# DEVELOPMENT OF AN ENHANCED ACTIVE POWER CONTROL TECHNIQUE FOR INTERFERENCE MITIGATION IN MACRO-FEMTO CELLULAR NETWORKS

**BY**

**DAWAR, Katfun Philemon MEng/SEET/2018/7932**

**DEPARTMENT OF TELECOMMUNICATION ENGINEERING FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA**

**NOVEMBER, 2021**

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**A THESIS SUBMITTED TO THE POSTGRADUATE SCHOOL, FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA NIGERIA IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF MASTER OF ENGINEERING IN COMMUNICATION ENGINEERING**

**NOVEMBER, 2021**

# DECLARATION

I hereby declare that this thesis titled: “Development of an Enhanced Active Power Control Technique for Interference Mitigation in Macro-Femto Cellular Networks” is a collection of my original research work and it has not been presented for any other qualification anywhere. Information from other sources (published or unpublished) has been duly acknowledged.

DAWAR, Katfun Philemon

MEng/SEET/2018/7932 SIGNATURE/DATE FEDERAL UNIVERSITY OF TECHNOLOGY

MINNA, NIGERIA

# CERTIFICATION

The thesis titled: “Development of an Enhanced Active Power Control Technique for Interference Mitigation in Macro–Femto Cellular Networks” by: DAWAR, Katfun Philemon (MEng/SEET/2018/7932) meets the regulations governing the award of the degree of MEng of the Federal University of Technology, Minna and it is approved for its contribution to scientific knowledge and literary presentation.

Engr. Dr. A. U. Usman

MAJOR SUPERVISOR Signature & Date

Engr. Dr. B. A. Salihu

CO-SUPERVISOR Signature & Date

Engr. Dr. A. U. Usman

HEAD OF DEPARTMENT Signature & Date

Engr. Prof. E. N. Onwuka

DEAN OF SCHOOL Signature & Date

Engr. Prof. O. K. Abubakre

DEAN OF POSTGRADUATE SCHOOL Signature & Date

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# ABSTRACT

Femtocells are overlayed on existing Macrocells to form Macro-Femto heterogeneous network (HetNet), to reduce cost of mounting expensive macrocell nodes, improve cellular network capacity and throughput performance. However, HetNet has a major problem of cross-tier and co-tier interference, which hinders its optimal performance, especially when the network capacity expands. With emergence of 5G technologies, interference would become more consequential. Therefore, curbing the effect of this interference is indispensable to sustain larger and efficient HetNet. In this work power control technique was explored to reduce the impact of interference in both Downlink and Uplink scenarios of 5G non-stand-alone (NSA) architecture of Macro-Femto HetNet. An enhanced active power control (EAPC) technique, was developed by hybridizing extended attenuation factor path loss model, Active Power Control (APC), and Power Control 1 (PC1) techniques. Attenuation factor model was extended by adding floor factor to capture both floor attenuation and wall factor, and used same in computing femtocell path loss. The EAPC technique also made use of a different step power value of 0.5 dB for adjusting it’s transmit power in order to maximize power and reduce interference. The hybridization when compared with APC and PC1 respectively yielded: 65% and 37% higher Home User Equipment (HUE) throughput; 37% and 21% higher Macro User Equipment (MUE) throughput; 41% and 63% higher throughput of femtocell node (Hen-gNB); 69% and 25% higher throughput of macrocell node (en-gNB). EAPC average power consumption compared to APC and PC1 respectively saved: 65% and 40% HUE battery energy; 38% and 42% MUE battery energy; 54% and 22% Hen-gNB energy. EAPC saved 21% en-gNB energy when compared to APC, but was limited by 8% when compared with PC1.

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# LIST OF ABBREVIATIONS

|  |  |
| --- | --- |
| Abbreviation | Meaning |
| 3GPP | Third Generation Partnership Project |
| 4G | Fourth Generation |
| 5G | Fifth Generation |
| AG | Aggressor |
| AN | Access Network |
| APC | Active Power Control |
| CDF | Cumulative Distributive Function |
| CQI | Channel Quality Indicator |
| CSG | Closed Subscriber Group |
| CSWF | Cross-tier Signal-Link-Plus-Noise-Ratio Based Water Filing |
| DL-DS | Downlink Desired Signal |
| DL-IN | Downlink Interference |
| DPCA | Dynamic Power Control Algorithm |
| DSL | Digital Subscriber Line |
| EAPC | Enhanced Active Power Control |
| EN-DC | Dual Connectivity to Evolved Universal Terrestrial Radio Access |
|  | Network and New Radio |
| eNB | evolved Node B |
| en-gNB | Non-Stand-Alone macrocell logical node |
| EPC | Evolved Packet Core |
| E-UTRAN | Evolved Universal Terrestrial Radio Access Network |
| FAF | Floor Attenuation Factor |
| FPCT | Fixed Power Control Technique |

|  |  |
| --- | --- |
| FUEAPCT | Femtocell User Equipment Assisted Power Control Technique |
| HeNB | Fourth Generation Femtocell Node |
| Hen-gNB | Fifth Generation Non-Stand-Alone Femtocell Node |
| Hen-gNB-GW | Fifth Generation Non-Stand-Alone Femtocell Node Gateway |
| HetNet | Heterogeneous Network |
| HP | Hewlett-Packard |
| HUE | Home User Equipment |
| ICI | Inter-Cell Interference |
| IDF | Interference Indication Function |
| IM | Interference Message |
| LTE | Long Time Evolution |
| MME | Mobile Management Entity |
| MUE | Macro User Equipment |
| NR | New Radio |
| NSA | Non-Stand-Alone |
| PAA | Power Adjustment Algorithm |
| PC1 | Power Control 1 |
| PCID | Physical Cell Identity |
| PJA | Power Adjustment Algorithm |
| PLR | Packet Loss Ratio |
| QIF | Quality of Service Indication Factor |
| QoS | Quality of Service |
| S-GW | Serving Gateway |
| SINR | Signal-to-Interference-plus-Noise-Ratio |
| SLNR | Signal-to-Leakage-plus-Noise-Ratio |

|  |  |
| --- | --- |
| UDN | Ultra Dense Network |
| UE | User Equipment |
| UP-DS | Uplink Desired Signal |
| UP-IN | Uplink Interference |
| VT | Victim |
| VoIP | Voice over Internet Protocol |

# CHAPTER ONE

# INTRODUCTION

## Background to the Study

The cellular communication network is a wireless system where users are clustered into cells and served by nodes. The number of mobile users served by macrocell node is increasing every day, with most of the subscribers located at homes and offices (indoor environment). This indoor mobile user has traffic that comprised of 30% voice and 70% data (Priya and Seema, 2017; Aneeqa, *et al.,* 2017; Onu *et al.*, 2018; Dawar *et al.,* 2021). Indoor propagation path loss is characterized by wall penetration loss, floor attenuation factor, and distance between an indoor node and user equipment. In a homogeneous macrocell network, the cost of mounting several macro nodes to meet up with subscriber’s need for high throughput and large coverage is a challenge. This necessitates the deployment of low-power and less expensive nodes to increase the throughput and capacity of the existing macrocell network, at the expense of increase interference.

Interference signals are undesired signals picked by a neighboring receiver, which is a common wireless communication network problem. This interference degrades the performance of the cellular network in terms of drop calls, latency, and poor quality of service; mostly in a partially dedicated channel or co-channel deployment (Priya and Seema 2017). Therefore, there is a need for a thorough study on interference within and between network tiers, in order to develop an efficient interference mitigation technique.

The fifth generation (5G) Ultra-Dense Network (UDN) have a target of increase coverage, throughput, and spectrum efficiency, to accommodate huge subscribers (Agiwal *et al.,* 2016; Asif *et al.*, 2019; Dawar *et al.*, 2021). This can be achieved by

deploying more nodes in a given area, using a large number of small nodes (Farah *et al.,* 2016; Mythili and Mahendran, 2017; Achonu *et al.,* 2020). Femtocell node is the smallest cell node that has high data rate, low latency, easy installation, low energy consumption, better coverage, security, and less packet loss. Researchers asserted that the use of this low-power femtocell on an existing macrocell network to form a heterogeneous network (HetNet) will accomplish the target of wider coverage, high efficiency, and enhanced throughput in the cellular network. (Onu *et al.,* 2018; Amandeep *et al*., 2019; Hassan and Gao, 2019; Haroon *et al*., 2021). However, the expanding installation of femtocells on the existing macrocell network comes with an interference problem. This interference is attributed to the random installation of femtocell nodes by users, and the contention for the same licensed spectrum by both femtocells and macrocells users.

## Statement of the Research Problem

The high demand for voice, data, and video streaming services by an ever-increasing mobile user's mostly located in an indoor environment is alarming (Heli *et al.,* 2015; Tuan, *et al.,* 2017). This is more pronounced with the increase in virtual meetings, telemedicine, smart agriculture, smart city, smart homes, and cloud computing. Ericsson's mobility report, as presented in Sajjad *et al.* (2018), indicated that in 2021, there will be nine billion mobile broadband subscriptions, out of which seven billion will use mobile data. Their report also pointed out, that smartphone data will increase by 20% and video traffic will increase by 25%. As the demands increase with the advent of 5G Ultra-Dense Network, the cell coverage, network capacity and throughput of homogeneous network will reduce, resulting into poor indoor network services.

According to literatures, the overlay of femtocell on existing macrocell netwok is said to be one of the promising technique that would provide the needed solution to the poor indoor network service, increased network coverage and capacity (Heli *et al*., 2015; Xu and Qui, 2018). However, femtocell node being a plug and play node, that used license frequency band, and is installed by subscribers without taking into cognizance its cell coverage or other nearby cells, have high chances of cell overlap, that causes an increase in interference. This interference is the main technical problem attributed with Macro-Femto HetNet (Al-omari *et al.*, 2016; Farah *et al.,* 2016; Feng, *et al*., 2018; Mohammad *et al*., 2019).

Researchers have postulated different power control techniques for curbing the interference problem with successes, even though there is still room for improvement. This research seeks to study interference in Macro-Femto HetNet and developed an enhanced power control technique from existing power control techniques; to contribute in solving the interference problem in Macro-Femto HetNet.

## Aim and Objectives of the Research

The research aims at developing an Enhanced Active Power Control (EAPC) technique for interference mitigation in 5G Non-Stand-Alone (NSA) architecture of Macro-Femto cellular communication networks. To achieve this, the following objectives were set:

* + 1. Hybridization of attenuation factor model, active power control technique and power control 1 techniques to develop an enhanced active power control (EAPC) technique.
    2. Simulate EAPC technique in Macro-Femto cellular communication network using MATLAB.
    3. To evaluate the performance of the EAPC technique and compare it with that of existing power control techniques, in terms of throughput and power consumption.

## Scope of the Study

The research work centred on developing an enhanced active power control technique, for mitigating co-tier and cross-tier interference in 5G NSA of Macro-Femto HetNet. The research system architecture, parameters, and assumptions would guide the MATLAB simulation of the Macro-Femto HetNet. The performance of the EAPC technique would be compared with that of PC1 and APC technique in terms of throughput and transmit power consumption.

## Justification for the Study

Interference is a major problem in wireless communication networks which reduced network throughput and increase drop calls.

The work of Hassan and Gao (2019) proposed an active power control technique for mitigating interference in Macro-Femto communication networks, which reduced interference in the network, gave high throughput and low node power consumption when benchmarked; but more need to be done to improve on the existing technique. Their network scenario considered static user equipment (UE) and cross-tier interference only; it did not considered co-tier interference and attenuation due to floor. Therefore there is a need to enhanced active power control technique, consider co-tier and cross-tier interference, attenuation due to floor factor, and mobile UEs to capture a realistic network scenario, further reduce power consumption and increase network throughput in 5G Macro-Femto communication networks.

## Thesis Outline

The remaining part of the thesis is organized as follows. Chapter two review 5G non-stand-alone architecture, femtocell network, femtocell access mode, Macro-Femto HetNet, network interference in Macro-Femto HetNet, mathematical models for Macro-Femto HetNet, and also related works of literature on interference mitigation using power control technique. Chapter three presents the research system model, and methodology. Chapter four presents and discusses the MATLAB simulation results in sections. And chapter five states the conclusion and recommendations of the research.

# CHAPTER TWO

# LITERATURE REVIEW

## Preamble

The rapid increase of smartphones and the growth of multimedia services with more mobile data and voice traffic emanating from indoor environments where the coverage of macrocell is not good enough is a problem in cellular communication. Researchers postulated in several works of literature the use of femtocell to curb the challenge of network coverage and throughput when interference is efficiently mitigated. This interference problem can be reduced using diverse mitigation techniques, such as power control, frequency reuse, and cognitive radio sensing technique, but cannot be eliminated completely. This research work centered on mitigating interference using power control technique, because of its merits which include: universal frequency reuse, transmit power utilization, and simplicity. The chapter presents a review on 5G non-stand-alone (NSA) architecture, femtocell network, HetNet, types of Macro-Femto interference, mathematical models, and related power control techniques for interference mitigation.

## Fifth Generation (5G) Non-Stand-Alone (NSA) Architecture

5G Mobile Systems (5GS) introduced a New Radio (NR) and interfaces that provide the required technology to support different types of services. 5GS has two architectures; the 5G Non-Stand-Alone (NSA) and 5G Stand-Alone (SA). In the 5G SA architecture, 5G user equipment communicates to the new 5G Access Network (AN), which in turn connects to the new 5G Core Network only (3rd Generation Partnership Project “3GPP” release. 15.0.0; Imane *et al*., 2020).

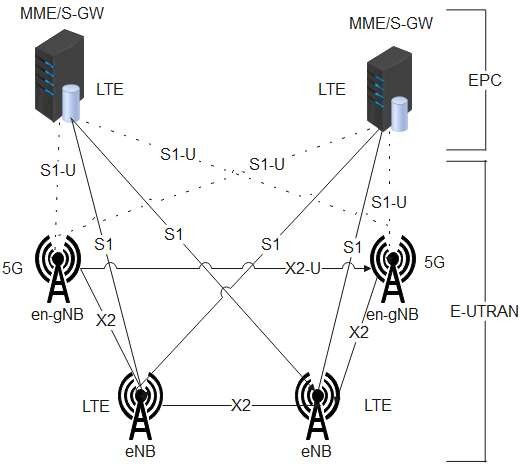
NSA architecture is a step toward full 5G implementation. The AN and NR interface of 5G NSA is compatible with 4G Long Time Evolution (LTE) node and its Evolved Packet Core (EPC) infrastructure. This makes 5G NSA NR technology accessible to 4G LTE users without replacing the 4G core network infrastructures. Figure 2.1 shows an illustration of 5G NSA architecture.

Figure 2.1: 5G NSA architecture (Source: 3GPP Release 15.0.0)

According to the architecture of 5G NSA, the NR node (logical node "en-gNB") connects to 4G LTE node (logical node "eNB") using an X2 interface. The en-gNBs connect each other via the X2-U interface and connects to EPC using the S1-U interface. In NSA, 5G handles the U-Plane, that has to do with data packets; while the C-plane that has to do

with control signals for call origination and termination, UE location and registration, are handled by the LTE eNB and EPC (Imane *et al*., 2019). The NSA is also called “EN-DC", for "E-UTRAN and NR Dual Connectivity” because it connects both 4G AN (E-UTRAN) and 5G AN (3rd Generation Partnership Project “3GPP” release 15.0.0; Imane *et al*., 2019).

## Femtocell Network

Femtocell network from the prefix femto is a very small cellular network, refer to as a home network. The femtocell node (Hen-gNB) is a very small access point that has low transmit power, low cost, and is installed by users. It has a cell coverage radius of 20 – 30m (Adeyemo *et al.*, 2015; Onu *et al*., 2018; Haroon *et al*., 2019). The femtocell connects user equipment to core network of mobile operator's using residential Digital Subscriber Line (DSL) backhaul, cable broadband, or fiber cable. The major benefit of femtocell network is an increase in system throughput when interference is well mitigated (Gurpreet *et al.,* 2016; Jundhare and Kulkarni, 2016; Priya and Seema 2017). Femtocell interference problem is characterized by uncertainty in the position of Hen-gNBs, irregular cell coverage, co-channel deployment, and Hen-gNB access mode (Jinlong *et al.*, 2015; Priya and Seema, 2017).

The 4G LTE-5G NSA architecture of femtocell is divided into two main segments. EPC and the enhanced universal terrestrial radio access network (E- UTRAN). The E-UTRAN is made up of femtocell nodes. While, the EPC consists of femtocell–gateway (Hen-gNB - GW), mobile management entity (MME), and serving gateway (S-GW). Figure 2.2 presents a schematic diagram of a typical 4G–5G NSA femtocell network.

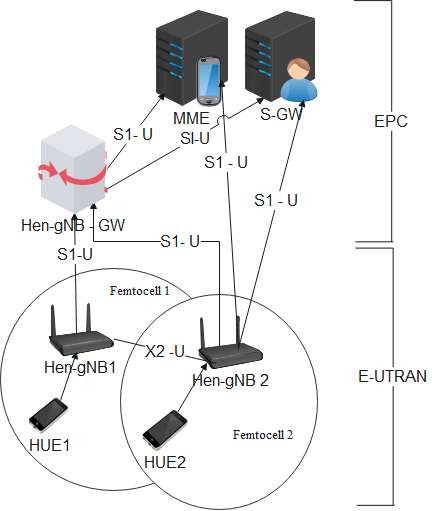


Figure 2.2: Femtocell network (Source: 3GPP release 15.00; Asif, *et al.,* 2019)

From Figure 2.2, HUE 1 stand for Home User Equipment (HUE) 1 of femtocell 1, HUE 2 stand for HUE 2 of femtocell 2. According to the 3GPP standard, femtocell node transfer information directly to MME and serving gateway (S-GW) using S1-U interface or optionally through Hen-gNB gateway (Hen-gNB-GW). The Hen-gNB-GW communicates with MME and S-GW through S1-U interface. It is responsible for aggregating a large number of connected Hen-gNBs, and connects them to a core network. MME helps to authenticate UEs, pages UEs, and tracks both active and idle UEs. S-GW routes and forwards user data packets and terminate downlink data for idle UEs. It also hold packets send to an idle UE until the idle UE is paged and a Radio Frequency (RF) channel is re-established. The S-GW is also responsible for Internet protocol backhaul admission and congestion control.

