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TCP Congestion Control: A Contributing Factor to Congestion in Long-Term Evolution Networks

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Abstract- Long-Term Evolution (LTE) has evolved the field of data transmission, bringing about the era of 4th Generation Networks capable of providing broadband speeds to mobile users based on the development experienced in the field of data transmission. There has been a sporadic increase in the utilization of Long-Term Evolution (LTE) networks, due to the ever-growing utilization of network links and network services, certain issues begin to rise, one of such issues is the problem of congestion. The more utilized a network becomes, the more vulnerable it is to congestion. Data networks become congested when network cannot keep up with the growing demand for the networks resources. Transmission Control Protocol (TCP) is the most used protocol today, and its application in Long-Term Evolution networks is analysed. This work show that TCP contributed to congestion in Long-Term Evolution networks.

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TCP Congestion Control: A Contributing Factor to Congestion in Long-Term Evolution Networks

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Abstract- Long-Term Evolution (LTE) has evolved the field of data transmission, bringing about the era of 4th Generation Networks capable of providing broadband speeds to mobile users based on the development experienced in the field of data transmission. There has been a sporadic increase in the utilization of Long-Term Evolution (LTE) networks, due to the ever-growing utilization of network links and network services, certain issues begin to rise, one of such issues is the problem of congestion. The more utilized a network becomes, the more vulnerable it is to congestion. Data networks become congested when network cannot keep up with the growing demand for the networks resources. Transmission Control Protocol (TCP) is the most used protocol today, and its application in Long-Term Evolution networks is analysed. This work show that TCP contributed to congestion in Long-Term Evolution networks.

I. Introduction

The Internet, created as far back as January 1983, has revolutionized communication, business and also wealth creation (Sagar & Shankar, 2013). The Internet and basically all kinds of networks can be viewed logically as a queue of packets. Packets are unit of data fragments that are constantly being transmitted between nodes, and this is the foundation of all forms of networking. Networks perform the tasks of packet transmission between nodes thereby reducing the number of packets remaining in the queue waiting to be transmitted. The exponential increase of network usage and also network capacity brings up more comprehensive issues which are paramount to the network's overall performance (Alkharashi, 2016).

Broadband services have been made available to mobile users at homes, offices, schools with static equipment such as hubs, switches and also routers providing high-speed data. As at 2007, it was estimated that over 1.8 to 2 billion people will have broadband services by 2012 and over two-thirds of them will be mobile broadband users subscribing to various networks built on the High-Speed Packet Access (HSPA) and Long-Term Evolution (LTE) technology (ERICSSON, 2007). It is estimated that global mobile users will surpass 5 billion by the end of year 2017 (GSMA, 2017), that is more than two-thirds of the world's population, one can only imagine the amount of traffic that will be generated with such great number of users (Internet World Stats, 2017). The Long-Term Evolution technology brings about so many beneficial advantages over previous technologies to both users and the network administrators, these advantages can be categorized into three major points; which are performance and capacity; simplicity and a wide range of terminals (Khalil, 2015).

The problem of congestion has existed far back as the creation of computer networks, it has persisted to modern networks and solutions are far from being absolute. Long-Term Evolution technologies offers high speed broadband services at cheap and efficient rates to users (Sauter, 2011). This technology is built on packet switching which means that data is broken down into packets and these packets are transported via routes to their destinations, due to the dynamic nature of packet switching the packets can follow different routes and on getting to the destination all the packets are gathered and the data is rebuilt from the packets (Willassen, 2003).

Congestion can easily disrupt network process, as a result of heavy traffic on the network packet can be delayed, timed out, contain error and sometimes even be lost. This is a serious problem leaving networks clogged with so much traffic and so little work is done. Although it should be stated that the Transmission Control Protocol (TCP) which is the integral protocol for the transfer of packets between network elements provides some sort of congestion control ensuring that the network is not filled to its capacity with traffic load (Jayakumari & Senthilkumar, 2015), but this method of congestion control is highly on ineffective when it is being applied to Long Term Evolution technology which provides high-speed broadband services due to the design of the protocol (Alkharashi, 2016). TCP favours reliability over performance and is not built to handle huge volumes of data. Thus, TCP congestion control policies tend to be ineffective when being implemented on Long Term Evolution networks.

