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A Study of Scheduling Algorithms in LTE -Advanced HetNet

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ABSTRACT

Long Term Evolution (LTE), known as 4G technology, is considered the choice for Third Generation Partnership Project (3GPP) and 3GPP2 mobile operators. LTE is expected to bring an improved user experience with full mobility support. However, to cope with the increasing number of mobile data subscribers that compete for the limited radio resources, effective network Quality of Service (QoS) mechanisms are necessary. A solution is to introduce small cells by adding low-power base stations to the existing macro-eNBs (Evolved Node B). The result is a Heterogeneous Network (HetNet) with large macro-cells combined with small cells (micro-, pico- and femto-cells) to cover areas not covered by the Macro-cells. Practically, HetNet is introduced in LTE-Advanced which is an extended version of LTE with more advanced features. Introducing HetNet in LTE-A brings challenges especially in terms of physical integration, QoS support and interference management. In this research, an architecture of HetNet integration is proposed. After that, some QoS scheduling algorithms are deployed for different types of on-going applications. Then, through the use of Riverbed Modeler, their performance parameters are studied with extensive simulations. Finally, an intensive comparison is done among the algorithms followed by a detailed discussion.

1. Introduction

Although the Long-Term Evolution (LTE) technology made a very big contribution in providing a better cellular network for the people's daily needs of connectivity, LTE's homogenous cellular networks cannot match the rapid increase of traffic demand. On

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one hand, number of subscribers and internet users are increasing very fast, and on the other hand, the number of technologies that are based on internet are growing, just like the Internet of Things (IoT) which makes almost all the aspects of the human life internet based by making all the household machines intelligent and controlled via Internet. Therefore, introduction of better cellular networks was a need that could not be ignored. Introducing Heterogeneous Networks (Hetnet) in 3GPP's LTE-Advanced is one of the best solutions to offload the high traffic demand on the LTE's homogenous Macrocells. With Hetnet, many smaller cells like Picocells, Femtocells and Relays could be deployed with the Macrocells. They will be either inside them, on the cell edges or even outside the Macrocells (Miran & Kadir, 2019). Doing this increases data rate, brings better coverage to the areas that are difficultly approached with the Macrocells, and reduces latency due to the high traffic on the Macrocells. It also brings many other advantages. Implementing Hetnet is not free of big challenges and problems, some of them are: integration of the heterogeneous network, interference between the different cells inside one single network, guaranteeing Quality of Service (QoS) to the subscribers…etc. In this research, the problem of QoS is tackled in LTE-A Hetnet. There are many mechanisms for guaranteeing QoS, such as Admission Control, Scheduling algorithms and QoS provisioning, this research however emphasizes on the QoS scheduling algorithms and hence studies the impact of applying different scheduling algorithms on the Hetnet.

2. Methods and Related Work

2.1 LTE-A HetNet Background

As the demand for mobile and wireless connections increase, internet and network providers try to bring the more advanced technologies. In this era, 4G LTE is the most promising and reliable technology that provides good performance, good capacity and low latency, to be used by people's daily lives. Long Term Evolution (LTE), also known as 4G LTE is a wireless communication standard with high-speed data communication (Kh. & Hamarash, 2020). This fully IP-based standard promised improvements on the capacity and speed, with enhancements to the core network. The LTE standard was settled by the 3rd Generation Partnership Project (3GPP) (Awasthi & Sharma, 2020). Its specifications were identified in 3GPP's Release 8, in

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2010. Then, there were some small enhancements made to it and identified as Release 9. Because this version of 4G LTE did not satisfy the rapid growth of need for better connectivity, 3GPP set a new standard, with better connectivity and performance, called LTE-Advanced (Release 10-16), and known to be the real 4G (Frenzel, 2013).

The LTE macrocells on the other hand got more and more overloaded with the rapid growth in the number of subscribers. Users of many areas could not connect to the networks and did not get good coverage due to their difficult geographical areas or due to the lack of the big expensive macrocells (Ibrahim, Toycan, & Mawlood, 2020). Hence, introduction of another solution was needed in the cell sizes as well, which was the introduction of Heterogeneous Networks (Hetnet). Fortunately, one of the features that LTE-A brought with itself was the support for Hetnet.

The rapid growth in network and mobile data subscribers has led the LTE Macrocells to be insufficient to cope with all the requirements. Users in crowded places and cell edges face difficulty connecting to the Macrocells and get a satisfactory bandwidth. Some operators tried to solve this problem by adding more Macrocells to the networks homogenously, or adding more Evolved NodeBs (eNode-Bs). However, these did not seem to be good solutions because there were some serious difficulties with them, such as:

- The costs for deploying, maintaining and repairing the big Macrocells are high and expensive;
- The costs for regular site visits to the Macrocells are also high;
- Macrocells are power consuming;
- They need large appropriate places (sites) for deployment, which cannot be afforded in many cases, especially in crowded cities where demand is very high for connectivity, but there is not enough space to deploy more Macrocells (Wannstrom & Mallinson, 2017).

According to Wannstrom & Mallinson, these difficulties with the LTE Macrocells led to the small cell deployment in the LTE-A context. They are small cells with their own base stations that are low-powered, such as the small eNode-Bs, Home eNodeBs

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(HeNodeBs), and the Relay Nodes (RN). These small cells help in supporting and offloading the available Macrocells by being installed in the less covered places, whether they are outdoor or indoor places. Consequently, the network ends up being Heterogeneous, consisting of Macrocells and small cells combined.

