Comparative Analysis of Macro-Femto Networks Interference Mitigation Techniques

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Abstract: When interference is reduced, the benefits of using a macrocell and femtocell heterogeneous network (Macro-Femto) heterogeneous network (HetNet) can be increased to their full potential. In this study, Enhanced Active Power Control (EAPC), Active Power Control (APC), and Power Control (PC1) interference mitigation strategies are applied, and their performances in uplink and downlink transmission of 5G Non-Stand-Alone (NSA) architecture are compared. According to the findings of a MATLAB simulation, the EAPC technique utilized a lower amount of transmit power for the Macro User Equipment (MUE), the Home User Equipment (HUE), and the femtocell logical node (Hen-gNB), in comparison to the APC and PC1 techniques. While PC1 approach required less en-gNB transmission power. The MUE, HUE, hen-gNB, and en-gNB throughput of the EAPC approach was much higher. This work will enable wireless system designers and network engineers know the appropriate technique to utilize to achieve desired Quality of Service (QoS) while conserving network resources.

Index Terms: Uplink, Downlink, Transmission Rate, Interference, Macro-Femto, HetNet.

1. Introduction

Fifth-generation (5G) network is an ultra-dense network (UDN) that works based on soft capacity. It calls for the

installation and maintenance of high-cost outdoor macrocell nodes by mobile network operators (MNOs) so as to make available the required network services to all subscribers. Small cell networks such as: microcell, picocell, and femtocells are integrated into the macrocell network so as to improve cellular network performance with reference to the received signal to interference plus noise ratio (SINR), throughput, area of coverage, and network capacity. Among the existing small cell networks, femtocell is the most promising technology with the lowest cost, and smallest coverage area suitable for millimeter-wave propagation from homes and offices [1,2] . The mounting and maintenance cost of femtocells is handled by network users, as a tradeoff for better network performance [2] . When femtocell is installed, user equipment (UEs) that have access to such femtocell are moved from macrocell to femtocell [1,3], thereby decongesting the macrocell network, and increasing coverage area (cell breath out). Fig. 1 gives an illustration of Non-Stand-Alone (NSA) architecture of 5G Macro-Femto HetNet.
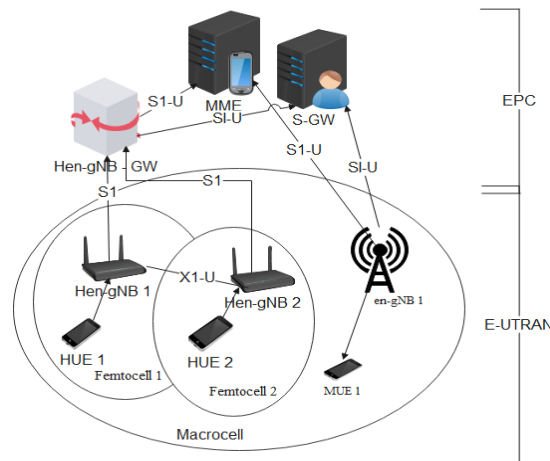

Fig. 1. Schematics of NSA architecture of 5G Macro-Femto HetNet [4–6]

In Fig. 1, EPC stands for enhanced packet core, E-UTRAN stands for enhanced universal terrestrial radio access network, S-GW denotes serving gateway, MME denotes mobile management entity, Hen-gNB represents femtocell node of 5G NSA architecture, en-gNB represents macrocell node of 5G NSA architecture, Hen-gNB – GW for femtocell gateway, while S1-U and X1-U represent communication interfaces.

The indiscriminate installation of femtocells by network user increases co-tier (intra-layer) and cross-tier (inter-layer) interference in Macro - Femto HetNet. This interference is an undesired signal picked by neighboring network devices that hampers the optimal performance of cellular communication networks [2,7–9]. Interference is classified into uplink co-tier, uplink cross-tier, downlink co-tier, and downlink cross-tier interference as depicted in Fig. 2 below.
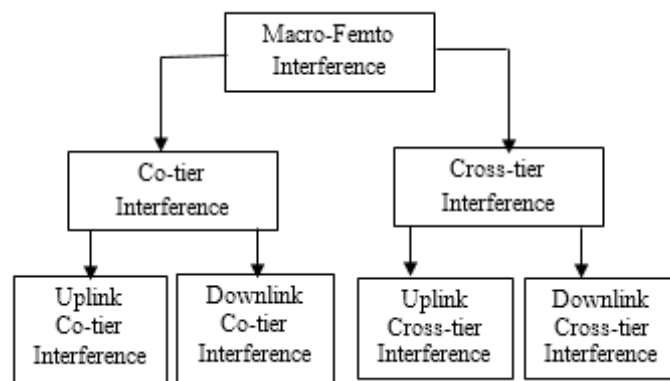

