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# INTERFERENCE MITIGATION USING ENHANCED ACTIVE POWER CONTROL TECHNIQUE FOR 5G DOWNLINK TRANSMISSION OF MACRO-FEMTO CELLULAR NETWORKS

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***Abstract*— Femtocells are overlayed on existing Macrocells to reduce cost of mounting expensive macrocell nodes, improve cellular network coverage, capacity and Data rate performance. However, Macro-Femto heterogeneous (HetNet) network has a major problem of co-tier and cross-tier interference, which hinders its optimal performance, especially when the network capacity expands. With emergence of 5G technologies, interference would become more consequential. This paper deployed an enhanced active power control (EAPC) technique in mitigating Macro-Femto interference along downlink transmission of 5G non-stand-alone (NSA) architecture. The EAPC technique when compared with APC and PC1 techniques respectively yielded: 65% and 37% higher home user equipment (HUE) data rate; 37% and 21% higher macro user equipment (MUE) data rate. EAPC average power usage compared to that of APC and PC1 conserved 54% and 22% Hen-gNB energy respectively. EAPC technique conserved 21% en-gNB energy when compared to APC, but was limited when compared with PC1 by 8%; which should be considered in further studies.**

***Keywords*— *Macro-Femto HetNet, Femtocell, Interference, Data rate, and Power Usage***

## I. INTRODUCTION

Increasing demand for voice and data service by new and existing network subscribers mostly located at offices and homes is a challenge to mobile network operators [1]. Literatures have it, that the mobile indoor traffic is made up of 30% voice traffic and 70% data traffic [2, 3, 4]. Ericsson mobility report, as in [1, 5], forecasted that in 2021, there will be 7 billion mobile data user out of 9 billion mobile broadband subscriptions.

Fifth generation (5G) mobile system (5GS) has two architecture, the non-stand-alone (NSA) and stand-alone (SA) architecture. 5G NSA is a step toward the full implementation of 5G, which is compatible with 4G long time evolution (LTE). The macrocell node of 5G NSA (en-gNB) can communicate with 4G node and it's enhanced packet core (EPC). Fig. 1 presents the macro-femto heterogeneous network (HetNet) of 5G NSA

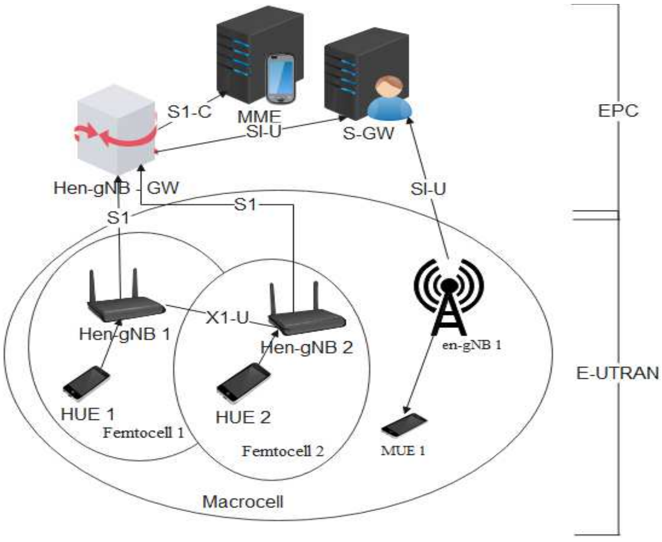

Fig. 1. 5G NSA of macro-femto heterogeneous network (source: [15] )

where S-GW stands for serving gateway, MME stands for mobile management entity, and eNB for 4G node. HUE 1 and HUE 2 stands for home user equipment in femtocell 1 and 2 respectively, MUE 1 stands for macrocell user and Hen-gNB – GW stands for femtocell gateway.

