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An Enhanced Active Power Control Technique for Interference Mitigation in 5G Uplink Macro-Femto Cellular Network

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Abstract— **Macro-femto heterogeneous network (HetNet) comes with tremendous inter and intra cell interference problems. This paper considered fifth generation (5G) non-stand-alone (NSA) architecture. An enhanced active power control technique (EAPC) is proposed to mitigate interference in uplink macro-femto HetNet. The MATLAB simulation result obtained in terms of average power consumption of macrocell user equipment (MUE) and femtocell user equipment (HUE) using EAPC technique stood at 6.7 dBm and 7.5 dBm respectively, as against that of active power control (APC), fixed power control (FPC) and power control 1 (PC1); which stood at 10.9 dBm, 23.0 dBm, 14.8 dBm for MUE and 11.1 dBm, 23.0 dBm, 14.8 dBm for HUE respectively. It indicates that HUE and MUE using EAPC technique had low average power consumption when benchmark. 5G NSA macrocell base station (en-gNB), 60% cumulative distributive function (CDF) of throughput based on EAPC, APC, PC1 and FPC techniques had 36.2 Mbps, 15.0 Mbps, 24.0 Mbps and 12.5 Mbps throughput respectively. And that of femtocell base station (Hen-gNB) according to EAPC, APC, PC1 and FPC was 25.0 Mbps, 23.0 Mbps, 10.0 Mbps and 18.6 Mbps throughout, respectively. This implies that EAPC has better Hen-gNB and en-gNB throughput when benchmarked with other related techniques. Hence, the proposed EAPC technique improves 5G network performance in terms of better throughput and conserving limited user equipment (UE) energy.**

Keywords—Heterogeneous Network, Femtocell Network; Inter-cell Interference; Throughput; and Average Power Consumption

I. INTRODUCTION

The population and the yearning of subscribers for voice and data services is increasing exponentially, with most of them located in offices and homes. The situation is more worrisome with the shift from the normal way of life to the new normal occasioned by coronavirus disease. The new normal brought about more people inclusiveness in digitized business, telemedicine, virtual meetings, seminars and conferences, among others, which further increased the demand for qualitative cellular network service. The indoor mobile users' traffic comprises of 30% voice and 70% data traffic as in [1], [2], and [3]. Ericsson mobility predicted that by 2021 there will be 9 billion mobile broadband subscriptions, 20% increase in smartphone data traffic and 25% video traffic increase as in [4]. This increase in network demand calls for a more robust and efficient network.

The cost of mounting several outdoor base stations by network operators to meet up with subscriber's needs for high throughput and large network cell coverage is a challenge in homogeneous macrocell network. This necessitates the use of low power base stations as an overlaid on existing macrocells to form a heterogeneous network (HetNet), to achieve wider coverage, higher efficiency, and enhanced throughput in cellular network as in [5], and [6]. 5G ultra dense network (UDN) was designed to increase throughput and spectrum efficiency of the network to accommodate more subscribers and reduced power consumption as in [7]. This can be achieved by depopulating the densely populated macrocell network using small cell (Femto) nodes and further reducing interference in the HetNet.

Femtocell being a plug and play base station is usually installed by subscribers without taking into cognizance its cell coverage radius or other nearby cells, resulting into cell overlap which increases inter-cell interference (ICI). This interference issue is considered as the major technical challenge associated with femtocell deployment on an existing macrocell layer as in [8], [9], and [10].

II. LITERATURE REVIEW

A. Related Power Control Techniques

Power is a critical resource in mobile networks, hence the need for its control. When power is mismanaged, it results into wastage, interference, high latency and drop calls. Transmitting with just enough power to maintain the required quality of service ensures minimal interference.

A.1. Power Control 1Technique

Dynamic power control technique (PC1) for mitigating interference, adjusted the transmit power of user equipment's (UEs) based on measurements from the surrounding as seen in [11]. The power control adjustment is centered on the difference (γ), between measured signal-to-interference-plus-noise ratio ($SINR_{measured}$) and target SINR ($SINR_{target}$) as expressed mathematically in (1)

$$\gamma = SINR_{measured} - SINR_{target} \tag{1}$$

When the $SINR_{measured}$ is less than $SINR_{target}$, the present transmit power of user equipment (UE) will increase in the next transmission by constant power value of 2 dB, but when $SINR_{measured}$ is greater than $SINR_{target}$, the present transmit power of the UE will be decrease by same constant power value of 2 dB in the next transmission. And If the $SINR_{measured}$ is equals to $SINR_{target}$, the present UE transmit power will be maintained in the next transmission.

