

Development of an Adaptive Hybrid Technique to Mitigate Cross-Tier Interference in a Femto-Macro Heterogeneous Network

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ABSTRACT

The deployment of small cell node such as femto-cell within macro area coverage has been considered a promising solution to provide better throughput and Quality of Experience (QoE) to users. However, co-channel deployment of femto-cell operating in a closed access mode (CSG) causes severe cross-tier interference. In this paper we have developed an adaptive Hybrid Power control and Time domain Technique (aHPTT) to mitigate cross-tier interference in HetNet. The hybrid technique was developed to handle limitations associated with using a single interference mitigation technique such as Power Control (PC) and Time Domain (TD). aHPTT integrates PC and TD to mitigate interference simultaneously depending on the position of the user in the network. The hybrid technique was implemented in a Graphical User Interface (GUI) using MATLAB R2013a. System level simulation was carried out to evaluate the performance of the hybrid technique in terms of user's throughput. The aHPTT was validated with the 3rd Generation Partnership Project (3GPP) enhanced Inter-cell Interference Coordination (eICIC) technique, results obtained showed that the aHPTT performs better than PC technique by 2.90% and TD technique by 82.60%.

General Terms

Interference Management

Keywords

Interference, Power Control, ABS, aHPTT, eICIC, HetNet, Signal-to-Interference plus Noise Ratio (SINR).

1. INTRODUCTION

Improving the indoor coverage and providing high-data-rate services in a cost effective manner and at the same time enhancing capacity is one of the major challenges in Next Generation Network (NGN) such as the 3rd Generation Partnership Project (3GPP) Long Term Evolution (LTE) network [1]. 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 [2]. Studies have shown that 70% of the total data traffic and 50% of the total voice traffic are generated indoors [3, 4]. This makes it important for the operators to find the means of improving indoor coverage. One of the ways to improve indoor coverage is to reduce transmit-receive distance by bringing the transmitter and receiver closer to each other.

Femto-cell is considered a promising solution for the mobile operators to provide better quality of service (QoS) for indoor users [5]. The advantages of deploying femto-cell is enormous in terms of technical and business point of view [1, 6]:

- i. Femto-cell improve coverage and capacity due to short transmit-receive distance.
- ii. Provides high data rate and call quality to its users.
- iii. Improves macro cell efficiency and reliability by offloading traffic away from macro cell.
- iv. Deployment of femto-cell is cost effective and self-optimizing, therefore reducing the capital and operational expenditure (CAPEX, OPEX) of the network.
- 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 requires less energy to connect to a closer base station.

Deployed femto-cell can make use of the same or different carrier frequencies with the existing macro network. The use of different carrier frequency avoids the interference between macro- and femto-cell, but requires more bandwidth. Due to the fact that licensed spectrum is expensive and scarce, operators prefer to use the same carrier frequency (co-channel) to reduce spectrum requirement [7]. Although, co-channel deployment ensures larger bandwidth and efficient spectrum utilization for both macro- and femto-cell, the resulting cross-tier interference may prevent macro cell users within the coverage area of femtocells from having high Signal-to-Interference plus Noise Ratio (SINR) [8]. Femto-cells are typically installed in a closed access mode [9] where only users enlisted in the closed subscriber group (CSG) can have access. Therefore in the downlink transmission, macro-users close to femto-cell operating in CSG mode experience severe interference from the femto-cell [9].

Interference is the major challenge in femto-cell deployment [4, 10]. Therefore, to fully utilize the advantages of femto-cell deployment, it is important to mitigate the interference that comes along with its deployment. Frequency Domain (FD), Time Domain (TD) and Power Control (PC) were introduced by the 3rd generation partnership project in its enhanced Inter-Cell Interference Coordination (eICIC) technique to mitigate interference in LTE-A rel. 10 standards [11, 12]. Several interference mitigation techniques in heterogeneous networks