The 5G network is an ultra-dense network (UDN) that has large network capacity, cell coverage, data rate and spectrum

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efficiency, to serve more subscribers using low user equipment (UE) power [6]. Such robust macrocell network with soft capacity requires the mounting of several expensive outdoor macrocell nodes to provide the needed services to all subscribers. But the high cost of mounting and running macrocell network by operators necessitated the use of low-cost femtocell nodes, whose mounting and running cost are handled by the network users, as a tradeoff for better quality of service (QoS). This femtocell nodes are installed as an overlaid on existing macrocell to offload the densely populated macrocell network, for high data rate, large cellular networks capacity and coverage in [7, 8]. Femtocell nodes are plug and play nodes that are often installed by subscribers without considering the cell coverage area, which leads to cell overlap with neighboring femtocells; causing an increase intra cell (co-tier) interference. This interference problem is said to be the major technical problem of Macro-Femto HetNet [1, 9, 10, 11], other problems include network security and handoff. There are works on mitigating interference in Macro-Femto cellular communication networks, but this particular research work used an enhanced active power control technique that was proposed in [1] for mitigating interference in Macro-Femto downlink transmission and evaluate it's performance. Fig.2. shows a typical downlink Macro-Femto HetNet interference scenario.

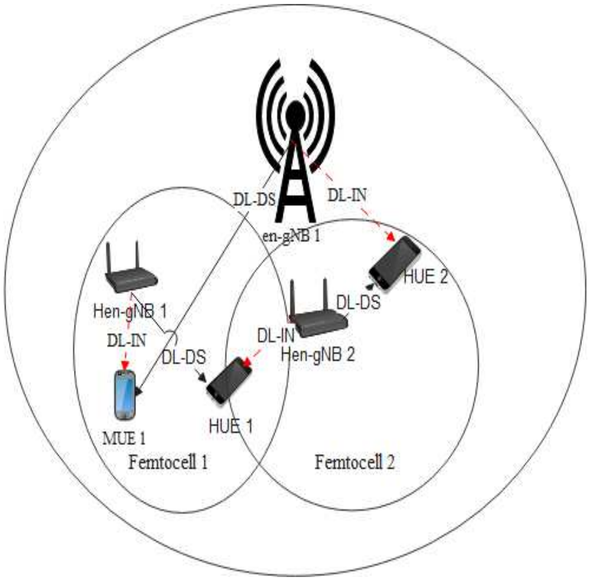

Fig. 2. Downlink macro-femto interference

where DL-Ds stands for downlink desired signal and DL-IN stands for downlink interference signal.

### A. Review on Interference Mitigation using Power Control Technique

Power is one of the key mobile network resource that is often tradeoff for bandwidth efficiency when mitigating interference. This limited power needs to be optimize to reduce interference in networks and to maximize power. The relationship between interference, Data rate and transmission power is express mathematically as (1):

$$Interference \propto \frac{Transmit\ Power}{Throughput} \qquad (1)$$

### A.1 Power Control 1 Technique

In [11] a dynamic power control technique called power control 1 (PC1) for mitigating interference was used. The technique adjust node transmission power based on the difference between computed UE signal-to-interference-plus-noise ratio ($SINR_{measured}$) and target UE SINR ($SINR_{target}$), expressed in (2)

$$\gamma_d = SINR_{measured} - SINR_{target} \qquad (2)$$

where $SINR_{measured}$ is computed UE SINR, $SINR_{target}$ is target UE SINR, and $\gamma$ is the difference between computed and target UE SINR. When the $SINR_{measured}$ is less than $SINR_{target}$, the node would increase its next transmission power by 2 dB. In situation whereby a UE has $SINR_{measured}$ that is greater than UE $SINR_{target}$, the next node transmission power would be the present power minus 2 dB. And when $SINR_{measured}$ of a particular UE is equals to $SINR_{target}$, the current transmission power of the node would be maintained in the next transmission. The mathematical expression for adjusting node transmission power according to PC1 technique is captured in (3):

$$P_{dtx} = \begin{cases} \min\left[P_{dtx}(t_j) + \Delta, P_{dmax}\right]; & \gamma_d < 0 \\ P_{dtx}(t_j); & \gamma_d = 0 \\ \max\left[P_{dtx}(t_j) - \Delta, P_{dmin}\right]; & \gamma_d > 0 \end{cases} \qquad (3)$$

where $P_{dtx}$ stands for the next downlink transmission power, $P_{dtx}(t_j)$ stands for the current downlink transmission power, $\Delta$ stands for step power value, $P_{dmin}$ stands for the minimum transmission power of a node, and $P_{dmax}$ is the maximum transmission power of node.