Fig. 2. Types of interference in Macro-Femto network [10,11]

Interreference mitigation techniques are therefore of great value to improve the quality-of-service (QoS) in femto cells [12]. A number of works on mitigating inference are covered in literature [13–15], knowing which to employ depends on a variety of variables such as the communication architecture of the wireless network, communication environment, type of inference in question, as well as the tradeoffs required to achieve the desired QoS level. This work uses MATLAB simulations to compare the performance of three interference mitigation techniques in femto networks. These techniques include Enhanced Active Power Control (EAPC), Active Power Control (APC), and Power Control (PC1) techniques in uplink and downlink transmission of 5G Non-Stand-Alone (NSA) architecture to help wireless system designers and network engineers understand the best technique to employ for desired results.

The following outline illustrates how the remaining parts of this work are structured. How each of the mitigation strategies works is examined in Section 2, along with examples of analogous projects in which they were implemented. The approach that was utilized for the analysis is addressed in Section 3, the outcome of the simulation is discussed in Section 4, while the study is brought to a close in Section 5.

2. Related Works

Power Control Techniques for Mitigation of Interference in Macro-Femto Cellular Communications. Power has been identified as one of the limited network resources aside from bandwidth in cellular communication. This calls for an optimization technique that will allow for better utilization of the scarce resource. There are several power control techniques being used today due to their simplicity when compared to the bandwidth allocation approach, or the cognitive radio sensing approach. The power control techniques for Macro-Femto networks that will be analyzed in this study are reviewed in the subsection following.

2.1 Management of Interference using Power Control for Macrocelll – Femtocell Cellular Communication Network.

In [8,9], the authors worked on the dynamic power control (PC1) technique for interference mitigation. They compared computed signal-to-interference-plus-noise ratio with threshold SINR as shown by the mathematical equation in (1), which they used for adjusting their transmission power.

$$SINR_{threshold} \quad \gamma_{diff} = SINR_{computed} \tag{1}$$

where γ_{diff} represents the discrepancy between the measured and the target UE SINR, $SINR_{computed}$ stands for computed SINR while $SINR_{threshold}$ for threshold SINR. The current transmission power would be increased in the next transmission by a scale factor of 2 dB when γ_{diff} is below 0. When γ_{diff} is above 0, the next transmission power would be the present transmission power minus 2 dB. But when γ_{diff} is equal to 0, the subsequent transmission power would be the same as the current transmission power. Mathematically, PC1 transmission power adjustment in [8,9] is expressed using (2).

$$P_{tx}(t_j + 1) = \begin{cases} \min[P_{tx}(t_j) + \omega, P_{max}]; \gamma_{diff} < 0 \\ P_{tx}(t_j); \qquad\qquad \gamma_{diff} = 0 \\ \max[P_{tx}(t_j) - \omega, P_{min}]; \gamma_{diff} > 0 \end{cases} \tag{2}$$

where $P_{tx}(t_j + 1)$ stands for PC1 next transmission power, $P_{tx}(t_j)$ represents PC1 present transmission power, ω represents the value for adjustment, $P_{\_min}$ is the minimum power of transmission, and P_{max} is the maximum power of transmission.

2.2 An Active Power Control for Management of Interference in Two-Tier Macro-Femto Network

Authors in [3] control the transmission power of aggressors (AGs) in a Macro-Femto cellular communication network premised on the calculated interference indication function (IDF). Victim (VT) of interference calculates IDF, using (3) and compares it with the value of the threshold interference. If the calculated IDF is greater than the threshold interference, the VT sends an interference message (IM) to its serving nodes or user equipment (UE), which then transmit the IM to the AG using network backhaul. The IM contains information about the AG cell identity (CID) used to identify the AG of a particular VT. Equations (3) and (4) as in [2] and [3] were used to determine when an IM should be sent.

$$I_{idf} = P_t^i \psi_i (d_{(tx-rx)})^{-\beta} \tag{3}$$

$$IM = \begin{cases} 0, & I_{idf} \le I_{Threshold} \\ 1 & otherwise \end{cases} \tag{4}$$

where P_t^i is the transmission power, ψ stands for log-normal shadowing, ($d_{(tx-rx)}$) is the gap or distance between the transmitter and the receiver, β denotes the path loss and I_idf represents the IDF. In (4), $I_{Threshold}$ is the interference threshold. When IM = 0, the received interference by VT is taken to be negligible and IM is not sent. However, when IM= 1, it means the VT received a significant level of interference thereby prompting the IM to be sent.