has been proposed in the open literature. However, existing interference technique in a femto-macro heterogeneous network mitigate interference using a single eICIC technique [13] which mitigate interference at the expense of throughput. In [14] the authors proposed an adaptive power level setting scheme to mitigate the interference in femto-macro Heterogeneous Network (HetNet), the scheme considered penetration losses and adjustable positive factors to estimate the priority of femto-cell power operations. Authors in [15] proposed a macro assisted Home enhanced Node B (HeNB) power control scheme to mitigate interference resulting from femto cell. The technique adjust the transmit power of HeNB when it receive interference message from a macro user equipment experiencing interference. [16] proposed a distributive technique to determine victim user equipment protection from interference by almost blank sub-frame. The assumed that all pico UE are scheduled only during ABS, while the number of ABS to be created is determine by the rule of thumb. An optimized time domain resource partitioning was carried out to obtain ABS density and configuration. In [17] an orthogonal ABS scheme was proposed. The number of sub frame to be blanked was dependent on the number of victim users and normal users who are not interfered by the aggressor node. [18] 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 was determine using ABS. The two solutions where implemented in a joint manner. Authors in [7] 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. In their model, femto cell was assume to be operating in open subscriber mode (OSG). ABS was used to mitigate the interference faced by users in the cell range expansion region (CRE). A novel technique which combine interference cancellation and interference avoidance to mitigate downlink interference in a femto-macro HetNet was developed in [19]. At the receiver side a downlink interference cancellation scheme was developed to reduce interference impact on users by optimizing their SINR. Interference avoidance techniques based on subframe blanking was used to mitigate interference at the aggressor cell. [8] 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.

It is evident from above that most work done on interference mitigation in HetNet is by either Power Control (PC) or time domain through the use of 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) has been developed to mitigate the cross-tier interference in heterogeneous femto-macro network. The technique mitigate the interference of victim users depending on their position in the network with insignificant reduction in the aggressor capacity.

2. 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 when deployed in closed access mode may lead to strong interference scenario in both uplink and downlink [11, 20]. 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 [21]. 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 [22]. 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 Closed Subscriber Group (CSG), the macro user 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 [15]. 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. Figure 1 describe cross-tier interference in femto-macro heterogeneous network.

3. SYSTEM MODEL

A femto-macro Heterogeneous Network (HetNet) where femto cell are deployed in CSG mode is considered. Figure 2 shows the system model, rectangular blocks representing buildings where femto cells are deployed and in between the buildings is the street. Because femto cells are deployed in CSG mode the introduce downlink interference to macro users within the femto coverage. This interference decrease the SNR of the user resulting to a decrease in its throughput

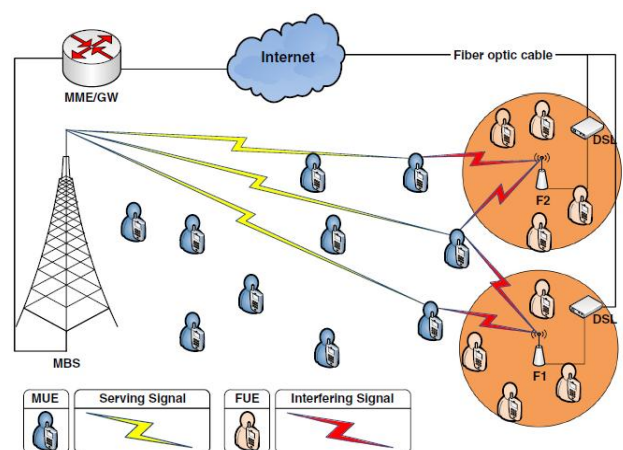


Fig1: Cross-Tier Interference in a Femto-Macro Network [8]

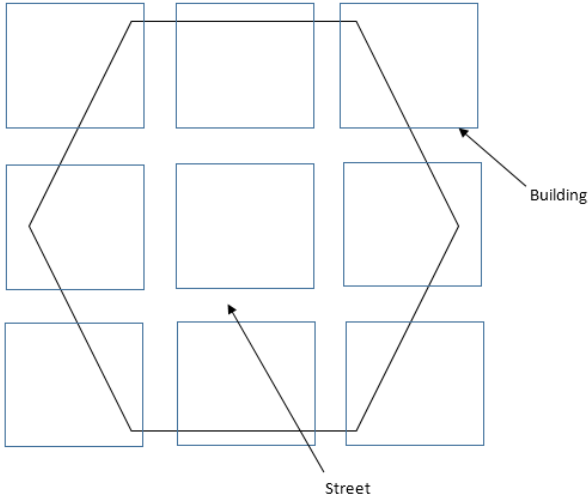


Fig 2: System Model

3.1 Pathloss Model

The path loss of the macro and femto user, from their serving eNodeB depends on the position and distance of the user from the macro or femto cell. When the user is inside the building, path loss between the user and the femto cell can be determine from equation [10].

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

For a femto user outside the building along the street, its path loss from the femto eNodeB is given by equation [23].

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

For a macro user roaming outside the street, the path loss between the user and the macro cell can be modelled as in [24].

$$PL (dB) = 15.3 + 37.6 \log_{10} R \quad (3)$$

Where , R and $0.7d_{2D, indoor}$

is transmit-recvie distance and penetration loss due to walls inside the appartment respectively, n is number of penetrated floors, q is number of walls separating appartments between UE and femto cell, L_{iw} is penetration loss of the wall separating appartments, $L_{ow,1}$ and $L_{ow,2}$ is the penetration loss of outdoor wall 1 and 2 respectively.