### A.2 Active Power Control Technique

Active power control (APC) technique in [8] was proposed for interference management in femtocell-macrocell HetNet. The authors used interference message (IM) received from victim (VT) of interference to determine the downlink transmission power of aggressor (AG). The VT of interference measures the interference indication function (IDF) and compare the value with set threshold interference value. If the computed IDF exceeds the set threshold interference, then, the VT would send an IM that contain the AG information, to its serving node. The node then forward the IM to the particular AG causing interference in the network using the backhaul connection. Equation (4) was used for measuring IDF ($I_i$), and (5) expressed determine the state of IM.

$$I_i = P_t^i \psi_i (R_i)^{-\beta} \qquad (4)$$

$$x_i = \begin{cases} 0, & I_i \leq I_{Threshold} \\ 1 & otherwise \end{cases} \qquad (5)$$

In (4), $P_t^i$ represents transmission power, $\psi$ stands for log–normal shadowing, R stands for distance between node and UE, $\beta$ is the path loss component and $I_i$ is the IDF. Whereas in (5), $I_{Threshold}$ is the set interference threshold and $x_i$ is the IM. When $x_i$ = 0, it connotes that interference is at an insignificant level and IM would not be send. When $x_i = 1$, it connotes that interference is high and IM would be send.

APC technique has two power control phases. The first phase, set three transmission power ( $P_x, P_y, P_z$) and two time levels ($TL_1, TL_2$). When an IM is received, $TL_1$ activates and the transmission power of the AG would be reduce from say $P_x$ to $P_y$ by set power value ($\Delta_{APC}$). If the same AG receives another IM within the time frame of $TL_1$, it would not further reduce its transmission power to $P_z$ level. In situation whereby the AG did not receive IM within $TL_1$, the $TL_2$ would activate at the expiration of $TL_1$ and its transmission power level would increase from say $P_y$ to $P_x$ by step power value ($\Delta_{up}$).

The second phase of APC technique work upon the first phase transmission power ($P_{dt}$) based on the minimum required quality of service indication function (QIF). The equation they used in computing QIF is given as (6):

$$QIF = \frac{P_{dref}\tau_{HUE}}{minRSRP_j} \qquad (6)$$

where $\tau_{HUE}$ refers to SINR threshold of HUE, $P_{dref}$ refers to downlink reference signal transmission power of Hen-gNB and $minRSRP_j$ is the reference signal received power of $HUE_j$. The mathematical model for the second phase of APC power control is presented as (7):

$$P_{APc} = \max(P_{dmin}\, min(QIF * P_{dt}, P_{dmax})) \qquad (7)$$

where $P_{dmin}$ and $P_{dmax}$ represents the minimum and maximum transmission power of UE respectively.

### B. *Attenuation Factor Model*

An attenuation factor model is an indoor propagation model that also captures signal loss due to type of building floors [13]. The attenuation factor model is presented as (8):

$$[P_L(d)]dB = [P_L(d_o)]dB + 10nlog_{10}(\frac{d}{d_o}) + faf \qquad (8)$$

where $P_L(d)$ is log-distance propagation path loss, $P_L(d_o)$ is free space path loss, $d_0$ stand for reference distance, $d$ is the distance between node and UE, $faf$ is floor attenuation factor and $n$ is path loss exponent of different environments.