## Femtocell access mode

The ability of UE to access Hen-gNB services can be restricted or unrestricted, this forms the basis for the three femtocell access modes, which are: open, closed, and hybrid (Sharanya *et al.,* 2015; Tarte and Hanchate, 2017; Hassan and Gao, 2019). Open access mode allows all UEs to connect to any close by Hen-gNB without any restriction or permission. HUE connects to an open access Hen-gNB whenever it receives a high signal from the nearby Hen-gNB. Closed access mode which is also called Closed Subscriber Group (CSG), is a restricted access mode that allows only registered UEs on a particular Hen-gNB to connect and use its services. Whereas, the hybrid access mode is a combination of open and closed access mode, where registered HUEs are given higher priority when compared to unregistered HUE. The registered HUEs have a large portion of reserved transmission bandwidth for their usage, while the unregistered HUEs contend for the remaining small transmission bandwidth.

## Macro-Femto Heterogeneous Network

The Macro-Femto heterogeneous network is a two tiers cellular communication network that comprises of macrocell and femtocell networks, co-existing together to expand network coverage, and increase throughput performance (Afolalu *et al*., 2016; Achonu *et al*., 2017)**.** There are other different types of small cell networks that can be integrated into existing macrocell network; examples of such small cell networks are microcell, and picocell (Meer and Kaleem 2020). Among the different small cell networks, femtocell have been the most promising, in terms of high quality of service to indoor users, low cost to network providers, and easy installation (Andrian *et al*. 2015; Xuan *et al.,* 2016; Haroon *et al.,* 2019). Figure 2.3 gives a schematic diagram of Macro-Femto HetNet.

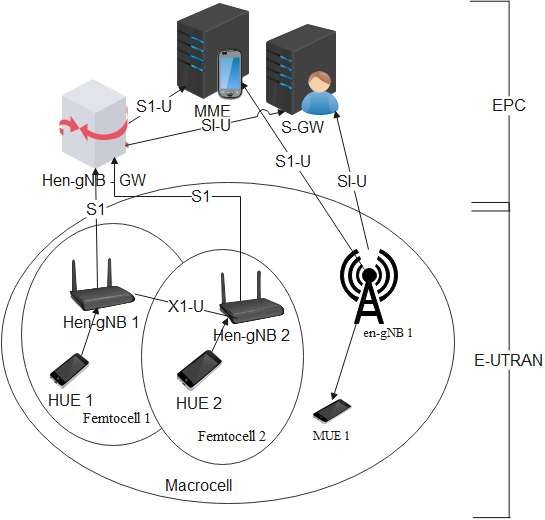


Figure 2.3: Macro-Femto heterogeneous network architecture (Source: 3GPP release 15.0.0; Feng *et al*., 2018; Asif, *et al*., 2019)

## Macro-Femto Interference

According to Achonu *et al.* (2020), interference greatly affects the performance and quality of service of 5G network. Macro-Femto interference largely depends on the type of channel deployment used in a particular cellular network. A channel deployment is said to be fully dedicated when the bandwidth is not shared by different network tiers; hence, there will be no cross-tier interference, a tradeoff for bandwidth utilization. In partial dedicated channel deployment, part of the available bandwidth is assigned only to macro user equipment (MUE), and the remaining part is shared by MUE and HUE. While in co-channel deployment the entire available bandwidth is used by both MUE and HUE simultaneously. Interference is more pronounced in Macro-Femto HetNet when co-channel deployment and femtocells closed access mode are considered (Sharanya *et al.,* 2015; Hassan *et al*., 2018).

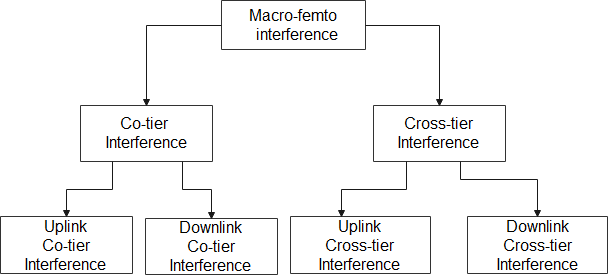
The works of Andrian *et al*. (2015); Syed and Aashish (2017); and Tuan *et al.* (2017) classified interference into cross-tier and co-tier interference based on aggressor (AG) and victim (VT) tier. Co-tier interference occurs among network devices that belong to the same tier. While Cross-tier interference occurs when devices in different network tiers share the same spectrum. Co-tier and cross-tier interference are subdivided into uplink co-tier, uplink cross-tier, downlink co-tier, and downlink cross-tier interference, as illustrated in Figure 2.4.

Figure 2.4: Types of interference in Macro-Femto heterogeneous network (Source: Andrian *et al*., 2015; Syed and Aashish 2017; Tuan *et al.,* 2017)

## Uplink co-tier interference

The uplink transmission, of HUE or MUE, causes uplink co-tier interference to nearby Hen-gNB or en-gNB, respectively, as illustrated in Figure 2.5.

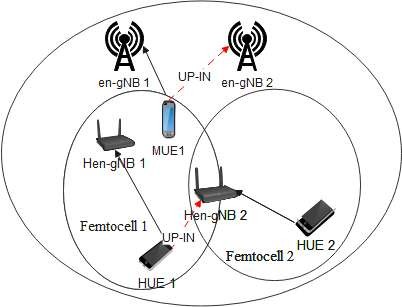


Figure 2.5: Uplink co-tier interference in Macro-Femto heterogeneous network (Source: Syed and Aashish 2017; Tuan *et al.,* 2017)

In Figure 2.5, Hen-gNB 1 and Hen-gNB 2 stand for femtocell node in cells 1 and 2 respectively. UP-IN stands for uplink co-tier interference signal. The uplink transmission of HUE 1 from femtocell 1 is received by nearby Hen-gNB 2 from cell 2 as an uplink co-tier interference, in which HUE 1 is the AG and Hen-gNB 2 is the VT. The uplink transmission of MUE 1 communicating to en-gNB 1 is received by nearby en-gNB 2 as an uplink co-tier interference, whereby MUE 1 is the AG and en-gNB 2 is the VT.

## Downlink co-tier interference

Downlink transmission of Hen-gNBs or en-gNBs are received by nearby HUEs or MUEs respectively as downlink co-tier interference. In such circumstances, Hen-gNBs and en-gNBs are AGs, while HUEs and MUEs are VTs. Figure 2.6 shows an illustration of downlink co-tier interference.

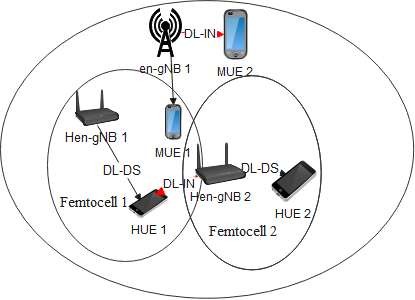


Figure 2.6: Downlink Co-tier interference in Macro-Femto heterogeneous network (Source: Syed and Aashish 2017; Tuan *et al.,* 2017)

In Figure 2.6, DL-DS stands for downlink desired signal, DL-IN stands for downlink co-tier interference signal. The downlink transmission of Hen-gNB 2 in femtocell 2 is received by nearby HUE 1 in femtocell 1 as downlink co-tier interference; whereby Hen-gNB 2 is the AG and HUE 1 is the VT. The downlink transmission of en-gNB 1 is received by nearby MUE 2 as downlink co-tier interference; where en-gNB 1 is the AG and MUE 2 is the VT.

## Uplink cross-tier interference

The uplink transmission of HUEs and MUEs are the source of cross-tier interference to nearby en-gNB and Hen-gNB, respectively. Figure 2.7 illustrates uplink cross-tier interference.

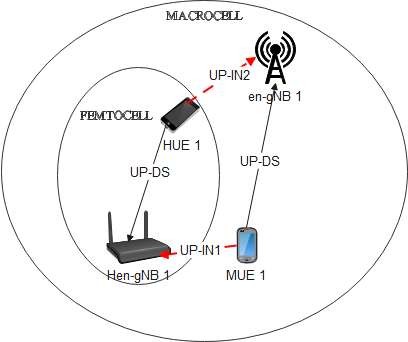


Figure 2.7: Uplink cross-tier interference in Macro–Femto heterogeneous network (Source: Syed and Aashish 2017; Tuan *et al.,* 2017)

In Figure 2.7, UP-DS stands for desired uplink signals, UP-IN1 stands for uplink cross-tier interference where MUE 1 is the AG and Hen-gNB 1 is the VT. Also UP-IN2 is an uplink cross-tier interference where HUE 1 is the AG and en-gNB 1 is the VT.

## Downlink cross-tier interference

The downlink transmission of en-gNB and Hen-gNB in a network causes downlink cross-tier interference to nearby HUEs and MUEs, respectively. Figure 2.8 presents an illustration of cross-tier interference in a typical Macro-Femto HetNet.

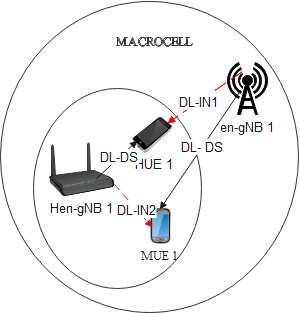


Figure 2.8: Downlink cross-tier interference in Macro-Femto heterogeneous network (Source: Syed and Aashish 2017; Tuan *et al.,* 2017)

In Figure 2.8, DL-IN1 stands for downlink cross-tier interference where en-gNB 1 is the AG and HUE 1 is the VT. DL-IN2 stands for downlink cross-tier interference where Hen-gNB 1 is the AG and MUE 1 is the VT.

## Mathematical Models

Mathematical models are description of systems using mathematical concepts and language. The analytical computation of path loss, signal-to-interference-plus noise ratio (SINR), and throughput, are all carried out using different mathematical models.

## Log-distance path loss model

The log-distance path loss model is an analytical approach, which was derived from Friis free space model. The propagation path loss experience in a radio propagation channel between a transmitter and receiver can be expressed as a function of distance by using a path loss exponent (n) that depends on the type of environment Rappaport (2002). The

general path loss model, which is referred to as log-distance Path Loss (PL) model is presented in equation (2.1).

𝑃𝐿 ∝ ( 𝑑 )

𝑛

(2.1)

𝑑0

The log-distance path loss model in decibel PL (dB) at an arbitrary distance 𝑑 > 𝑑0 is given in equation (2.2).

𝑃𝐿

(𝑑𝐵)

= 𝑃𝐿

(𝑑0

)[𝑑𝐵] + 10𝑛𝑙𝑜𝑔 ( 𝑑 )

(2.2)

𝑑0

The value of path loss at reference distance of 𝑑0 𝑃𝐿(𝑑0) is obtained using Friis path loss as expressed in equation (2.3) or by field measurement at 𝑑0. Equation (2.1), (2.2), and (2.3) were all sourced from Rappaport (2002).

𝑃𝐿(𝑑

𝜆

𝑑𝐵 = −10𝑙𝑜𝑔 (

)[ ]

2

(2.3)

)

0

4𝜋𝑑

where 𝜆 is the wavelength of the signal, 𝜋 is pie, 𝑛 is path loss exponent, 𝑑0 is the close-in or reference distance, that ranges from 1 – 10m in an indoor propagation, d is the distance between the transmitter and the receiver and 𝑃𝐿(𝑑0) is reference path loss due to reference distance 𝑑0. Table 2.1 presents a summary of path loss exponent range based on the different environments.

## Table 2.1: Path loss exponent of different environments

|  |  |  |
| --- | --- | --- |
| 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 |

(Source: Rappaport, 2002)

## Attenuation factor model

Attenuation factor model is an indoor propagation model that was derived from log-distance path loss model, by adding floor attenuation factor (𝑓𝑎𝑓) to log-distance model. The attenuation factor model as presented in Rappaport (2002) is given in equation (2.4).

[ ( )] 𝑑

(2.4)

𝑃𝐿𝐴 𝑑

𝑑

𝑑𝐵 = [𝑃𝐿(𝑑𝑜)]𝑑𝐵 + 10𝑛𝑙𝑜𝑔10( ) + 𝑓𝑎𝑓

𝑜

where [𝑃𝐿𝐴(𝑑)] is log-distance path loss from transmitter to receiver, [𝑃𝐿(𝑑𝑜)] is free space path loss, 𝑛 is path loss exponent, 𝑑𝑜 stands for close-in reference distance, 𝑑 is the distance between transmitter and receiver, and 𝑓𝑎𝑓 is floor attenuation factor.

## Signal-to-interference-plus-noise ratio

Signal-to-Interference-plus-Noise Ratio (SINR) is used in wireless communication, which is similar to Signal-Noise Ratio (SNR) in wired communication. The SINR is defined as particular signal power received divide by interference power and noise in the communication system. When the background noise in the system is zero, then SINR becomes Signal-to-Interference Ratio (SIR). SINR is mathematical expressed in equation

(2.5).

𝑆𝐼𝑁𝑅𝑥

= 𝑅𝑒𝑐𝑖𝑒𝑣𝑒𝑑 𝑝𝑜𝑤𝑒𝑟𝑑𝑒𝑠𝑖𝑟𝑒𝑑 𝑠𝑖𝑔𝑛𝑎𝑙

∑ 𝐼𝑛𝑡𝑒𝑟𝑓𝑒𝑟𝑒𝑛𝑐𝑒 𝑃𝑜𝑤𝑒𝑟 +𝑛𝑜𝑖𝑠𝑒

(2.5)

where 𝑆𝐼𝑁𝑅𝑥 is the SINR of receiver *x,* 𝑅𝑒𝑐𝑖𝑒𝑣𝑒𝑑 𝑝𝑜𝑤𝑒𝑟𝑑𝑒𝑠𝑖𝑟𝑒𝑑 𝑠𝑖𝑔𝑛𝑎𝑙 is the power of received desired signal, and ∑ 𝐼𝑛𝑡𝑒𝑟𝑓𝑒𝑟𝑒𝑛𝑐𝑒 𝑃𝑜𝑤𝑒𝑟 is the sum of all interference in the wireless network.

## Cumulative distribution function

The cumulative distribution function (CDF) of a real-valued random variable *X* is a function expressed in equation (2.6) (Deisenroth *et al*., 2020).

𝐹𝑋(𝑥) = 𝑃(𝑋 ≤ 𝑥) (2.6)

where 𝐹𝑋(𝑥) is the probability that the random variable *X* takes on a value less than or equal to *x*. The probability that the random variable *X* lies in the semi-closed interval (a, b), where a < b, is therefore given in equation (2.7).

𝑃(𝑎 < 𝑋 ≤ 𝑏) = 𝐹𝑋(𝑏) − 𝐹𝑋(𝑎) (2.7)

The CDF of a continuous random variable *X* can be expressed as the integral of its probability density (𝑓𝑥) as given in equation (2.8).

∫

𝐹𝑋

(𝑥) = ∞

−∞

𝑓𝑥(𝑡)𝑑𝑡

(2.8)

## Floor Attenuation Factor

In indoor system propagation, floor causes loss in signal strength, referred to as floor attenuation factor. The value of floor attenuation factor varies, due to materials used in constructing the floor within the same and different floors of a building. The Floor Attenuation Factor (FAF) for one, two, three, and four floors in two office buildings as presented in Rappaport (2002) is captured in Table 2.2.

## Table 2.2: Total floor attenuation factors in office buildings

|  |  |
| --- | --- |
| Building | FAF (dB) |
| Through One Floor | 16.2 |
| Through Two Floors | 27.5 |
| Through Three Floors | 31.6 |

(Source: Rappaport 2002)

## Related Power Control Techniques

Power is one of the limited resources in mobile networks; which if not properly manage will cause significant increase in interference. Hence, the need for UEs and nodes to transmit with the required power that can guaranty a good link quality.

## An active power control technique

Hassan and Gao (2019) worked on addressing interference problem in Macro-Femto HetNet to maximize high data rate for indoor mobile users; using proposed Active Power Control (APC) technique. Their system model considered downlink transmission of Macro-Femto HetNet, one macrocell, one femtocell configured in closed access mode.

In APC the transmit power of AG is adjusted based on received Interference Message (IM). The VT of interference compute Interference Indication Function (IDF) and compared it with set IDF threshold to determine whether to send an IM or not. When the computed IDF is greater than the set threshold interference, the VT send an IM that contained the AG information to its transmitter, which then forwards the IM using backhaul link to the AG; otherwise it does not send an IM. Equation (2.9) presents the mathematical equation for computing IDF, and equation (2.10) expresses mathematically when IM is sent or not.