The APC technique has two phases, which they used in controlling the transmission power of nodes and UEs. In the first phase, the authors set three transmission power (P_l, P_m, P_n) levels and two-time frames (TL_1, TL_2). Where P_l is the maximum, followed by P_m and lastly P_n transmission power levels. On receiving an IM, the transmission power of the AG would decrease from P_l to P_m by downward power value (Δ_{down}) of - 2dB and (TL), 1 would be activated. If the same AG gets another IM within TL_1, it would not further decrease its power to P_n level until TL_1 elapses; then it would reduce its transmission power from P_m to P_n. But when the AG has no IM and TL_{-1} has elapsed, the second time level TL_{-2} activates and the transmission power level increases from; say P_m to P_l by upward power value (Δ_{up}) of 2 dB. The first phase of APC transmission power control is expressed mathematically as shown in (5) – (9).

$$P_{fp} = P_l \qquad \text{No interference message} \tag{5}$$

$$P_{fp} = P_m = P_l - \Delta_{down} \qquad \text{Interference Message and } TL_1 \text{ starts} \tag{6}$$

$$P_{fp} = P_n = P_m - \Delta_{down} \qquad \text{New interference Message and } (TL_1) \text{starts} \tag{7}$$

$$P_{fp} = P_m = P_n + \Delta_{up} \qquad \text{No interference Message and } TL_2 \text{ starts} \tag{8}$$

$$P_{fp} = P_l = P_m + \Delta_{up} \qquad \text{No interference Message and } TL_2 \text{ running} \tag{9}$$

The second phase of the APC power control modifies the transmission power (P_{fp}) of the first phase based on the minimum required quality of service (QoS) indication function (QoS-IF). The equation used for calculating QIF is shown in (10) as in [2,3].

$$QoS - IF = \frac{P_{ref}\tau_{\min}}{\min RSRP_j} \tag{10}$$

where τ_{min} is minimum required SINR, P_{ref} is the reference signal transmission power and $minRSRP_j$ is the reference signal received power. The mathematical model for APC second phase power control is captured in (11) as in [2,3].

$$P_{APC} = \max(P_{\min} \min(QoS - IF * P_{fp}, P_{\max})) \tag{11}$$

where $P_{\max}$ and $P_{\min}$ are maximum and minimum transmission power respectively.

2.3 Enhanced Active Power Control Technique

The EAPC technique employed the path loss model of en-gNB in (12) taken from [3], [8], and [9] and the loss path model of Hen-gNB in (13) taken from [2]. The path loss model ($PL_{Hen-gNB}(dB)$) in (14) is an extension of the log-distance path loss model given in (15) [2]

$$PL_M(dB) = \begin{cases} 15.3 + 37.\log(R1) + l_p & (Indoor) \\ 15.3 + 37.\log(R1) & (outdoor) \end{cases} \tag{12}$$

$$[P_L(d)]dB = [P_L(d_0)]dB + 10n\log_{10}(\frac{d_2}{d_0}) + faf \tag{13}$$

$$PL_{Hen-gNB}(dB) = -\log_{10}(\frac{c}{f * 4\pi * d_0})^2 + 60\log_{10}(\frac{d_2}{d_0}) + 16.2 + l_p \tag{14}$$

Substituting $d_0 = 1m$ and in (14) gives (15).

$$PL_{Hen-gNB}(dB) = 20\log_{10}(f_{MHz}) + 60\log_{10}(d_2) - 11.4 \tag{15}$$

where $P_L(d_0)$ is free space path loss, c is the speed of light, f is the frequency of transmission in MHz, and is the reference distance, while, d is the distance between the transmitter and the receiver. The received SINR is computed using (16) as in [2,9].