3.2 SINR Model

Signal to interference plus noise ratio of a user at any point depends on the interference added by other cells within the network. The SINR of a macro user from the macro cell is modelled as

$$SINR_{m,k} = \frac{P_{M,k} G_{m,M,k}}{N_0 \Delta f + \sum_{M'} P_{M',k} G_{m,M',k} + \sum_F P_{F,k} G_{m,F,k}} \quad (4)$$

Where ,

$P_{M,k}$ and $P_{M',k}$ is the transmit power of serving macro-cell M and the neighbouring macro cell M' on sub-carrier k , respectively.

$G_{m,M,k}$ is the channel gain between macro user m and serving macro cell M on sub-carrier k .

$G_{m,M',k}$ represent the channel gain from neighboring macro-cell.

$P_{F,k}$ is the transmit power of neighbouring femto cell F on sub-carrier k .

$G_{m,F,k}$ is the channel gain between macro user m and neighboring femto cell F on sub carrier k .

N_0 is the white noise power spectral density, and Δf is sub-carrier spacing.

Similarly, SINR for a femto user can be modelled as:

$$SINR_{f,k} = \frac{P_{F,k} G_{f,F,k}}{N_0 \Delta f + \sum_M P_{M,k} G_{f,M,k} + \sum_{F'} P_{F',k} G_{f,F',k}} \quad (5)$$

where:

$P_{F,k}$ and $P_{F',k}$ is the transmit power of serving and neighbouring femto cell on sub-carrier k , respectively.

$G_{f,F,k}$ is the channel gain between femto user f and serving femto cell on sub-carrier k . $G_{f,F',k}$ represent the channel gain from neighbouring femto cell.

$P_{M,k}$ is the transmit power of neighbouring macro cell on sub-carrier k .

$G_{f,M,k}$ is the channel gain between femto user f and neighbouring macro cell on sub carrier k .

N_0 is the white noise power spectral density, and Δf is sub-carrier spacing.

3.3 Throughput Model

After determining the SINR and path loss model of a user depending on its environment, next is the determination of it throughput. Throughput of the macro user m and femto user f on a sub-carrier k can be given by [10]:

$$C_{m,k} = \Delta f \cdot \log_2(1 + \alpha SINR_{m,k}) \quad (6)$$

$$C_{f,k} = \Delta f \cdot \log_2(1 + \alpha SINR_{f,k}) \quad (7)$$

where:

α is a constant for target Bit Error Rate (BER)

BER is set to 10^{-6} .

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

$C_{f,k}$ is femto user capacity on sub carier 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.

Therefore the total Capacity of serving macro and femto-cell can be express as follows [24]:

$$T_M = \sum_m \sum_k \beta_{m,k} C_{m,k} \quad (8)$$

Similarly for a femto-cell it is given as [25]

$$T_M = \sum_f \sum_k \beta_{f,k} C_{f,k} \quad (9)$$

Where $\beta_{f,k}$ and $\beta_{m,k}$ represent subcarriers assignment for macro and femto users respectively. When it is equal to 1 it means the subcarrier is assign otherwise it is equal to zero.

4. POWER CONTROL

Power control technique involves increasing and decreasing the transmit power of femto cell to avoid interference caused to nearby users who are not connected to the cell. This interference is mitigated by adjusting the power of femto eNode. The femto eNodeB transmit power is calculated in decibels as [26]:

$$P_f = \min(P_m + G_\theta - PL_m(d) + PL_f(r), P_{max}) \quad (10)$$

where:

$PL_f(r)$ is the line of sight path loss at the target cell radius r .

P_m is the transmit power of the macro eNodeB where the femtocell is located.

$PL_m(d)$ is the average macrocell pathloss at femtocell distance d .

G_θ is the antenna gain in direction of femto-cell.

θ is the angle to the femtocell with respect to the sector angle and can be calculated for the case of tree sector site as:

$$G_\theta = G_{max} - \min \left[12 \left(\frac{\theta}{\beta} \right)^2, G_s \right] \quad (11)$$

where:

β is 70/180 the angle where gain pattern is 3dB down from peak.

G_s is 20dB the sidelobe gain level.

G_{max} is 16dB the maximum gain level.