### C. *Signal to Interference Plus Noise Ratio (SINR)*

SINR of MUE and that of HUE is compute using (9) as in [12]

$$SINR_{rx} = \frac{P_{tr}\, PL_{tr-rx}}{\sum_f I_{co-tier} + \sum_f I_{cross-tier} + P_n} \qquad (9)$$

where $P_{tr}$ is the transmission power, $PL_{tx-rx}$ is transmission path loss. $\sum_f I_{co-tier}$ is the sum co-tier interference . $\sum_f I_{cross-tier}$ is the sum cross-tier interference. $P_n$ is the thermal noise density.

### D. *Network Data Rate*

Network data rate is compute using (10) according to works of authors in [8, 9]

$$c = \propto Blog_2(1 + SINR_{UE}) \qquad (10)$$

where $c$ is network data rate, $B$ is system bandwidth, $\propto$ is attenuation factor and $SINR_{UE}$ is computed SINR of user UE.

As presented in [14] average data rate is obtained using (11).

$$C^{Avg}_{throughput} = \frac{\sum_{i=1}^{n} C_{rx}}{N_{rx}} \qquad (11)$$

$\sum_{i=1}^{n} C_{rx}$ stands for sum of all received data rate in the network , $N_{rx}$ stands for number of receiver's in the HetNet.

## II. DESCRIPTION OF SYSTEM MODEL

The research system model captured an interference scenario between the primary (macrocell) and secondary (femtocell) network, and also within the secondary network. In this work, co-channel deployment, femtocell closed access mode, cross-tier and co-tier interference were considered. Fig.3 present the system model considered.

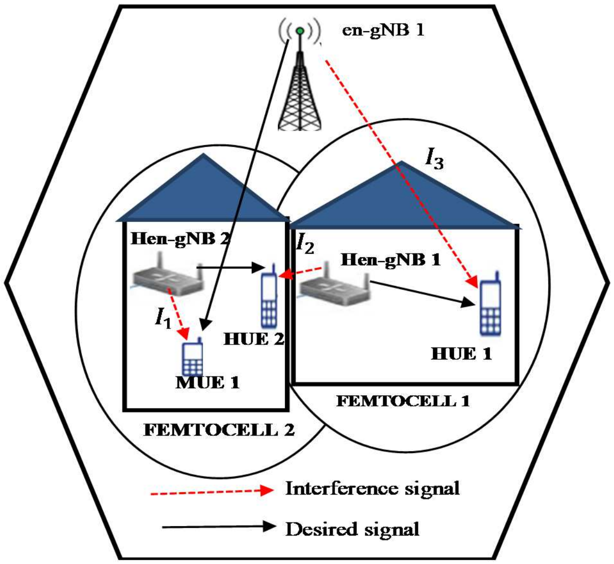

Fig. 3. System model

In Fig. 3. It is assume that Hen-gNB 2 is in close access mode and MUE 1 is not registered on it, therefore MUE 1 cannot access its service, even though located close. Hence the downlink signal from Hen-gNB 2 is received as downlink cross-tier interference ($I_1$) by MUE 1. en-gNB 1 downlink transmission is received at HUE 1 as downlink cross-tier interference ($I_3$). And HUE 2 situated at cell edge receives downlink transmission signal from Hen-gNB1 as downlink co-tier interference ($I_2$).

## III. ENHANCED ACTIVE POWER CONTROL TECHNIQUE

The downlink transmission power of en-gNB and Hen-gNB, propagation path loss, and received UE SINR are computed. The value of the computed SINR is compared to UE target SINR. The difference between the SINRs is denoted as $\delta_d$, which determines when to increase, maintain or reduce the downlink transmission power of nodes as expressed mathematically in (12) – (14).