𝐼𝑖 = 𝑃𝑖𝜓𝑖(𝑅𝑖)−𝛽 (2.9)

𝑡

0,

𝑥𝑖 = { 1

𝐼𝑖≤ 𝐼𝑇ℎ𝑟𝑒𝑠ℎ𝑜𝑙𝑑

𝑜𝑡ℎ𝑒𝑟𝑤𝑖𝑠𝑒

(2.10)

where 𝐼𝑖stands for IDF, 𝑃𝑖 stands for transmitting power, 𝜓 stands for log – normal shadowing, and (𝑅𝑖)−𝛽 represents the path loss component for the indoor transmission. In equation (2.10), 𝑥𝑖 stands for IM, and 𝐼𝑇ℎ𝑟𝑒𝑠ℎ𝑜𝑙𝑑 stands for set interference threshold. When 𝑥𝑖 = 0, there is no interference and IM is not sent, but when 𝑥𝑖 = 1, it implies there is interference and IM is sent. The APC technique has two power adjustment stages: the first stage, set three transmit power (𝑃𝑥, 𝑃𝑦, 𝑃𝑧), where 𝑃𝑥 was their maximum, followed by 𝑃𝑦 and lastly 𝑃𝑧 as the minimum transmit powers. Also, the APC technique considered two-time levels (𝑇𝐿1, 𝑇𝐿2). First phase of APC power adjustment would activate whenever an IM is received. On receiving an IM, the transmit power of the AG

𝑡

would change from 𝑃𝑥 to 𝑃𝑦 by downward step power value (∆𝑑𝑜𝑤𝑛). If the same AG receives another IM within the first time level (𝑇𝐿1), it would not further reduce its power to 𝑃𝑧 level until 𝑇𝐿1 expires. Similarly, when the AG has no IM and 𝑇𝐿1 expired, then the second time level (𝑇𝐿2) starts and the next transmit power level would increase from

𝑃𝑦 to 𝑃𝑥 by upward step power value (∆𝑢𝑝). The value of ∆𝑑𝑜𝑤𝑛 and ∆𝑢𝑝 steps power were both set to 2 dB. The mathematically expression used for adjusting the first stage, APC transmit power is captured in equations (2.11) – (2.15).

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| 𝑃𝑡 = 𝑃𝑥 |  |  | No interference message | (2.11) |
| 𝑃𝑡 = 𝑃𝑦 = | 𝑃𝑥 − | ∆𝑑𝑜𝑤𝑛 | Interference Message and 𝑇𝐿1 starts | (2.12) |
| 𝑃𝑡 = 𝑃𝑧 = | 𝑃𝑦 − | ∆𝑑𝑜𝑤𝑛 | New interference Message and 𝑇𝐿1 starts | (2.13) |
| 𝑃𝑡 = 𝑃𝑦 = | 𝑃𝑧 + ∆𝑢𝑝 | | No interference Message and 𝑇𝐿2 starts | (2.14) |
| 𝑃𝑡 = 𝑃𝑥 = | 𝑃𝑦 + ∆𝑢𝑝 | | No interference Message and 𝑇𝐿2 running | (2.15) |

where 𝑃𝑡 is APC first stage transmit power. The second stage of active power control technique shapes was based on first stage power value and the minimum required Quality of Service (QoS) for received signal. The mathematical model for computing the QoS

Indication Function (QIF) is presented in equation (2.16).

QIF = 𝑃𝑟𝑒𝑓𝜏𝐻𝑈𝐸

𝑚𝑖𝑛𝑅𝑆𝑅𝑃𝑗

(2.16)

where 𝑃𝑟𝑒𝑓 is the reference signal transmit power, 𝜏𝐻𝑈𝐸 is the minimum required signal-to-interference-plus-noise ratio (SINR) for HUE, and 𝑚𝑖𝑛𝑅𝑆𝑅𝑃𝑗 is the reference signal received power. The second and final stage of APC transmit power (𝑃𝐴𝑃𝑐) is expressed mathematically in equation (2.17) and the path loss models used are equation (2.18) and (2.19).

𝑃𝐴𝑃𝑐 = max(𝑃𝑚𝑖𝑛 𝑚𝑖𝑛(𝑄𝐼𝐹 ∗ 𝑃𝑡, 𝑃𝑚𝑎𝑥)) (2.17)

where 𝑃𝑚𝑖𝑛 and 𝑃𝑚𝑎𝑥 are minimum and maximum transmit power respectively, and 𝑃𝐴𝑃𝑐 is the second stage transmit power, known as APC transmit power.

𝑃𝐿

= { 15.3 + 37.6𝑙𝑜𝑔10(𝑑) (𝑂𝑢𝑡𝑑𝑜𝑜𝑟 𝑈𝐸)

(2.18)

𝑚𝑎𝑐𝑟𝑜

15.3 + 37.6𝑙𝑜𝑔10(𝑑) + 𝑙𝑝 (𝐼𝑛𝑑𝑜𝑜𝑟 𝑈𝐸)

38.46 + 20𝑙𝑜𝑔10(𝑑2) (𝐼𝑛𝑑𝑜𝑜𝑟)

𝑃𝐿𝑓𝑒𝑚𝑡𝑜 = {

max (15.3 + 37.6𝑙𝑜𝑔10

(𝑑2

), 38.46 + 20𝑙𝑜𝑔10

(𝑑2

)) + 𝑙𝑝

(𝑂𝑢𝑡𝑑𝑜𝑜𝑟)

(2.19)

Where 𝑃𝐿𝑚𝑎𝑐𝑟𝑜 stands for propagation path loss when a macrocell node is transmitting to its receiver, 𝑃𝐿𝑓𝑒𝑚𝑡𝑜 is propagation path loss when a femtocell node is transmitting to its receiver. 𝑑 is the distance from the macrocell node to its user equipment, 𝑑2 is the distance between the femtocell node and its user equipment. 𝑙𝑝 is wall penetration loss. Equations (2.9) – (2.19) were all sources from (Hassan and Gao, 2019).

The simulation result in their work indicated that APC reduces Inter-Cell Interference (ICI) and had better MUE throughput compared to Fixed Power Control technique (FPCT), Femtocell User Equipment Assisted Power Control Technique (FUEAPCT) and macrocell User Equipment Assisted Power Control Technique (MUEAPCT).

## An adaptive network sensing power control technique

Hassan *et al*. (2018) work, titled interference management in femtocells by the adaptive network sensing power control technique, contributed in solving the problem of ICI in downlink transmission of Macro-Femto HetNet. Their system model considered a cross-tier interference scenario where the MUE computed received IDF and compared it with set value of interference threshold. If the computed IDF is greater than the interference threshold value, the MUE would send a message to its node that contains

information of the interfering femtocell node. They computed IDF and IM using equations (2.9) and (2.10). Equation (2.18) and (2.19) were used for computing path loss. They adjusted their femtocell transmit power using equation (2.20) and (2.21).

𝑃𝑓 = 𝑃𝑚𝑎𝑐𝑟𝑜 − 𝑃𝐿𝑀𝐵𝑆−𝐹𝐵𝑆 + 𝑃𝐿𝐹𝑒𝑚𝑡𝑜(𝑅1) (2.20)

𝑃𝐴𝑁𝑆 = max(𝑃𝑚𝑖𝑛,min(𝑃𝑓, 𝑃𝑚𝑎𝑥)) (2.21)

where 𝑃𝑚𝑎𝑐𝑟𝑜 is macrocell power, 𝑃𝐿𝑀𝐵𝑆−𝐹𝐵𝑆 is macrocell to femtocell path loss,

𝑃𝐿𝐹𝑒𝑚𝑡𝑜(𝑅1) is the line of sight (LOS) path loss with cell range of 𝑅1, and 𝑃𝐴𝑁𝑆 is the adaptive network sensing power.

The simulation result of ANS indicated that the proposed technique when compared to FUEAPCT, MUEAPCT, and FPCT gave a better MUE throughput, and decrease in HUE throughput.

## Dynamic power control technique

The work of Susanto *et al.* (2017)a, titled downlink power control for interference management in Femtocell-Macrocell cellular communication network, was tailored towards solving the interference problem in downlink Femtocell – Macrocell cellular communication network. They used a power control approach called power control 1 (PC1) technique to mitigate the interference problem in Femtocell – Macrocell network.

In PC1, the transmit power of en-gNBs and Hen-gNBs were adjusted based on interference received by UE. The difference between computed UE SINR (𝑆𝐼𝑁𝑅𝑐𝑜𝑚𝑝𝑢𝑡𝑒𝑑) and target SINR (𝑆𝐼𝑁𝑅𝑡𝑎𝑟𝑔𝑒𝑡) was used to determine interference in the two-tier network. The difference between measured SINR and target SINR is expressed mathematically in equation (2.22).

𝛾 = 𝑆𝐼𝑁𝑅𝑐𝑜𝑚𝑝𝑢𝑡𝑒𝑑 − 𝑆𝐼𝑁𝑅𝑡𝑎𝑟𝑔𝑒𝑡 (2.22)

When the computed SINR is less than the target SINR, the next transmit power of en-gNB, or Hen-gNB, would be increased by 2 dB. When the computed SINR is greater than the target SINR, the next transmit power of en-gNB, or Hen-gNB would be decreased by 2 dB. When the computed SINR is equal to the target SINR (SINR𝑡𝑎𝑟𝑔𝑒𝑡), the next transmit power of en-gNB, or Hen-gNB would be the present transmit power. Mathematically, the PC1 transmit power adjustment is expressed in equation (2.23).

min[ 𝑃𝑡𝑥(𝑡𝑗) + ∆𝑢𝑝, 𝑃𝑚𝑎𝑥]; 𝛾 < 0

𝑃𝑡𝑥(𝑁) = { 𝑃𝑡𝑥(𝑡𝑗); 𝛾 = 0 max[𝑃𝑡𝑥(𝑡𝑗) − ∆𝑑𝑜𝑤𝑛, 𝑃𝑚𝑖𝑛] ; 𝛾 > 0

(2.23)

where ∆𝑢𝑝 and ∆𝑑𝑜𝑤𝑛 stand for step power values used to increase and reduce next transmission power respectively. 𝑃𝑡𝑥(𝑡𝑗) is the current transmit power and 𝑃𝑡𝑥(𝑁) is the next transmit power. The mathematical equations used for computing macrocell and femtocell path loss are presented in equation (2.18) and (2.24) respectively.

𝑃𝐿𝑃𝐶1\_𝑓𝑒𝑚𝑡𝑜𝑐𝑒𝑙𝑙

(𝑑𝐵) = 127 + 30𝑙𝑜𝑔10

( ) (2.24)

1000

𝑑2

where 𝑃𝐿𝑃𝐶1\_𝑓𝑒𝑚𝑡𝑜𝑐𝑒𝑙𝑙(𝑑𝐵) stand for the propagation path loss in femtocell network. Their result was plotted in terms of Cumulative Distribution Function (CDF) of SINR, where the proposed PC1 technique outperformed that of no power control.

The work of Susanto *et al*. (2017)b, titled interference management using power control for uplink transmission in Femtocell-Macrocell Cellular Communication used same PC1 technique to mitigate interference problem in uplink transmission of Femtocell-Macrocell network. The result obtained indicated that PC1 technique outperformed when there is no power control in terms of CDF of SINR.

## An interference mitigation scheme for LTE based femtocell networks

Ali *et al.* (2016) work, titled an interference mitigation scheme for LTE based femtocell networks considered only co-tier interference. The work pointed out interference as the major challenge of femtocell network which it seeks to address using proposed technique. Their proposed interference mitigation technique had two parts: the self-configuration and self-optimization part. In the self-configuration stage, the femtocells boots and automatically start transmitting with maximum transmit power. While in the self- optimization stage, the initialized femtocell checked, if there was a neighboring femtocell. In a situation where there was at least one neighboring femtocell, the femtocell would be switched to Transmit Power Control Mode (TPCM) and adjust its next transmit power to reduce interference on the neighboring femtocell. Otherwise, it continue to transmit with maximum power.

The results of video and Voice over Internet protocol (VoIP) Packet Loss Ratio (PLR) using TPCM were both lower compared to static power approach. The average throughput of video and VoIP flow was better compare to static power approach; it also showed that as the number of femtocells in the network increases, the throughput decreases.

## Cross-tier signal-leak-noise-ratio based water filling power allocation algorithm

Su *et al.* (2016) work titled power allocation scheme for femto-to-macro downlink interference reduction for smart devices in ambient intelligence, was geared towards using power allocation technique to solve the problem of cross-tier interference in closed access mode femtocells. It centered on allocating Physical Resource Block (PRB) power

of 4G femtocell node (HeNB), based on modified water filing power algorithm; called cross-tier signal-to-leakage-plus-noise ratio (SLNR) based water filling (CSWF). Where

the CSWF method generate the water bottom (𝑋𝑛 ). The water bottom is defined

𝑓,𝑢

𝑓

mathematically in equation (2.25).

𝑛

𝑓,𝑢𝑓

𝑛 𝑛

𝑖,𝑢𝑓 𝑖

𝑋 =

∑ 𝐺 𝑃 + 𝜂

𝐺𝑛

𝑓,𝑢𝑓

(2.25)

where ∑ 𝐺𝑛 𝑃𝑛 stands for the total of interference on HUE, 𝜂 for thermal noise per

𝑖,𝑢𝑓 𝑖

PRB, and 𝐺𝑛 for channel gain of PRB 𝑛 between HeNB f and HUE 𝑢𝑓. The transmit power of a HeNB f at PRB 𝑛 (𝑃𝑛), is determined where 𝑢 is a set water level. The mathematically expression of 𝑃𝑛 is presented in equation (2.26).

𝑓

𝑓

𝑓,𝑢𝑓

𝑢 − 𝑋𝑛 , 𝑋𝑛 < 0

𝑃𝑛 = {

𝑓,𝑢𝑓

𝑓,𝑢𝑓

(2.26)

𝑓 0, 𝑋𝑛 ≥ 0

𝑓,𝑢

𝑓

The path loss model they used for macrocell and femtocell networks is given in equation (2.18) and (2.19) respectively. Their result indicated that CSWF technique had better MUE throughput compared to when their no power management; as a tradeoff for HUE throughput, which decreased by 1.1%.

## Dynamic power control algorithm

Xuan *et al.* (2016) work, titled dynamic power control for maximizing system throughput in enterprise femtocell networks, used a Dynamic Power Control Algorithm (DPCA) for femtocell nodes (HeNBs) to solve the problem of system throughput in a centralized network. The HeNBs applied the DPCA algorithm in a distributed manner. Where HeNB adjusted it’s transmit power based on the transmit power of neighboring HeNB or received SINR of HUE. Their system model considered cross-tier interference,

co-channel deployment, multiple HUEs, and HeNBs. The DPCA was in two phases: the permission judgment algorithm (PJA) and power adjustment algorithm (PAA).

A HeNB has a list of all its neighboring HeNBs and their transmitting power. During the PJA, the HeNB listened to the network for any change in transmit power of any adjacent neighbor; where there is change, it would not adjust its transmit power, and when there is no change, it would then move into the second phase of the algorithm to adjust it transmit power. All non-adjacent neighbors can adjust their power giving rise to multiple femtocells performing dynamic power control in a distributed manner.

The PAA has two modules, the non-periodic with the highest priority and the periodic modules. The periodic module is activated by PJA, while the non-periodic module is activated when UE(s) at a distance (𝑑𝑈𝐸) needs to be handover to another HeNB or the received HUE SINR is less than the set HUE SINR threshold value. The new transmit power is adjusted using the mathematical expression in equation (2.27) and (2.28).

𝑃 𝑟𝑛𝑒𝑤

𝛽

𝑛𝑒𝑤 = (

)

𝑟𝑜𝑙𝑑

× 𝑃𝑜𝑙𝑑 (2.27)

𝑟 𝑑𝑈𝐸, 𝑑𝑈𝐸 ≤ 𝑟𝑚𝑎𝑥

𝑛𝑒𝑤 = {𝑟𝑜𝑙𝑑, 𝑜𝑡ℎ𝑒𝑟𝑤𝑖𝑠𝑒 (2.28)

where 𝛽 is path loss of indoor transmission, 𝑃𝑜𝑙𝑑 is the old transmit power, 𝑟𝑜𝑙𝑑 is old cell radius 𝑟𝑛𝑒𝑤 is new cell radius and 𝑟𝑚𝑎𝑥 is maximum HeNB radius with maximum transmit power. The path loss model they used within femtocell network is captured in equation (2.29).

𝑃𝐿𝑓𝑒𝑚𝑡𝑜𝑐𝑒𝑙𝑙(𝑑𝐵) = 38.5 + 20𝑙𝑜𝑔10(𝑑2) (2.29) The result of using the proposed DPCA power control technique gave a 40% improvement in system throughput when compared to when their no power control.

## Stochastic approximation algorithm

Haining *et al.* (2015) work, titled femtocell power control for interference management based on macro-layer feedback used stochastic approximation algorithm for downlink power control in femtocell networks to solve the problem of cross-tier interference in Macro-Femto network. Stochastic approximation (SA) algorithm is a distributed femtocell node power control approach for managing interference in a Macro-Femto network. The system model they used had one macrocell, femtocell nodes, fixed MUE and HUE.

During downlink transmission, HeNB does not received feedback from eNB or communicate with MUE directly, rather it listens to feedback that was send from interfered MUE to its serving eNB. When HeNB overheard the feedback sent by MUE, it knows that it is causing interference to MUE and thereby reducing it’s transmit power using a stochastic algorithm. This work did not spell out the propagation path loss model used.

## Dynamic power tuning technique

Sharanya *et al.* (2015), work titled dynamic power tuning for downlink interference mitigation in heterogeneous LTE network aimed at solving cross-tier interference in uplink, downlink transmission of Macro-Femto HetNet using proposed dynamic power tuning technique.

In dynamic power tuning technique, when a MUE received an interference signal from HeNB, it will send the reference signal received power with the corresponding physical cell identity (PCID) of the AG and channel quality indicator (CQI) message to its serving

eNB. The eNB determined the femtocell causing the interference and sends an IM back to its MUE, which then forwards the interference message to the interfering HeNB. When the AG received the interference message it reduces its transmit power based on the number of HUEs within its cell. If the number of HUEs in the interfering HeNB is greater than one, the HeNB would reduce its current transmit power by 4 dBm in the next transmission, and if the number of HUE is exactly one the HeNB will reduce it’s transmit power to 10 dBm.