$$SINR_{recieved} = \frac{P_{tx_j} PL_{ch}}{\sum_f I_{co-tier} + \sum_f I_{cross-tier} + P_n} \tag{16}$$

where $SINR_{recieved}$ is the received SINR, P_{tx_j} is the transmission power of jth transmitter, PL_{ch} is the propagation path loss, $\sum_f I_{co-tier}$ is the sum of co-tier interference, $\sum_f I_{cross-tier}$ is the sum of cross-tier interference and P_n is the thermal noise. The difference between the calculated SINRs and the threshold SINR as in (1), was used to determine the power control, which is expressed mathematically in (17) – (19).

$$if \; \delta_{diff} = \begin{cases} < 0 & assign \; S = +1 \\ > 0 & assign \; S = -1 \\ = 0 & assign \; S = 0 \end{cases} \tag{17}$$

$$P_{tx} = P_{present} + S\Delta_{EAPC} \tag{18}$$

$$P_{EAPC} = \max(P_{\min}, \min(P_{tx}, P_{d\max})) \tag{19}$$

where P_{EAPC} is the next transmission power of EAPC, $P_{present}$ is the present transmission power, and is the adjustment power of EAPC with a value of 0.5 dB. The result of the computation from (19) will be the next transmission power for a set time duration (Tf_1). After the expiration of Tf_1, the system starts from the beginning to determine the next transmission power to be used.

The network transmission rate of nodes is measured using (20) - (24) as in [2].

$$T = Bw\log_2(1 + SINR_{received}) \tag{20}$$

$$C_{Hen-gNB}^{Avg} = \frac{\sum_{i=1}^n C_{Hen-gNB}}{N_{Hen-gNB}} \tag{21}$$

$$C_{en-gNB}^{Avg} = \frac{\sum_{i=1}^n C_{en-gNB}}{N_{en-gNB}} \tag{22}$$

$$C_{HUE}^{Avg} = \frac{\sum_{i=1}^n C_{HUE}}{N_{HUE}} \tag{23}$$

$$C_{MUE}^{Avg} = \frac{\sum_{i=1}^n C_{MUE}}{N_{MUE}} \tag{24}$$

where T stands for throughput, Bw for bandwidth, and $SINR_{received}$ for received SINR. $\sum_{i=1}^n C_{en-gNB}$ stands for the sum of all en-gNB throughput, $\sum_{i=1}^n C_{Hen-gNB}$ for the sum of all Hen-gNB throughput, $\sum_{i=1}^n C_{MUE}$ stands for the sum of all MUE throughput, $\sum_{i=1}^n C_{HUE}$ for the sum of all HUE throughput. While N_{en-gNB}, $N_{Hen-gNB}$, N_{MUE}, and N_{NUE} stands for the number of en-gNB, Hen-gNB, MUE, and HUE respectively.

The average power used by nodes and UE in communicating at different UE locations is computed using (25).

$$P_{tx}^{Average} = \frac{\sum_{L=1}^{L=NL} P_{tx}}{N_{tx} \times UE_p} \tag{25}$$

where $P_{tx}^{Average}$ is the average power consumption of a node or UE. $\sum_{L=1}^{L=NL} P_{tx}$ is the sum of all nodes or UE_s transmission power at all positions of UEs. N_{tx} stands for the number of nodes or UE_s. UE_p stands for the total number of UE positions.

In this study, the power consumption rate and throughput performance of EAPC, APC, and PC1 interference mitigation techniques along uplink and downlink transmissions of 5G NSA in a Macro-Femto cellular communication were analyzed and compared for wireless system designs and reference purposes.