$$\delta_d = SINR_{measured} - SINR_{target} \qquad (12)$$

$$if\ \ \delta_d = \begin{cases} < 0 & assign\ \ S = +1 \\ > 0 & assign\ \ S = -1 \\ = 0 & assign\ \ S = 0 \end{cases} \tag{13}$$

$$P_{EAPC} = max\left(P_{dmin,}\ min\left((P_{current} += S\Delta_{EAPC}), P_{dmax}\right)\right) \tag{14}$$

where $P_{EAPC}$ is the next transmission power of enhanced active power control, $P_{current}$ is the current transmission power of node, and $\Delta_{EAPC}$ is EAPC step power value of 0.5 dB. The outcome of (14) computation will be the next transmission power of the Hen-gNB, or en-gNB for a set time duration ($Tf_1$). After the expiration of $Tf_1$ the EAPC technique start all over again to ascertain the next transmission power. The EAPC technique used en-gNB path loss model in (15) adopted from [8, 12] and Hen-gNB path loss model in (16) adopted from [1].

$$PL_M(dB) = 15.3 + 37.log(R1) + l_p \tag{15}$$

$$PL_f(dB) = -log_{10}\left(\frac{c}{f*4\pi*d_0}\right)^2 + 60log_{10}\left(\frac{d_2}{d_0}\right) + 16.2 + l_p \tag{16}$$

Substituting $d_0 = 1m$, in (16) will give (17)

$$PL_f(dB) = 20\log(f_{MHz}) + 60\log(d_2) - 11.4 + l_p \tag{17}$$

where $P_L(d_o)$ is free space path loss, $f$ is carrier frequency in MHz, c is speed of light, and $d_0$ is reference distance, $d$ is the distance between node and UE. The algorithm of the EAPC is presented in table 1.

TABLE 1. ALGORITHM OF EAPC

**Algorithm of an Enhanced Active Power Control**

```
1  Initialization: booting of UE, Hen-gNB, and
   en-gNB
2  Loading of System Parameter:
   $B, f, L, SINR_{target}, P_d, P_{max}, P_{min,}\ \Delta_{EAPC}$
3  $for\ x = 1{:}L$
   Compute:
       • Path loss using (15) and (17)
       • SINR using (9)
             $\delta_d = SINR_{measured} - SINR_{target}$
       • Data rate using (10)
4    $if\ \delta_d < 0$
         $S = -1$
       $elseif\ \delta_d > 0$
         $S = +1$
       $else\ S = 0$
   End if
5  Power Adjustment: using (14)
6  Increment loop: $L += 1$
7  End for loop
```

## IV. Novelty of Work

The deployment of an enhanced active power control technique (EAPC) in downlink transmission of Macro-Femto HetNet for interference mitigation in 5G NSA of Macro-Femto HetNet. And also, the evaluation of the performance of an EAPC technique in conserving node power and optimizing network data rate when compared with related interference mitigation techniques.

## V. RESULTS AND DISCUSSION

Due to the existing relationship between interference, data rate and transmission power; where interference is directly proportional to transmission power and inversely proportional to data rate. The study used data rate and node transmission power as its key performance indicators (KPIs). The input variables used for the simulation as presented in Table 2 were sourced from [1, 8, 11, 14, 16]. The data rate performance of UEs and transmission power of node using EAPC technique were compared with that of other related techniques, and presented in Fig. 4 – 7. The evaluated en-gNB transmission power is captured in Fig. 4.

TABLE 2. DOWNLINK SIMULATION VARIABLES

| No. | Variable | Value |
|---|---|---|
| 1. | Maximum transmission power of Hen-gNB | 23 dBm |
| 2. | Maximum transmission power of en-gNB | 46 dBm |
| 3. | Minimum transmission power of Hen-gNB | 0 dBm |
| 4. | Minimum transmission power of en-gNB | 5 dBm |
| 5. | Initial transmission power of HUE | 8 dBm |
| 6. | Initial transmission power of MUE | 34 dBm |
| 7. | Bandwidth | 60 MHz |
| 8. | Carrier frequency | 2.6 GHz |
| 9. | Thermal noise | -174 dBm |
| 10. | Target SINR | 10 |