2.2 HetNet Architecture

Hetnet is a combination of several different cells all integrated with a Macrocell. The small cells are: Microcell, Femtocell, Picocell, and Relay Nodes (RN). All these cells are connected through connection links called "X2 Interface" and connected to the Core Network (CN) through a connection link called "S1 Interface". The CN in LTE is also called Evolved Packet Core (EPC). The EPC is IP-Based and provides both data and voice services. It mainly consists of four different elements: Serving Gateway, Packet Data Network Gateway (PDN), Mobility Management Entity (MME), and Policy and Charging Rules Function (PCRF) (Sridhar, 2012).

2.3 QoS and its Mechanisms

Quality of Service (QoS) is defined as a group of application or service functionalities required by the users and provided by the network. Users of Hetnet and other networks specify some performance parameters such as low delay, low packet loss and good throughput and expect the networks to provide them. The networks on the other hand apply different QoS mechanisms to satisfy their users (Gouveia & Magedanz, n.d.).

There are many mechanisms and challenges for the network operators to overcome to guarantee the QoS for their subscribers (Al-Alkawi, Hanfesh, & Rauof, 2019). Some of the QoS mechanisms are: Classification, Channel Access mechanism, Traffic Policing Mechanism, Resource Reservation, Signaling Mechanisms, Admission Control and Packet Scheduling Mechanisms. In this research, the Packet Scheduling Mechanism is thoroughly studied.

2.4 Related Work on QoS Scheduling Algorithms

According to (Ganz, Ganz, & Wongthavarawat, 2003), Packet scheduling is "the mechanism that selects a packet for transmission from the packets waiting in the transmission queue. It decides which packet from which queue and station are scheduled for transmission in a certain period". In the following section, related research studies are discussed grouped by different scheduling algorithms.

2.4.1 First-In-First-Out (FIFO) Scheduling Algorithm

It is the simplest scheduling algorithm in which all types of packets in all the different entrances are going to one queue based on their arrival time. In fact, (Balchunas, 2010) states that all the default queueing algorithms in hardware are FIFO. However, if prioritizing and giving preference is needed, software queueing will be provided, which includes many scheduling algorithms, and FIFO is one of them again.

According to (Haas, 2009), FIFO scheduling algorithm is the simplest and fastest between the other algorithms because no calculation, no classification and no prioritizing is needed. It is a common solution in many platforms, such as in Cisco platforms. Nevertheless, if the packet sizes are big and congestion happen in the queue, the last packets simply get dropped, and that is called Tail Drop.

FIFO is used in many scientific researches in order to study the behavior of systems or technologies. In a research (Mustafa & Talab, 2016), FIFO queueing is used as their first scheduling algorithm to study the effects of different scheduling algorithms on network routers and applications. In this research, the authors used Opnet Modeler as their simulation environment to compare FIFO with Priority Queueing (PR) and many other algorithms to see their effect on the network router's CPU and memory usage in terms of load, delay and throughput. As a result, they found out that amongst all the other algorithms, FIFO has the lowest delay because of its simple working mechanism, but on the other hand, it has taken the largest memory size for packet forwarding.

To be realistic, any scheduling algorithm has its advantages and disadvantages. As it is mentioned in (Inner Mongolia University, 2001), some benefits of using FIFO scheduling algorithm are: simplicity, being fast as there is no classification mechanism and being supported by the majority of platforms. On the other hand, some of its drawbacks include the unfairness in bandwidth allocation between the packet flows, starvation and packet dropping when delay happens or the queue size gets full.

2.4.2 Round Robin (RR) Scheduling Algorithm

In (Ludovici, 2006), which is a research done on performance analysis of scheduling algorithms on reconfigurable routers using NS-2 simulator, Round Robin is used as one of the queueing algorithms. The research suggests that this algorithm does not guarantee QoS. It does not give preference to the more important flows of packets. Instead, it works in a so-called fair manner by giving each flow of packet the opportunity to send one packet per each round. In this case it takes so long for a flow with a real-time application to get to their destinations. The article highlights that although RR is famous for its fairness amongst the flows, this fairness only happens if all the packet lengths are of the same size. This is because the RR ignores packet length and gives the same time quantum to all.

A research paper (Abduljalil, 2014) investigates the use of Round Robin scheduling algorithm in LTE using MATLAB simulator to find out the behavior of Round Robin in terms of throughput and fairness, and this is by comparing RR with another scheduling algorithm called Channel Quality Indicator (CQI) scheduling algorithm. In the paper, the researcher proposes mathematical equations and uses them in MATLAB to find out throughput. As a result, Round Robin loses the competition by showing a very low throughput compared to CQI scheduling algorithm. The research suggests that RR does not take into consideration the channel quality information. It also claims that RR preempts the packet flows very frequently that is why it does not give an acceptable throughput result.

2.4.3 Fair Queueing (FQ) Scheduling Algorithm

Fair Queueing is explained in a comparative research (Islam & Rashed, n.d.) carried out to analyze the impact of traditional and hybrid queueing mechanisms on Voice Over Internet Protocol (VoIP)'s QoS. This research combines the traditional CQ, PQ, and FQ and makes a Hybrid queueing mechanism. Then, they test them on some parameters of VoIP, such as delay and quality of the voice. The research explains that Fair Queueing is an old simple queueing mechanism suggested in 1987 by John Nagle which later became the basis for all the other class-based scheduling mechanisms, such as the Weighted Fair Queueing (WFQ) scheduling algorithm.

