac{(\mathrm{n}+2)}{(\mathrm{n}+1)-0.46}\right) + \mathrm{q} * \mathrm{L}_{\mathrm{iw}} + \mathrm{L}_{\mathrm{ow}} \quad (1.2)$$

When the femto user equipment and femtocell is inside a different room but in the same building. The path loss can be obtain as follows [22]:

$$\mathrm{PL(dB)} = \max\left(15.3 + 37.6\log_{10}\mathrm{R}, 38.46 + 20\log_{10}\mathrm{R} + 0.7\mathrm{d}_{2\mathrm{D\,indoor}} + 18.3\mathrm{n}\left(\frac{(\mathrm{n}+2)}{(\mathrm{n}+1)-0.46}\right) + \mathrm{q} * \mathrm{L}_{\mathrm{iw}} + \mathrm{L}_{\mathrm{ow1}} + \mathrm{L}_{\mathrm{ow2}}\right. \quad (1.3)$$

where:

R and $0.7d_{2D\ indoor}$ are respective transmit-receive distance and penetration loss due to walls inside the apartment respectively.

n is number of penetrated floors.
q is number of walls separating apartments between UE and femtocell.
L_{iw} is penetration loss of the wall separating apartments.

L_{ow1} and L_{ow2} are the penetration loss of outdoor walls 1 and 2, respectively.

Channel Gain (G) is a function of path loss and differs depending on the path loss model, whether it is indoor or outdoor. In order to determine G, the calculation of path loss is required according to the following expression [9]:

$$G = 10^{\frac{-PL}{10}} \quad (1.4)$$

Where, PL is path loss between the UE and the eNodeB.

3.1.2 Signal-to-Interference-plus-Noise Ratio Model

The estimation of the received Signal-to-Interference-plus-Noise Ratio (SINR) of a macro user, m on a sub-carrier, k associated to a macrocell, M when it is interfered by neighboring macrocells, M' and femtocell, F is determined by [23] as:

$$\mathrm{SINR}_{m,k} = \frac{P_{M,k}G_{m,M,k}}{N_0\Delta f + \sum_{M'} P_{M',k}G_{m,M',k} + \sum_F P_{F,k}G_{m,F,k}} \quad (1.5)$$

where:

$P_{M,k}$ and $P_{M',k}$ are the respective transmit power of serving macrocell and the neighboring macrocell on sub-carrier, respectively.
$G_{m,M,k}$ is the channel gain between macro user and serving macrocell on subcarrier.
$G_{m,M',k}$ is the channel gain from neighboring macrocell.

$P_{F,k}$ is the transmit power of neighboring femtocell on sub-carrier.
$G_{m,F,k}$ *is* the channel gain between macro user and neighboring femtocell on sub carrier.

N_0 is the white noise power spectral density

Δf is sub-carrier spacing.

Similarly, for a femto user, f on sub-carrier, k associated with a femtocell, F when it is interfered by all neighboring femtocell, F' and macrocell, M, the SINR can be obtained as follows [21]:

$$\mathrm{SINR}_{f,k} = \frac{P_{F,k}G_{f,F,k}}{N_0\Delta f + \sum_M P_{M,k}G_{f,M,k} + \sum_{F'} P_{F',k}G_{f,F',k}} \quad (1.6)$$

where:

$P_{F,k}$ and $P_{F',k}$ are the respective transmit power of serving and neighboring femtocell on subcarrier respectively.
$G_{f,F,k}$ is the channel gain between femto user, and serving femtocell on subcarrier.
$G_{f,F',k}$ is the channel gain from neighboring femtocell.
$P_{M,k}$ is the transmit power of neighboring macrocell on subcarrier.
$G_{f,M,k}$ is the channel gain between femto user, and neighboring macrocell on subcarrier.

N_0 is the white noise power spectral density

Δf is subcarrier spacing.

3.1.3 Throughput Model

The throughput is determined after determining the path loss and the SINR of a user depending on its environment. The capacity of the macro user, m, and femto user, f, on a sub-carrier k, is given by [21]:

$$C_{m,k} = \Delta f . \log_2(1 + \alpha SINR_{m,k}) \quad (1.7)$$

$$C_{f,k} = \Delta f . \log_2(1 + \alpha SINR_{f,k}) \quad (1.8)$$

$$\alpha = \frac{-1.5}{\ln(5BER)} \quad (1.9)$$

where:

$C_{m,k}$ is macro user capacity on a sub-carrier k.
$C_{f,k}$ is femto user capacity on sub-carrier k.