Results they obtained shows that the proposed dynamic power tuning technique reduced interference to MUE when compared to dynamic power allocation and HUE based power control techniques, and HeNB had low transmission power when compared to dynamic power allocation and HUE based power control techniques.

## Research Gap

The active power control technique used in the work of Hassan and Gao 2019 gave better throughput and low power consumption when compared with MUE assisted power control and HUE assisted power control techniques. However, their work did not consider co-tier interference and the method used in determining interference was complex, having several equations and parameters. The complexity and second stage of computing their node transmit power will result into increase processing delay and high memory requirement due to many variables involved in the computations. Also all the UEs were considered at fixed position. Hassan *et al.* 2018 mitigated interference using an adaptive network sensing power control technique, which yielded better MUE throughput when compared to node assisted power technique. Their work did not considered co-tier interference, and power consumption of nodes and UE. Also, their technique had complex

means of determining interference. The work of authors in Susanto *et al.* (2017)a,b, on interference management in downlink and uplink transmission of Femtocell-Macrocell network, presented a simple approach to determining interference in a network which yielded better SINR and also captured both co-tier and cross-tier interference. However, their work did not considered the throughput of UEs and nodes, and the power consumption of nodes and UEs. The power allocation scheme for femto-to-macro downlink interference reduction for smart devices in ambient intelligence, presented by Ali *et al*. (2016) where only co-tier interference was considered. Even thou their power control technique was simple. Authors in Xuan *et al.* (2016), centered on maximizing system throughput in enterprise femtocell network using dynamic power control approach; which yielded a better throughput when benchmark with fixed power control technique. But their work did not captured the effect of co-tier interference, and had a second stage, which will increase memory usage and processing delay, due to more parameters involved. The works of authors in Su *et al.* (2016), considered co-tier and cross-tier interference, their approach gave an average SINR. But they used a complex technique called modified water filing power algorithm for adjusting transmit power. The power control approach in Haining et *al.* (2015), optimized femtocell power. Their research architecture did not considered co-tier interference. While Authors in Sharanya *et al.* (2015) only considered cross-tier interference, though their work when compared with that of dynamic power tuning and HUE power tuning had better femtocell power consumption.

The reviewed works in literatures could not captured in a particular study: co-tier and cross-tier interference, mobile UEs, power consumption of nodes and UEs, and throughput of nodes and UEs. Most of the previous works used complex approach in

determining and adjusting transmit power. The complex mathematical model increase processing time and require more memory for storing various computational variable, which increase the memory requirement of nodes and UEs. This study seeks to address such gaps, by using a simple mathematical model to determine interference in Macro-Femto network. It also seeks to consider both co-tier and cross-tier interference and evaluate the throughput and power usage performance. Table 2.3 presents a summary of the strength and weakness of related and existing power control techniques used for mitigating interference in Macro-Femto HetNet.

## Table 2.3: Summary of relevant power control technique for interference mitigation

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| S/N | Author | Year | Topic | Type of  Interference | Strength | Weakness |
| 1 | Hassan and Gao | 2019 | An Active Power Control Technique for Downlink Interference Management in a Two-  Tier Macro – Femto Network | Cross –tier only | Good throughput | co-tier interference was not considered, complex  and static network |
| 2 | Hassan  *et al* | 2018 | Interference Management in Femtocells by the Adaptive Network Sensing Power Control Technique | Cross–tier only | Moderate Macro user throughput | Co-tier interference was not considered |
| 3 | Susanto  *et al* | 2017b | Interference Management Using Power Control for Uplink Transmission in Femtocell- Macrocell Network | Co–tier and cross-tier | Good UE SINR when benchmarked | UEs are static and their throughput was not considered. |
| 4 | Susanto  *et al* | 2017a | Downlink Power Control for Interference Management in Femtocell-Macrocell Cellular Communication Network | Co–tier and cross-tier | Good base stations SINR | UEs were static and throughput not considered |
| 5 | Ali | 2016 | An interference mitigation scheme for LTE | Co–tier only | A simple power | Consider only co-tier |
|  | *et al* |  | based femtocell networks |  | control algorithm | interference |
| 6  7 | Xuan  *et al*  Su *et al* | 2016  2016 | Dynamic Power Control for Maximizing System Throughput in Enterprise Femtocell Networks  Power Allocation Scheme for Femto-to-Macro | Cross-tier  Co-tier and | High throughput  Average received | Complex and Co-tier interference was not considered  A complex modified water |
| 8 | Haining | 2015 | Downlink Interference Reduction for Smart Devices in Ambient Intelligence  Femtocell Power Control for Interference | Cross-tier  Cross-tier | SINR  Optimized | filing (WF) power algorithm was used  Co-tier interference and |
|  | *et al.* |  | Management Based on Macro-Layer Feedback |  | femtocell transmit  power | uplink transmission was  not considered |

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# CHAPTER THREE

# RESEARCH METHODOLOGY

The Enhanced Active Power Control (EAPC) technique is derived from the hybridization of Active Power Control (APC) Technique, Power Control 1 (PC1) technique, and extended attenuation factor model. Step power value of 0.5 dB was used in EAPC. This chapter explains the development of an enhanced power control technique in stages using block diagram and flowchart. It also presents the research Macro-Femto architecture and assumptions in Table 3.1.

## Table 3.1: Research assumptions

S/N Assumptions

1. UEs are in an obstructed building

2. All UEs are indoor

3. Femtocell close access mode

4. Co-channel deployment

5. HUE1 is close to en-gNB1

6. MUE 1 is close to Hen-gNB 2

7. HUE 2 is close to Hen-gNB 1

## Block Diagram of an Enhanced Active Power Control Technique

The block diagram of an enhanced active power control technique is presented in Figure 3.1 and the various blocks are explained thereafter.

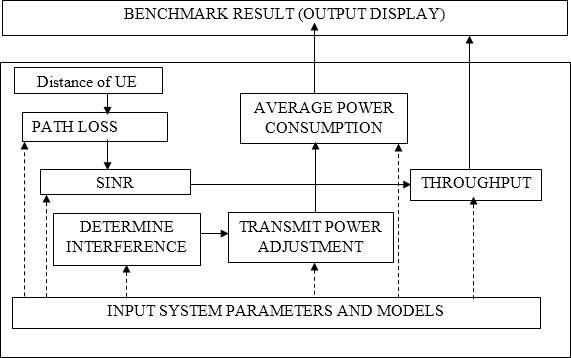


Figure 3.1: A block diagram of enhanced active power control technique

## Path loss block

The transmission path loss is computed using mathematical models, system parameters in Table 3.2, and the distance between UEs from their respective nodes. The system parameters were adopted from the anchored papers (Susanto *et al.* 2017a,b, Hassan and Gao, 2019).

## Table 3.2: System parameters of enhanced active power control technique

|  |  |  |
| --- | --- | --- |
| No. | Parameter | Value |
| 1. | Maximum transmit power of Hen-gNB | 20 dBm |
| 2. | Maximum transmit power of en-gNB | 46 dBm |
| 3. | Maximum transmit power of HUE and MUE | 23 dBm |
| 4. | Minimum transmit power of Hen-gNB, HUE and MUE | 0 dBm |
| 5. | Minimum transmit power of en-gNB | 5 dBm |
| 6. | Initial transmit power of HUE and MUE | 5 dBm |
| 7. | Initial transmit power of Hen-gNB | 8dB |
| 8. | Initial transmit power of en-gNB | 34 dBm |
| 9. | Thermal noise | -174 dBm |
| 10. | Target SINR | 10 |

(Source: Susanto *et al.* 2017a,b, Hassan and Gao, 2019)

The path loss between en-gNBs and MUEs is computed using equation (2.14), adopted from Susanto *et al.* (2017) and Hassan and Gao (2019). The femtocell path loss model used to compute propagation loss between Hen-gNBs and HUE is presented in equation (3.4). Equation (3.1), is an extension of attenuation factor model in equation (2.4). It was extended by adding wall attenuation factor (𝑙𝑝).

𝑃𝐿

𝑑𝑓

(3.1)

𝐻𝑒𝑛−𝑔𝑁𝐵−𝑈𝐸𝑠 = [𝑃𝐿(𝑑0)]𝑑𝐵 + 10𝑛𝑙𝑜𝑔10 (𝑑 ) + 𝑓𝑎𝑓 + 𝑙𝑝

0

where 𝑃𝐿𝐻𝑒𝑛−𝑔𝑁𝐵−𝑈𝐸𝑠 stand for path loss when considering femtocell node and its UE,

𝑑𝑓 is the distance between femtocell node and UE, [𝑃𝐿(𝑑0)]𝑑𝐵 is free space path loss given in equation (2.3). Substituting equation (2.3) in equation (3.3) give rise to equation

(3.2).

𝑃𝐿

𝜆 2

= −10𝑙𝑜𝑔 (

𝑑𝑓

(3.2)

0

𝐻𝑒𝑛−𝑔𝑁𝐵−𝑈𝐸𝑠

)

4𝜋𝑑

+ 10𝑛𝑙𝑜𝑔10 (𝑑 ) + 𝑓𝑎𝑓 + 𝑙𝑝

substitute path loss exponent (𝑛) of 6 (Table 2.1), 𝑓𝑎𝑓 of 16.2 from Table 2.1 in equation (3.2) to get equation (3.3).

𝑃𝐿

𝜆 2

= − log (

𝑑𝑓

(3.3)

𝐻𝑒𝑛−𝑔𝑁𝐵−𝑈𝐸𝑠

)

4𝜋∗𝑑0

+ 60 (𝑑 ) + 16.2 + 𝑙𝑝

where 𝜆 stand for wavelength, which is mathematically given in equation (3.4).

0

𝜆 = 𝑠𝑝𝑒𝑒𝑑 𝑜𝑓 𝑙𝑖𝑔ℎ𝑡 (𝑐)

𝑓𝑟𝑒𝑞𝑢𝑒𝑛𝑐𝑦 (𝑓)

(3.4)

substituting equation (3.4) in equation (3.3) gives equation (3.5).

𝑃𝐿

𝑐 2

= − log (

𝑑𝑓

(3.5)

𝐻𝑒𝑛−𝑔𝑁𝐵−𝑈𝐸𝑠

)

𝑓∗4𝜋∗𝑑0

+ 60 (𝑑 ) + 16.2 + 𝑙𝑝

substituting 𝜋 = 22, 𝑐 = 3 × 108𝑚/𝑠 and 𝑑

0

0

7

= 1𝑚 and carrier frequency of 2.6 GHz

(Rehman *et al.* 2020) in equation (3.5) gives equation (3.6).

𝑃𝐿𝐻𝑒𝑛−𝑔𝑁𝐵−𝑈𝐸𝑠 = 20 log(𝑓𝑀𝐻𝑧) + 60𝑙𝑜𝑔(𝑑𝑓) − 11.4 + 𝑙𝑝 (3.6)

where 𝑃𝐿𝐻𝑒𝑛−𝑔𝑁𝐵−𝑈𝐸𝑠 is propagation path loss between 𝐻𝑒𝑛 − 𝑔𝑁𝐵 and 𝐻𝑈𝐸, 𝑓𝑀𝐻𝑧

stands for carrier frequency in MHz, and 𝑑𝑓 is the distance between 𝐻𝑒𝑛 − 𝑔𝑁𝐵 and

𝐻𝑈𝐸. According to Rehman *et al.* (2020), a carrier frequency of 2.6 GHz is used for 5G.

## Signal-to-interference-plus-noise-ratio block

At each position of UEs from their serving nodes, the SINR of en-gNB, Hen-gNBs, MUE, and HUEs, is computed using equation (3.9) sourced from Hassan and Gao, 2019, and Susanto *et al*, 2017b.

𝑆𝐼𝑁𝑅

= 𝑃𝑡𝑥𝑃𝐿𝑡𝑥−𝑟𝑥

(3.7)

𝑟𝑥

∑ 𝐼𝑐𝑜−𝑡𝑖𝑒𝑟+ ∑𝐼𝑐𝑟𝑜𝑠𝑠−𝑡𝑖𝑒𝑟

+ 𝑃𝑛

where ∑ 𝐼𝑐𝑟𝑜𝑠𝑠−𝑡𝑖𝑒𝑟 is total cross-tier interference, ∑ 𝐼𝑐𝑜−𝑡𝑖𝑒𝑟 is total co-tier interference

𝑃𝑡𝑥 is transmit power of transmitter, 𝑃𝐿𝑡𝑥−𝑟𝑥 is path loss from transmitter to receiver and

𝑆𝐼𝑁𝑅𝑟𝑥 is SINR of receiver.

The average SINR of Hen-gNBs, HUEs, en-gNBs, and MUEs considering all the positions of UEs from their nodes is compute using (3.8), (3.9), (3.10), and (3.11) respectively.

𝑝=𝐻𝑈𝐸𝐿𝑝

𝐴𝑣𝑒𝑟𝑎𝑔𝑒 ∑𝑝=1

𝑆𝐼𝑁𝑅 =

𝐻𝑒𝑛−𝑔𝑁𝐵

(𝑆𝐼𝑁𝑅𝐻𝑒𝑛−𝑔𝑁𝐵1+ 𝑆𝐼𝑁𝑅𝐻𝑒𝑛−𝑔𝑁𝐵2+⋯+𝑆𝐼𝑁𝑅𝐻𝑒𝑛−𝑔𝑁𝐵𝑛)

𝑁𝐻𝑒𝑛−𝑔𝑁𝐵 × 𝐻𝑈𝐸𝐿𝑝

(3.8)

where 𝑆𝐼𝑁𝑅𝐴𝑣𝑒𝑟𝑎𝑔𝑒 stand for average SINR of Hen-gNB in the network.

𝐻𝑒𝑛−𝑔𝑁𝐵

∑𝑝=𝐻𝑈𝐸𝐿𝑝(𝑆𝐼𝑁𝑅

+ 𝑆𝐼𝑁𝑅

+ ⋯ + 𝑆𝐼𝑁𝑅

) stand for sum of

𝑝=1

𝐻𝑒𝑛−𝑔𝑁𝐵1

𝐻𝑒𝑛−𝑔𝑁𝐵2

𝐻𝑒𝑛−𝑔𝑁𝐵𝑛

all Hen-gNB SINR in the network, considering all positions of HUEs, 𝑆𝐼𝑁𝑅𝐻𝑒𝑛−𝑔𝑁𝐵1 +

𝑆𝐼𝑁𝑅𝐻𝑒𝑛−𝑔𝑁𝐵2 + ⋯ + 𝑆𝐼𝑁𝑅𝐻𝑒𝑛−𝑔𝑁𝐵𝑛 stand for sum all Hen-gNB SINR at particular position of HUE, 𝑁𝐻𝑒𝑛 − 𝑔𝑁B is the number of Hen-gNB in the network and 𝐻𝑈𝐸𝐿𝑝 stand for last position of 𝐻𝑈𝐸.

𝑝=𝐻𝑈𝐸𝐿𝑝

𝑆𝐼𝑁𝑅𝐴𝑣𝑒𝑟𝑎𝑔𝑒 = ∑𝑝=1

𝐻𝑈𝐸

(𝑆𝐼𝑁𝑅𝐻𝑈𝐸1+ 𝑆𝐼𝑁𝑅𝐻𝑈𝐸2+⋯+𝑆𝐼𝑁𝑅𝐻𝑈𝐸𝑛)

𝑁𝐻𝑈𝐸 × 𝐻𝑈𝐸𝐿𝑝

(3.9)

where 𝑆𝐼𝑁𝑅𝐴𝑣𝑒𝑟𝑎𝑔𝑒 stands for average SINR of HUE in the network,

𝐻𝑈𝐸

∑𝑝=𝐻𝑈𝐸𝐿𝑝(𝑆𝐼𝑁𝑅

+ 𝑆𝐼𝑁𝑅

+ ⋯ + 𝑆𝐼𝑁𝑅

) stand for sum of all HUEs SINR

𝑝=1

𝐻𝑈𝐸1

𝐻𝑈𝐸2

𝐻𝑈𝐸𝑛

in the network, considering all positions of HUEs, 𝑆𝐼𝑁𝑅𝐻𝑈𝐸1 + 𝑆𝐼𝑁𝑅𝐻𝑈𝐸2 + ⋯ +

𝑆𝐼𝑁𝑅𝐻𝑈𝐸𝑛 stand for sum all HUE SINR at particular position of HUE, 𝑁𝐻𝑈𝐸 is the number of HUE in the network and 𝐻𝑈𝐸𝐿𝑝 stand for last position of 𝐻𝑈𝐸.

𝐴𝑣𝑒𝑟𝑎𝑔𝑒

𝑆𝐼𝑁𝑅

𝑒𝑛−𝑔𝑁𝐵

𝑖=𝑀𝑈𝐸𝐿𝑝

∑ (𝑆𝐼𝑁𝑅𝑒𝑛−𝑔𝑁𝐵1+ 𝑆𝐼𝑁𝑅𝑒𝑛−𝑔𝑁𝐵2+⋯+𝑆𝐼𝑁𝑅𝑒𝑛−𝑔𝑁𝐵𝑛)

= 𝑖=1

𝑁𝑒𝑛−𝑔𝑁𝐵 × 𝑀𝑈𝐸𝐿𝑝

(3.10)

where 𝑆𝐼𝑁𝑅𝐴𝑣𝑒𝑟𝑎𝑔𝑒 stand for average SINR of en-gNB, ∑𝑖=𝑀𝑈𝐸𝐿𝑝(𝑆𝐼𝑁𝑅 +

𝑒𝑛−𝑔𝑁𝐵

𝑖=1

𝑒𝑛−𝑔𝑁𝐵1

𝑆𝐼𝑁𝑅𝑒𝑛−𝑔𝑁𝐵2 + ⋯ + 𝑆𝐼𝑁𝑅𝑒𝑛−𝑔𝑁𝐵𝑛) stand for sum of all en-gNB SINR in the network, considering all positions of MUEs, 𝑆𝐼𝑁𝑅𝑒𝑛−𝑔𝑁𝐵1 + 𝑆𝐼𝑁𝑅𝑒𝑛−𝑔𝑁𝐵2 + ⋯ + 𝑆𝐼𝑁𝑅𝑒𝑛−𝑔𝑁𝐵𝑛 stand for sum all en-gNB SINR at particular position of HUE, 𝑁𝑒𝑛 − 𝑔𝑁B is the number of en-gNB in the network and 𝑀𝑈𝐸𝐿𝑝 stand for last position of 𝑀𝑈𝐸.