2.4.4 Weighted Fair Queueing (WFQ) Scheduling Algorithm

It is another scheduling algorithm that works with different priority levels and gives a guaranteed bandwidth for each type of flow. WFQ has many queues with packets of various flows (Priya, et al., 2021). According to (Islam & Rashed, n.d.) the working principle of WFQ is that each flow type is ordered in a FIFO manner into a separate queue and the scheduler gives different weights to each queue. This weight controls the percentage of bandwidth that each queue will get. Not to forget, a minimum weight must be specified to the last queue to make sure that there is no queue with no service. The scheduler then starts to serve the queues one by one in a Round Robin manner according to their assigned weight (bandwidth percentage). If queue1 is given 50%, queue2 and queue3 are given 25%, then queue1 gets a bandwidth worth of twice as the bandwidth given to queue2 and queue3 in each round. In other words, if two bits of queue1 get served, then 1 bit of queue2, then 1 bit of queue3 get served, until there is no packet in the queues.

In another research (Priya, et al., 2013) the efficiency of some scheduling algorithms are studied for IEEE 802.16e WiMAX. Weighted Fair Queue is one of the used algorithms of the research (Ali & Yahiya, 2018). The other algorithms are: Deficit Weighted Round Robin (DWRR), Novel Weighted Fair Queuing (NWFQ) and Novel Deficit Weighted Round Robin (NDWRR). The simulation environment is Network Simulator 2 (NS-2). A WiMAX network scenario is created using different NS-2 nodes then some different QoS parameters are applied on it to compare the efficiency of each scheduling algorithm. Some of the QoS parameters are: Loss rate, delay, throughput and jitter. As a result, the researchers claimed that WFQ is giving the least QoS compared to the aforementioned scheduling algorithms.

2.4.5 Priority Queueing (PQ) Scheduling Algorithm

In a research (Momanyi, et al., 2014), the effect of Priority Queueing and FIFO scheduling algorithms are investigated on Mobile Ad Hoc Networks (MANET) in order to enhance its QoS. The research uses three applications: Video, FTP and VoIP and

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compares the scheduling algorithms on it. The used simulation environment is Opnet Modeler and the statistics are: packet end-to-end delay, traffic dropped, and traffic received. In the research, a MANET scenario is created using Opnet Modeler and the two scheduling algorithms are applied on it using the above-mentioned applications and statistics. As a result, PQ proved to win the competition against FIFO in terms of the VoIP and Video applications. The PQ scheduling algorithm showed less jitter and packet-end-to-end delay in both video and VoIP. On the other hand, FIFO showed better results in terms of FTP response and upload time. The research claims that these results come from the fact that PQ is giving more priority to the real-time applications like video and VoIP but does not have a good performance on the non-real time applications like FTP.

Another research (Kumar & Garg, 2011) studies the effect of implementing some scheduling algorithms like FIFO, Weighted Fair Queue (WFQ), and PQ on a WiMAX network using the Opnet Modeler as their simulator. The effect of these scheduling algorithms are compared through the use of some performance factors. The parameters are: delay, throughput and load. The Priority Queueing algorithm is advantageous for sensitive real-time applications with high priority and gives them the best service. Yet, the research claims that PQ has the disadvantage of unfairly treating the low priority applications, which in some cases leads to service starvation. After developing a WiMAX network using the Opnet Modeler 14.0 with WiMAX Wireless Advanced Module, the two researchers investigated the impact of the abovementioned scheduling algorithms. As a result, the paper claims an outstanding performance of PQ scheduling algorithm for the real-time applications like video and voice compared to the other scheduling algorithms. When comparing the type of applications that benefits most from the PQ, a research claims that videoconferencing has the highest, followed by telephony and IPTV (Attar, et al., 2020).

3. Simulation Setup

3.1 Riverbed Modeler

In this research, Riverbed Modeler is used which is a modeling and simulation environment that allows researchers and developers to design network topologies, equipment and communication protocols in a professional detailed way. Technologists and network designers use Riverbed Modeler because it gives better understanding and clear vision of their system or product in an early stage of developing, before going into buying expensive hardware prototypes. Hence, it reduces the time needed and the cost as well (Ochieng, 2014). Riverbed Modeler provides its users with tools for all the stages of designing and studying, such as modeling all sorts of networks and different technologies, simulating the designed networks and comparing the effect of different types of technologies on the behavior of the network (Al-Alkawi, Hanfesh, & Raouf, 2020). In order to enhance the current standards and protocols of networking and communication designs, Riverbed Modeler lets the researchers and designers collect data and perform data analysis on the outcomes, whether it is a wired or wireless technology (Riverbed, 2017).

Riverbed Modeler has important features and benefits that encourages researchers to choose it as their simulation environment. It has the ability to perform detailed simulation and analysis. It supports a very large scale of wired and wireless protocols, working with both 32-bit and 64-bit simulation kernel. Besides, what makes Riverbed Modeler the right option for many academics and researchers is its nice interface! It is user-friendly and Graphical User Interface (GUI)-based and these make it easier for the non-advanced researchers to get their hands on Riverbed and do their simulations on it. The necessary objects like nodes and links could be dragged and dropped from a big list of objects called the “Object Palette” (Riverbed, 2017).

Riverbed Modeler 18.6 supports Long Term Evolution (LTE) which is standardized by 3rd Generation Partnership Project (3GPP). This is an IP based wireless protocol that is developed from the old Global System for Mobile Communications (GSM). Within its promising features, LTE provides better data rate, coverage, signal, response time, efficiency and many other features that make academics, researchers and network providers work on it.