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Mathematically, PC1 transmit power adjustment is expressed in (2).

$$P_{tx} = \begin{cases} \min[P_{tx}(t_j) + \Delta, P_{max}]; & \gamma < 0 \\ P_{tx}(t_j); & \gamma = 0 \\ \max[P_{tx}(t_j) - \Delta, P_{min}]; & \gamma > 0 \end{cases} \quad (2)$$

where P_{tx} is the next transmit power, $P_{tx}(t_j)$ is the present transmit power, Δ is the constant power value, P_{min} is the minimum transmit power, and P_{max} is the maximum transmit power.

A.2. Active Power Control Technique

An active power control (APC) technique for interference management, adjusted the transmit power of aggressor (AG) based on interference message (IM) as captured in [6]. The victim (VT) computes the interference indication function (IDF) and determine whether to send an IM or not. When the computed IDF is greater than the set threshold interference, the VT sends an IM including the AG information to its transmitter, which then uses the backhaul and forward the IM to the AG indicating interference in the network, otherwise it does not send an IM. Equation (3) presents the mathematical equation for computing IDF, and (4) express when an IM is or is not sent.

$$I_i = P_t^i \psi_i (R_i)^{-\beta} \quad (3)$$

$$x_i = \begin{cases} 0, & I_i \leq I_{Threshold} \\ 1 & otherwise \end{cases} \quad (4)$$

where P_t^i is the transmit power, ψ represents log – normal shadowing, R is the distance between the transmitter and receiver, β is the pathloss component for the indoor transmission and I_i is the IDF. In (4), $I_{Threshold}$ is the set interference threshold. x_i stands for IM, when $x_i = 0$, it implies there is no interference and IM is not sent, and when $x_i = 1$, it implies there is interference and IM is sent.

The APC technique basically has two power adjustment stages: the first stage, set three transmit power (P_x, P_y, P_z) and two-time levels (TL_1, TL_2). They set P_x as the maximum transmit powers, followed by P_y and lastly P_z as minimum transmit powers. When an IM is received, the APC power adjustment activates, and the transmit power of the AG is reduced from say P_x to P_y by constant down power value (Δ_{down}). If the same AG receives another IM within the first-time level (TL_1), it will not further reduce its AG power to P_z level until TL_1 expires. Similarly, when the AG has no IM and TL_1 expires, then the second time level (TL_2) starts and the transmission power level increases from P_y to P_x by constant up power value (Δ_{up}). Δ_{down} and Δ_{up} are fixed power value of -2 dB and 2 dB respectively. The transmit power adjustment is mathematically expressed in (5) – (9).

$$P_t = P_x \qquad \text{No IM} \qquad (5)$$

$$P_t = P_y = P_x - \Delta_{down} \qquad \text{IM and } TL_1 \text{ starts} \qquad (6)$$

$$P_t = P_z = P_y - \Delta_{down} \qquad \text{New IM and } TL_1 \text{ starts} \qquad (7)$$

$$P_t = P_y = P_z + \Delta_{up} \qquad \text{No IM and } TL_2 \text{ start} \qquad (8)$$

$$P_t = P_x = P_y + \Delta_{up} \qquad \text{No I and } TL_2 \text{ running} \qquad (9)$$

The second stage of active power control technique shapes the first stage APC transmit power based on the minimum required quality of service (QoS) of signal received. The mathematical computation of QoS Indication Function (QIF) is expressed in (10)

$$QIF = \frac{P_{uref}\tau_{HUE}}{minRSRP_j} \quad (10)$$

where τ_{HUE} is the minimum required SINR for user equipment, P_{uref} is the uplink reference signal transmit power and $minRSRP_j$ is the minimum reference signal received power. The second and final stage of APC transmit power adjustment is given mathematically in (11).

$$P_{APc} = \max(P_{min}\, min(QIF * P_t, P_{max})) \quad (11)$$

where P_{min} and P_{max} are minimum and maximum transmit power, respectively.

