Inter Cell Interference Mitigation for 4G Networks Using Intelligent Multi Cell Resource Coordination Algorithm

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Abstract: **This work presents the mitigation of inter cell interference for 4G networks using intelligent multi cell resource coordination algorithm. The study was embarked on to effectively manage and coordinate the effect of interference on 4G network which has resulted to poor throughput performance, latency and main effect on voice communication. The problem was solved developing an algorithm for the management of interference and deploying on the cells with priority on voice over internet data. This was implemented using Long term evolution toolbox, communication toolbox, signal processing toolbox and then deployed on the 4G eNodeB using Matlab. The system was tested on femto cell and the result showed that signal to noise to interference ratio was coordinated and average throughput percentage recorded is 70% which according to the ITU-T standard is good quality of service in 4G Network.**

Keywords**: 4G Networks, eNodeB, Voice, Interference, Latency, Throughput, Matlab, Femto cell.**

I. INTRODUCTION

According to the global internet penetration (GIP, 2021) report, in the year 2016, 43.3% of the world population is already making use of internet. Today, this percentage increased to 51.4%, now in 2021 over 4.66 billion active internet users are available worldwide making up over 59.5% of the global population (Alozie, 2021). From the percentage pattern, it is clear that in the next decade over 85% of the world population will be active internet users.

This increase in number of users have been fuelled by the rapid growth in the field of information and communication technology, science and engineering, leading to the invention of varieties of information technology user equipment's which aid limitless data exchange and communication processes. However the present internet network architecture globally struggles to manage the data traffic as a result of high density of nodes, thus leading to high demand for better internet services. The need to meet up with these increased demand for high speed internet services as the global population of active users keep increasing motivated the development of the Long Time Evolution Advance (LTE-A) network commonly known as 4G network in 2009 (Vilches, 2010).

The design architecture for 4G network accommodated multi cells such as the Pico, Micro, Femto and Macro. Each of the cells has specific area of coverage, are often housed within the coverage area of a Macro cell. During data transmission, frequency reuse technique which allows repetition of same frequency spectrum for various cells are employed as it saves cost and resources, however the problem of this technique is that some times, users are assign the same spectrum at the same time from multi cell for data transmission which sometimes causes interference at the cell edge. This interference is the biggest threat to 4G network and lead to issues such as poor throughput, losses, latency, noise, poor transmission energy efficiency among other challenges to mention a few.

Overtime techniques like geometric algorithm, Power algorithms, dynamic frequency reuse among others (Mendrzik et al., 2016; Daeinabi et al., 2015; Trend, 2017; Merwaday et al., 2017) have been applied to combat this problem; however it was observed that when user mobility moves closer to the cell edge which is the point where two or more cells range intercepts, the quality of network service becomes very poor due to high level of interference. Hence there is need to dynamically control and manage the behaviour of these cells using intelligent multi cell resource coordination algorithm. The benefit of solving this problem include; improvement of transmission energy efficiency of data from any of the multi cells, increased throughout percentage, elimination of interfering signal from busy channels, minimization of latency, reduce packet loss and improvement of the overall quality of service. This problem of interference when address will go a long way to improve overall quality of livelihood as the average individual depends on information technology to achieve the objectives of every day to day activities such as business, social activities among others.