II. Literature Review

Congestion occurs when the request for packet service is greater than the available resource the network has at that present moment. This leads to the loss of data packets due to the long queues of packets waiting to be transmitted. As computer networks continues in the state of congestion the throughput of the network drops while utilization sky rockets meaning that although the network is heavily utilized, little or no work is done (Khalil, 2015). This is a complex problem

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Global Journal of Computer Science and Technology (E) Volume XVIII Issue III Version I Year 2018

for network administrators to deal with due to the fact that congestion occurs at the interlink between nodes, the network's gateway and also at routing point. Also, various networks operate with numerous protocols, traffic control schemes and varying equipment. Therefore, looking for a solution to fit all network works is tasking.

Networks in a state of congestion are also in a state of deadlock, new packets entering the networks will create a clogging effect. This is the primary reason for the drop-in network throughput (Mohamed, Sahib, Suryana & Hussin, 2016).

Congestion occurs when the request for packet service is greater than the available resource the network has at that present moment (Ullah, Shahzad, Khurram, & Anwer, 2014). Although congestion can be described as a resource allocation problem, making resources more accessible is not a viable solution. Some of the solutions that has been widely provided include:

1. Congestion is caused by lack of sufficient buffer memory so the solution to this is that memory has to become cheap enough thereby allowing for infinite storage.
2. Slow links between connecting nodes is the cause of congestion. Having high speed connecting links will solve the problem.
3. Having slow processing power will lead to congestion, having high speed processors will solve the problem.

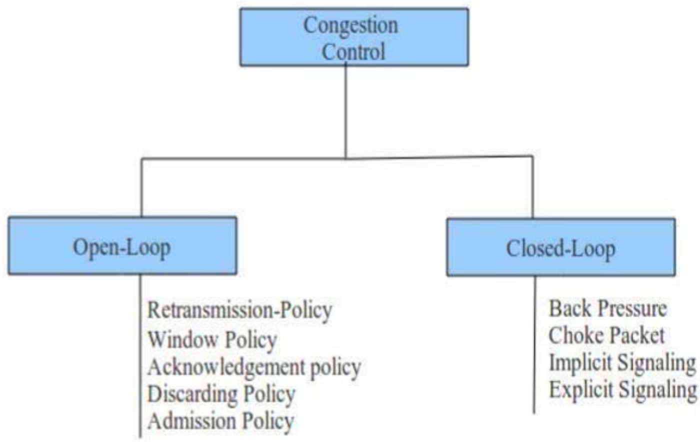
All these solutions listed only provide just a temporary fix to the problem, if they are seen as fact by network administrators it could lead to improper network planning and implementation. On the contrary to all these assumptions, proper network protocol designing and implementation is needed to establish a network to combat congestion. Hence, by implementing any of these assumptions above, would reduce the overall throughput and also reduce performance thereby adding more congestion to the network system (Amoroso, 2009).

Infinite buffer storage although not a bad idea cannot offer a total solution to the problem, it gives just a temporal solution which will not last for long. Although small memory buffers when faced with too much traffic suffer from buffer overflow and loss of packets but if we are to have infinite butter storage during heavy traffic would result in long queues of packets, delays and so on. Finally, when packets leave the queue, so much time would have passed and these packets would time out (Floyd & Fall, 1999).

Also, having high speed links between nodes will not make much difference to solve the problem of congestion, at the time when the Internet began, the speed for nodes and workstation available as at the time was not more than 300 bits per seconds (300b/s). Gradually with increase in technology speeds of up to 1.5 megabits per seconds (1.5Mb/s) was attainable with the introduction of Local Area Networks (LANs) and also Ethernet speeds of about 10 megabits per seconds (10Mb/s) was possible (Jain, 1990) (Mohamed, Sahib, Suryana, & Hussin., 2016). It was at this point in history the issue of congestion started to gain recognition due to a mismatch such that fast-high speed LANs were connected via slow links and slow nodes that cannot keep up to the speed of these links. Today, when it come to the speed of data or Internet connections we can have speeds up to Gigabits or even Terabits but the issue of congestion still persists. Therefore, having high speed links is not the solution. Also, the same can be taught of for slow processors, having high speed processors can lead to a mismatch.

a) TCP Congestion Control

Congestion Control is a network layer problem that is concerned with how the network responds to situations where we have huge amounts of data packets in the network than can be sent, this causes a clogging effect in the network. Congestion control is different from other issues such as Flow Control, Flow Control is a data link layer issue and also it is concerned with just one sender overloading the network with packets (Moses, 2010). Congestion Control refer to the specific means and methods that have been adopted over time to control the effect congestion possess to various networks (Ramb, 2011). Congestion Control mechanisms can broadly be divided into 2 main Categories: Open-Loop Congestion Control which provides ways and procedures for the prevention of congestion and Closed-Loop Congestion Control which provides ways of the removal of congestion completely from a network.