𝑆𝐼𝑁𝑅𝐴𝑣𝑒𝑟𝑎𝑔𝑒

𝑀𝑈𝐸

𝑖=𝑀𝑈𝐸𝐿𝑝

∑ (𝑆𝐼𝑁𝑅𝑀𝑈𝐸1+ 𝑆𝐼𝑁𝑅𝑀𝑈𝐸2+⋯+𝑆𝐼𝑁𝑅𝑀𝑈𝐸𝑛)

= 𝑖=1

𝑁𝑀𝑈𝐸 × 𝑀𝑈𝐸𝐿𝑝

(3.11)

where 𝑆𝐼𝑁𝑅𝐴𝑣𝑒𝑟𝑎𝑔𝑒 stands for average SINR of MUE in the network,

𝑀𝑈𝐸

∑𝑖=𝑀𝑈𝐸𝐿𝑝(𝑆𝐼𝑁𝑅

+ 𝑆𝐼𝑁𝑅

+ ⋯ + 𝑆𝐼𝑁𝑅

) stand for sum of all MUEs SINR

𝑖=1

𝑀𝑈𝐸1

𝑀𝑈𝐸2

𝑀𝑈𝐸𝑛

in the network, considering all positions of MUEs, 𝑆𝐼𝑁𝑅𝑀𝑈𝐸1 + 𝑆𝐼𝑁𝑅𝑀𝑈𝐸2 + ⋯ +

𝑆𝐼𝑁𝑅𝑀𝑈𝐸𝑛 stand for sum all MUE SINR at particular position of HUE, 𝑁𝑀𝑈𝐸 is the number of MUE in the network and 𝑀𝑈𝐸𝐿𝑝 stand for last position of 𝑀𝑈𝐸.

## Determine interference block

The Macro-Femto HetNet interference is determined using a simple approach adopted from Susanto *et al*. 2017. Where each nodes and UEs in the network, after measuring it’s

received SINR compared it with target SINR to determine interference in the network. The mathematical expression for determining interference in the network is given in equation (3.12).

𝜆𝐸𝐴𝑃𝐶 = 𝑆𝐼𝑁𝑅𝑐𝑜𝑚𝑝𝑢𝑡𝑒𝑑 − 𝑆𝐼𝑁𝑅𝑡𝑎𝑟𝑔𝑒𝑡 (3.12) when 𝑆𝐼𝑁𝑅𝑐𝑜𝑚𝑝𝑢𝑡𝑒𝑑 is greater than 𝑆𝐼𝑁𝑅𝑡𝑎𝑟𝑔𝑒𝑡, it implies there is approximately no interference and the transmit power is above the minimum power required for communication, hence the power should be reduce. When 𝑆𝐼𝑁𝑅𝑐𝑜𝑚𝑝𝑢𝑡𝑒𝑑 is less than

𝑆𝐼𝑁𝑅𝑡𝑎𝑟𝑔𝑒𝑡, it implies that there is interference and the transmit power needed for communication needs to be increased. And when 𝑆𝐼𝑁𝑅𝑐𝑜𝑚𝑝𝑢𝑡𝑒𝑑 is equal to 𝑆𝐼𝑁𝑅𝑡𝑎𝑟𝑔𝑒𝑡, the present transmit power will be used for the next transmission.

## Power adjustment block

The adjustment of nodes and UEs transmit power is anchored on interference in the Macro-Femto HetNet. The conditions for reducing, maintaining, or even increasing the downlink, uplink transmit power are based on the difference between 𝑆𝐼𝑁𝑅𝑐𝑜𝑚𝑝𝑢𝑡𝑒𝑑 and

𝑆𝐼𝑁𝑅𝑡𝑎𝑟𝑔𝑒𝑡. When 𝑆𝐼𝑁𝑅𝑐𝑜𝑚𝑝𝑢𝑡𝑒𝑑 > 𝑆𝐼𝑁𝑅𝑡𝑎𝑟𝑔𝑒𝑡, adjustment factor (*S*) is assigned a value of -1 and the next transmit power of UEs, Hen-gNB or en-gNB is reduced by EAPC power step value. When 𝑆𝐼𝑁𝑅𝑐𝑜𝑚𝑝𝑢𝑡𝑒𝑑 = 𝑆𝐼𝑁𝑅𝑡𝑎𝑟𝑔𝑒𝑡, 0 is assign to *S* and the next transmit power of UEs, Hen-gNB or en-gNB will maintain the present value. And when 𝑆𝐼𝑁𝑅𝑐𝑜𝑚𝑝𝑢𝑡𝑒𝑑 < 𝑆𝐼𝑁𝑅𝑡𝑎𝑟𝑔𝑒𝑡, +1 is assigned to *S* and the next transmit power of serving UE, Hen-gNB, or en-gNB is increased by EAPC power step value. The mathematical expressions that show the assignment of value to adjustment factor is given in equation (3.13) and that which gives the adjustment of the next transmit power is given in equation (3.14).

𝑖𝑓 𝜆𝐸𝐴𝑃𝐶 = {

< 0 𝑎𝑠𝑠𝑖𝑔𝑛 𝑆 = +1 𝑖𝑛𝑡𝑒𝑟𝑓𝑒𝑟𝑒𝑛𝑐𝑒, 𝑖𝑛𝑐𝑟𝑒𝑎𝑠𝑒 𝑝𝑜𝑤𝑒𝑟

> 0 𝑎𝑠𝑠𝑖𝑔𝑛 𝑆 = − 1 𝑛𝑜 𝑖𝑛𝑡𝑒𝑟𝑓𝑒𝑟𝑛𝑐𝑒, 𝑟𝑒𝑑𝑢𝑐𝑒 𝑝𝑜𝑤𝑒𝑟

= 0 𝑎𝑠𝑠𝑖𝑔𝑛 𝑆 = 0 𝑛𝑜 𝑖𝑛𝑡𝑒𝑟𝑓𝑒𝑟𝑒𝑛𝑐𝑒. 𝑚𝑎𝑖𝑛𝑡𝑎𝑖𝑛 𝑡𝑟𝑎𝑛𝑠𝑚𝑖𝑡 𝑝𝑜𝑤𝑒𝑟

(3.13)

𝑃𝐸𝐴𝑃𝐶 = 𝑚𝑎𝑥 (𝑃𝑚𝑖𝑛, 𝑚𝑖𝑛 ( (𝑃𝑝𝑟𝑒𝑠𝑒𝑛𝑡 + 𝑆∆𝐸𝐴𝑃𝐶), 𝑃𝑚𝑎𝑥 )) (3.14) where, 𝑃𝑝𝑟𝑒𝑠𝑒𝑛𝑡 stands for present transmit power of Hen-gNB, ∆𝐸𝐴𝑃𝐶 stands for EAPC step power value. 𝑃𝑚𝑖𝑛 stands for the minimum transmit power of the transmitter, 𝑃𝑚𝑎𝑥

stands for the maximum transmit power of transmitter, and 𝑃𝐸𝐴𝑃𝐶 stands for the next

transmit power using EAPC technique for the set time duration (𝑇𝑓1). After the expiration of 𝑇𝑓1 the system starts all over again to determine the next transmit power.

## Power consumption block

The transmit power used by nodes and UEs at different positions are collated in an array form, and used in calculating the average power consumption of node and UE. The average power used by Hen-gNB in communicating to their respective HUE considering all Hen-gNBs, was computed using equation (3.15).

𝑝=𝐻𝑈𝐸𝐿𝑝

𝐴𝑣𝑒𝑟𝑎𝑔𝑒 ∑𝑝=1

𝑃 =

𝐻𝑒𝑛−𝑔𝑁𝐵𝑠

(𝑃𝐻𝑒𝑛−𝑔𝑁𝐵1+ 𝑃𝐻𝑒𝑛−𝑔𝑁𝐵2+⋯+𝑃𝐻𝑒𝑛−𝑔𝑁𝐵𝑛)

𝑁𝐻𝑒𝑛−𝑔𝑁𝐵 × 𝐻𝑈𝐸𝐿𝑝

(3.17)

where 𝑃𝐴𝑣𝑒𝑟𝑎𝑔𝑒 is the average transmit power of Hen-gNB. ∑𝑝=𝐻𝑈𝐸𝐿𝑝(𝑃 +

𝐻𝑒𝑛−𝑔𝑁𝐵𝑠

𝑝=1

𝐻𝑒𝑛−𝑔𝑁𝐵1

𝑃𝐻𝑒𝑛−𝑔𝑁𝐵2 + ⋯ + 𝑃𝐻𝑒𝑛−𝑔𝑁𝐵𝑛) is the sum of transmit power used by all the Hen-gNBs in communicating to their HUEs at different HUE positions. 𝑃𝐻𝑒𝑛−𝑔𝑁𝐵1 + 𝑃𝐻𝑒𝑛−𝑔𝑁𝐵2 +

⋯ + 𝑃𝐻𝑒𝑛−𝑔𝑁𝐵𝑛 stand for sum of transmit power used by all Hen-gNBs in the network at a particular position of HUEs, 𝑁𝐻𝑒𝑛−𝑔𝑁𝐵𝑠 stands for the number of Hen-gNBs in the HetNet and 𝐻𝑈𝐸𝐿𝑝 stand for last HUE position. The average transmit power of en-gNB considering all positions of MUE is compute using equation (3.16).

𝐴𝑣𝑒𝑟𝑎𝑔𝑒

𝑖=𝑀𝑈𝐸𝐿𝑝

∑ (𝑃𝑒𝑛−𝑔𝑁𝐵1+ 𝑃𝑒𝑛−𝑔𝑁𝐵2+⋯+𝑃𝑒𝑛−𝑔𝑁𝐵𝑛)

𝑃 = 𝑖=1

𝑒𝑛−𝑔𝑁𝐵𝑠

𝑁𝑒𝑛−𝑔𝑁𝐵 × 𝑀𝑈𝐸𝐿𝑝

where 𝑃𝐴𝑣𝑒𝑟𝑎𝑔𝑒 is the average transmit power of en-gNB. ∑𝑖=𝑀𝑈𝐸𝐿𝑝(𝑃

(3.16)

+

𝑒𝑛−𝑔𝑁𝐵𝑠

𝑖=1

𝑒𝑛−𝑔𝑁𝐵1

𝑃𝑒𝑛−𝑔𝑁𝐵2 + ⋯ + 𝑃𝑒𝑛−𝑔𝑁𝐵𝑛) is the sum of transmit power used by all the en-gNBs in communicating to their MUEs at different HUE positions. 𝑃𝑒𝑛−𝑔𝑁𝐵1 + 𝑃𝑒𝑛−𝑔𝑁𝐵2 + ⋯ +

𝑃𝑒𝑛−𝑔𝑁𝐵𝑛 stand for sum of transmit power used by all en-gNBs in the network at a particular MUE position, 𝑁𝑒𝑛−𝑔𝑁𝐵𝑠 stands for the number of en-gNBs in the HetNet, and

𝑀𝑈𝐸𝐿𝑝 stand for last MUE position. The average power used by HUE to their serving Hen-gNB is computed using (3.17).

𝑝=𝐻𝑈𝐸𝐿𝑝

𝐴𝑣𝑒𝑟𝑎𝑔𝑒 ∑𝑝=1

𝑃 =

𝐻𝑈𝐸𝑠

(𝑃𝐻𝑈𝐸1+ 𝑃𝐻𝑈𝐸2+⋯+𝑃𝐻𝑈𝐸𝑛)

𝑁𝐻𝑈𝐸𝑠 × 𝐻𝑈𝐸𝐿𝑝

(3.17)

where 𝑃𝐴𝑣𝑒𝑟𝑎𝑔𝑒 is the average transmit power of HUE. ∑𝑝=𝐻𝑈𝐸𝐿𝑝(𝑃

+ 𝑃 +

𝐻𝑈𝐸𝑠

𝑝=1

𝐻𝑈𝐸1

𝐻𝑈𝐸2

⋯ + 𝑃𝐻𝑈𝐸𝑛) is the sum of transmit power used by all the HUEs at different HUE positions. 𝑃𝐻𝑈𝐸1 + 𝑃𝐻𝑈𝐸2 + ⋯ + 𝑃𝐻𝑈𝐸𝑛 stand for sum of transmit power used by all HUEs in the network at a particular HUE position, 𝑁𝐻𝑈𝐸𝑠 stand for the number of HUEs in the HetNet, and 𝐻𝑈𝐸𝐿𝑝 stand for last HUE position. The average transmit power of MUEs at all positions is compute using equation (3.18).

𝐴𝑣𝑒𝑟𝑎𝑔𝑒

𝑃

𝑀𝑈𝐸

𝑖=𝑀𝑈𝐸𝐿𝑝

∑ (𝑃𝑀𝑈𝐸1+ 𝑃𝑀𝑈𝐸2+⋯+𝑃𝑀𝑈𝐸𝑛)

= 𝑖=1

𝑁𝑀𝑈𝐸𝑠 × 𝑀𝑈𝐸𝐿𝑝

(3.18)

where 𝑃𝐴𝑣𝑒𝑟𝑎𝑔𝑒 is the average transmit power of MUE. ∑𝑖=𝑀𝑈𝐸𝐿𝑝(𝑃

+ 𝑃 +

𝑀𝑈𝐸𝑠

𝑖=1

𝑀𝑈𝐸1

𝑀𝑈𝐸2

⋯ + 𝑃𝑀𝑈𝐸𝑛) is the sum of transmit power used by all the MUEs at different MUE positions. 𝑃𝑀𝑈𝐸1 + 𝑃𝑀𝑈𝐸2 + ⋯ + 𝑃𝑀𝑈𝐸𝑛 stand for sum of transmit power used by all MUEs in the network at a particular MUE position, 𝑁𝑀𝑈𝐸𝑠 stand for the number of MUEs in the HetNet, and 𝑀𝑈𝐸𝐿𝑝 stand for last MUE position.

## Throughput block

The throughput of each receiver is computed using equation (3.19) sourced from Hassan and Gao 2019, and 3GPP release. 8.2.

𝐶 =∝ 𝐵𝑙𝑜𝑔2(1 + 𝑆𝐼𝑁𝑅𝑅𝑥) (3.19)

From equation (3.19), the throughput of each HUE, MUE Hen-gNB, and en-gNB are computed using equation (3.20), (3.21), (3.22) and (3.23) respectively.

𝐶𝐻𝑈𝐸 =∝ 𝐵𝑙𝑜𝑔2(1 + 𝑆𝐼𝑁𝑅𝐻𝑈𝐸) (3.20)

𝐶𝑀𝑈𝐸 =∝ 𝐵𝑙𝑜𝑔2(1 + 𝑆𝐼𝑁𝑅𝑀𝑈𝐸) (3.21)

𝐶𝐻𝑒𝑛−𝑔𝑁𝐵 =∝ 𝐵𝑙𝑜𝑔2(1 + 𝑆𝐼𝑁𝑅𝐻𝑒𝑛−𝑔𝑁𝐵) (3.22)

𝐶𝑒𝑛−𝑔𝑁𝐵 =∝ 𝐵𝑙𝑜𝑔2(1 + 𝑆𝐼𝑁𝑅𝑒𝑛−𝑔𝑁𝐵) (3.23) where 𝑆𝐼𝑁𝑅𝐻𝑈𝐸, 𝑆𝐼𝑁𝑅𝑀𝑈𝐸, 𝑆𝐼𝑁𝑅𝐻𝑒𝑛−𝑔𝑁𝐵, and 𝑆𝐼𝑁𝑅𝑒𝑛−𝑔𝑁𝐵 are received SINR by HUE, MUE, *Hen-gNB* and *en-gNB*, respectively. 𝐶 is channel throughput, ∝ is attenuation factor, 𝐵 is system bandwidth, and 𝑆𝐼𝑁𝑅𝑅𝑥is SINR of receiver. 𝐶𝐻𝑈𝐸,

𝐶𝑀𝑈𝐸, 𝐶𝐻𝑒𝑛−𝑔𝑁𝐵and 𝐶𝑒𝑛−𝑔𝑁𝐵 are throughput of *HUE*, *MUE*, *Hen-gNB* and *en-gNB*,

respectively. System bandwidth of 60 MHZ for 5G network was used, adopted from the work of authors in Rehman *et al.* (2020).

## Research System Architecture and Description

The architecture of the research Macro-Femto HetNet captured both co-tier and cross-tier interference, as illustrated in Figure 3.2. It has one macrocell and two overlaid femtocells.



en-gNB 1

𝑰𝟑

Hen-gNB 2

𝑰𝟏

HUE

MUE 1

**FEMTOCELL 1**

**FEMTOCELL 2**

Interference signal

Desired signal

HUE 1

Hen-gNB 1

𝑰𝟐



a. Downlink transmission b. Uplink transmission Figure 3.2: Research system architecture

From the research architecture in Figure 3.1, 𝐼1 represents downlink cross-tier interference, where MUE 1 is the VT and Hen-gNB 2 is the AG. 𝐼2 is a downlink co-tier interference, in which Hen-gNB 1 is the AG and HUE 2 is the VT. 𝐼3 is a downlink cross-tier interference, en-gNB 1 is the AG and HUE 1 is the VT. 𝐼4 is an uplink cross-tier interference, by which MUE1 is the AG and Hen-gNB 2 is the VT. 𝐼5 is an uplink co-tier interference whereby HUE 2 is the AG and Hen-gNB 1 is the VT. And 𝐼6 is an uplink cross-tier interference, in which HUE 1 is the AG and en-gNB 1 is the VT.