In Riverbed Modeler, an LTE network can be created in two ways, automatically and manually. The first method is applied by using the “Wireless Network Deployment Wizard” available in the modeler. This wizard is used to create any wireless network such as LTE, WLAN, MANET, WiMAX, TDMA or other custom wireless networks. The second method of creating an LTE network is the manual method. It can be applied in three ways. First ways is by dragging and dropping the needed LTE objects from the object palette to the scenario. Second way is by going to the menu bar and selecting "Topology", then choosing "Rapid Configuration". After that, using the command to bring up the needed LTE Objects, or programmatically get them by using the "OPNET Development Kit" (Riverbed, 2015). In this research, the first method (Wireless Network Deployment Wizard) is used.

3.2 Network Topology

The network topology consists of two main parts. First, a small Macrocell LTE network is created, then the Hetnet part is added to it consisting of femto and picocells. Below is a description of each of the two main parts.

3.2.1 Macrocell LTE Part

The LTE network is created using the automatic method "Wireless Network Deployment Wizard". The network consists of only a few Objects (Nodes) as the major nodes of an LTE network in Riverbed Modeler. After that, some other necessary nodes were added to it manually from the Object Palette. The major nodes are eNodeB, EPC, and some User Equipment (UE).

In order for the major LTE objects to connect with each other, specific links are chosen. As mentioned in the previous section, the user devices (UEs) are connected wirelessly to the eNodeB. However, the eNodeB and EPC are connected through a specific link called "ppp_adv", found in the "object palette". It is a point-to-point protocol link that supports both IP version 4 and IP version 6 as well. In its description it is mentioned that many data rates could be selected using this "ppp_adv' link, such as "DS0, DS1, DS3, T1, T3, OC3, OC12, OC36, OC48 data rates" (Riverbed Technology, 2016).

3.2.2 Macrocell LTE with HetNet Part Added

Smaller cells were added to the Macrocell in order to improve the network. The small cells are a Picocell and a Femtocell. Picocells are cells smaller than a Macrocell with a

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smaller eNodeB specific for small indoor/outdoor places like an apartment, company or an office with difficulty connecting to the Macrocells or do not have good coverage. But just like the Macrocells, they are provided, powered and maintained by the network operators, not the users themselves (Semenov, Voloshyn, & Ahmed, 2019). On the other hand, Femtocells are also small cells for small specific areas, but they are autonomous and not directed centrally by the network operator. Instead, they are bought, installed and maintained by the end-users. In this case, if more femtocells are added to a network, no change will be necessary like frequency reusing and re-planning as the femtocells are completely stand alone in their power and frequency (Chambers, 2008).

3.3 Attributes and Configurations

After creating the LTE topology, adding the Hetnet parts and having all the nodes connected, the scenario is still incomplete because there are 4 very essential nodes without which the network could not run or give the desired results. The 4 nodes are called “LTE Attributes”, “Application Configuration”, “Profile Configuration” and the “QoS Configuration”. The following is a description for each one of them in briefly.

3.3.1 LTE Attributes

This node’s name is “lte_adv_definer_adv”. It could be added manually from the object palette, however, in the case of this research, it is added by default when creating the LTE network using the “Wireless Network Deployment Wizard”. The node has its own attributes that could be changed according to the user’s needs. In this research its default attributes are kept unchanged, such as the bearers. Although the attributes are not changed, the bearer’s information is re-called by all the UEs in the network. Hence, if this “LTE Attributes” node was not used, the LTE features would not work for the UEs (Kh. & Hamarash, 2021).

3.3.2 LTE Application Configuration

Another very essential node is the “Application Config”. All the applications that are going to be supported in the created network are specified and configured here in this node. After that, they will be selected in the “Profile Configuration” to be used by the whole network. The specified applications in this research are (Voice, Video

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Conferencing and HTTP). Notice that each of these have their tables which are used for customizing the application parameters. However, the default parameters are kept unchanged in this research.

3.3.3 LTE Profile Configuration

After selecting the Applications in the "Application Config" node, a profile is created using the "Profile Config" node and given all the three pre-chosen applications. This created profile will be called for all the UEs in the network or any other node that needs to support the three chosen applications. The applications are (voice, video conferencing and HTTP). In this research the profile is named "App Profile". This node can be added manually by dragging and dropping from the object palette.

3.3.4 LTE QoS Configuration

The "QoS Configuration" node is used to apply the global QoS attributes and use the supported queueing profiles. This object can be added manually by dragging and dropping from the object palette. To utilize this object, Committed Access Rate (CAR) profiles should be created for traffic policing (Sethi & Vasil, 2013). For this research, three CAR profiles are created, the HTTP traffic limit, the video profile and the voice profile. Besides these three, there is one default CAR profile named "All Traffic Limit". Notice that the QoS scheduling algorithms will be chosen for each scenario later on in the "Protocols → IP→ QoS→ QoS Configuring". This will be discussed in more detail in another section. Figure 3.9 shows the attributes of "QoS Configuration" node and the three created CAR profiles.