Source: Ramb, 2011

Figure 1: The 2 main categories of congestion control

Over the years several techniques, algorithms and methods has been developed and also proposed for Congestion Control, these section gives an overview of some of the them (Jiao, Gao, Yang, Xia, & Zhu, 2014).

The Transmission Control Protocol employs a congestion avoidance algorithm which includes various schemes such as:

1. *Additive Increase/Multiplicative Decrease*: This is a feedback congestion control algorithm with is known for its deployment in TCP congestion control. It brings together the linear increase of the congestion widow coupled with the reduction as soon as congestion takes place. The algorithm increases the transmission rate also know has the congestion window size while examining for usable bandwidth. When congestion is detected in the network, the transmitting node decreases the rate of transmission by a multiplicative factor thereby reducing the congestion window.

Understanding this mathematically, let's assume *w*(*t*) is the congestion window size i.e. the sending rate during a time slot *t, a (where a > 0)* is the additive increase parameter and *b (where 0<b<1)* be the multiplicative decrease factor, Therefore,

$$w(t+1) = \begin{cases} w(t) + a & \textbf{if congestion is not detected} \\ w(t) \times b & \textbf{if congestion is detected} \end{cases}$$

2. *Slow Start:* This is also part of the congestion control strategy adopted by TCP, as we know Transmission Control Protocol is the mostly used protocol by most devices and application on the Internet. Slow start is employed together with other algorithms to avoid the transmission of huge data packets that surpasses the network threshold. These can help avoid having to deal with a congested network.

In other to avoid having a congestive collapse, TCP employs a multi-faceted congestion control policy, for every connection, TCP maintains a fixed window size thereby limiting the total number of packets which will be unacknowledged (Shahzad, et al., 2015). TCP also uses the slow start algorithm to increase the congestion window size after the initialization of a connection. TCP favours reliability over performance and is not built to handle huge volumes of data. Thus, TCP congestion control policies tend to be ineffective when being implemented on Long Term Evolution Networks. Long Term Evolution Networks provide high-speed broadband services and this huge demand for data services makes the use of TCP Congestion Control to fall short of performance and increase the overall network load (Pawar & Pawar, 2012).

III. TCP Simulation Results in Long-Term Evolution Network Environment

A Long-Term Evolution Network environment was created using the NS-2 installed on a Linux Operating System. The network comprised of 3 eNodeBs and each of these eNodeBs was be connected to 10 User Equipment, also a Relay Node was added in other to make the simulation appear as realistic as possible. A packet size of about 1500 Bytes was used with a simulation time of 100 seconds. The TCP protocols employed were TCP Reno and SCTP.

The link parameters employed for the Long-Term Evolution network environment includes allocating 100 megabits per second of bandwidth to the server with a delay of 100 micro-second and also have 2 routers with bandwidth of 1 gigabits per second with a delay of 3 micro-second each. The 3 eNodeBs would have a bandwidth of 1 gigabits per second and a delay of 3 micro second and the same parameter was used for the relay node.