B. Attenuation Factor Model

This propagation model was described by Siedel, which considered the effects of building type and obstacles as in [12]. The attenuation factor model equation is given in (12) and pathloss exponent of different environments is captured in Table 1.

$$[P_L(d)]dB = [P_L(d_o)]dB + 10nlog_{10}(\frac{d}{d_o}) + faf \quad (12)$$

where $P_L(d)$ is log-distance pathloss from transmitter to receiver, $P_L(d_o)$ is free space pathloss, n is pathloss exponent, d_0 stand for reference distance, d is the distance between transmitter and receiver, and faf is floor attenuation factor.

Table 1. Pathloss exponent of different environments (Source: [12])

S/N	Environment	Path loss exponent *n*
1.	Free space	2
2.	Urban area cellular radio	2.7 - 3.5
3.	Shadowed urban cellular radio	3 – 5
4.	In building line-of-sight	1.6 - 1.8
5.	Obstructed in building	4 – 6
6.	Obstructed in factories	2 – 3

C. Signal to Interference Plus Noise Ratio (SINR)

en-gNB SINR and Hen-gNB SINR is calculated using (15) and (16) as presented in [11].

$$SINR_{en-gNB} = \frac{P_{MUE}PL_{MUE-en-gNB}}{\sum_M P_M^k PL_M + \sum_F P_F^k PL_F + P_n} \quad (15)$$

$$SINR_{Hen-gNB} = \frac{P_{HUE}PL_{HUE-Hen-gNB}}{\sum_M P_M^k PL_M + \sum_F P_F^k PL_F + P_n} \quad (16)$$

where P_{MUE} and P_{HUE} are the transmit power by macro user equipment (MUE) and home user equipment (HUE) respectively. $PL_{MUE-en-gNB}$ and $PL_{HUE-Hen-gNB}$ are propagation pathloss within; MUE and en-gNB, and HUE and Hen-gNB respectively. $\sum_M P_M^k PL_M$ is the sum product of interfering MUE transmit power and its propagation pathloss. $\sum_F P_F^k PL_F$ is the sum product of interfering HUE transmit power and its propagation pathloss. P_n is the thermal noise density.

D. Network Throughput

The throughput of the network is computed using Shannon-Hartley equation for throughput, given in (17)

$$c = Blog_2(1 + SINR_{Base\ station}) \qquad (17)$$

where c is network throughput, B is system bandwidth, and $SINR_{Base\ station}$ is SINR of base station.

Average throughput of Hen-gNB, en-gNB and total throughput of the entire femto– macro network is obtained using equations (18), (19) and (20) respectively, as in [13].

$$c^{Avg}_{Hen-gNB} = \frac{\sum_{i=1}^{n} c_{Hen-gNB}}{N_{Hen-gNB}} \qquad (18)$$

$$c^{Avg}_{en-gNB} = \frac{\sum_{i=1}^{n} c_{en-gNB}}{N_{en-gNB}} \qquad (19)$$

$$c_{overall} = \frac{(N_{en-gNB} \times c^{Avg}_{en-gNB}) + (N_{Hen-gNB} \times c^{Avg}_{Hen-gNB})}{(N_{en-gNB} + N_{Hen-gNB})} \qquad (20)$$

where $\sum_{i=1}^{n} C_{en-gNB}$ stand for sum of all en-gNB throughput, $\sum_{i=1}^{n} C_{Hen-gNB}$ for sum of all Hen-gNB throughput, while N_{en-gNB} and $N_{Hen-gNB}$ stands for number of en-gNB and Hen-gNB respectively in the HetNet.

III. SYSTEM DESCRIPTION AND MODEL

The system architecture in this paper captures an inter-cell interference (ICI) scenario between and within the primary and secondary system. The HetNet has one macrocell (primary system) and two overlaid femtocells (secondary system). Worst case scenario of interference in macro-femto HetNet occasioned by femtocell closed access mode, co-tier and cross-tier interference, and co-channel deployment is considered in this research. Fig. 1 present the system architecture considered in this work