3.3.5 The QoS Scheduling Algorithms

After having the LTE network completely developed and the heterogeneity feature added, the network needs to be enhanced with providing QoS, using different scheduling algorithms that work best for each type of application. Among the scheduling algorithms that Riverbed Modeler 18.6 supports, this research uses 3 different algorithms: Custom Queueing, Weighted Fair Queueing (WFQ), and Priority Queueing. In this research, each one of these scheduling algorithms are applied on the created network topology in a separate simulation scenario so as to analyze them, study their behavior, and then compare their different impact on the network to find

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out which algorithm works the best for which type of application. As mentioned in the previous section, the first step toward applying these scheduling algorithms was by adding the "QoS Configuration" node. In this stage they are chosen one by one by going to Protocol → IP → QoS → Configure QoS→ then the desired scheduling algorithm, and saving it as a separate scenario.

4. Simulation Results and Performance Analysis

In this section, results of scenarios are shown using the selected statistics and their important parameters, all based on the three scheduling algorithms; Custom Queueing, Priority Queueing, and Weighted Fair Queueing. In order to see the differences and similarities between the QoS scheduling algorithms and their different behaviors, in each graph only one parameter is shown but using all the three QoS scheduling algorithms. The behavior of the scenario results are discussed and reasoned with small explanation for each.

4.1 Results of HTTP Application Parameters: Object Response Time (sec)

Figure (1) below shows that WFQ scheduling algorithm has the highest response time while the Custom Queueing and Priority Queueing are the second and third respectively. WFQ having the highest response time means that it is the worst in HTTP response time because there is a lot of dispatching in it and dispatching takes a lot of time. However, Custom Queueing and Priority Queueing behave better because they have to prioritize, and once it is HTTPs turn, they serve the queue without that much dispatching in between the queues.

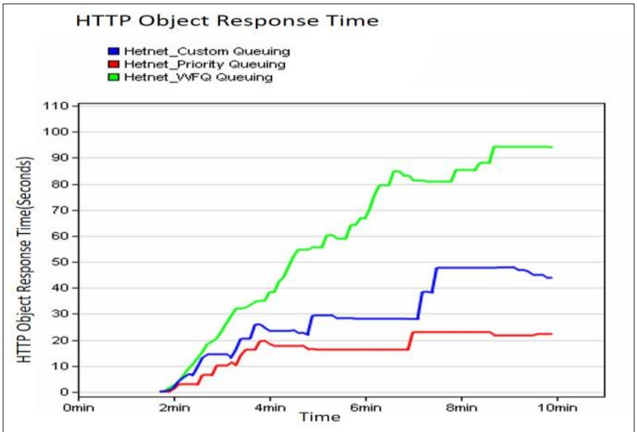

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Figure (1): HTTP Object Response Time (Seconds)

4.2 Results of Video Conferencing Parameters: Traffic Received (bytes/sec)

Figure (2) proves that Priority Queueing is the best choice for receiving traffic in Video Conferencing with the best QoS, while WFQ and Custom Queueing come in the second and third place. In the Priority Queueing the highest priority is given to Video Conferencing. However, in WFQ and Custom Queueing there is some fairness between the application services and that reduces the Video Conferencing QoS. WFQ and CQ behave similarly. WFQ is trying to give fairness to traffics regardless their types, and CQ is trying to guarantee the bandwidth for each type of traffics. Note that, the explanation here is about traffic received in the destination and does not relate to the medium of transfer or the process behavior of packets.

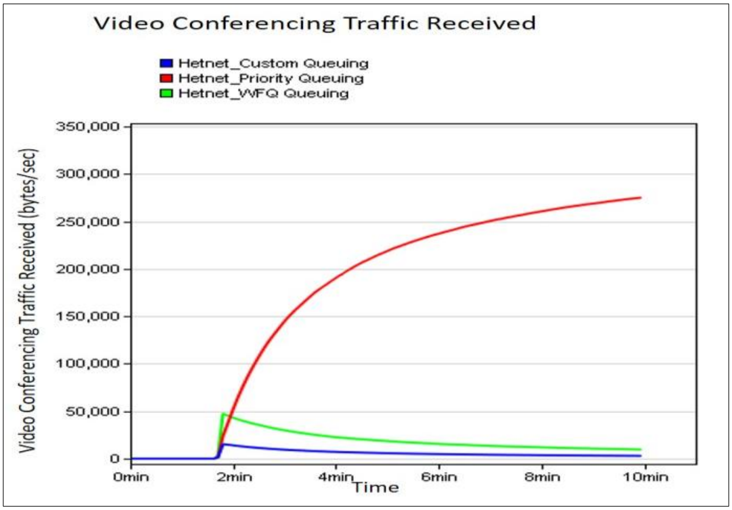

Figure (2): Video Conferencing Traffic Received (bytes/sec)

4.3 Results of Video Conferencing Parameters: Packet End-to-End Delay

Figure (3) shows that the lowest End-to-End Delay in Video Conferencing is in the case of using Priority Queueing as the scheduling algorithm, with a result of zero second delay. This is because Priority Queueing gives the most priority for the Video Conferencing queues and serves them without delay. The second best is the Custom Queue with a similar result. On the other hand, WFQ has the maximum delay of approximately 16 seconds, and that is because it gives fairness between the application serves like HTTP and voice as well, not only Video.