3. Methodology

In the section, the technique used for the comparative analysis is discussed. In the research system model used, the UEs are assumed to be uniformly distributed and MUE1 is not registered on Hen-gNB2. The model is comprised of one primary cell (macrocell) and two secondary cells (femtocells) sharing the same bandwidth. Femtocell closed access mode, was considered. The non-stand-alone (NSA) 5G model as in [6], denotes macrocell logical node B as en-gNB, and femtocell or home logical node B as Hen-gNB. Fig. 3 shows the research system model.
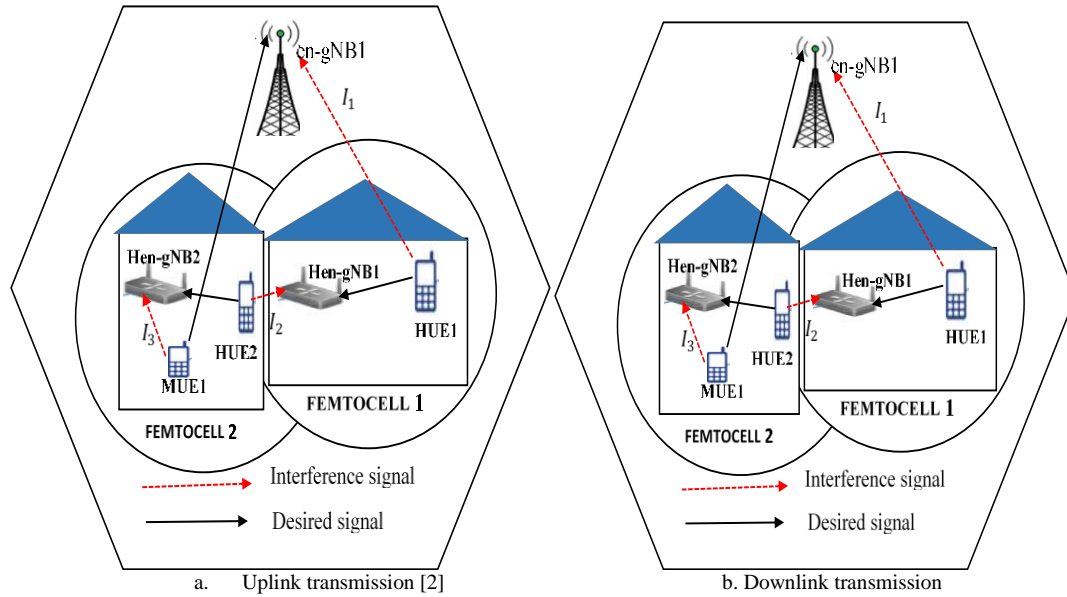

a.   Uplink transmission [2]   b. Downlink transmission

Fig. 3. System model

In Fig. 3, I_1 is an interference of the uplink cross-tier, while HUE 1 is the AG, and en-gNB is the VT. I_2 is an interference of the uplink co-tier, HUE 2 is the AG, and its Hen-gNB1 is the VT. I_3 is an interference of uplink cross-tier, MUE 1 is the AG, and   Hen-gNB 2 is the VT. The downlink signal from Hen-gNB 2 is received as downlink cross-tier interference (I_4) by MUE 1. HUE 2 positioned at the cell edge receives the signals from Hen-gNB 1 as downlink co-tier interference (I_5). The downlink transmission of en-gNB1 is received by HUE1 as downlink cross-tier interference (I_6).

4. Result and Discussion

The result from the simulation was in agreement with the system model and input variables as seen in Table 1 where P_{TX} is the transmit power. The system input variables were sourced from [2,3,8,9]. Transmission power and throughput were used as the key performance indicators (KPIs) because interference increases when transmission power increases and throughput increases when interference reduces in networks.

Table 1. Simulation Variables

No.	Parameter	Value
1.	Maximum P_{TX} of Hen-gNB	21 dBm
2.	Maximum P_{TX} of en-gNB	46 dBm
3.	Maximum P_{TX} of HUE and MUE	23 dBm
4.	Minimum P_{TX} of Hen-gNB	0 dBm
5.	Minimum P_{TX} of en-gNB	5 dBm
6.	Minimum P_{TX} of HUE and MUE	0 dBm
7.	Initial P_{TX} of HUE	8 dBm
8.	Initial P_{TX} of MUE	34 dBm
9.	System bandwidth	10 MHz
10.	Carrier frequency	3.2 GHz
11.	Thermal noise	-174 dBm
12.	Target SINR	10

The throughput performance of the network and the transmission power of en-gNB and Hen-gNB, using EAPC is benchmarked with that of other associated techniques, and described in Fig. 4 – 7. Fig. 4 shows the transmission power used by en-gNB and MUE in communicating with each other.