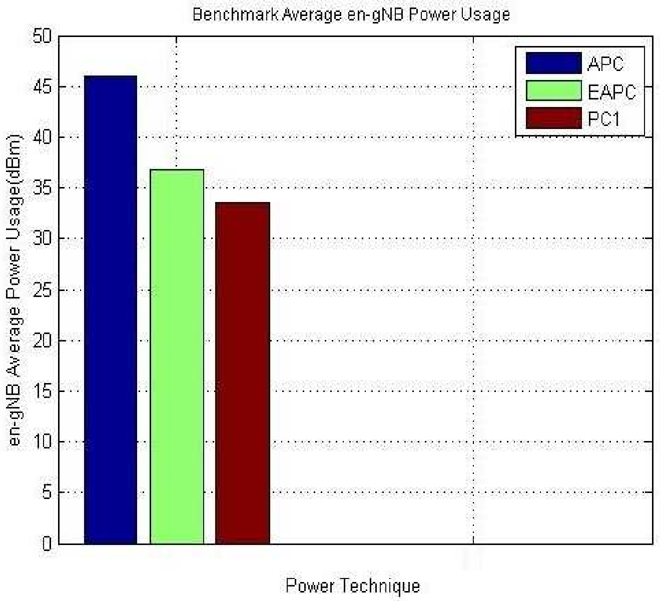

Fig. 4. Evaluated power usage of en-gNB

The power usage of en-gNB using APC, EAPC, and PC1 techniques gave 46.00 dBm, 36.45 dBm, and 33.50 dBm respectively. The EAPC technique when compare to APC conserved 21% of en-gNB power. While PC1 technique when compared to EAPC and APC techniques conserved 8% and 27% en-gNB power respectively. Fig. 5 presents the average power usage of Hen-gNB, when transmitting to its UEs.

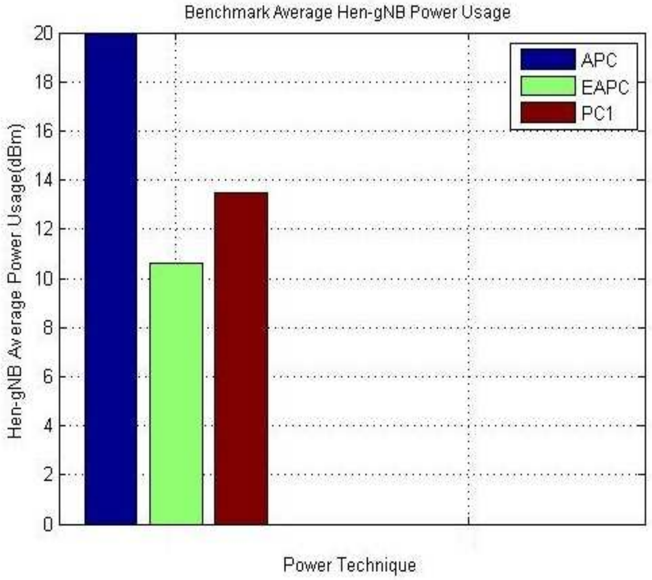

Fig. 5. Evaluated power usage of Hen-gNB

From Fig. 5 APC, EAPC, and PC1 techniques had an average Hen-gNB power usage of 20.00 dBm, 10.65 dBm, and 13.50 dBm respectively. The EAPC technique conserved 47% and 33% Hen-gNB power when compared to APC and PC1 techniques respectively. This implies that EAPC technique is most efficient in conserving node power when communicating to UEs; then closely followed by PC1 and lastly APC technique.