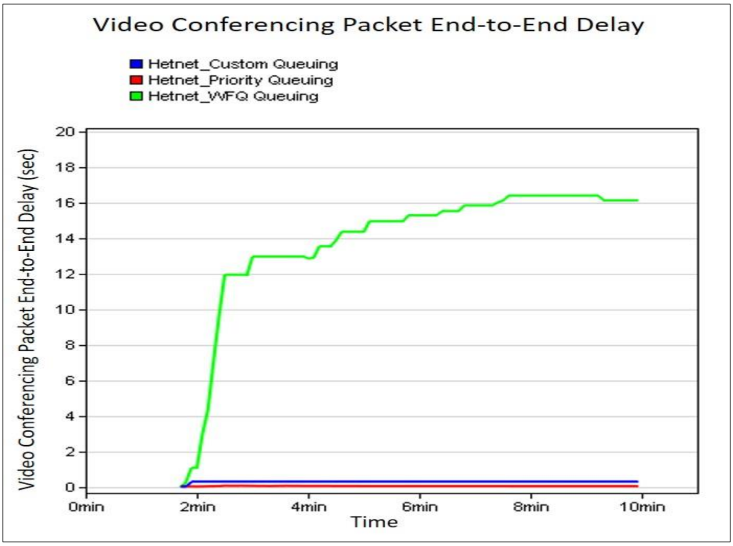

Figure (3): Video Conferencing Packet End-to-End Delay (seconds)

4.4 Results of Voice Application Parameters: Jitter (sec)

Figure (4) shows that WFQ has the highest jitter for the Voice application while Custom Queueing and Priority Queuing have a similar behavior. As mentioned in the previous chapter, Jitter is the inter packet delay. The reason why WFQ has more jitter is because it has more dispatching and switching between the queues in order to give fairness between all the three types of application serves such as voice, video and http, while priority and custom queueing have less switching and give priority to voice because it is a real time application. The jitter values are very small numbers that flatten very quickly to become zero. This is because delay between packets (jitter) is a very sensitive parameter in Voice application, no one stands a voice call full of voice lags and delays, therefore, having delay between packets indicates a bad QoS. In this scenario, the small jitter values indicate a successful and good QoS for the voice users.

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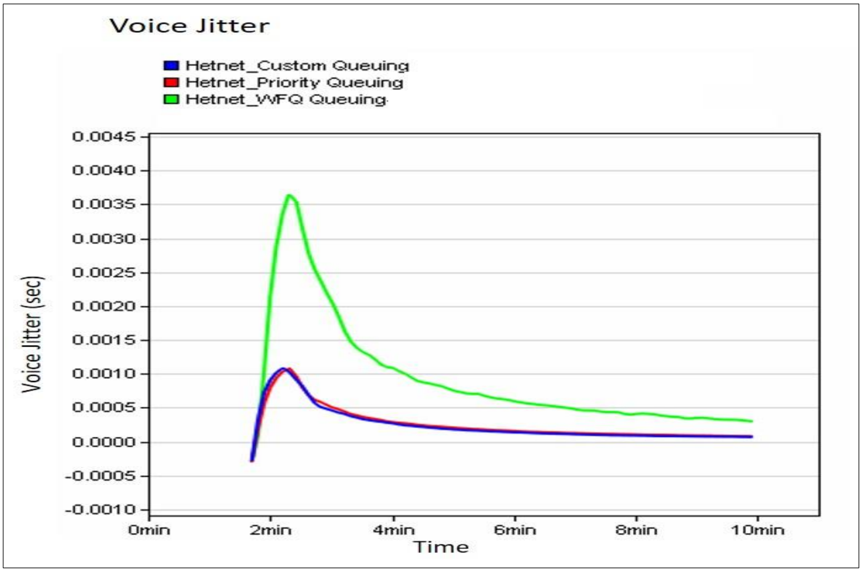

Figure (4): Voice Jitter (sec)

4.5 Results of Voice Application Parameters: Traffic Received (bytes/sec)

As shown in Figure (5), Custom Queueing and WFQ have the first and second place in receiving video traffic while Priority Queueing is the worst. This is because the first two have fairness which provides a guaranteed bandwidth for the voice application, whilst the Priority Queue is giving the highest priority to video conferencing which makes it lose the competition for the voice application.

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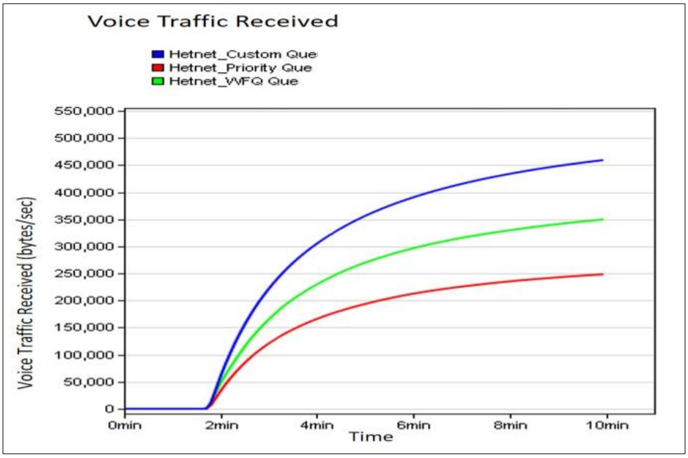

Figure (5): Voice Traffic Received (bytes/sec)

4.6 Results of Delay (sec) in LTE Statistics: Comparison of Macrocell, Femtocell, and Picocell

For the delay of LTE, the Figures (6.A), (6.B) and (6.C) are representing the delay of link layer and that means the delay of frames submitted to this layer. It does not include the delay of higher layers. Since this thesis is focusing more on LTE, these figures include the Macrocell, Femtocell, and Picocell's link layer delay. The behaviors are identical for all the three figures. As it is seen, the WFQ has higher delay than the other algorithms which is a natural result as WFQ is trying to guarantee the QoS equally among all types of traffic. The value of delay in Macrocell is higher than the one of Femtocell and Picocell. The reason is there are more users served by the Macrocell. To compare Picocell and Femtocell, Picocell has lower delay because it offers high data rate and it is not overloaded in this scenario. The Femtocell on the other hand is offering low data rate with reasonable number of users. To increase the delay in the Picocell, more users should be supported in the office topology as there is a tight relationship between data rate and the delay in the link layer.