II. SYSTEMATIC REVIEW

Author	Title	Technique	Method/work done	Contribution to knowledge /limitation
Tian et al. (2019)	Adaptive bias configuration strategy for range extension in LTE advanced HetNet	Adaptive cell range extension	The study reviewed the various effects of interference in LTE-A networks and the proposed the mitigation with adaptive CRE technique	The ICI was mitigated within the LTE-A when tested, but other network parameters like losses and throughput has to be improved as well.
Mendrzik et al. (2016)	Coordination of Interference based on downlink scheduling for HetNet LTE-A networks	Dynamic fractional frequency reuse	The scheduler coordinated ICI for the vulnerable LTE-A users. This was achieved using resource allocation algorithm which exploited co channel interference and inform cells for frequency reservations for vulnerable users.	The approach when tested showed great performance when compared to static frequency reuse technique, however other network parameters performance like latency and losses need to be improved.
Cierny et al. (2015)	On number of almost blank sub frames in heterogeneous cellular networks number of ABS	Almost blank sub (ABS) frame	The research coordinated interference based on station placement statistics and the result showed moderate performance gain when tested in Macro and Femto cells	The performance despite the success still has room for improvement.
Miemik and James (2014)	Development of Algorithm for enhanced inter cell interference coordination in LTE-A HetNet	Optimal dynamic enhanced inter cell interference cancellation configuration	The research developed two algorithms for the study; the first was used for determining optimal bias value with vulnerable users. The other algorithm then provided the resource patterns for the sub frames	The limitation is the high computation complexity due to the hybrid algorithm leading to about 15minutes latency
Daeinabi et al. (2015)	Dynamic almost blank sub frames scheme for video steaming traffic model in Heterogamous networks	Genetic algorithm	The research used genetic scheme for the mitigation of inter cell interference for video streaming congestion in Macro cell with FFR	Throughput was increased with 9dB, but can be improved in further studies.
Naganuma et al, (2016)	Adaptive control of cell range extension technique for enhanced ICIC in HetNet	Cell range extension (CRE)	Literatures on cell range extension were reviewed within LTE-A. Then an adaptive cell range extension algorithm was proposed for better performance.	The study identified interference as still major challenge affecting LTE-A network as it expands
Sun et al. (2016)	A method for Pico specific upper bound CRE bias setting in HetNet	Cell range extension bias estimation algorithm	The study identified the time domain (TD) ICIC with CRE as an important parameters in planning of cell	The research was limited to Pico cells only
Merwaday et al. (2017)	HetNet capacity with reduced power sub frames	Low power sub frames	The technique was developed for the mitigation of inter cell interference in LTE-A with 11 cells to prevent degradation	The research revealed that the low power sub frames is a better alternative to almost blank sub frame (ABS) for better resource efficiency.
Trend (2017)	Discussion on the features and signalling support for non-zero transmit power in ABS	Reduced power sub frames configuration	The study revealed that RPS provides stable gain and throughout performance compared to the ABS configuration	The approach minimized interference to certain extent but the computation time can be improved.

III. SYSTEM MODELLING

The system modeling of the proposed 4G HetNet, showing how interference from bigger cells affects quality of service in the smaller cells. The 4G network considered of this study is the multi tier network consisting of a Macro cell supported by three smaller cells which are Femto, Micro and the Pico cell. The architectural model of the network is presented as shown figure 1 with the respective distance of the small cells from the Macro cells.