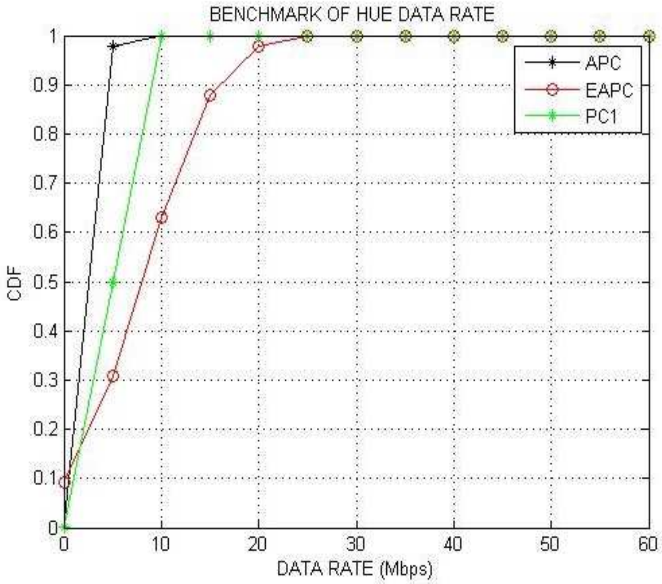

Fig. 6. Evaluated data rate of home user equipment

Based on Fig. 6, generally from CDF of 0.2 and above, the performance of EAPC technique outperforms that of APC and PC1 techniques. APC technique performs better than EAPC from CDF value of 0 to 0.1. While PC1 technique had the best data rate performance from CDF of 0 to approximately 0.2. The HUE data rate of APC, EAPC, and PC1 technique at 0.5 CDF gave data rate of 2.9 Mbps, 8.2 Mbps, and 5.2 Mbps respectively. The HUE data rate of EAPC technique outperforms that of APC and PC1 technique by 65% and 37% respectively. Fig. 7 presents the result of evaluated MUE Data rate.

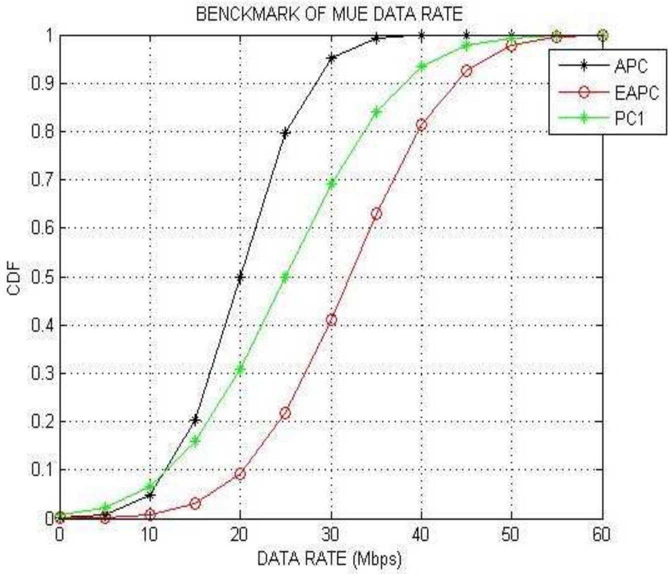

Fig. 7. Evaluated data rate of macro user equipment

From Fig. 7, the MUE data rate using APC, EAPC, and PC1 technique at 0.5 CDF gave data rate of 20.0 Mbps, 31.7 Mbps, and 25.1 Mbps respectively. The MUE data rate of EAPC technique outperforms that of APC and PC1 technique by 37% and 21% respectively.

## VI. CONCLUSION

The downlink transmission of Macro–Femto HetNet was considered in this study. Femtocell closed access mode, co-channel deployment, co-tier and cross-tier interference were all taken into cognizance. The network simulation was carried out using MATLAB software; in accordance with the research system model and input variables. The results obtained are presented in Fig. 4 – 7. From the evaluated results, EAPC technique had the best MUE and HUE data rate performance, as well as, the lowest Hen-gNB power usage. However, EAPC technique when compared with PC1 was limited in conserving en-gNB power by 8%. The better performance of EAPC technique when compared with APC and PC1 technique in conserving power and improving data rate of mobile UEs is attributed to the extended attenuation factor model used in computing femtocell path loss and the use of an adaptable step power value of 0.5 dB.

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