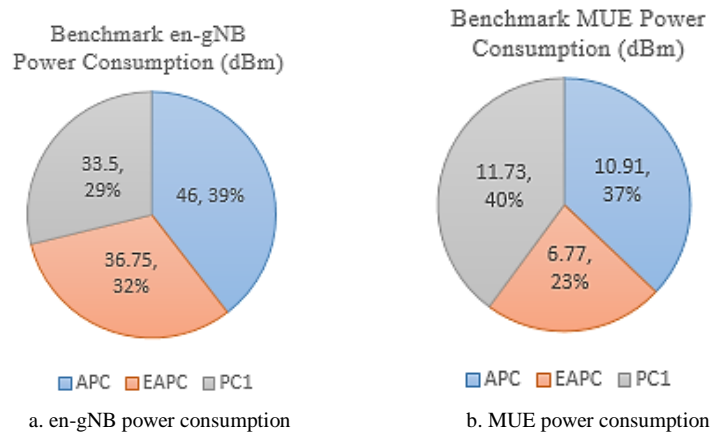a. en-gNB power consumption   b. MUE power consumption

Fig. 4. Comparison of macrocell power consumption

The results in Fig. 4 indicate that APC, EAPC, and PC1 used an average of 10.91 dBm, 6.77 dBm, and 11.73 dBm MUE transmit power respectively. The EAPC technique has the least MUE transmit power. It conserved 37.92% power when compared with APC and 42.25% when compared with PC1. The APC, EAPC, and PC1 techniques used an average of 46.00 dBm, 36.75 dBm, and 33.50 dBm. The en-gNB transmit power of the EAPC technique conserved 27.17% and 8.84% power in comparison to APC and PC1 respectively. Fig. 5 shows the power consumption of Hen-gNB and HUE when transmitting to each other.

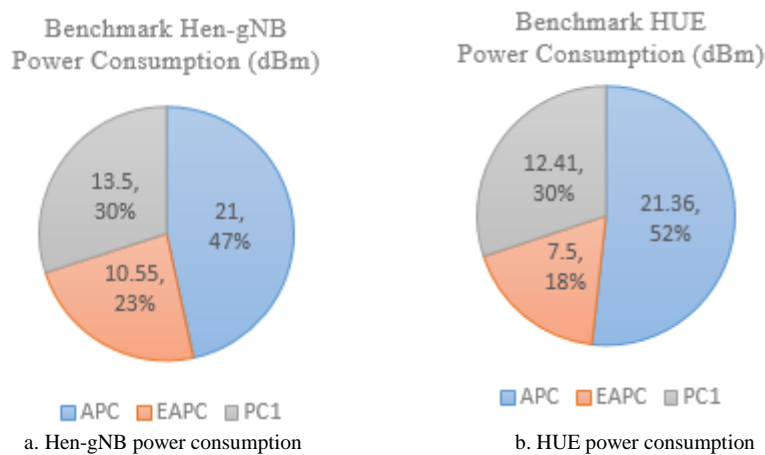a. Hen-gNB power consumption   b. HUE power consumption

Fig. 5. Comparison of femtocell transmission power

The downlink transmission of Hen-gNB used an average power of 21.00 dBm, 10.55 dBm, and 13.50 dBm in communicating to its UEs based on APC, EAPC, and PC1 techniques respectively. PC1 technique used the least power, lower than that of APC, and EAPC techniques by 27.17% and 8.84% respectively. The uplink transmission of HUE an average power of 21.36dBm, 7.50dBm, and 12.41dBm were used by APC, EAPC, and PC1 techniques respectively for communicating with their nodes. In comparison with APC and PC1 techniques, the EAPC technique consumed the least power. It surpassed APC by 37.92% and PC1 by 42.25%. Fig. 6 presents the Cumulative Distributive Function (CDF) of femtocell transmission rate performance.
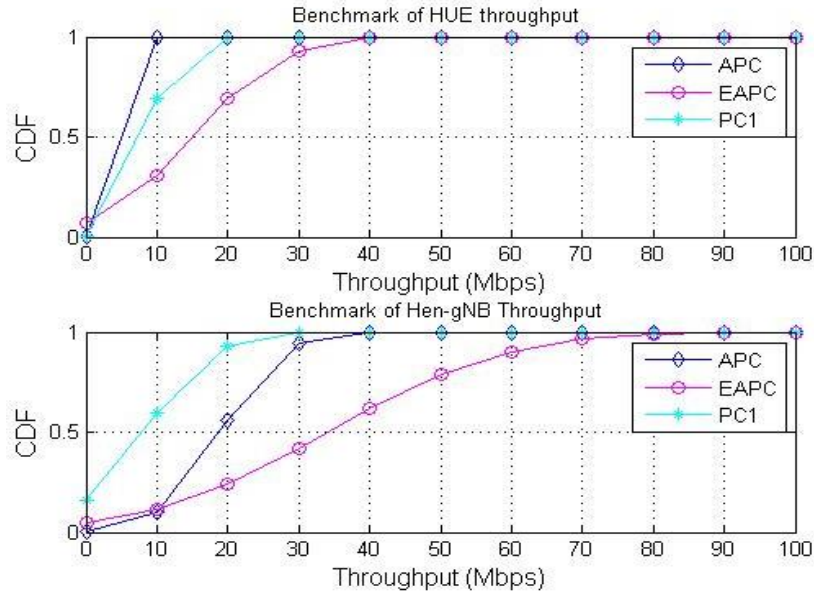