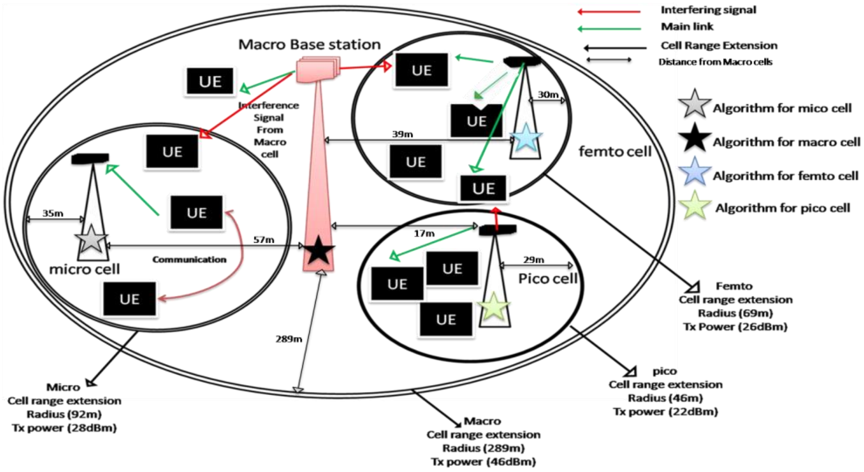

Figure 1: The proposed 4G network Model

From the figure 1, an interference coordination algorithm was developed for the multi cells in the network. One can argue with the researcher, “why not deploy the algorithm on just the Macro cell as it cell radius covers that of the other cells”? This argument is true if the entire cell types have the same characteristics. Even though all the cells operates using the same methods, there are some attributes such as signal strength, number of users and cell radius which varies among all cells types, with the Macro have more of this superiority and hence will suppress users in the smaller cells, thus leading to problems of congestion. Due to this reason the ideal solution will be to develop a separate algorithm for each cell which will function having a handshake with other cells to ensure signal which are delay sensitive to have higher priority and eliminate the problem of latency and overall poor quality of service. This will enable each cell to intelligently manage its own resources an d ensure that signal from other cells do not interfere and cause poor service quality.

3.1 Signal to Interference to Noise Ratio Model on the Network

This model relates the number of interfering signal, useful signal from the main link and detect interfering signal colliding with the main link from other cells, power of transmission and the scheduler as defined in Ahmed *et al*. (2017) where the model of the Macro cell is presented as;

$$\mathrm{SINR_{ma}} = \frac{\mathrm{S_c^u.Pt}}{\sum_{j\neq b} \mathrm{I_j^u} *\mathrm{Gm} *\mathrm{Pma} \;+\; \mathrm{N_b} + \sum_{j\neq b} \mathrm{I_j^u} *\mathrm{Gpn} *\mathrm{Pn}} \qquad 1$$

Where $\mathrm{S_c^u}$ is the allocated signal from the user cell station defined as b, based on normal sub carrier u or reduced power sub carrier resource block c; $\mathrm{I_j^u}$ is the interfering signal from other scheduled cell station j detected by the user equipment u; Pma is the transmission power for the Macro cell, Pn is the low transmission power for other cells (Pico, Femto and Micro), Gm is the antenna gain by the Macro cell and Gpn is the channel gain by other low powered cells within the multi-tier network. On the other hand the signal to interference noise ratio for users (u) in the Pico cell (pnx) is presented as;

$$\mathrm{SINR_p} = \frac{\mathrm{S_c^u.Ptp}}{\lambda + \mathrm{Gpnx} + \sum_{j\neq b} \mathrm{I_j^u} *\mathrm{Gm} *\mathrm{Pma} \;+\; \mathrm{N_b} + \sum_{j\neq b} \mathrm{I_j^u} *\mathrm{Gpn} *\mathrm{Pn}} \qquad 2$$

Where Ptp is the transmission power of the Pico cell; λ is the resource block for normal carrier sub-frames, reduced power sub-frames or almost blank sub-frames; Gpn is the gain channel by the Pico cell; consequently for the signal model of the Micro cell (mnx) and Femto cell (fnx) is presented as in equation 3 and 4 respectively;

$$\mathrm{SINR_m} = \frac{\mathrm{S_c^u.Ptm}}{\lambda + \mathrm{Gmnx} + \sum_{j\neq b} \mathrm{I_j^u} *\mathrm{Gm} *\mathrm{Pma} \;+\; \mathrm{N_b} + \sum_{j\neq b} \mathrm{I_j^u} *\mathrm{Gpn} *\mathrm{Pn}} \qquad 3$$

$$\mathrm{SINR_f} = \frac{\mathrm{S_c^u.Ptf}}{\lambda + \mathrm{Gfnx} + \sum_{j\neq b} \mathrm{I_j^u} *\mathrm{Gm} *\mathrm{Pma} \;+\; \mathrm{N_b} + \sum_{j\neq b} \mathrm{I_j^u} *\mathrm{Gpn} *\mathrm{Pn}} \qquad 4$$

Where the representation for λ as in the equation 2 is the same, Gmnx is the signal gain by the Micro cell; Ptm is the transmission power of the Micro cell, $\mathrm{SINR_p}$ is the signal to noise to interference ratio of the Micro cell; $\mathrm{SINR_f}$ is the signal to noise to interference ratio of the Femto cell, Gfnx is the channel gain be the Femto cell, Ptf is the power of transmission for Femto cell.