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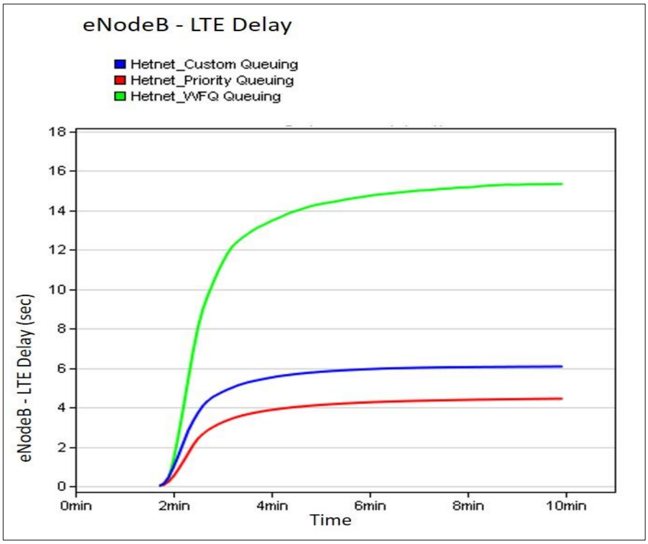

Figure (6.A): Macrocell eNodeB LTE Delay (sec)

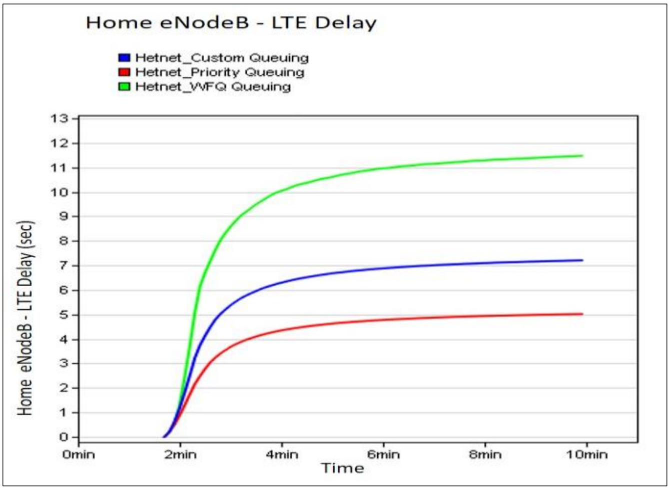

Figure (6.B): Femtocell Home eNodeB - LTE Delay (sec)

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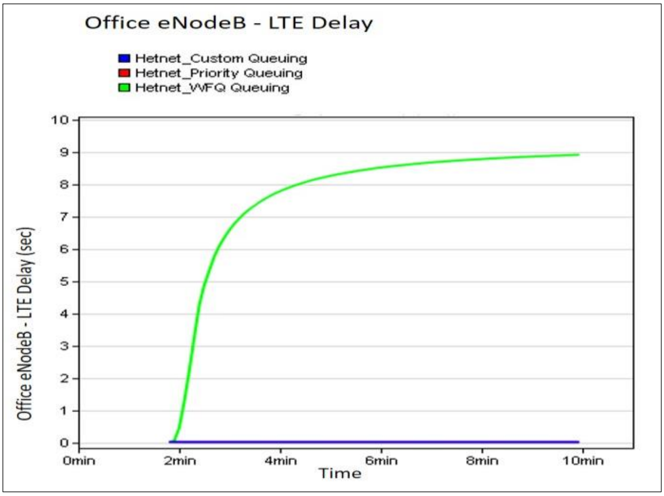

Figure (6.C): Picocell Office eNodeB - LTE Delay (sec)

5. Conclusion

The main goal of this research was the investigation of QoS performance for an integrated architecture of different types of networks, namely; HetNet in LTE-A. The HetNet was composed of a Macrocell, Picocell and Femtocell. The first major work was to integrate such a diverse network with diverse characteristics, and hence loose coupling type of architecture was selected for the integration. Once the integration was achieved, then scheduling algorithms were deployed in to study the different QoS parameters for the different types of on-going applications, such as: real-time and non-real-time applications. Comprehensive simulation analysis and performance studies were carried out during this research.

QoS parameters in both layers of IP and link layer were evaluated through different types of scheduling algorithms. These algorithms were Priority Queue, Custom Queue and Weighted Fair Queueing. The applications used in the scenarios were HTTP, Voice and Video Conferencing. The behavior of these algorithms were studied through simulation analysis. The results proved different performance for the different algorithms depending on many factors, such as: type of the application, load on the network in terms of number of users, and the number of requests. Test results showed that the PQ had a clear behavior since it was giving priority to real-time applications all the time. Consequently, it had higher performance for these types of applications. However, for non-real-time applications WFQ showed better performance as it is a fairness-oriented scheduler.

Regarding the link layer, the most important analyzed parameters were delay and load in all types of Base Stations. The used base stations were: eNodeB, HeNodeB and Office eNodeB. Number of users played a great role on the results of delay and load inside each cell individually. For example, delay in Macrocell gained highest values while it gained lowest value in the Picocell.