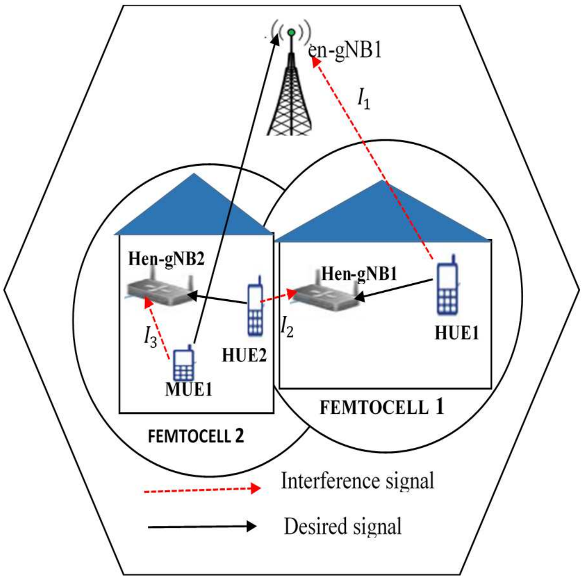

Fig. 1. System Architecture

The NSA 5G macrocell base station, called logical Node B is denoted as en-gNB and NSA 5G femtocell base station is denoted as Hen-gNB in accordance with NSA 5G system architecture presented in 3GPP standard release 15 [14]. Considering closed access mode configuration, MUE1 is not registered on Hen-gNB2 and cannot access its services; even though located close. The uplink signal from MUE1 is received as uplink cross-tier interference by Hen-gNB2. HUE1 uplink transmission is received by en-gNB as uplink cross-tier interference. Hen-gNB1 receives uplink transmission signal from HUE2 as uplink co-tier interference. In the proposed system architecture, I_1 represents uplink cross-tier interference, where en-gNB is the VT and HUE1 is the AG. I_2 is an uplink co-tier interference, where HUE2 is the AG and Hen-gNB1 is the VT. I_3 is an uplink cross-tier interference where MUE1 is the AG and Hen-gNB2 is the VT.

3.1 Pathloss Model

The proposed enhanced active power control (EAPC) technique uses pathloss model in (13) and (14) for uplink transmission from MUEs and HUEs respectively. The pathloss model ($PL_{UEs-base\ station}$) in (14) is an extension of attenuation factor model, where an obstructed building pathloss exponent of 6 and faf through one floor of 16.2 dB is used [12]. While the propagation pathloss model from MUE to base station (indoor and outdoor) in (13) is according to 3GPP LTE-Advanced pathloss model for urban deployments as in [15].

$$PL_{MUE-base\ station}(dB) = \begin{cases} 15.3 + 37.6log(R1) + l_p & (Indoor) \\ 15.3 + 37.6log(R1) & (outdoor) \end{cases} \qquad (13)$$

$$PL_{UEs-base\ station}(dB) = -log\left({}^{c}/_{f} * 4\pi * d_0\right)^2 + 60log\left({}^{d}/_{d_0}\right) + \qquad (14)$$

In (13) $PL_{MUE-base\ station}$ is pathloss from MUE to base station, $R1$ is distance between MUE and base station, and l_p is penetration loss. In (14) $PL_{UEs-base\ station}$ is the pathloss from UE to base station, c is speed of light, f is transmit frequency in MHz, d_0 is a reference distance, and d is the distance between transmitter and receiver.