Δf is bandwidth of operation.

$SINR_{m,k}$ is macro SINR on subcarrier k.

$SINR_{f,k}$ is femto SINR on subcarrier k.

α is a constant for target bit error rate
BER is bit error rate which is set to 10^{-6}

3.1.4 Spectral Efficiency

Increasing the profitability of the available radio spectrum is one of the major objectives of telecommunication operators. Let R_k be the mean throughput achieved by UE k. The spectral efficiency is therefore defined as follows [24]:

$$S.\mathrm{E} = \frac{\sum_{k=1}^{k} R_k[\text{bit/s}]}{\text{Total spectrum [Hz]}} \quad (1.10)$$

Table 1.1 shows the simulation parameters used in the course of this work

Table 1.1: System Level Simulation Parameters

PARAMETERS	**VALUE/DESCRIPTION**
Cellular layout	Single macrocell
Number of Macrocell	1
Macrocell radius	250m
Macro eNodeB TX power	46dBm
Carrier frequency	2GHz

Femto eNodeB max TX power	20dBm
Femto eNodeB default TX power	11dBm
D_{min}	75% Femto range (0-50m)
Exterior wall loss	15dBm
Interior wall loss (low)	7dBm
Bandwidth	20MHz
Modulation Type	64QAM
Subcarrier spacing	15KHz
Number of Femtocell Users	5
Number of Femtocells	2
Number of macro users	5

The flowchart of the work is shown on figure 2. The procedures and conditions of implementing the two techniques simultaneously are shown on the flowchart.