θ is a range from $-\pi$ to π

Power control technique can avoid interference completely without degrading its user's capacity or increasing the number of outage only when the interfered users are at the boundary of femto cell. When the interfered users are in close proximity, for example in the same building with the femto eNodeB, the femto eNodeB could adjust its power so much that some of its users will go out of coverage, thereby increasing the number of outage which in turn decreases the total capacity of the system. The flow chart for power control scheme can be seen in fig 3.

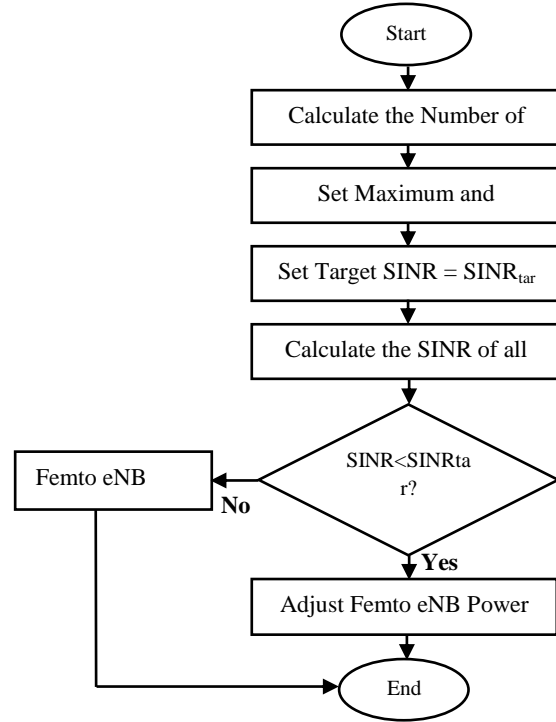


Fig 3: Flow Chart of Power Control eICIC Technique

4.1 Time Domain

Time domain scheme for mitigating cross tier interference involve the muting of sub frames by the aggressor eNodeB so that victim UE can be assign during these sub-frames. Time domain technique mitigate interference at the expense of reducing capacity as the eNodeB does not transmit in all sub-frames. Figure 4 present the flow chart for a time domain eICIC technique.

4.2 Developed Hybrid Power Control and Time Domain Technique

The developed hybrid interference mitigation scheme, integrate Power Control (PC) and Time Domain (TD) technique. The hybrid technique mitigate cross-tier interference in a femto-macro HetNet. PC and TD technique when implemented separately, each has its own disadvantage. As in the case of PC technique, mitigating interference becomes a challenge when the victim user is in close proximity to femto eNodeB because it can result to increased percentage outage. While in time domain where interference is mitigated at the expense of reducing the capacity of femto eNodeB since it does not transmit in some sub-frame, especially when the muting ratio is above 50%. In the developed hybrid scheme, a target SINR to be guaranteed to all users and a threshold distance D_{min} which is referred to as target SINR range is set. For cell edge macro users, that is, users that are at distance above D_{min} the technique implement power control by reducing and increasing its power adaptively. But for macro users at distance below D_{min} the technique implements time domain ABS because of the close proximity to the femto eNodeB. The hybrid technique is able to mitigate interference better in comparison to when the techniques are implemented individually and also combines the advantages of both techniques. Fig is a flow chart of the hybrid technique figure 6.

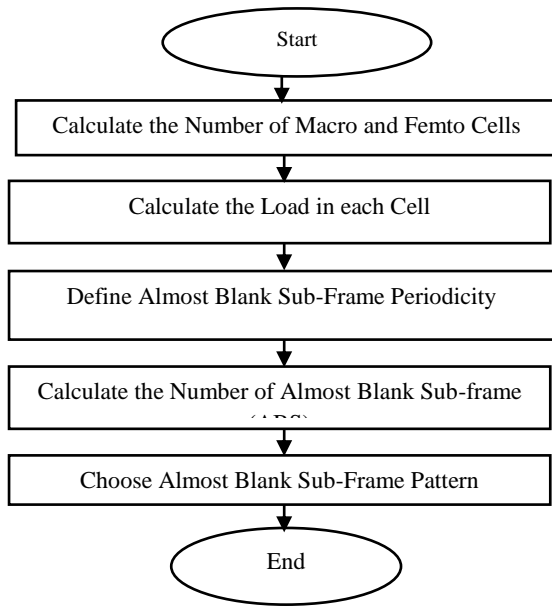


Fig 4: Time Domain eCIC technique flow chart

4.3 Simulation

The simulation frame work is a Graphical User Interface (GUI) built with MATLAB which the user can interact with by providing simulation parameter. Fig 5 shows the GUI interface, the user interacts with the GUI and provides all the necessary inputs. The path loss of the provided custom set up is calculated depending on the position of the user. The results obtain from the path loss is used to calculate the gain which is used to obtain the SINR of every user. Throughput and sum capacity of the users is calculated from the SINR. The system model topology and configuration depend on the inputs provided by the user at every particular scenario. For the purpose of simulation and result analysis, the configuration of Figure 3.7(a) and 3.7(b) are investigated. Firstly, the model scenario is simulated considering only power control scheme of target SINR after which results is collected for users of interest. Secondly, the model is simulated considering only time domain scheme with different muting ratio and lastly simulation is carried out for the hybrid power control and time domain scheme.