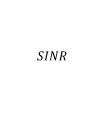
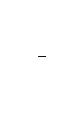
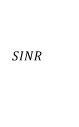
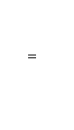
## Flowchart of an Enhanced Active Power Control Technique

The flowchart of the an enhanced active power control technique, as presented in Figure

3.3 shows the series of actions and the order in which such actions would be executed to update the uplink transmit power of UEs and downlink power of Hen-gNBs, and en-gNB.

Figure 3.3: Flowchart of enhanced active power control technique simulation

Figure 3.3: Flowchart of enhanced active power control technique simulation



## 3.4.1 Description of flowchart

When the nodes and UEs boots successfully, the system parameters presented in Table

3.1 are load into their respective memories. The different nodes and UE performed mathematical computation to determine when to adjust or even maintain their transmit power, using mathematical models and specified system parameters. The computations include that of path loss, SINR, the difference between measured and target SINRs, throughput, power adjustment, and average transmit power.

The flowchart of EAPC technique comprises one input stage where system parameters are specified. It has six processes, the first process handles the computation of path loss using equation (3.1) and (3.8) for macrocell and femtocell path loss respectively. The second, third and fourth processes used outcome of computing the difference between measured SINR and target SINR, from the first process to assigned a value to 𝑆. The fifth process does the actual adjustment of next transmit power within the minimum and maximum transmit power range of nodes and UEs. This is done using the present or initial transmit power, adjustment factor, and EAPC step power value and equation (3.16). The sixth process count the number of iterations. The flowchart has three decision boxes. The first and second decision boxes are used to alter the value assigned to 𝑆. The third decision box is used to control the number of iterations to be performed.

# CHAPTER FOUR

# RESULTS AND DISCUSSION

## Presentation of Results and Discussion

The chapter presents the simulation results of the research Macro-Femto HetNet. The results are broadly categorized into downlink and uplink transmission results. The entire MATLAB codes used for the simulation of the Macro-Femto HetNet are bulky, hence some of the codes that captured all stages of the simulation are presented in appendix A.

The researchers used throughput and energy consumption of UEs and nodes as key performance indicators of the research. This is because of the relationship between interference, throughput and transmit power. Interference in a network is inversely proportional to throughput and directly proportional to transmit power, when other factors are kept constant. That is, the higher the interference the lower the throughput, the higher the throughput the lower the interference. The higher the transmit power the higher the chances of interference, the lower the transmit power the lower the interference. In other words, the higher the transmit power the higher the interference and the lower the throughput. The lower the transmit power the lower the interference and the higher the throughput.

## Downlink Transmission Results

The downlink results obtained from the research simulation includes the throughput of HUE and MUE, and the power consumption of femtocell and macrocell logical node. The average HUE and MUE throughput performance at different position of UEs was computed using equations (3.22) and (3.23), respectively and the result presented in Figures (4.1) and (4.2), respectively. The received SINR was computed using (3.9),

depending on the path loss valued computed using different techniques. When Hen-gNBs transmitted to its HUE at different HUE positions, and en-gNB transmitted to its MUE at different MUE positions. An array of Hen-gNBs and en-gNBs transmit powers was used in computing the average Hen-gNBs and en-gNB transmit power using equations (3.17) and (3.18), respectively; and the results are presented in Figures (4.3) and (4.4) respectively.

## Throughput performance of home user equipment

The throughput performance of HUE using APC, EAPC, and PC1 techniques, is presented in Figure 4.1.

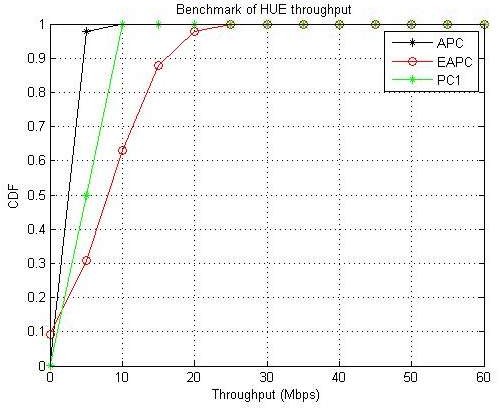


Figure 4.1: Benchmark throughput performance of HUE

In Figure 4.1, at Cumulative Distribution Function (CDF) of 0.2 and above, the EAPC technique had an average HUE that outperformed that of APC and PC1 techniques. Table

4.1 presents the average throughput performance of HUE within the CDF range of 0 – 1.

## Table 4.1: Throughput performance of HUE at various CDF values

HUE Throughput Performance Based on Techniques

|  |  |  |  |
| --- | --- | --- | --- |
| CDF | APC | EAPC | PC1 |
| 0.0 | 0.0 | 0.0 | 0.0 |
| 0.1 | 9.0 | 0.0 | 1.7 |
| 0.2 | 1.4 | 2.6 | 2.2 |
| 0.3 | 1.8 | 5.2 | 3.0 |
| 0.4 | 2.3 | 6.5 | 4.3 |
| 0.5 | 2.9 | 8.2 | 5.2 |
| 0.6 | 3.5 | 9.6 | 6.1 |
| 0.7 | 3.9 | 11.7 | 7.0 |
| 0.8 | 4.3 | 13.5 | 7.8 |
| 0.9 | 4.8 | 16.1 | 9.1 |
| 1.0 | 10.0 | 25.0 | 10.0 |

According to Table 4.1, at CDF of 0.1, the HUE throughput of PC1 outperformed that of APC and EAPC techniques by 47% and 100% respectively. At CDF of 0.2, the HUE throughput of EAPC compared to APC and PC1 techniques was higher by 46% and 15%, respectively. At CDF of 0.3, the EAPC HUE throughput compared to APC and PC1 techniques was higher by 65% and 42% respectively. At CDF of 0.4, the EAPC HUE throughput compared to APC and PC1 techniques was higher by 64% and 34% respectively. At CDF of 0.5, EAPC had 65% and 37% higher HUE throughput when compared to APC and PC1 techniques, respectively. At CDF of 0.6, EAPC had 64% and 37% higher HUE throughput when compared to APC and PC1 techniques respectively. At CDF of 0.7, EAPC had 67% and 40% higher HUE throughput when compared to APC and PC1 techniques respectively. At CDF of 0.8, EAPC had 68% and 42% higher HUE throughput when compared to APC and PC1 techniques respectively. At CDF of 0.9, EAPC had 70% and 44% higher HUE throughput when compared to APC and PC1

techniques respectively. At CDF of 1, EAPC had HUE throughput that outperformed that of both APC and PC1 techniques by 60%.

## Throughput performance of macro user equipment

The result of comparison between APC, EAPC and PC1 techniques in terms of MUE throughput is presented in Figure 4.2.

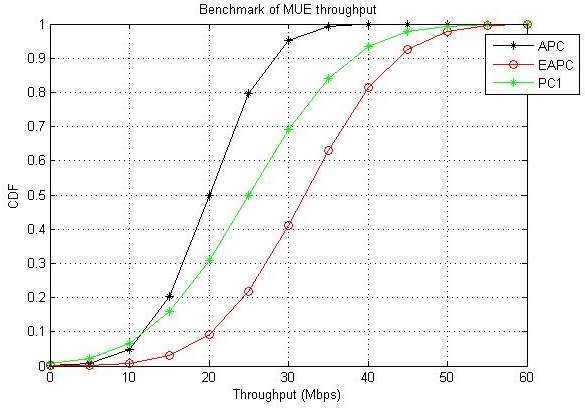


Figure 4.2: Benchmark of MUE throughput

Within the range of 0.1 to 1.0 CDF in Figure 4.2, the MUE throughput, of EAPC technique outperformed that of APC and PC1 techniques. Table 4.2 presents the MUE throughput performances, within the range of 0.1– 1.0 CDF.

## Table 4.2: Throughput performance of MUE at various CDF values

MUE Throughput Performance Based on Techniques in Mbps

|  |  |  |  |
| --- | --- | --- | --- |
| CDF | APC | EAPC | PC1 |
| 0 | 0 | 0 | 0 |
| 0.1 | 11.7 | 20.0 | 11.7 |
| 0.2 | 15.0 | 25.0 | 16.7 |
| 0.3 | 16.7 | 26.7 | 20.0 |
| 0.4 | 18.3 | 29.2 | 21.7 |
| 0.5 | 20.0 | 31.7 | 25.0 |
| 0.6 | 21.7 | 35.0 | 26.7 |
| 0.7 | 23.3 | 36.7 | 30.0 |
| 0.8 | 25.0 | 40.0 | 33.9 |
| 0.9 | 28.3 | 43.3 | 38.2 |
| 1.0 | 40.0 | 55.0 | 50.0 |

According to Table 4.2, at 0.1 CDF, the MUE throughput of EAPC outperform that of APC, and PC1 techniques by 42%. At 0.2 CDF, EAPC when compared to APC and PC1 techniques had 40% and 33% higher MUE throughput respectively. At 0.3 CDF, EAPC when compared to APC and PC1 techniques had 38% and 25% higher MUE throughput. At 0.4 CDF, EAPC when compared to APC and PC1 techniques had 37% and 26% higher MUE throughput respectively. At 0.5 CDF, EAPC when compared to APC and PC1 techniques had 37% and 21% higher MUE throughput respectively. At 0.6 CDF, EAPC when compared to APC and PC1 techniques had 38% and 24% higher MUE throughput respectively. At 0.7 CDF, EAPC had 37% and 18% higher MUE throughput when compared to APC and PC1 techniques respectively. At 0.8 CDF, EAPC when compared to APC and PC1 techniques had 38% and 15% higher MUE throughput respectively. At

0.9 CDF, EAPC when compared to APC and PC1 techniques had 35% and 12% higher MUE throughput respectively. At CDF of 1, EAPC when compared to APC and PC1 had 27% and 9% higher MUE throughput techniques respectively.

## Transmit power of femtocell node

The benchmark result of the average power used by Hen-gNBs in communicating with their respective HUEs is presented in Figure 4.3.

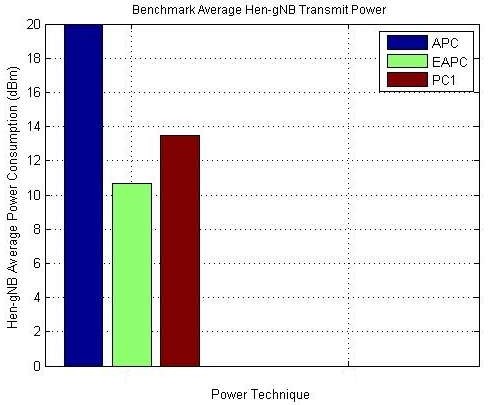


Figure 4.3: Benchmark Hen-gNB power consumption

In Figure 4.3, APC, EAPC, and PC1 techniques had an average Hen-gNB transmit power 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.

The path loss model used in EAPC gave rise to less signal losses, which improved on received Hen-gNB SINR. When received SINR is above the target SINR, the node will not increase transmit power, rather reduced the transmit power, which accounted for low average Hen-gNB transmit power of EAPC.

## Macrocell node power consumption

The benchmark average power consumed by en-gNB in communicating to its MUE is presented in Figure 4.4.

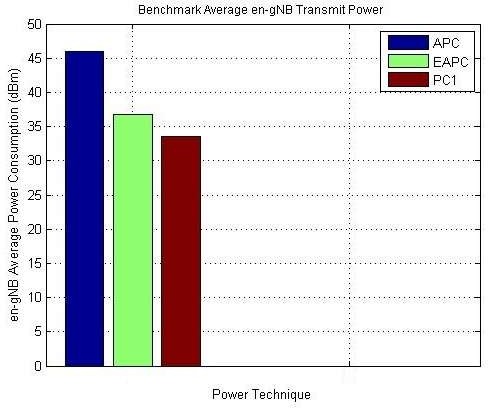


Figure 4.4: Average transmit power of en-gNB

In Figure 4.4, APC, EAPC, and PC1 techniques, had an average en-gNB transmit power of 46.00 dBm, 36.45 dBm, and 33.50 dBm respectively. EAPC technique was limited in conserving en-gNB energy when compare with PC1, while APC technique transmitted at maximum power all through. The EAPC technique conserved 21% of en-gNB power when compared to that of APC technique. While PC1 technique conserved 8% and 27% en-gNB power when compared to EAPC and APC techniques.

## Uplink Transmission Results

The uplink results include the average transmission power of HUE and MUE; and the throughput performance of Hen-gNB and en-gNB. The throughput performance of

Hen-gNB and en-gNB was computed using equations (3.24) and (3.25), respectively and the results presented in Figures (4.5) and (4.6), respectively. The array of HUE and MUE transmit powers was used in computing the average transmit power of HUE and MUE using equations (3.19) and (3.20), respectively, and the results presented in Figures (4.7) and (4.8) respectively.

## Throughput performance of femtocell node

The comparison of APC, EAPC, and PC1 techniques in regards to throughput performance of Hen-gNB is presented in Figure 4.5.

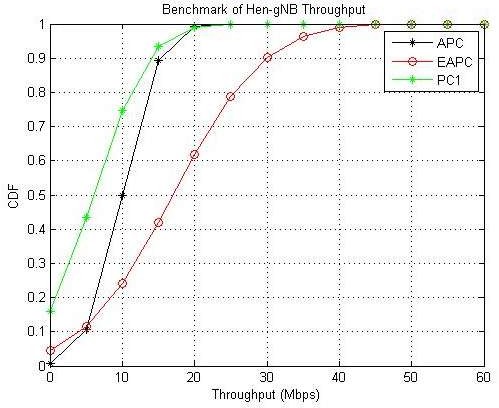


Figure 4.5: Benchmark of Hen-gNB throughput

From Figure 4.5, the Hen-gNB throughput performance of APC, EAPC, and PC1 techniques at different CDF values are presented in Table 4.3.

## Table 4.3: Hen-gNB throughputs at various CDF values

Hen-gNB Throughput Performance Based on Techniques

|  |  |  |  |
| --- | --- | --- | --- |
| CDF | APC | EAPC | PC1 |
| 0.0 | 0.00 | 0.00 | 0.00 |
| 0.1 | 05.4 | 04.6 | 00.0 |
| 0.2 | 06.2 | 08.5 | 01.5 |
| 0.3 | 07.7 | 12.3 | 03.1 |
| 0.4 | 08.5 | 14.6 | 04.6 |
| 0.5 | 10.0 | 16.9 | 06.2 |
| 0.6 | 11.2 | 19.2 | 07.7 |
| 0.7 | 13.1 | 23.1 | 09.2 |
| 0.8 | 13.8 | 25.4 | 12.3 |
| 0.9 | 15.4 | 30.0 | 14.6 |
| 1.0 | 20.0 | 40.0 | 20.0 |

From Table 4.3, at CDF of 0.1, APC compared to EAPC and PC1 techniques had 15% and 100% higher Hen-gNB throughput. At CDF of 0.2, EAPC compare to APC and PC1 techniques had 27% and 82% higher Hen-gNB throughput. At CDF of 0.3, EAPC had 37% and 75% higher Hen-gNB throughput when compared to APC and PC1 techniques respectively. At CDF of 0.4, EAPC had 42% and 69% higher Hen-gNB throughput when compared to APC and PC1 techniques. At CDF of 0.5, EAPC had 41% and 63% higher Hen-gNB throughput compare to APC and PC1 techniques respectively. At CDF of 0.6, EAPC had 42% and 60% higher Hen-gNB throughput when compared to APC and PC1 techniques respectively. At CDF of 0.7, EAPC had 43% and 60% higher Hen-gNB throughput when compare to APC and PC1 techniques respectively. At CDF of 0.8, EAPC had 46% and 52% higher HUE throughput when compared to APC and PC1 techniques respectively. At CDF of 0.9, EAPC had 49% and 51% higher throughput than APC and PC1 techniques. At CDF of 1, the Hen-gNB throughput of EAPC outperformed that of both APC and PC1 techniques by 50%. EAPC technique had the best Hen-gNB throughput at CDF values ranging from 0.2 - 1, while APC technique had the best Hen-gNB throughput at CDF value of 0.1.

## Throughput performance of macrocell node

The result of en-gNB throughput based on APC, EAPC and PC1 technique is presented in Figure 4.6.

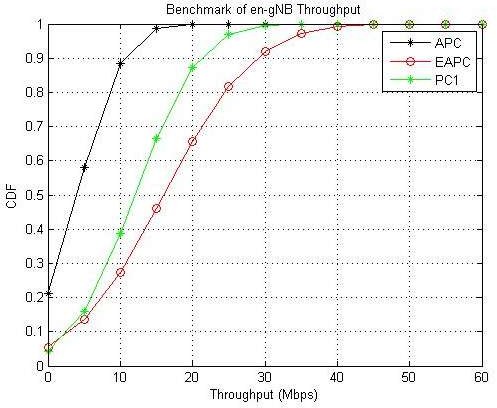


Figure 4.6: Benchmark of en-gNB throughput

From Figure 4.6, the different en–gNB throughput at particular CDF values for APC, EAPC and PC1 techniques are presented in Table 4.3.