3.2 Throughput Model

The research considers voice over internet as the service packet and the amount of user (u) data been able to be transmitted and successfully delivered to the end user is presented using the relationship between the size of the packet transmitted, the time of service request and time of packet transmission as below;

$$\text{Throughput} = \frac{\mathrm{VS_u}}{\mathrm{T_{tx,u}} - \mathrm{T_{r,u}}} \qquad 5$$

Where $\mathrm{VS_u}$ is the amount of packet to be transmitted by user u, $\mathrm{T_{r,u}}$ is the time for service request and $\mathrm{T_{tx,u}}$ is the transmission time for each packet. From the model in equation 5, the average packet flow rate is modelled as the mean throughput using the overall number of user in the 4G network base station cell at a given time as shown below;

$$\mathrm{A_{th}} = \frac{1}{\mathrm{N}} \sum_{\mathrm{u}=1}^{\mathrm{N}} \frac{\mathrm{VS_u}}{\mathrm{T_{tx,u}} - \mathrm{T_{r,u}}} \qquad 6$$

IV. DEVELOPMENT OF THE ALGORITHM

This section presented the methods for the development of the multi cell coordination algorithm for the mitigation of interference at the cell edge. The method includes resource allocation (Ahmed, 2017) for the generation of blank subcarriers scheduled for UE transmission. The algorithm also considers the prioritization of user equipment devices and the packet types or transmission, then power of transmission cell was also considered and all used for the development of the algorithm. The explanation of the methods such as resource allocation, physical downlink share channel (PDSCH), demodulated reference signal (DM-RS), frequency domain resources control (FDRC) and user prioritization among others are discussed in (Victor *et al*., 2015; Alozie, 2021).

4.1 Prioritization of the multi cells users

The aim of this prioritization of users is to coordinate the behaviour of cells since the power emitting from each cells varies. For instance a user in the cell extension range of any Micro cell will be affected with the signal from the Macro cells based on the high transmission power of the cell. This is to say that a user in the Pico cell extension range in the network will experience interference with high signal strength from the Macro cell which has over double the transmitting power of Pico cell. To avoid this problem, a multi cell resource coordination algorithm was developed which allocates subcarrier channels intelligently based on user cell station and packet type. In the conventional system, the frequency and time control scheduling algorithm in (Victore *et al*., 2015) was used however this affects packet which are time sensitive like voice and thus results to latency, hence this algorithm will consider the voice over internet packet ahead of other packets and try to effectively manage its routing performance in each cells and at the same time manage signal interference from other cells.

4.2 VOIP Packet Prioritization

The prioritization of the packet in the subcarriers from the multi cell was done using priority queuing (PQ) technique. In this method, sensitive data like voice are given highest priority over other packets for transmission based on frequency domain resource control used to detect location of the subcarrier indicating source of the cell station. From the station, the packet in the subcarrier are identified and computed as in Ahmed (2015) and if it is less than 176kb according to Hiroyuki *et al*. (2007), then the data has a high chance of being VoIP and then prioritized as high of immediate scheduling. PQ allows Evolved node B in the cells to organize buffered packets from the user equipment's and then service one class of traffic differently from other classes of traffic. The priorities are set so that real time applications such as interactive voice and video get priority over applications that do not operate in real time. The algorithmic flow chart is presented below;