Fig. 6. Comparison of femtocell throughput

As captured in Fig. 6, the EAPC technique at 0.5 CDF has an average HUE throughout of 15.63 Mbps which outperforms those of APC (8.00 Mbps) and PC1 (7.50 Mbps) by 48.82 % and 52.02% respectively. At 0.5 CDF, the EAPC technique has an average Hen-gNB throughout of 33.75 Mbps that outperforms those of APC (8.13 Mbps) and PC1 (18.75 Mbps) by 75.91% and 44.44% respectively. Fig. 7 presents the result of MUE and en-gNB throughput.
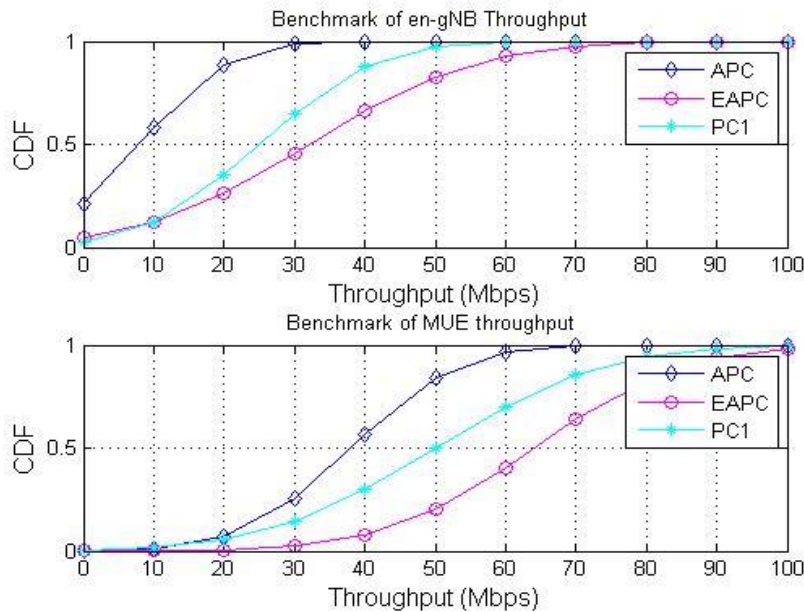

Fig. 7. Comparison of macrocell throughput

In Fig. 7, the EAPC technique at 0.5 CDF has an average MUE throughout of 63.75 Mbps, which outperforms those of APC (37.5 Mbps) and PC1 (50.00 Mbps) by 41.18% and 21.57% respectively. The EAPC technique at 0.5 CDF has an average en-gNB throughout of 32.50 Mbps that outperforms those of APC (7.50 Mbps) and PC1 (25.00 Mbps) by 76.92% and 23.08% respectively.

5. Conclusion

This research considered the downlink and uplink transmission of Macro–Femto HetNet, and compared the power consumption and throughput performance of APC, EAPC, and PC1 techniques. Findings from the MATLAB of the three (3) techniques revealed that the EAPC technique has less MUE, HUE, and Hen-gNB power consumption rate when benchmarked with APC and PC1 techniques. The EAPC technique was limited in conserving en-gNB power when benchmarked with PC1. Conversely, the EAPC throughput of MUE, HUE, Hen-gNB, and en-gNB at 0.5 CDF outperforms those of APC and PC1 techniques. The improved EAPC throughout is attributed to the fact that the EAPC technique is characterized by less interference and reduced transmission power in the Macro-Femto cellular communication networks. The result of this work will be very useful in selecting a suitable interference mitigation technique in the design of wireless systems for Macro-Femto heterogenous networks.

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Authors' Profiles

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