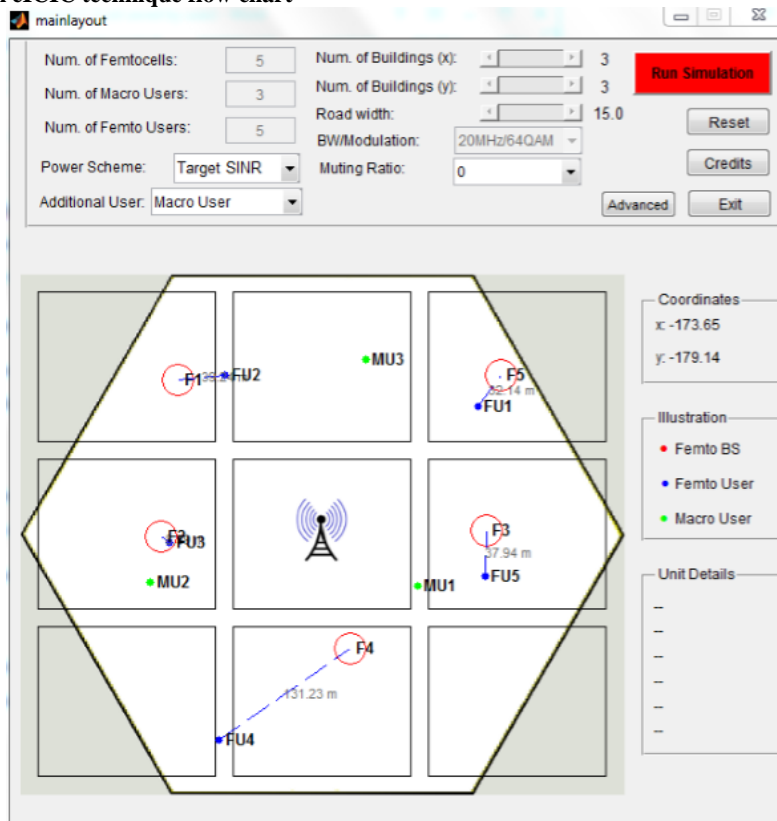


Fig 5: GUI for Simulation

Simulations assumptions and parameters is shown in table 1

5. RESULTS AND DISCUSSIONS

In Figure 7, throughput against distance was plotted for a macro user moving towards a femto eNodeB. The plot was obtained by first determining the path loss of the user from equation (3), the path loss depends on the distance of the user from the serving eNodeB. SINR was obtained from equation (4), finally the throughput was obtained from equation (6) and plotted. From the graph of Figure 7 it is seen that as the macro

user moves away from the macro eNodeB towards the femto eNodeB its throughput begins to decrease. The femto eNodeB is at 200 meters away from the macro eNodeB, therefore at that point the throughput of the macro user is zero due to interference the macro user experience from the femto eNodeB.