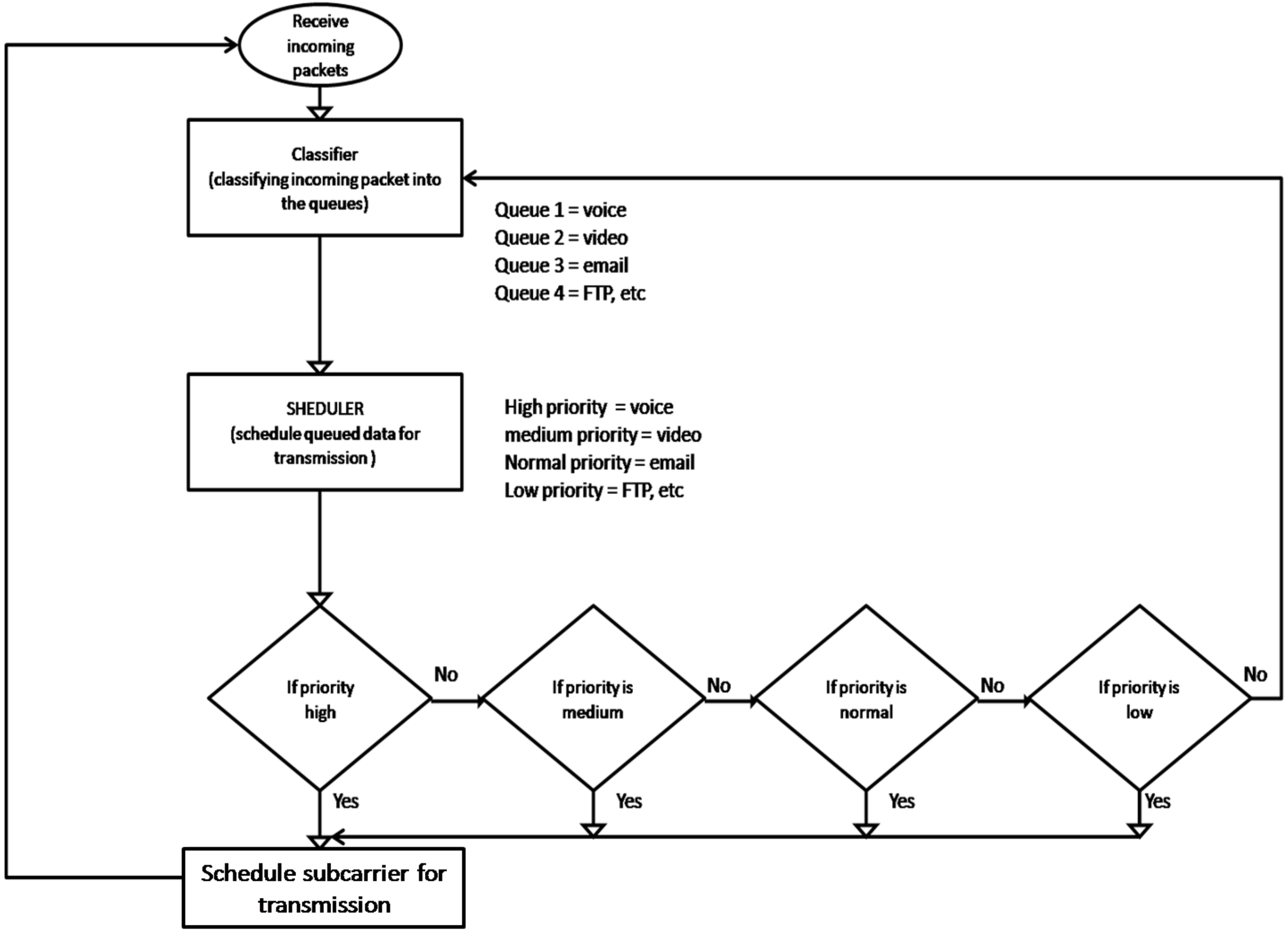

Figure 2: data flow chart of the priority queuing algorithm

In the Priority Queuing Technique (PQT) of figure 2, the incoming packets from the subcarriers was received and queues by the classifier with queuing label (queue 1, 2, 3 and 4).These queuing labels represented the various priorities assigned to the different packet types (voice, video, email, File Transfer Protocol (FTP)) transmitted over the network. Voice packet is classified as high priority, the video packet is classified as medium priority; email is classified as the normal priority, while the FTP packet type is classified as low priority. With these classifications the scheduler grants subcarrier to the various packets based on the priority granted and the process returns to the classifier to prioritize new incoming packets into queued and then process continues.