## Table 4.4: en-gNB throughputs at various CDF values

en-gNB Throughput Performance Based on Techniques in Mbps

|  |  |  |  |
| --- | --- | --- | --- |
| CDF | APC | EAPC | PC1 |
| 0 | 0.00 | 0.00 | 0.00 |
| 0.1 | 0.00 | 08.0 | 05.0 |
| 0.2 | 0.00 | 16.0 | 11.5 |
| 0.3 | 04.0 | 22.0 | 15.0 |
| 0.4 | 06.0 | 26.0 | 19.5 |
| 0.5 | 08.0 | 32.0 | 23.0 |
| 0.6 | 11.5 | 36.0 | 26.0 |
| 0.7 | 13.5 | 42.5 | 30.0 |
| 0.8 | 17.0 | 48.5 | 34.5 |
| 0.9 | 22.0 | 56.0 | 41.0 |
| 1.0 | 40.0 | 80.0 | 60.0 |

According to Table 4.2, at CDF of 0.1, EAPC compare to APC, PC1 and techniques had 100% and 25% higher en-gNB throughput. At CDF of 0.2, EAPC compare to APC and PC1 techniques had 100% and 25% higher en-gNB throughput. At CDF of 0.3, EAPC compare to APC and PC1 techniques had 82% and 23% higher en-gNB throughput. At CDF of 0.4, EAPC compare to APC and PC1 techniques had 78% and 22% higher en-gNB throughput. At CDF of 0.5, EAPC compare to APC and PC1 techniques had 69% and 25% higher en-gNB throughput. At CDF of 0.6, EAPC compare to APC and PC1 techniques had 67% and 22% higher en-gNB throughput. At CDF of 0.7, EAPC compare to APC and PC1 techniques had 65% and 26% higher en-gNB throughput. At CDF of 0.8, EAPC compare to APC and PC1 techniques had 63% and 23% higher en-gNB throughput. At CDF of 0.9, EAPC compare to APC and PC1 techniques had 62% and 26% higher en-gNB throughput. At CDF of 1, EAPC compare to APC and PC1 techniques had 50% and 25% higher en-gNB throughput. EAPC technique had higher en-gNB throughput at CDF of 0.1 – 1.

## Transmit power of femtocell user equipment

The average power used for communication between HUE and its respective Hen-gNB in the research Macro-Femto HetNet is presented in Figure 4.7.

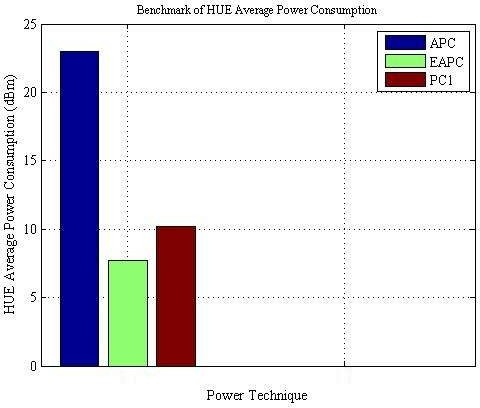


Figure 4.7: Benchmark HUE power consumption

In Figure 4.7 the average transmit power of HUE using EAPC has the lowest power consumption of 7.45 dBm, followed by PC1 with 12.41 dBm, then APC with 21.36 dBm. EAPC technique conserved 65.12 % and 39.97 % of HUE battery when compared with APC and PC1 techniques respectively. The low HUE energy consumption of EAPC technique will increase the battery lifespan of HUE and reduce the probability of having high co-tier and cross-tier interference in the network.

## Macrocell user equipment power consumption

The average power used by MUE and en-gNB in communicating at all positions of MUE is presented in Figure 4.8.

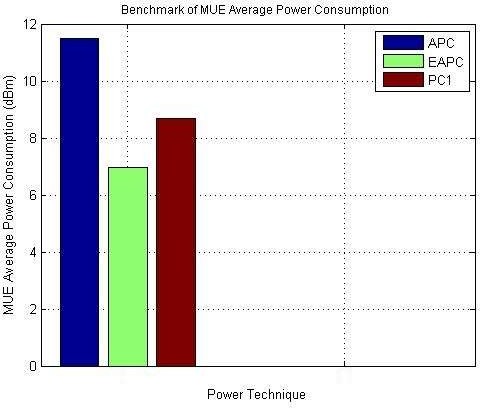


Figure 4.8: Average transmit power of MUE

The MUE transmit power of EAPC had the lowest value of 6.95 dBm, followed by PC1 with 8.70 dBm, and lastly APC with 11.50 dBm. EAPC technique outperformed APC and PC1 in conserving MUE battery by 37.95 % and 42.28 %, respectively.

When interference is reduced, the transmit power of UE also reduced thereby having a less average transmit power. The less interference in uplink transmission of Macro-Femto HetNet when EAPC was used gave less average transmit power of UEs.

# CHAPTER FIVE

# CONCLUSION AND RECOMMENDATIONS

## Conclusion

This research work hybridized extended attenuation factor model, power control technique 1, active power control technique, and used a power step value of 0.5 dB to develop an enhanced active power control technique. The research Macro-Femto HetNet architecture considered mobile UEs, two femtocells, one macrocell, two HUEs and one MUE, femtocell close access mode, co-tier and cross-tier interference.

The simulation of the research Macro-Femto HetNet, and comparison of the performance of, the developed EAPC technique with that of APC and PC1 was carried out using MATLAB software, guided by the research assumptions and system parameters. The uplink, downlink Macro-Femto transmission results obtained, as presented in Figures 4.1 – 4.8 indicated that APC technique generally transmitted at high power which accounted for its poor throughput performance, the higher the transmit power the higher the chances of interference and the lower the SINR and throughput. The APC high transmit power is attributed to the second stage power adjustment when mobile UEs were considered. The benchmark results obtained also showed that the EAPC technique that has low interference; as seen in its better throughput and low energy consumption. However the EAPC technique was limited in conserving macrocell node power when compared to that of PC1 technique by. The PC1 technique was better in conserving en-gNB power when compared to EAPC by 8%.

## Recommendations

The developed EAPC technique should be modified to address its limitation of en-gNB power consumptions. As well, the network architecture should be enhanced to capture at least four femtocell nodes, eight home user equipment, and two macro user equipment.

## Contribution to Knowledge

The study developed an enhanced active power control technique for interference mitigation in Macro-Femto cellular network. It also provided a comparative analyses of the performance of EAPC, APC, and PC1 power control techniques, in mobile Macro-Femto HetNet.

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## APPENDIX A (Some Macro-Femto Mobile Network Simulation Codes)

clc; clear all; close all;

% PROGRAM TO COMPUTE AND COMPARE PC 1, APC AND EAPC MODEL NETWORK CAPACITY

HeNB\_Min\_P = 0; % min transmit power of HeNB HeNB\_Max\_P= 20; % max transmit power of HeNB eNB\_Min\_P = 5; % min transmit power of eNB eNB\_Max\_P= 46; % max transmit power of eNB APC\_P\_HeNB = HeNB\_Initial\_Power= 8;

APC\_P\_eNB = eNB\_Initial\_Power; EAPC\_P\_eNB = eNB\_Initial\_Power = 34; EAPC\_P\_HeNB = HeNB\_Initial\_Power; PC1\_P\_eNB = eNB\_Initial\_Power; PC1\_P\_HeNB = HeNB\_Initial\_Power; HeNB\_RSTP = 20;

eNB\_RSTP = 46;

HUE\_Min\_P = MUE\_Min\_P = 0; % min transmit power of HUE HUE\_Max\_P= MUE\_Max\_P= 23; % max transmit power of HUE MUE\_initial\_P = 5;

HUE\_initial\_P = 5; PC1\_P\_MUE = MUE\_initial\_P; PC1\_P\_HUE = HUE\_initial\_P; APC\_P\_MUE = MUE\_initial\_P; APC\_P\_HUE = HUE\_initial\_P; EAPC\_P\_MUE = MUE\_initial\_P; EAPC\_P\_HUE = HUE\_initial\_P; MUE\_RSTP = 23;

HUE\_RSTP = 23;

Number\_of\_eNB = 1; % number of eNB Number\_of\_MUE = 1; % number of MUE Number\_of\_HeNB = 2; % number of HeNB Number\_of\_HUE = 2; % NUMBER OF HUE

APC\_Log\_N\_Sha\_Macro = 8; % APC eNB LOG SHADOWING STANDARD DEVIATION APC\_Log\_N\_Sha = 4; % APC HeNB LOG SHADOWING STANDARD DEVIATION

APC\_INT\_THRESHOLD = -72;

APC\_L1 = 20;

EAPC\_L1 = 10;

PC1\_L1 = 10;

FAF = 16.2; % FLOOR ATTENUATION FACTOR

f = 2600; % carrier frequency in MHz

R = 4900; % distance between eNB and indoor MUEs (DESIRED) R1 =1000; % DISTANCE BETWEEN eNB AGGRESSOR AND indoor HUE

R2 = 10; % distanc between HeNB and indoor UEs (DESIRED)

R3 = 5; % DISTANCE BETWEEN HeNB AGGRESSOR AND indoor UE VICTIM R4 = 10; % DISTANCE B/W HeNB2 AND MUE (UNDESIRED CROSS-TIER)

N = -174; % value of thermal noise BW = 60; % MHz

lf =0.05; %

SINR\_target = 10; EAPC\_MACRO\_THROUGHPUT\_ARRAY = cell(1,10); EAPC\_FEMTO\_THROUGHPUT\_ARRAY = cell(1,10); EAPC\_HeNB\_P\_ARRAY = cell(1,10); EAPC\_eNB\_P\_ARRAY = cell(1,10); EAPC\_MUE\_SINR\_ARRAY= cell(1,10); EAPC\_HUE\_SINR\_ARRAY= cell(1,10); EAPC\_MUE\_THROUGHPUT\_ARRAY = cell(1,10); EAPC\_HUE1\_THROUGHPUT\_ARRAY= cell(1,10); EAPC\_HUE2\_THROUGHPUT\_ARRAY= cell(1,10); EAPC\_MUE\_HUE\_THROUGHPUT\_ARRAY = cell(1,10);

UPLINK\_EAPC\_MACRO\_ARRAY = cell(1,10); UPLINK\_EAPC\_FEMTO\_ARRAY = cell(1,10); EAPC\_HUE\_P\_ARRAY = cell(1,10); EAPC\_MUE\_P\_ARRAY = cell(1,10); EAPC\_eNB\_SINR\_ARRAY = cell(1,10); EAPC\_HeNB\_SINR\_ARRAY = cell(1,10); EAPC\_eNB\_THROUGHPUT\_ARRAY= cell(1,10); EAPC\_HeNB1\_THROUGHPUT\_ARRAY= cell(1,10); EAPC\_HeNB2\_THROUGHPUT\_ARRAY= cell(1,10); UPLINK\_EAPC\_FM\_ARRAY = cell(1,10);

spv = 0.5;

Number\_of\_loop = 10;

for x = 1:Number\_of\_loop, % BEGINNING OF LOOP

R = R +10 ; % distance between eNB and indoor MUEs (DESIRED) R1 =R1 +10; % DISTANCE BETWEEN eNB AGGRESSOR AND indoor HUE VICTIM(UNDESIRED CROSS-TIER)

R2 =R2+ 2; % distanc between HeNB and indoor UEs (DESIRED)

R3 =R3 +2; % DISTANCE BETWEEN HeNB AGGRESSOR AND indoor UE VICTIM R4 =R4 +1; % DISTANCE B/W HeNB2 AND MUE (UNDESIRED CROSS-TIER)

% path loss of en-gNB to indoor MUE based on APC model APC\_PL\_eNB\_indoor\_MUEs\_dB= 10\*log10(37.6\*log10(R) + 15.3) +

APC\_L1;

% path loss of en-gNB to indoor MUE based on EAPC model EAPC\_PL\_eNB\_indoor\_MUEs\_dB = 10\*log10(37.6\*log10(R) + 15.3) +

EAPC\_L1;

% PATH LOSS OF en-gNB TO INDOOR MUEs using PC1 Model PC1\_PL\_eNB\_indoor\_MUEs\_dB = 10\*log10(37.6\*log10(R) + 15.3) +

PC1\_L1;

% path loss from Hen-gNB to INdoor DESIRED HUE using APC APC\_PL\_HeNB\_to\_indoor\_HUE\_dB = 10\*log10(log10(R2)\*20 + 38.46);

% path loss from Hen-gNB to INdoor HUE using EAPC EAPC\_PL\_HeNB\_to\_indoor\_HUE\_dB = 20\*log10((4\*3.142\*f)/(3\*10^8)) +

60\*log10(R2)+ FAF ;

% path loss from Hen-gNB - DESIRED indoor HUEs using PC1 model PC1\_PL\_HeNB\_indoor\_HUE\_dB = 10\*log10(30\*log10(R2/1000) + 127);

% path loss from Hen-gNB AGGRESSOR to INdoor HUE VICTIM using APC:CO- TIER

APC\_INT\_PL\_HeNB\_to\_indoor\_HUE\_dB = 10\*log10(log10(R3)\*20 + 38.46)+APC\_L1;

% path loss from Hen-gNB AGGRESSOR to INdoor HUE VICTIM using EAPC: CO

- TIER

EAPC\_INT\_PL\_HeNB\_to\_indoor\_HUE\_dB = 20\*log10((4\*3.142\*f)/(3\*10^8))

+ 60\*log10(R3)+ FAF ;

% path loss from Hen-gNB AGGRESSOR - indoor HUEs VICTIM using PC1 model: CO TIER

PC1\_INT\_PL\_HeNB\_indoor\_HUE\_dB = 10\*log10(30\*log10(R3/1000) + 127)+PC1\_L1;

% path loss from Hen-gNB AGGRESSOR to INdoor MUE VICTIM using APC:CROSS TIER

APC\_INT\_PL\_HeNB\_to\_indoor\_MUE\_dB = 10\*log10(20\*log10(R4) + 38.46);

% INTERFERENCE PATH LOSS

% path loss from Hen-gNB AGGRESSOR to INdoor MUE VICTIM using EAPC: CROSS TIER

EAPC\_INT\_PL\_HeNB\_to\_indoor\_MUE\_dB = 20\*log10((4\*3.142\*f)/(3\*10^8))

+ 60\*log10(R4)+ FAF ;

% path loss from Hen-gNB AGGRESSOR - indoor MUEs VICTIM using PC1 model: CROSS TIER

PC1\_INT\_PL\_HeNB\_indoor\_MUE\_dB = 10\*log10(30\*log10(R4/1000) + 127);

% path loss of en-gNB AGGRESSOR to indoor HUE VICTIM USING APC MODEL: CROSS

% TIER interference scenario

APC\_INT\_PL\_eNB\_indoor\_HUEs\_dB = 10\*log10(37.6\*log10(R1) + 15.3)+ APC\_L1; % INTERFERENCE PATH LOSS

% path loss of en-gNB AGGRESSOR to INdoor HUE VICTIM USING EAPC MODEL: CROSS TIER

EAPC\_INT\_PL\_eNB\_indoor\_HUEs\_dB = 10\*log10(37.6\*log10(R1) + 15.3)+EAPC\_L1;

% PATH LOSS OF en-gNB Aggressor TO INDOOR HUEs using PC1 Model: CROSS TIER

PC1\_INT\_PL\_eNB\_indoor\_HUEs\_dB = 10\*log10(37.6\*log10(R1) + 15.3) + PC1\_L1; % INTERFERENCE PATH LOSS

% SINR OF HUE1 BASED ON EAPC APPROACH EAPC\_SINR\_HUE1 =

EAPC\_P\_HeNB1\*EAPC\_PL\_HeNB\_to\_indoor\_HUE\_dB/((EAPC\_P\_eNB\*EAPC\_INT\_PL\_eN B\_indoor\_HUEs\_dB) + N);

% SINR OF HUE2 BASED ON EAPC APPROACH EAPC\_SINR\_HUE2 =

EAPC\_P\_HeNB2\*EAPC\_PL\_HeNB\_to\_indoor\_HUE\_dB/((EAPC\_P\_HeNB1\*EAPC\_INT\_PL\_ HeNB\_to\_indoor\_HUE\_dB) + N);

% SINR OF MUE BASED ON EAPC APPROACH EAPC\_SINR\_MUE =

EAPC\_P\_eNB\*EAPC\_PL\_eNB\_indoor\_MUEs\_dB/(EAPC\_P\_HeNB2\*EAPC\_INT\_PL\_HeNB\_t o\_indoor\_MUE\_dB + N);

%PROGRAM TO COMPUTE EAPC AND PC1 POWER ALPOSITION EAPC\_HUE1\_SINR\_DIFF = EAPC\_SINR\_HUE1 - SINR\_target; EAPC\_HUE2\_SINR\_DIFF = EAPC\_SINR\_HUE2 - SINR\_target; EAPC\_eNB\_MUE\_SINR\_DIFF = EAPC\_SINR\_MUE - SINR\_target;

%PROGRAM TO COMPUTE eNB POWER ALPOSITION

% EAPC power control codes if EAPC\_eNB\_MUE\_SINR\_DIFF > 0

EAPC\_eNB\_c1 = -1;

elseif EAPC\_eNB\_MUE\_SINR\_DIFF < 0 EAPC\_eNB\_c1 = 1;

else

EAPC\_eNB\_c1 = 0;

end

% EAPC power control codes if EAPC\_HUE1\_SINR\_DIFF > 0

EAPC\_c2 = -1;

elseif EAPC\_HUE1\_SINR\_DIFF < 0

EAPC\_c2 = 1;

else

EAPC\_c2=0;

end

if EAPC\_HUE2\_SINR\_DIFF > 0

EAPC\_c22 = -1;

elseif EAPC\_HUE2\_SINR\_DIFF < 0

EAPC\_c22 = 1;

else

EAPC\_c22=0;

end

% COMPUTE POWER ADJUSTMENT OF HeNB TRANSMIT POWER

EAPC\_P\_HeNB1 = min(max(HeNB\_Min\_P,(EAPC\_P\_HeNB1 + (EAPC\_c2\*spv))),HeNB\_Max\_P);% to ensure that transmit power (P\_2) is between EAPC\_P\_HeNB2 = min(max(HeNB\_Min\_P,(EAPC\_P\_HeNB2 + (EAPC\_c22\*spv))),HeNB\_Max\_P);% to ensure that transmit power (P\_2) is between