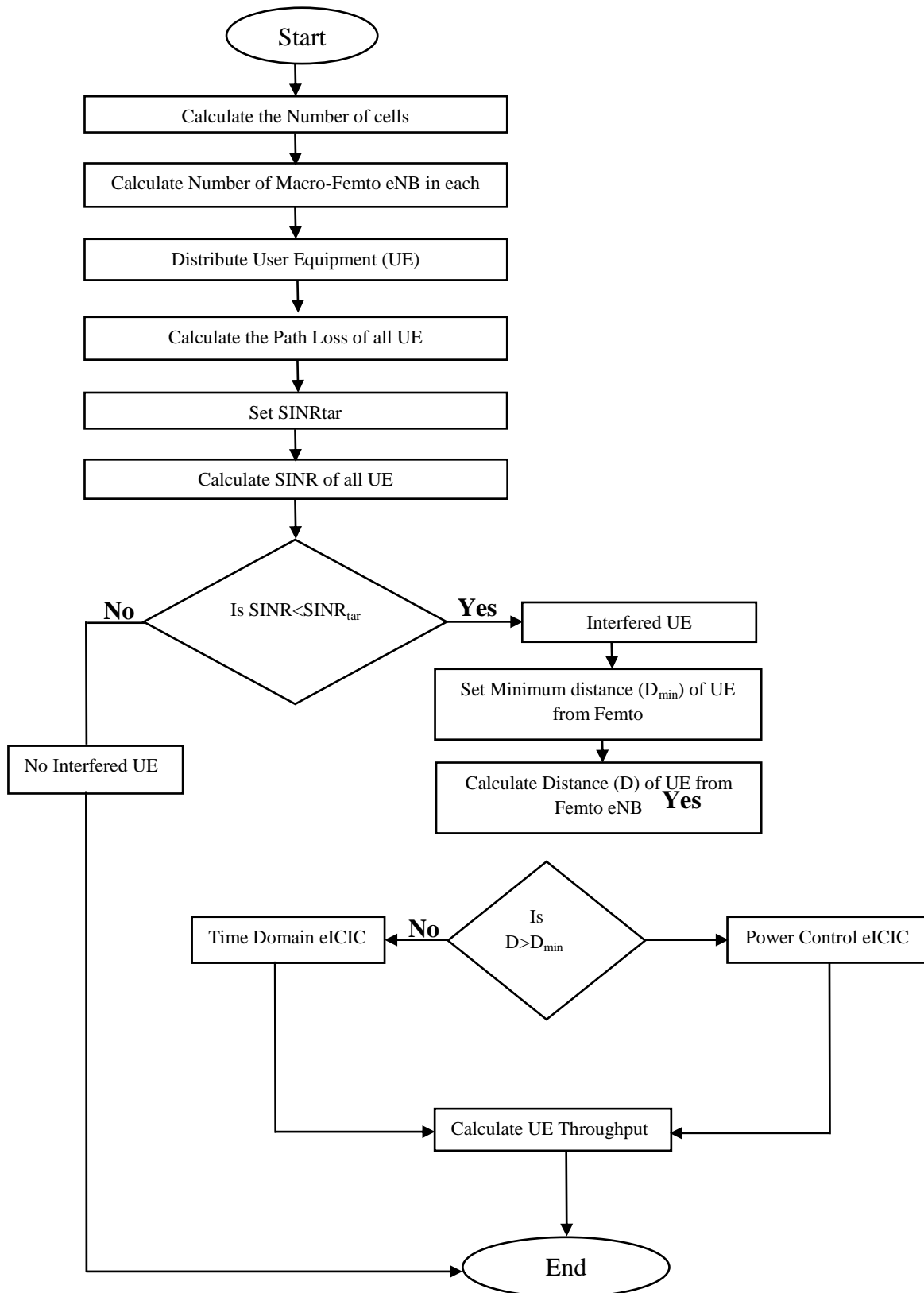


Fig 6: Flow Chart for Hybridized Power Control and Time Domain

Table 1: System Level Simulation Parameters

Parameters	Value/Description		
Cellular layout	Single Macrocell		
Number of Macro eNodeB	1		
Macrocell radius	250m		
Macro eNodeB TX power	46dBm		
Carrier frequency	2GHz		
Femto eNodeB max TX power	20dBm		
Femto eNodeB default TX	11dBm		
D_{min}	75% Femto Range		
Exterior wall loss	15dBm		
Interior wall loss (low)	7dBm		
Bandwidth (20MHz)	20	15	10
Modulation type	64QAM	16QAM	QPSK
Subcarrier Spacing	15 kHz		
White noise power density	-174dBm/Hz		
Target SINR	4dBm		
Max. Throughput	12Mbps		

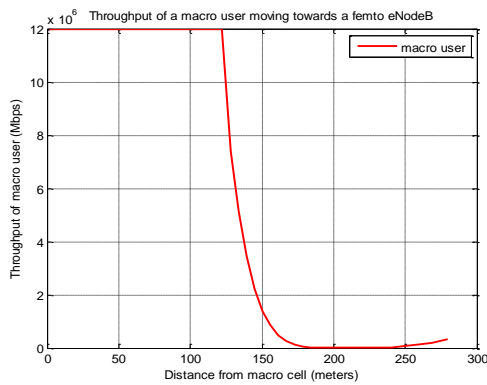


Fig 7: Throughput of Macro User Moving Towards a Femto eNodeB

Figure 8 is a plot of throughput against distance of a femto user moving away from its serving eNodeB. It can be seen that as the user moves away from the serving eNodeB its throughput decreases. However, the decrease is pronounced in the case of femto user because of the size of the cell and high path loss caused by the walls of the building. The decrease in throughput for the case of femto user begins at 23m, where the throughput is 18Mbps. At 40m the throughput has decreases to about 5Mbps, which is about 28% decrease in an interval of 17m. Similarly, the throughput of the macro user begin to decrease at 125m away from the macro eNodeB with a throughput of 12Mbps. At 150m the throughput has decreased to 1.5Mbps, which is about 12.5% decrease in an interval of 25m.