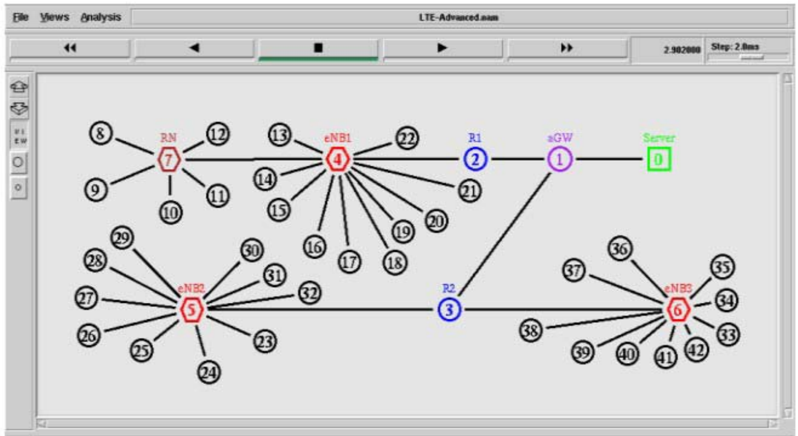


Figure 2: View of the Simulated Long-Term Evolution Network Environment

Figure 2 shows the real-time simulation of the Long-Term Evolution network environment. The green node in the Figure 2 represents the server, which symbolizes the Packet Data Network (PDN) aspect of the network and it is directly connected to the gateway. The two routers are connected to the gateway with a bandwidth of 1 gigabits per second and all the eNodeBs are connected to it in order to gain access to the server and this represents the Evolved UMTS Terrestrial Radio Access Network (E-UTRAN) segment of the network. Also, there are various User Equipment connected via the air interface to the eNodeBs.

The results obtained from the Long-Term Evolution network environment simulation gives a general overview of network operations.

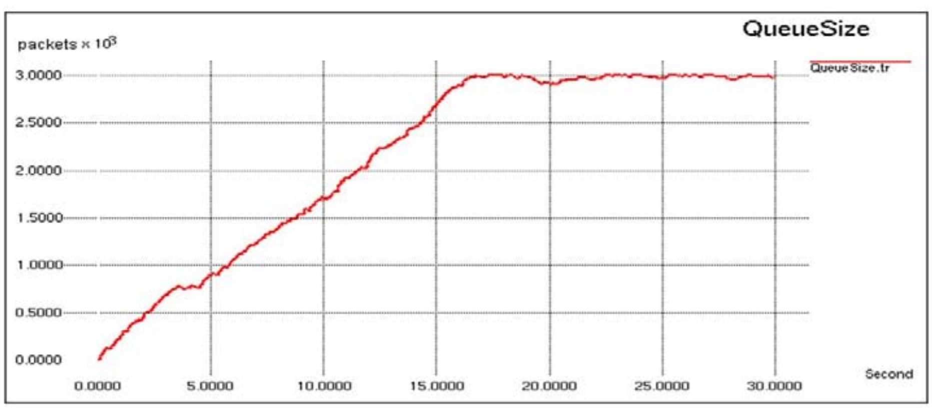


Figure 3: Queue Size against time of TCP Reno over Long-Term Evolution network

Figure 3 shows how the queues size increases over time in the Long-Term Evolution network environment. It can be seen that over time more packets are added to the queue and if these packets are not attended to, they tend to build up and become so much that it will leads to packet loss.

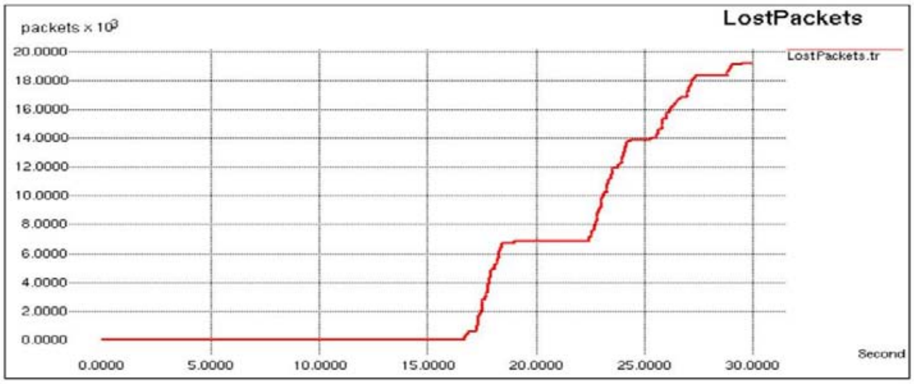


Figure 4: Lost Packets versus time of TCP Reno over Long-Term Evolution network

Figure 4 shows the effect of packets queuing up, as these packets queue up it leads to some of these packets being lost. As shown from the simulations as packets and data traffic increases over time the queue size would increase leading to packets being lost and congestion is created within the network.

IV. Performance Evaluation of TCP in Long-Term Evolution Simulated Network Environment

The simulated Long-Term Evolution network which uses the traditional Long-Term Evolution network architecture was evaluated using the following metrics: Throughput, Average End-to-End Delay, Network Utilization and Packet Delivery Ratio. These metrics show how effective the model is and how it is affected by congestion.