4.3 Carrier-to-Interference Ratio (CIR)

CIR expressed in decibels (dB) is a measurement of signaling effectiveness and it is defined as the ratio of the power in the carrier to the power of the interference signal. The reference signals are cell specific and thus are differentiated between cells using complex cyclic shift calculations so that the measurements from other cells can be differentiated. To address this problem of interference on the femto cell, the coordination algorithm is presented in the pseudo codes below;

4.4 The Pseudo Code Of The Algorithm

Algorithm 1 (Macro cell Resource coordination algorithm)

```
Start
        Identify the subcarriers channels in PDSCH based on OFDMA
        Check for the carrier channels per 1ms using Phase Tracking Reference Signal (PT-RS)
        Detect idle channel with Demodulated reference signal (DM-RS)
If
      Blank subcarrier is available for schedule
         Identify the primary cell requesting for the channels
Else
        Rest time and check again for available subcarrier
        If true
               Then (check the source)
        Else
              Return
              Check carriers availability
        If low powered cell is true
               Then check packet type
        If VOIP is true for low powered cell
               Then schedule carrier for user equipment using downlink control information (DCI)
Else if
         Low powered cell is false
                Then Macro cell is true
                Check for VOIP
         If true
              Then schedule subcarrier using downlink control information (DCI)
         Else
         Check low powered cell for VOIP
If true
         Schedule subcarrier
Else
         Schedule subcarrier for other packet of Macro cell user equipment's
Else
         Schedule subcarrier for other packet in low powered cell
End
Return
```

Algorithm 2 (The Micro cell Resource coordination algorithm)

```
Start
      Identify the subcarriers channels in PDSCH based on OFDMA
      Check for the carrier channels every 1ms using Phase Tracking Reference Signal (PT-RS)
      Detect idle channel with Demodulated reference signal (DM-RS)
If
      Blank subcarrier is available for schedule
      Identify the primary cell requesting for the channels
Else
      Rest delay time and check again for available subcarrier
    If true
    Then (check the source)
     Else
Return
     Check carrier availability with demodulated reference signal (DM-RS)
     If low Micro cell is true
Then check packet type
If
     VOIP is true
      Then schedule carrier for user equipment using downlink control information (DCI)
Else if
    Micro cell is false for VOIP
    Then other cells are true
    Check for VOIP in Femto, Pico and Macro
    If true
    Then schedule subcarrier
    Else
    Check Micro cell for other packet
If true
```

```
        Schedule subcarrier
Else
        Schedule subcarrier for other packet of Macro, Pico or Femto cell user equipment’s
End
Return
```

Algorithm 3 (The Femto Resource coordination algorithm)

```
Start
        Identify the subcarriers channels in PDSCH based on OFDMA
        Check for the carrier channels every 1ms using Phase Tracking Reference Signal (PT-RS)
        Detect idle channel with demodulated reference signal (DM-RS)
If
        Blank subcarrier is available for schedule
        Identify the primary cell requesting for the channels
Else
      Rest delay time and check again for available subcarrier
 If true
Then (check the source)
      Else
      Return
      Check carriers availability
If low Femto cell is true
Then check packet type
If VOIP is true
Then schedule carrier for user equipment using downlink control information (DCI)
Else if
        Micro cell is false for VOIP
        Then other cells are true
        Check for VOIP in Micro, Pico and Macro
If true
     Then schedule subcarrier
Else
      Check Femto cell for other packet
If true
      Schedule subcarrier
Else
      Schedule subcarrier for other packet of Macro, Pico or Micro cell user equipment’s
End
Return
```

V. IMPLEMENTATION

The system developed was implemented on a simulated 4G network using Simulink. This was achieved using LTE-A toolbox configured with multi cells of Pico, Femto, Macro and Micro to form a multi-tier network. The specifications for each cell were defined as presented in table1. Communication toolbox was used to simulate user action on the network defining the user equipment’s and data type transmitted over the network. To deploy the algorithm developed, the Matlab script was used to program the algorithm in the 4G eNodeB and then integrated on the network using Simulink. The packet transmitted over the network with the interfering effects were modelled from equation 1 to 4, while the throughput perform was model in equation 5;the prioritization of the signal was done using the model in figure 2 and the implementation result is presented below;