IV. PROPOSED ENHANCED ACTIVE POWER CONTROL TECHNIQUE

The EAPC technique is described using a flowchart presented in Fig. 2

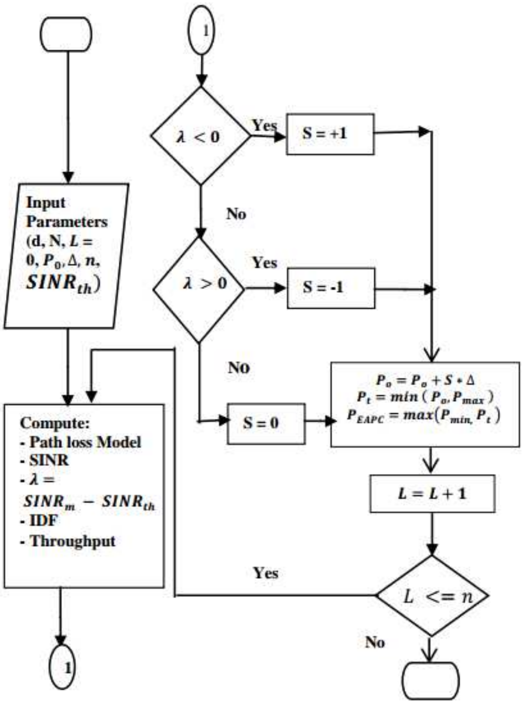

Fig. 2. EAPC flowchart

where input parameters d, N, L, $P_0, \Delta, n, SINR_{th}$ stands for initial distance between transmitter and receiver, thermal noise density, initial loop number, initial transmit power, constant power value, final loop number, and threshold SINR respectively. $SINR_m$ stands for measured $SINR$, λ is the difference between $SINR_m$ and $SINR_{th}$ ($\lambda = SINR_m - SINR_{th}$), S for adjustment parameter, P_{max} for maximum transmit power of UEs, and P_{min} for minimum transmit power of UEs. P_{EAPC} is the enhanced active power control transmit power use for next transmission for set time duration (Tf_1) of 200ms after which the system starts all over again to determine the next transmit power. Target SINR of 10 [6] was used.

The uplink transmission power of MUE and HUEs is measured alongside their respective propagation pathloss. The transmit power of the MUEs, HUE and their computed propagation losses is used to calculate SINRs. If λ is greater than zero the present UE transmit power will be reduce by constant power value for the next transmission; when it is less than zero, the present UE transmit power will be increase by same constant power value for the next transmission and when it is equal to zero, the present UE transmit power will be maintain for the next transmission.

V. SIMULATION PARAMETERS, RESULTS AND DISCUSSION

The simulation and results were obtained with the help of research system architecture and parameters sourced from ([6], [11], and [16]) and presented in Table 2.

Table 2. Uplink Simulation Parameters

No.	Parameter	Value
1.	Maximum transmit power of HUE and MUE	23 dBm
2.	Minimum transmit power of HUE and MUE	0 dBm
3.	Initial transmit power of HUE and MUE	5 dBm
4.	System bandwidth	10 MHz
6.	Carrier frequency	2.57 GHz
7.	Thermal noise	-174 dBm

The performance of the proposed technique is compared with three other related techniques, in terms of network throughput and average power consumption. Fig. 3 shows the average power used by MUE in communicating to en-gNB, considering ten transmissions at different time instances.

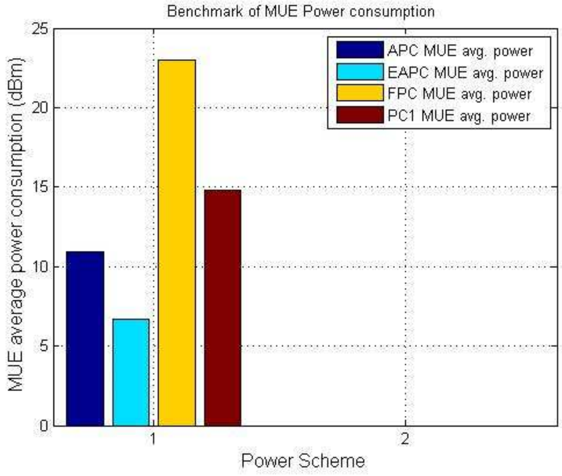

Fig. 3. Benchmark of MUE Average Power Consumption

The MUE average power consumption using APC, EAPC, FPC and PC1 power control techniques stood at 10.9 dBm, 6.7 dBm, 23.0 dBm and 14.8 dBm respectively. This indicates that EAPC technique has the lowest average power consumption followed by APC, then PC1, and lastly FPC. Fig. 4 presents an average power consumption of HUE techniques, when transmitting to UEs.