% COMPUTE power ADGUSTMENT OF eNB transmit power EAPC\_P\_eNB = max(min(eNB\_Max\_P,(EAPC\_P\_eNB +

(EAPC\_eNB\_c1\*spv))),eNB\_Min\_P); % to ensure that transmit power (P\_3) is

% MUE SINR ARRAY

EAPC\_MUE\_SINR\_ARRAY{x}= EAPC\_SINR\_MUE ;

% HUE AVERAGE SINR ARRAY EAPC\_HUE\_SINR\_ARRAY{x}=

(EAPC\_SINR\_HUE1+EAPC\_SINR\_HUE2)/Number\_of\_HUE ;

% COMPUTE CAPACITY OF EACH UE (MUE, )

EAPC\_Capacity\_MUE = lf\*BW\*log2(1 + EAPC\_SINR\_MUE);

% COMPUTE CAPACITY OF MACROCELL AND FEMTOCELL

EAPC\_Avg\_Capacity\_Macro = EAPC\_Capacity\_MUE/ Number\_of\_MUE ; EAPC\_MACRO\_THROUGHPUT\_ARRAY{x}= EAPC\_Avg\_Capacity\_Macro ;

% CAPACITY BASED ON EAPC

EAPC\_Capacity\_HUE1 = lf\*BW\*log2(1 + EAPC\_SINR\_HUE1); EAPC\_Capacity\_HUE2 = lf\*BW\*log2(1 + EAPC\_SINR\_HUE2);

% COMPUTE CAPACITY OF MACROCELL AND FEMTOCELL EAPC\_MUE\_THROUGHPUT\_ARRAY{x}=EAPC\_Capacity\_MUE EAPC\_HUE1\_THROUGHPUT\_ARRAY{x}=EAPC\_Capacity\_HUE1; EAPC\_HUE2\_THROUGHPUT\_ARRAY{x}=EAPC\_Capacity\_HUE2; EAPC\_MUE\_HUE\_THROUGHPUT\_ARRAY{x}=EAPC\_Capacity\_MUE +

EAPC\_Capacity\_HUE1 +EAPC\_Capacity\_HUE2;

% computation of Avg cpacity of femto and macro network (sum/no) EAPC\_Avg\_Capacity\_Femto = (EAPC\_Capacity\_HUE1

+EAPC\_Capacity\_HUE2)/Number\_of\_HUE ;

EAPC\_FEMTO\_THROUGHPUT\_ARRAY{x}= EAPC\_Avg\_Capacity\_Femto ;

%HeNB Average power consumption

EAPC\_HeNB\_P\_ARRAY{x} =(EAPC\_P\_HeNB1 +EAPC\_P\_HeNB2)/Number\_of\_HeNB ;

%eNB power consumption EAPC\_eNB\_P\_ARRAY{x} = EAPC\_P\_eNB;

% COMPUTE UPLINK SINR OF HeNB1 BASED ON EAPC MODEL UPLINK\_EAPC\_SINR\_HeNB1 =

EAPC\_P\_HUE1\*EAPC\_PL\_HeNB\_to\_indoor\_HUE\_dB/((EAPC\_P\_HUE2\*EAPC\_INT\_PL\_He NB\_to\_indoor\_HUE\_dB) + N)

% UPLINK SINR OF HeNB2 BASED ON EAPC MODEL UPLINK\_EAPC\_SINR\_HeNB2 =

EAPC\_P\_HUE2\*EAPC\_PL\_HeNB\_to\_indoor\_HUE\_dB/((EAPC\_P\_MUE\*APC\_INT\_PL\_HeNB

\_to\_indoor\_MUE\_dB) + N);

% UPLINK SINR OF eNB BASED ON EAPC APPROACH UPLINK\_EAPC\_SINR\_eNB =

EAPC\_P\_MUE\*EAPC\_PL\_eNB\_indoor\_MUEs\_dB/((EAPC\_P\_HUE1\*EAPC\_INT\_PL\_eNB\_in door\_HUEs\_dB) + N);

end

%PROGRAM TO COMPUTE EAPC AND PC1 UPLINK (MUE) POWER ALPOSITION SINR\_eNB\_DIFF\_EAPC = UPLINK\_EAPC\_SINR\_eNB - SINR\_target;

% PROGRAM TO COMPUTE EAPC AND PC1 HUE UPLINK POWER ALPOSITION SINR\_HeNB1\_DIFF\_EAPC = UPLINK\_EAPC\_SINR\_HeNB1 - SINR\_target; SINR\_HeNB2\_DIFF\_EAPC = UPLINK\_EAPC\_SINR\_HeNB2 - SINR\_target;

% EAPC power control codes

if SINR\_HeNB1\_DIFF\_EAPC > 0

EAPC\_HUE\_ADJ = -1;

elseif SINR\_HeNB1\_DIFF\_EAPC< 0

EAPC\_HUE\_ADJ = 1;

else

EAPC\_HUE\_ADJ = 0;

end

if SINR\_HeNB2\_DIFF\_EAPC > 0

EAPC\_HUE2\_ADJ = -1;

elseif SINR\_HeNB2\_DIFF\_EAPC < 0

EAPC\_HUE2\_ADJ = 1;

else

EAPC\_HUE2\_ADJ = 0;

end

% EAPC power control codes if SINR\_eNB\_DIFF\_EAPC > 0

EAPC\_MUE\_ADJ = -1;

elseif SINR\_eNB\_DIFF\_EAPC < 0

EAPC\_MUE\_ADJ = 1;

else

EAPC\_MUE\_ADJ = 0;

end

% COMPUTE QOS OF MUE/HUE

EAPC\_P\_MUE = min(max(MUE\_Min\_P,(EAPC\_P\_MUE + (EAPC\_MUE\_ADJ\*spv))),MUE\_Max\_P);

% to ensure that transmit power (P\_3) is between Min & Max EAPC\_P\_HUE1 =

min(max((EAPC\_P\_HUE1+(EAPC\_HUE\_ADJ\*spv)),HUE\_Min\_P),HUE\_Max\_P);

% to ensure that transmit power (P\_3) is between Min & Max

to ensure that transmit power (P\_3) is between Min & Max EAPC\_P\_HUE2 =

min(max((EAPC\_P\_HUE2+(EAPC\_HUE2\_ADJ\*0.5)),HUE\_Min\_P),HUE\_Max\_P);% to ensure that transmit power is between Min & Max

UPLINK\_EAPC\_Capacity\_eNB = lf\*BW\*log2(1 + UPLINK\_EAPC\_SINR\_eNB);

% COMPUTE CAPACITY OF MACROCELL AND FEMTOCELL

% computation of Avg cpacity of Macrocell network (sum/no) UPLINK\_EAPC\_Avg\_Capacity\_Macro = UPLINK\_EAPC\_Capacity\_eNB/

Number\_of\_eNB;

UPLINK\_EAPC\_MACRO\_ARRAY{x}= UPLINK\_EAPC\_Avg\_Capacity\_Macro ;

% COMPUTE CAPACITY OF EACH HeNBs

% CAPACITY BASED ON EAPC

UPLINK\_EAPC\_Capacity\_HeNB1 = lf\*BW\*log2(1 + UPLINK\_EAPC\_SINR\_HeNB1);

UPLINK\_EAPC\_Capacity\_HeNB2 = lf\*BW\*log2(1 + UPLINK\_EAPC\_SINR\_HeNB2);

% ARRAY OF THROUGHPUT

EAPC\_eNB\_THROUGHPUT\_ARRAY{x}= UPLINK\_EAPC\_Capacity\_eNB; EAPC\_HeNB1\_THROUGHPUT\_ARRAY{x}= UPLINK\_EAPC\_Capacity\_HeNB1; EAPC\_HeNB2\_THROUGHPUT\_ARRAY{x}= UPLINK\_EAPC\_Capacity\_HeNB2; UPLINK\_EAPC\_FM\_ARRAY{x}= EAPC\_eNB\_THROUGHPUT\_ARRAY{x} + EAPC\_HeNB1\_THROUGHPUT\_ARRAY{x}+EAPC\_HeNB2\_THROUGHPUT\_ARRAY{x};

% COMPUTE UPLINK CAPACITY OF FEMTOCELL

% computation of Avg capacity of femto UPLINK\_EAPC\_Avg\_Capacity\_Femto =(UPLINK\_EAPC\_Capacity\_HeNB1 +

UPLINK\_EAPC\_Capacity\_HeNB2)/Number\_of\_HeNB ; UPLINK\_PC1\_Avg\_Capacity\_Femto = (UPLINK\_PC1\_Capacity\_HeNB1 +

UPLINK\_EAPC\_FEMTO\_ARRAY{x}= UPLINK\_EAPC\_Avg\_Capacity\_Femto ;

% average power consumption

% power consumption

EAPC\_HUE\_P\_ARRAY{x} =(EAPC\_P\_HUE1 +EAPC\_P\_HUE2)/Number\_of\_HeNB;

EAPC\_MUE\_P\_ARRAY{x} = EAPC\_P\_MUE

end

% AVERAGE THROUGHPUT

EAPC\_MUE\_THR\_SUM = (EAPC\_MUE\_THROUGHPUT\_ARRAY{1}+ EAPC\_MUE\_THROUGHPUT\_ARRAY{2}+EAPC\_MUE\_THROUGHPUT\_ARRAY{3}+EAPC\_MUE\_THR OUGHPUT\_ARRAY{4}+EAPC\_MUE\_THROUGHPUT\_ARRAY{5}+EAPC\_MUE\_THROUGHPUT\_ARRA Y{6}+ EAPC\_MUE\_THROUGHPUT\_ARRAY{7}+EAPC\_MUE\_THROUGHPUT\_ARRAY{8}+EAPC\_MUE\_THR OUGHPUT\_ARRAY{9}+EAPC\_MUE\_THROUGHPUT\_ARRAY{10});

% MUE CAPACIITY bar chart analysis

EAPC\_MACRO\_THROUGHPUT\_bar= [EAPC\_MACRO\_THROUGHPUT\_ARRAY{1}; EAPC\_MACRO\_THROUGHPUT\_ARRAY{2};EAPC\_MACRO\_THROUGHPUT\_ARRAY{3}; EAPC\_MACRO\_THROUGHPUT\_ARRAY{4}; EAPC\_MACRO\_THROUGHPUT\_ARRAY{5};EAPC\_MACRO\_THROUGHPUT\_ARRAY{6}; EAPC\_MACRO\_THROUGHPUT\_ARRAY{7};EAPC\_MACRO\_THROUGHPUT\_ARRAY{8}; EAPC\_MACRO\_THROUGHPUT\_ARRAY{9}; EAPC\_MACRO\_THROUGHPUT\_ARRAY{10}];

PC1\_MACRO\_THROUGHPUT\_bar = [PC1\_MACRO\_THROUGHPUT\_ARRAY{1};

% HUE throughput bar chart analysis

EAPC\_FEMTO\_THROUGHPUT\_bar = [EAPC\_FEMTO\_THROUGHPUT\_ARRAY{1}; EAPC\_FEMTO\_THROUGHPUT\_ARRAY{2};EAPC\_FEMTO\_THROUGHPUT\_ARRAY{3}; EAPC\_FEMTO\_THROUGHPUT\_ARRAY{4}; EAPC\_FEMTO\_THROUGHPUT\_ARRAY{5};EAPC\_FEMTO\_THROUGHPUT\_ARRAY{6}; EAPC\_FEMTO\_THROUGHPUT\_ARRAY{7};EAPC\_FEMTO\_THROUGHPUT\_ARRAY{8}; EAPC\_FEMTO\_THROUGHPUT\_ARRAY{9}; EAPC\_FEMTO\_THROUGHPUT\_ARRAY{10}];

PC1\_FEMTO\_THROUGHPUT\_bar = [PC1\_FEMTO\_THROUGHPUT\_ARRAY{1}; y\_HUE\_THROUGHPUT =

[abs(APC\_FEMTO\_THROUGHPUT\_bar),abs(EAPC\_FEMTO\_THROUGHPUT\_bar),abs(PC1\_ FEMTO\_THROUGHPUT\_bar)]

% HUE SINR

EAPC\_HUE\_SINR\_bar = [EAPC\_HUE\_SINR\_ARRAY{1}; EAPC\_HUE\_SINR\_ARRAY{2};EAPC\_HUE\_SINR\_ARRAY{3};EAPC\_HUE\_SINR\_ARRAY{4};E APC\_HUE\_SINR\_ARRAY{5};EAPC\_HUE\_SINR\_ARRAY{6}; EAPC\_HUE\_SINR\_ARRAY{7};EAPC\_HUE\_SINR\_ARRAY{8};EAPC\_HUE\_SINR\_ARRAY{9};E APC\_HUE\_SINR\_ARRAY{10}];

% eNB AVERAGE POWER CONSUMPTION EAPC\_eNB\_P\_bar =[(EAPC\_eNB\_P\_ARRAY{1}+

EAPC\_eNB\_P\_ARRAY{2}+EAPC\_eNB\_P\_ARRAY{3}+EAPC\_eNB\_P\_ARRAY{4}+EAPC\_eNB\_P

\_ARRAY{5}+EAPC\_eNB\_P\_ARRAY{6}+ EAPC\_eNB\_P\_ARRAY{7}+EAPC\_eNB\_P\_ARRAY{8}+EAPC\_eNB\_P\_ARRAY{9}+EAPC\_eNB\_P

\_ARRAY{10})/(Number\_of\_loop);0];

Y\_eNB\_Power = [APC\_eNB\_P\_bar,EAPC\_eNB\_P\_bar,PC1\_eNB\_P\_bar] UPLINK\_MACRO\_y =

[abs(UPLINK\_APC\_MACRO\_bar),abs(UPLINK\_EAPC\_MACRO\_bar),abs(UPLINK\_PC1\_M ACRO\_bar)]

UPLINK\_FEMTO\_y =

[abs(UPLINK\_APC\_FEMTO\_bar),abs(UPLINK\_EAPC\_FEMTO\_bar),abs(UPLINK\_PC1\_F EMTO\_bar)]

% eNB\_HeNB bar chart analysis UPLINK\_FM\_y =

[abs(UPLINK\_APC\_FM\_bar),abs(UPLINK\_EAPC\_FM\_bar),abs(UPLINK\_PC1\_FM\_bar)

]

% MUE POWER CONSUMPTION

Y\_MUE\_P = [APC\_MUE\_P\_bar,EAPC\_MUE\_P\_bar,PC1\_MUE\_P\_bar]

% HUE POWER CONSUMPTION

Y\_HUE\_P = [APC\_HUE\_P\_bar,EAPC\_HUE\_P\_bar,PC1\_HUE\_P\_bar]

% cdf plot

% sort command arrange the datas (eNB throughput) in ascending order UPLINK\_x1\_EAPC\_MACRO =sort(abs(UPLINK\_EAPC\_MACRO\_bar))

UPLINK\_EAPC\_M= ceil(mean(UPLINK\_x1\_EAPC\_MACRO)) UPLINK\_EAPC\_s= ceil(std(UPLINK\_x1\_EAPC\_MACRO))

% eNB OBJECT OF DISTRIBUTION UPLINK\_EAPC\_PD =

makedist('Normal','mu',UPLINK\_EAPC\_M,'sigma',UPLINK\_EAPC\_s) UPLINK\_PC1\_PD =

HeNB\_eNB\_x\_axis =0:5:60

HeNB\_x\_axis = 0:5:60;

eNB\_x\_axis = 0:5:60;

% y component in cdf for HeNB throughput UPLINK\_cdf\_normal\_EAPC\_FEMTO =

cdf(UPLINK\_EAPC\_FPD,HeNB\_x\_axis)

% y component in cdf for eNB throughput

UPLINK\_cdf\_normal\_EAPC\_MACRO = cdf(UPLINK\_EAPC\_PD,eNB\_x\_axis) Y\_HeNB\_Power = [APC\_HeNB\_P\_bar,EAPC\_HeNB\_P\_bar,PC1\_HeNB\_P\_bar]

x\_axis\_macro\_throu = 0:5:60;

x\_axis\_femto\_throu = 0:5:60;

figure (1) % macrocell power bar(Y\_eNB\_Power)

title('Benchmark Average en-gNB Transmit Power ','FontSize',9); xlabel('Power Technique','FontSize',10)

ylabel('en-gNB Average Power Consumption (dBm)','FontSize',10) grid on

legend('APC','EAPC','PC1')

legend('APC','EAPC','PC1')

figure(5) % Femto throughput DOWNLINK\_J\_FEMTO =

plot(x\_axis\_femto\_throu,DOWNLINK\_cdf\_normal\_APC\_FEMTO,'-\*k'); title('Benchmark of HUE throughput ','FontSize',10); xlabel('Throughput (Mbps)','FontSize',10) ylabel('CDF','FontSize',10)

grid on hold on;

DOWNLINK\_K\_FEMTO =

plot(x\_axis\_femto\_throu,DOWNLINK\_cdf\_normal\_EAPC\_FEMTO,'-or'); DOWNLINK\_L\_FEMTO =

plot(x\_axis\_femto\_throu,DOWNLINK\_cdf\_normal\_PC1\_FEMTO,'-g\*'); legend([DOWNLINK\_J\_FEMTO DOWNLINK\_K\_FEMTO DOWNLINK\_L\_FEMTO

],'APC','EAPC','PC1');

hold off;

## APPENDIX B (Publication)

Dawar, K. P., Usman, A. U., & Salihu, B. A. (2021). An Enhanced Active Power Control Technique for Interference Mitigation in 5G Uplink Macro-Femto Cellular Network. *IEEE International Conference on cyberspace (CYBER NIGERIA)*, 2, 85-90.