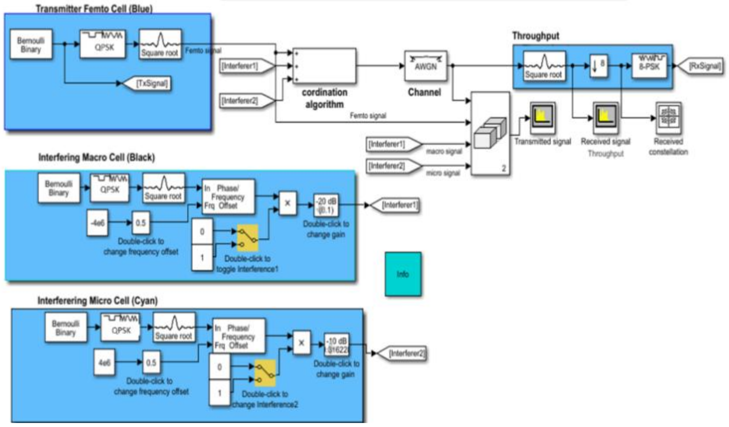

Figure 3: Simulink model of the Heterogeneous network

From the model in figure 3, shows the Femto cell transmitting packet data in the network but the neighbouring Macro and Micro cell signal induced interference on the signal by allocating the same resource block, but was coordinated using the intelligent mitigation algorithm designed to allow throughput for the desired signal transmitted by the Femto cell. To achieve this, 4G cell transmitter, the Bernoulli Binary block was used to generate the packet which is feed to the QPSK modulator. The reason for this modulation technique is that the eNodeB by default performs transmission using different modulation approaches such as Quadrature phase shift keying (QPSK) and Quadrature Amplitude Modulation (QAM) depending on the signal strength of the cell at the time of transmission, if it is less than -9dB, then the QPSK is used, else the QAM is used. The modulated signal is filtered using the cosine square wave before throughput to the cloud. The frequency/phase offset block in the Micro and Macro cell was used to induce interference on the cells which is coordinated using the developed algorithm.

Table 1: Simulation parameters for the 4G HetNet

Parameters	**Values**
Carrier frequency	2.14GHz
System bandwidth	12MHz
Standard deviation shadow fading	8Db
SINR threshold	-4.5dB
UE gain UE noise speed	560km/h
Inter site distance	500m
Noise spectral density	-174dBm/Hz
Special sub frame ratio	2/8 (1 ABS + 1 RPS)
Traffic model	Fill buffer, VOIP
Total voice packet used for the simulation	0.6mb
Channel model	Typical Urban
Modulation	16QAM, 64QAM, QPSK
Sub-frame duration	1s
Subcarrier number	12
Time window size	9
Frequency window size	13
Specification for VOIP	2 x 88bit
The Macro Cell Station	
Parameters	**Values**
Transmission power	46dBm (40W)
Reduced transmission power	23dBm(200mW)
Antenna gain	15dBi
Antenna height	20m
Distance in radius	289m
Micro Cell Station	
Parameters	**Values**
Transmission power	28dBm (1W)
Reduced transmission power	14dBm(15mW)
Antenna gain	7dBi
Antenna height	12.5m
Distance in radius	92m
Pico Cell Station	
Parameters	**Values**
Transmission power	22dBm (1W)
Reduced transmission power	11dBm(12mW)
Antenna gain	5dBi
Antenna height	12.8m
Distance in radius	46m
Femto Cell Station	
Parameters	**Values**
Transmission power	26dBm (1W)
Reduced transmission power	13dBm(14mW)
Antenna gain	7dBi
Antenna height	10m
Distance in radius	69m

VI. RESULTS

The result presented the performance of the algorithm developed during interferences due to transmission on the same resource block by multi cells.