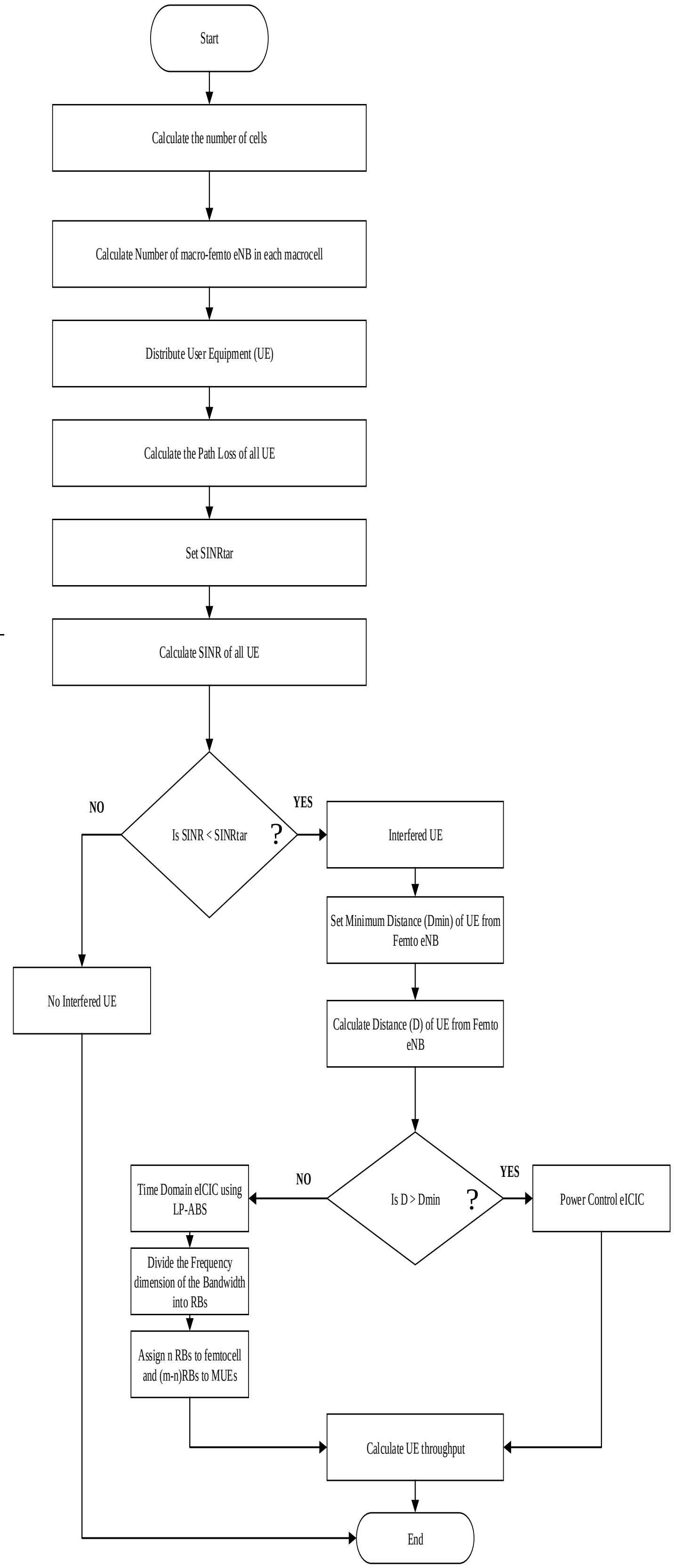

Figure 2: Flowchart of the Developed Improved Cross-tier Interference mitigation scheme.

3.2 IMPLEMENTATION

The implementation of the Zero-power ABS scheme makes the throughput of the macro users in the vicinity of the femtocell to significantly improve due to the reduction in interference seen by these users. Conversely, this leads to the decrease in throughput of the femtocells because femtocells are only allowed to transmit in the normal subframes.

With respect to this, a mechanism was developed for the efficient utilization of the spectrum resources. The developed mechanism allows data transmission of the femtocell users in the ABS subframes under special conditions, which also reduces interference generation to the macro users. The conditions are stated in terms of the maximum allowed transmit power and the allowed RBs in the frequency domain.

Equation for separating the resource blocks into reserved and non-reserved blocks in this strategy is given as follows:

$$\varepsilon = \min([\alpha.numMU], numRB) \qquad (1.11)$$

where:

ε is number of reserved resource blocks

numMU is number of macro users in the vicinity of the femtocell

α is the average number of reserved resource block per subframe

$numRB$ is the number of resource blocks

Instead of devoting all the RBs to the macro users in the vicinity of the femtocell in the ABS subframes as in the Zero power ABS scheme, the data transmission was separated into two by splitting the frequency domain. This was achieved by allocating RBs to femtocell and macro users respectively as shown in Figure 3.

The macro users, being the victim users in the vicinity of the femtocell are allocated the reserved RBs. Meaning only macro user data transmissions are permitted during these ε RBs. Femtocell data transmissions takes place in both the non-reserved RBs ($numRB - \varepsilon$) with the restriction of low transmit power and the normal subframes with high transmit power in the ABS subframes. By this, the interference experienced by macro users is reduced to low level. Also, the non-silencing of the ABS subframe results to an increase in the femto user capacity.

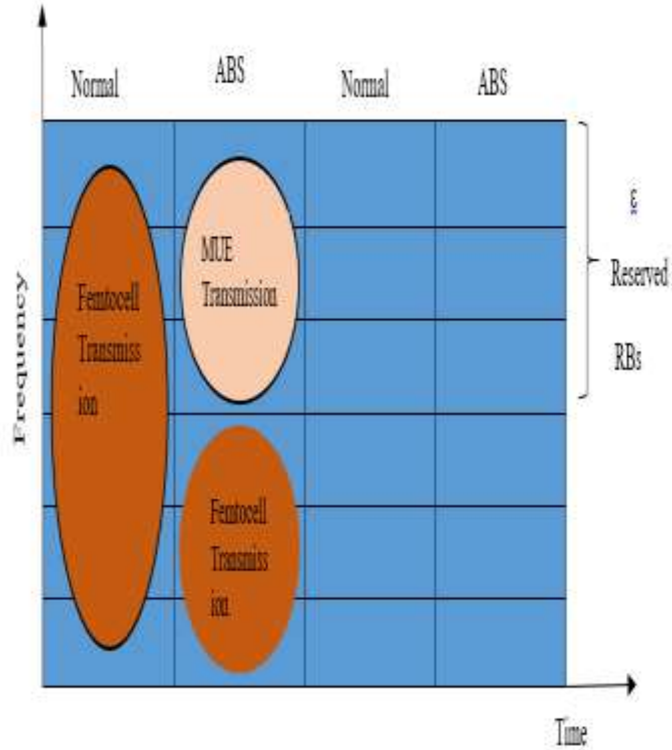

Figure 3: Developed User Allocation Principles.