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Syah, R., Davarpanah, A., Nasution, M. K., Wali, Q., Ramdan, D., Albaqami, M. D., ... & Noori, S. M. (2021). The Effect of Structural Phase Transitions on Electronic and Optical Properties of CsPbI3 Pure Inorganic Perovskites. *Coatings*, *11*(10), 1173.

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پوختە:

تەکنەلۆژیای پەرەسەندنی درێژەماوە (LTE) کە بە تەکنەلۆژیای G4 ناسراوە، هەڵبژێردراوە بۆ پڕۆژەی هاوبەشی نەوەی سێیەم (GPP3) و بە کارپێکەری مۆبایلی GPP23 دادەنرێن. پێشبینی دەکرێت LTE ئەزموونی بەکارهێنەری بەرەوپێشچوو و پاڵپشتی تەواوی گەرۆک بوون دابهێنێت. لەگەڵ ئەوەشدا، بۆ ڕووبەڕووبونەوەی زیادبونی ژمارەی بەشداربووە گەڕۆکەکانی داتا، کە کێبڕکێ دەکەن بۆ سەرچاوە ڕادیۆییە سنووردارەکان، میکانیزمەکانی کوالیتی خزمەتگوزاری تۆڕی (QoS) جێبەجێ بکرێن. چارەسەر ئەوەیە کە خانەی بچووک بۆ تۆڕەکان زیادبکرێن لە ڕێگەی زیادکردنی وێستگەی هێز نزم بۆ خانە گەورەکان (ماکرۆ-eNBs). لەئەنجامدا تۆڕێکی هێتەریۆجینۆس (هێت نێت) دروست دەبێت کە پێکدێت لە خانە گەورەکان بە تێکەڵ لەگەڵ خانەی بچووکی (مایکرۆ، پیکۆ، فێمتۆ) بۆ داپۆشینی ئەو ناوچانەی کە لە خانەکانی ماکرۆ دانەپۆشراون و خەڵک بێبەشن لە خزمەتگوزاریەکان. بە کرداری، هێت نێت لە LTE پەرەسەندوودا دەناسرێت، کە ڤێرژنی درێژکراوەی LTE ە و تایبەتمەندی پێشکەوتووتری هەیە. ناساندنی هیتنێت لە LTE-A بەرەنگاری زۆر لەگەڵ خۆی دەهێنێت، بە تایبەتی لە ڕووی پێکبەستنەوە و پاڵپشتی کوالێتی خزمەتگوزاری و بەڕێوەبردنی بەیەکداچوونی شەپۆلی. لەم توێژینەوەیەدا، نەخشەیەکی تۆڕی بە تێکەڵکردنی خانە بچوک و گەورەکان پێشنیارکراوە. پاشان، هەندێک لە لۆگاریتمەکانی خشتەی کوالێتی خزمەتگوزاری بەکارهێنراوە بۆ چەند جۆرێکی تری بەرنامەی بەردەوام. دواتر، لە ڕێگەی بەکارهێنانی ڕیڤەربێد مۆدێلەر، پارامیتەرەکانی ئەدا بە فراوانی تاقی دەکرێنەوە ودەخوێندرێن. دواجار، بەراوردێکی چڕ لەنێوان ئەو ئەلگۆریتمانە دەکرێت و بەدوایدا گفتوگۆیەکی ورد ودەربەرەی ئەنجامەکان خراوەتەڕوو .

الملخص:

يعتبر التطور طويل الأجل (LTE)، المعروف باسم تقنية الجيل الرابع، الخيار لمشروع شراكة الجيل الثالث (GPP3) ومشغلي الهواتف المحمولة GPP23. من المتوقع أن توفر LTE تجربة مستخدم محسنة مع دعم

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التنقل الكامل. ومع ذلك ، للتعامل مع العدد المتزايد من المشتركين في بيانات الهاتف المحمول التي تتنافس على الموارد الراديوية المحدودة ، من الضروري وجود آليات فعالة لجودة الخدمة في الشبكة (QoS). هناك حل وهو إدخال خلايا صغيرة منخفضة الطاقة من خلال إضافتهم للمحطات الأساسية القائمة، الماكرو eNBs (العقدة المتطورة B). والنتيجة هي شبكة غير متجانسة (HetNet) مع خلايا ماكرو كبيرة مركبة مع خلايا صغيرة (الخلايا الصغرى، بيكو- وفيمتو) لتغطية المناطق التي لا تغطيها الخلايا الكبيرة. عمليا، يتم تقديم الشبكات الغير متجانسة في LTE المتقدمة وهو إصدار ممتد من LTE مع ميزات أكثر تقدما. إن إدخال الشبكات الغير متجانسة في LTE-A يجلب تحديات خاصة من حيث التكامل المادي ودعم جودة الخدمة وإدارة التداخل. في هذا البحث ، يقترح تكامل هيكل الشبكة مع اضافة الشبكات الغير متجانسة. ثم يتم اختبار بعض خوارزميات لفعالية جودة الخدمة من خلال انواع مختلفة من التطبيقات الجارية. علاوة على ذلك ،من خلال استخدام Riverbed Modeler، تتم دراسة معلمات أدائها من خلال محاكاة واسعة النطاق. وأخيرا، يتم إجراء مقارنة مكثفة بين الخوارزميات وتليها مناقشة مفصلة عن النتائج.