1. *Throughput:* This refers to the total amount of packets that is successfully transmitted to the destination network element from the source network element. The network throughput is measured in bits per second.

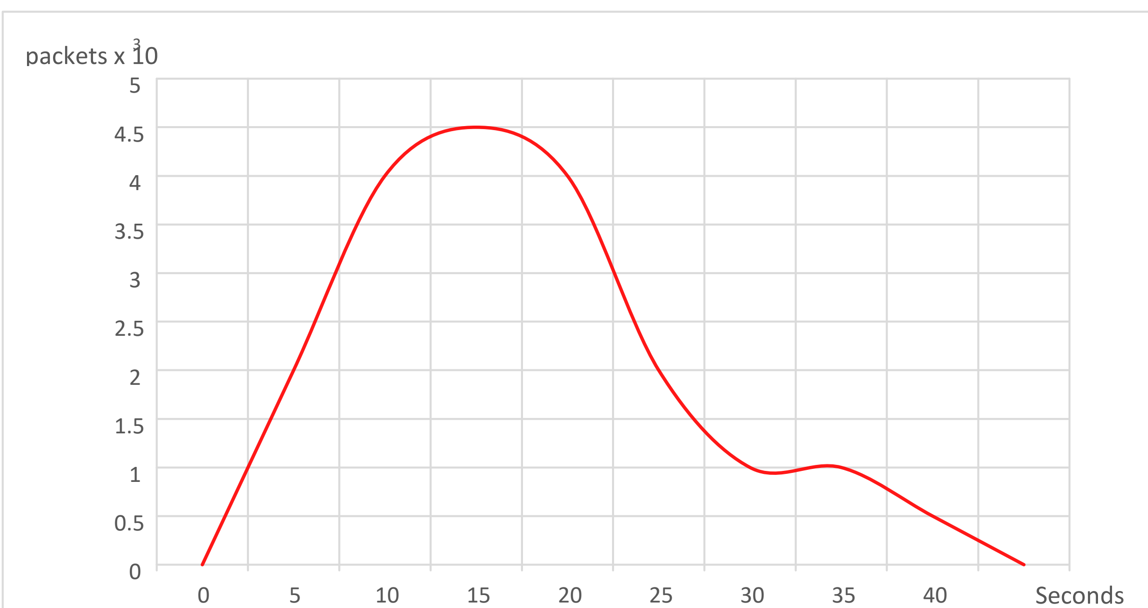


Figure 5: Throughput Analysis of Simulated Long-Term Evolution Network Environment

Figure 5 shows how throughput is affected in the Long-Term Evolution network. From the result obtained, it can be seen that as traffic increases over time, a pick level of throughput is reached after which throughput starts to decline. If this goes unchecked it can lead to a situation where no reasonable work can be done on the network. At the stage the network is said to be in a stage of congestive collapse. Figure 5 shows how congestive collapse is reached when traffic and the requests of data packets gets so high that the network itself cannot handle the incoming traffic.

2. *Average End-to-End Delay:* This refers to the amount of time spent from the creation of data packets to the time it is delivered to the destination network element. This performance metric is automatically increased when the rate of re-routing in a network is increased.