RESULTS AND DISCUSSION

The SINR of the femtocell users using 0.5 muting ratios is shown in Figures 4. The plots were obtained by first determining the path loss of the user from equation (1.1), the path loss depends on the distance of the user from the serving eNodeB. Gain between the femto user and femto eNodeB was obtained by inputting the path loss value into equation (1.4). SINR was obtained by inputting the gain in the equation (1.6). Figure 4 shows the graph of SINR against distance, It is observed that the maximum SINR achieved was 8.2dB for both the Zero power and Reduced power schemes at 0m distance up to about 30m away from femtocell. At 40m away from the femtocell, the improved scheme has a SINR of 2.9dB as against the adaptive scheme that has SINR of 2.6dB at 0.5 muting ratio which depicts a better quality of signal reception and thus a better quality of service for users of improved scheme.

The throughput of the femtocell users using 0.5 muting ratios is shown in Figures 5. The plots were obtained by first determining the path loss of the user from equation (1.1), the path loss depends on the distance of the user from the serving eNodeB. Gain between the femto user and femto eNodeB was obtained by inputting the path loss value into equation (1.4). SINR was obtained by inputting the gain in the equation (1.6) and finally the throughput was obtained from equation (1.8) and plotted against distance from femtocell. Figure 5 shows the graph of throughput against distance. It is observed that the maximum throughput achieved was 24Mbps for both the Zero power and Reduced power schemes at 0m distance up to about 35m away from femtocell. At 40m away from the femtocell, the improved adaptive scheme has a throughput of 19.2Mbps as against the adaptive scheme that has throughput of 13.5Mbps at 0 muting ratio which depicts a better quality of signal reception and thus a better quality of service for users of improved adaptive scheme.

The spectral efficiency of the femtocell is show on figure 6. Using 0.5 muting ratio, the developed improved scheme presented better spectral efficiency of 2.4 bit/s/Hz as against the zero-power scheme that has 1.6 bit/s/Hz.