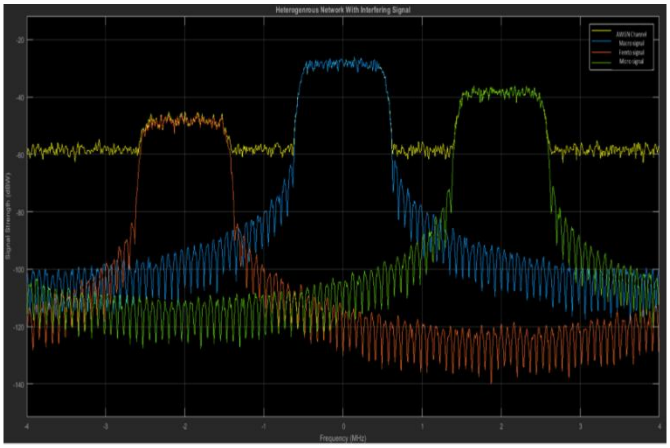

Figure 4: performance of the heterogeneous network without coordination algorithm

From the result in figure 4; shows inter cell interference that occurs at the cell edge as a result of the SINR model in equation 1 to 4 or the multi cells. To solve this problem, the intelligent coordination algorithm developed for the Femto cell was used to manage and coordinate the interference parameters (time, frequency and power) to mitigate inference at the cell edge. The transmitted signal is presented in figure 5;

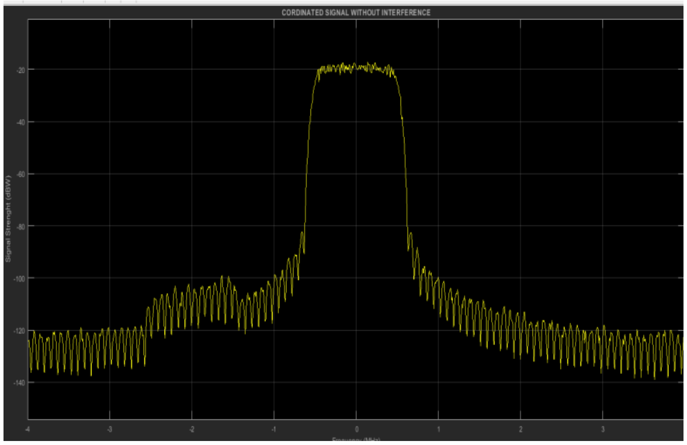

Figure 5: Coordinated Femto cell signal without interference

The result showed how the interference from other cells were managed and coordinated by Femto cell algorithm and then transmitted to the receiver. The implication of the result showed that the despite the higher transmitting power of the Macro and Micro cells, the algorithm was able to coordinate the resources properly to avoid interference at the cell edge. The next result presented the throughput performance of the data transmitted. From the simulation of the 4G network, the total packet transmitted by all users for voice communication is 0.6MB as specified in the simulation parameters in table 1 and was transmitted to produce the result of the throughput performance in figure 6.

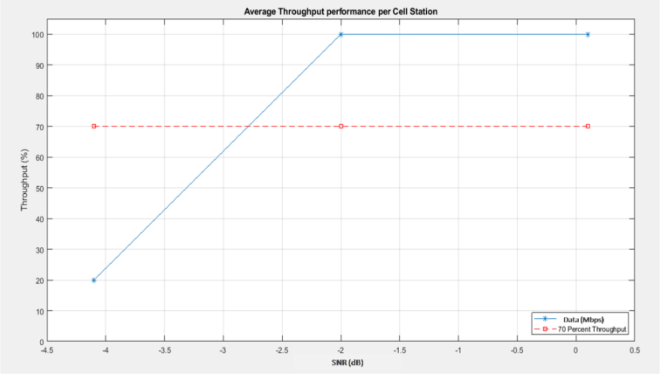

Figure 6: the percentage throughout performance

The figure 6 presented the percentage throughput performance of the average user within the cell station. From the result it was observed that the signal to interference noise ratio model in equation 4 for the femto cells station was intelligently managed and the throughput percentage recorded is 70% which is good according to ITU-T G.114 recommendation for service quality.

VII. CONCLUSION

This study has successfully developed an interference coordination algorithm for 4G HetNet. The algorithm was implemented on the multi cells within the HetNet and the result showed that it was able to coordinate resource allocation and hence prevent interference problem. The performance of the cells was checked with the algorithm and it was observed that mean throughput of 70% was recorded which is good according to the ITU-T standard for 4G LTE Networks.

CONTRIBUTION TO KNOWLEDGE

- This paper presented an intelligent inter cell interference coordination algorithm for 4G HetNet.

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