Figure 9 is a plot of the total capacity of a femto eNodeB against distance obtained from equation (9) with different muting ratio using time domain scheme. It is seen from the plot that at any particular distance from the femto eNodeB the higher the muting ratio, the lower the total capacity of the femto eNodeB. This is so because the eNodeB does not transmit any data during ABS frames. At 20m distance away from the femto eNodeB the throughput are 0.8Mbps, 3.5Mbps, 4.2Mbps and 6.2Mbps for muting ratio of 0.8, 0.5, 0.3 and 0, respectively. This implies that optimal muting ratio needs to be selected to avoid degrading the femto eNodeB total capacity.

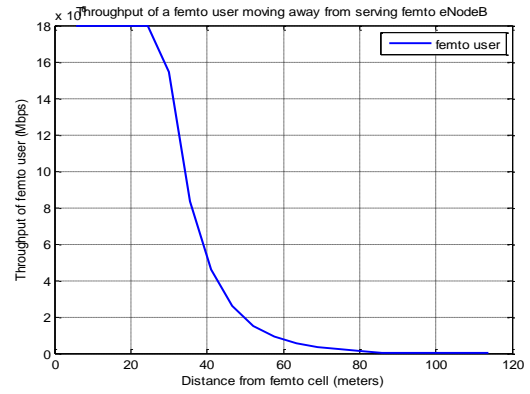


Fig 8: Throughput of a femto user moving away from femto eNodeB

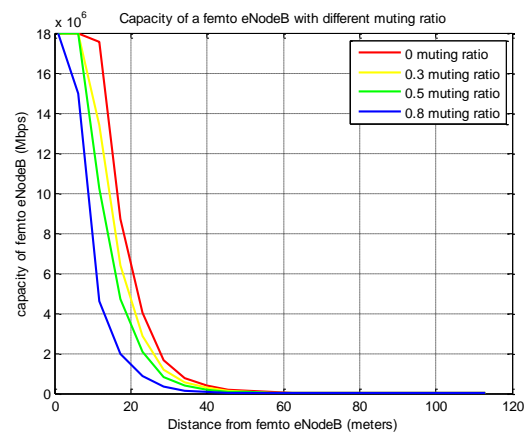


Fig 9: Capacity of Femto eNodeB

Figure 11 is a colour map representing the throughput of a macro user at any point in the macro cell. The result was obtained from the configuration of Figure 10 and colored based on equation [24]. Simulation was carried out for PC and TD with different muting ratio of 0.3, 0.5 and 0.8. For MU1 the summary of results is shown in Table 2. It can be seen that hybrid techniques with time domain muting ratio of 0.8 gives the highest value of throughput for MU1. This means that the more the increase in the muting ratio at the femto eNodeB the higher the throughput obtained by the macro user. Implementing only TD technique gives lower throughput for muting ratio of 0.3 and 0.5, but a better throughput is obtained for PC. The result shows that PC is best used to mitigate interference when the victim user is at the edge of the cell.

For the same configuration of Figure 10 the additional user was changed to Femto User (BS1). This means that the macro cell was coloured based on the throughput of the users connected to femtocell F1 in the configuration. Simulation was also carried out for PC and TD techniques with different muting ratio. The summary of results obtained is shown in Table 3. From this table it is seen that TD is the best technique that provides FU1 with the best throughput for different muting ratios.

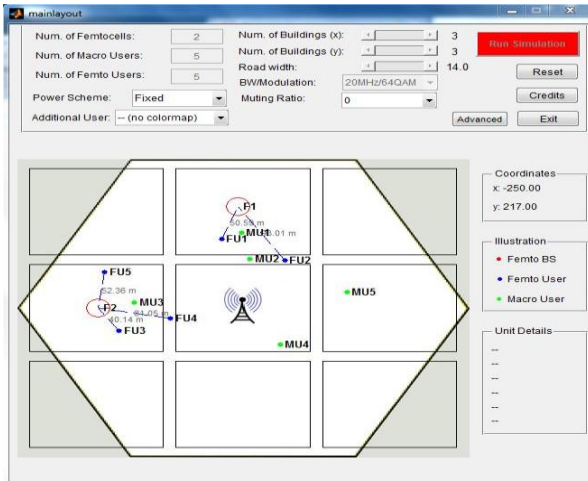


Fig 10: System Model Topology for Analysis

This is because during TD FU1 still has a better coverage from the femto eNodeB only that some sub-frame are muted to serve MU1. PC gives a very low throughput for FU1 because during PC the femto eNodeB has reduced its power to enable it provide the target SINR for the MU1 and as a result leaves FU1 with little or no coverage. This makes PC technique efficient only when the victim users are at the edge of the cell, where adjusting the power of the femto eNodeB make the femto users to experience very low SINR and eventually go out of coverage.