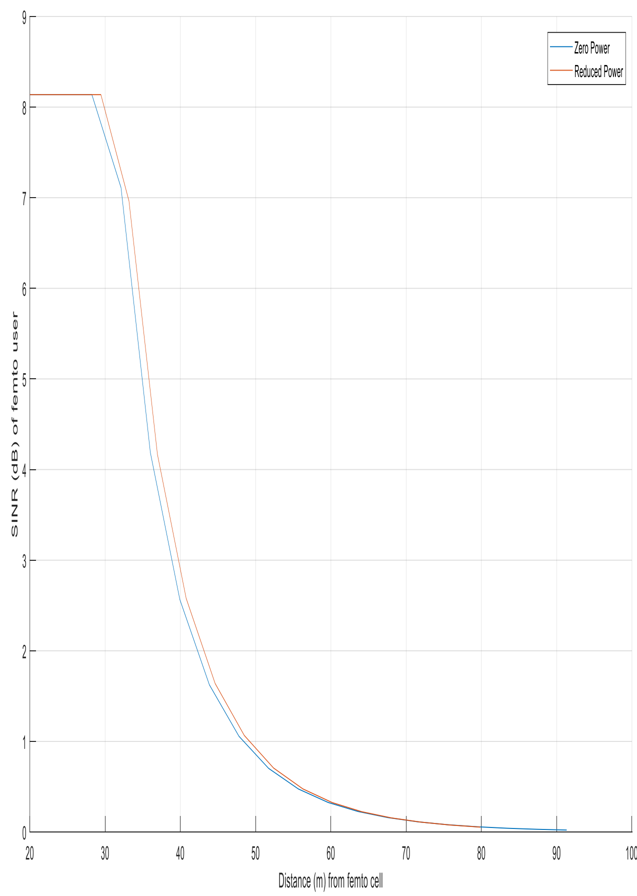

Figure 4: SINR of a Femto User using ABS with 0.5 Muting Ratio

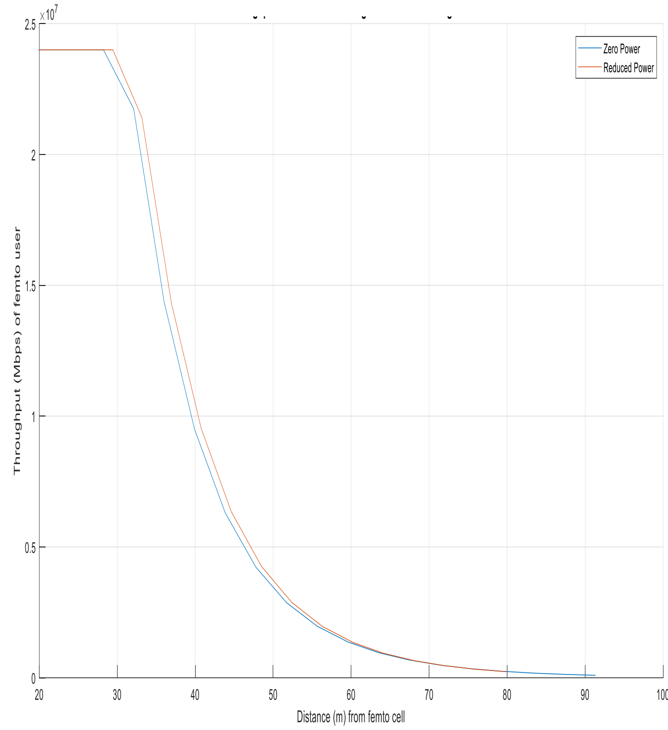

Figure 5: Throughput of a Femto User using ABS with 0.5 Muting Ratio.

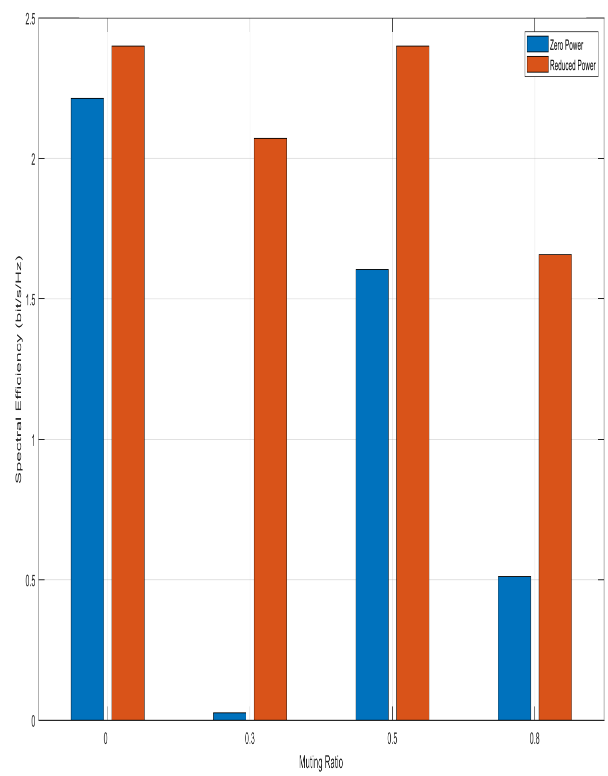

Figure 6: Spectral Efficiency of the Femtocell.

CONCLUSION

One of the major technical challenges of HetNet deployment is cross-tier interference which limits the potentials of HetNet in improving total network capacity. Most researches conducted focused on using the Zero-power ABS to mitigate interference in a femto-macro HetNet scenario which presents some drawbacks when it comes to the femtocell user capacity. This research work has developed an improved adaptive hybrid scheme that mitigated cross-tier interference in femto-macro HetNet. Using an ABS muting ratio of 0.5, the significant contributions of the developed improved adaptive hybrid technique when compared with the adaptive technique that used Zero power scheme are that the:

Throughput of the femtocell users was improved by 15.2%. SINR of the femtocell users was increased by 11.5%. Spectral efficiency of the femtocell was enhanced by 50%.

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