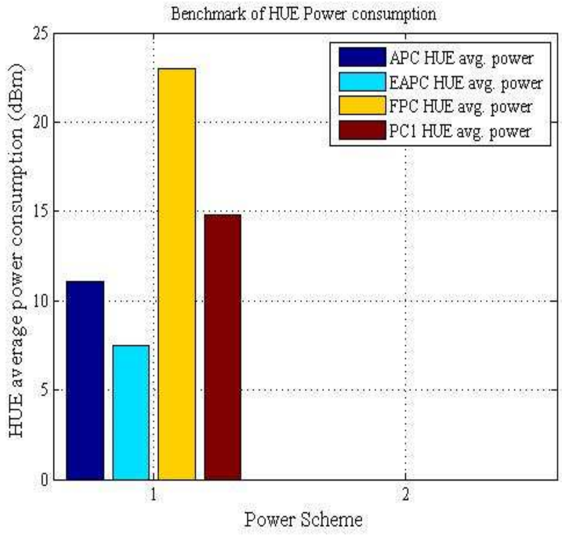

Fig. 4. Benchmark of HUE Average Consumption Power

The average consumption of HUE using APC, EAPC, FPC and PC1 power control techniques was 11.1 dBm, 7.5 dBm, 23.0 dBm and 14.8 dBm respectively. Again, EAPC has the lowest power consumption and FPC has the highest average power consumption.

Fig. 5 presents uplink cdf of Heng-NB throughput

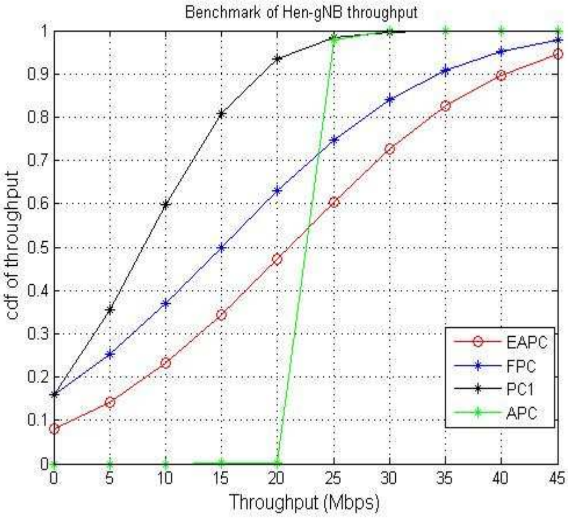

Fig. 5. Throughput of Hen-gNB

From the Hen-gNB throughput result obtained, the proposed EAPC technique at 0.6 or 60% cdf of throughput had 25.0 Mbps, while APC, PC1 and FPC had throughputs of 23.0 Mbps, 10.0 Mbps, and 18.6 Mbps respectively.

Fig.6 presents the result of uplink cdf of MUE throughput.

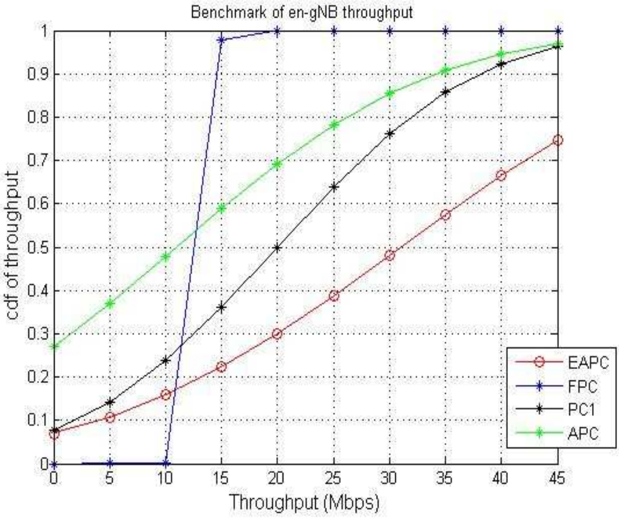

Fig. 6. Benchmark of en-gNB throughput

The en-gNB throughput result pointed out that the proposed EAPC at 0.6 or 60% cdf of throughput had 36.2 Mbps throughput; while FPC, PC1 and APC had 12.5 Mbps, 24.0 Mbps, and 15.0 Mbps throughput respectively.

VI. CONCLUSION

This research considered uplink transmission of macro–femto HetNet. The network simulation in MATLAB environment was guided by the research system architecture and simulation parameters, where worst case scenarios of co-channel and femtocell closed access mode deployment were employed. The proposed technique was analyzed and its performance benchmarked, as presented in figure 2 – 5. The result indicated that EAPC has the least MUE average power consumption of 6.7 dBm, and also least HUE average power consumption of 7.5 dBm.

EAPC at 60% cdf has the highest en-gNB throughput of 36.2 Mbps and highest Hen-gNB throughput of 25.0 Mbps. This implies that EAPC technique gives higher en-gNB and Hen-gNB throughput; and conserves UEs limited power in macro-femto HetNet.

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