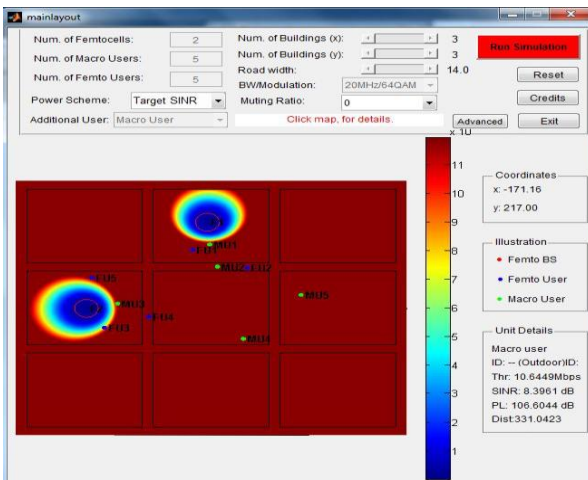


Fig 11: Throughput Colour Map for Implementing PC only

Table 2: Summary of Results obtain for MU1

Parameter	PC	TD	aHPTT
Throughput (Mbps)	10.6449	1.0871	11.0000
SINR (dB)	8.3961	-2.7788	9.1048

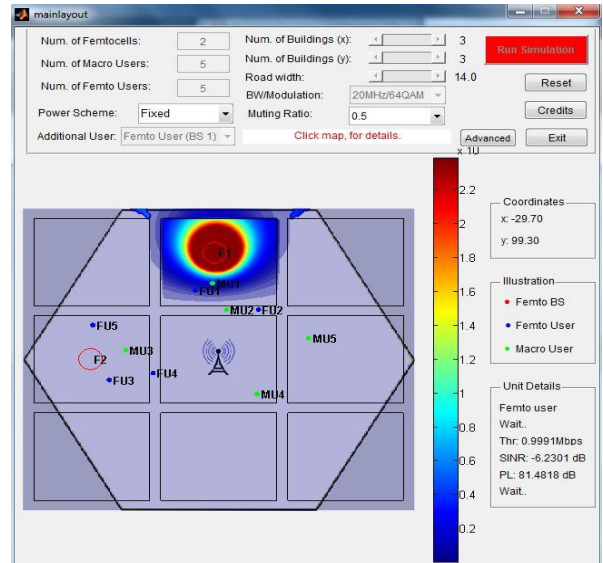


Figure 4.5: Throughput Colour Map for Implementing TD only

Table 2: Summary of Results obtain for FU1

Parameter	PC	TD	aHPTT
Throughput (Mbps)	10.6449	1.0871	11.0000
SINR (dB)	8.3961	-2.7788	9.1048

4.1 Summary of Results

From the results obtained it can be summarized that hybrid scheme performs better in terms of higher throughput and SINR when compared to implementing either PC or TD only. PC is efficient and performs better only when the victim users are at the edge of the femto eNodeB or when they victim users are passer-by within the vicinity of the femto eNodeB. TD involves muting sub-frames this reduces the capacity of the femto eNodeB, especially at higher muting ratio. TD is efficient when the victim user is not at the edge of the femto eNodeB but closer to femto eNodeB. However, optimal muting ratio need to be selected to avoid degrading the capacity of the femto eNodeB. The Hybrid technique has integrated PC and TD into a single scheme where for victim users at the edge of the femto eNodeB the scheme performs PC and for victim users who are not at the edge of the cell the scheme performs TD. This is done simultaneously depending on the position of the victim user in the network.

5. CONCLUSION

An adaptive hybrid power control and time domain technique to mitigate interference has been proposed and implemented. The technique has integrated PC and TD to mitigate downlink interference as a single technique. The hybrid scheme performs PC and TD simultaneously depending on the position of the victim user in the macro cell. PC was implemented on users who are at the sell edge or passer-by that is for users at distant position greater than D_{min} . TD was implemented on users who are at close proximity to the femto eNodeB, that is, at a distant

less than D_{\min} . The aHPTT shows better improvement in terms of total user throughput than PC and TD when implemented separately.

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