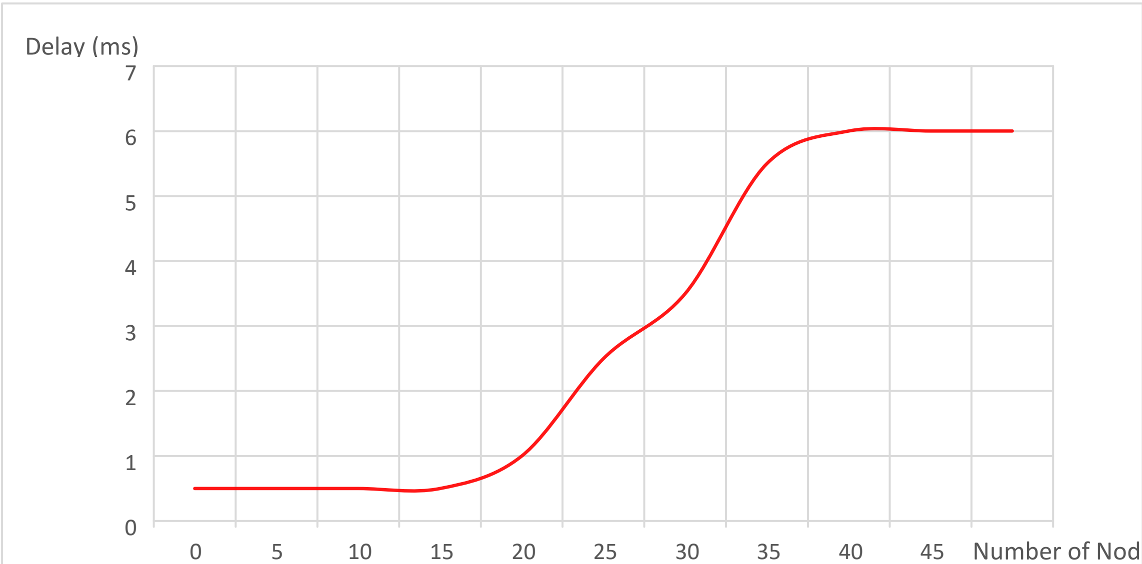


Figure 6: Average End-to-End Delay Analysis of Simulated Long-Term Evolution Network Environment

Figure 6 shows how the average end-to-end delay is affected by congestion. As shown in Figure 3, the Long-Term Evolution simulated network environment has loads of packets in the queue waiting to processed. The queue increases as shown in Figure 3, the average time spent for a packet to move from source to destination increases as shown in Figure 6.

3. *Network Utilization:* This refers to the ratio of the current traffic being experienced in the network to the maximum traffic that can be handled by the traffic. It shows the state of the network whether it is in a busy, normal or idle state.

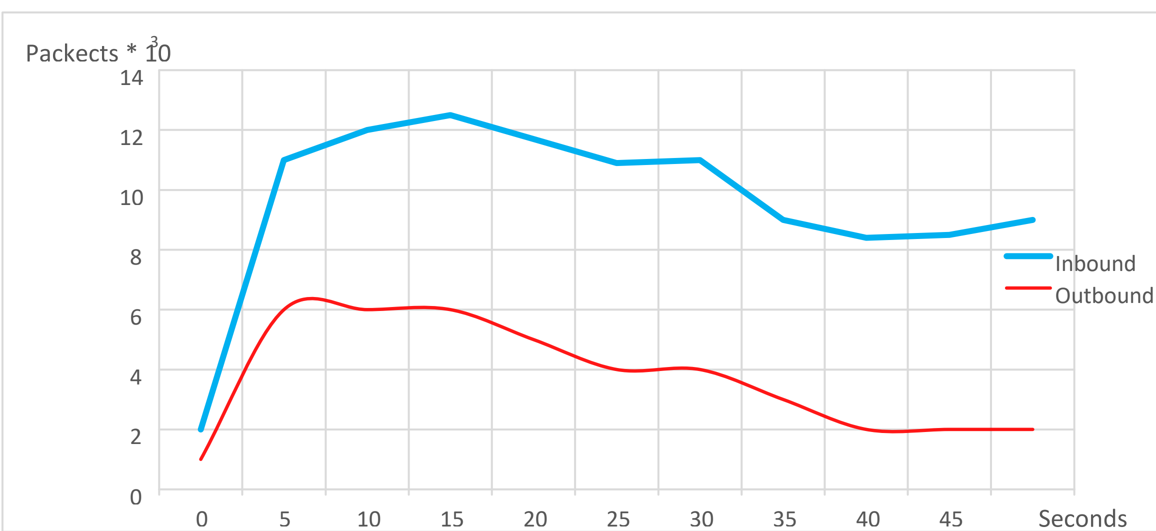


Figure 7: Network Utilization Analysis of Simulated Long-Term Evolution Network Environment

Figure 7 shows both inbound and outbound network utilization gotten from the network simulations Long-Term Evolution Network. The Figure 7 shows a massive difference between inbound and outbound traffic. The inbound traffic will keep piling up and will not be processed because the network is taking so much traffic and it cannot process it all.

4. *Packet Delivery Ratio:* This refers to the ration of data packets which are received successfully at the destination node to the total amount of packet sent.

Global Journal of Computer Science and Technology (E) Volume XVIII Issue III Version I Year 2018
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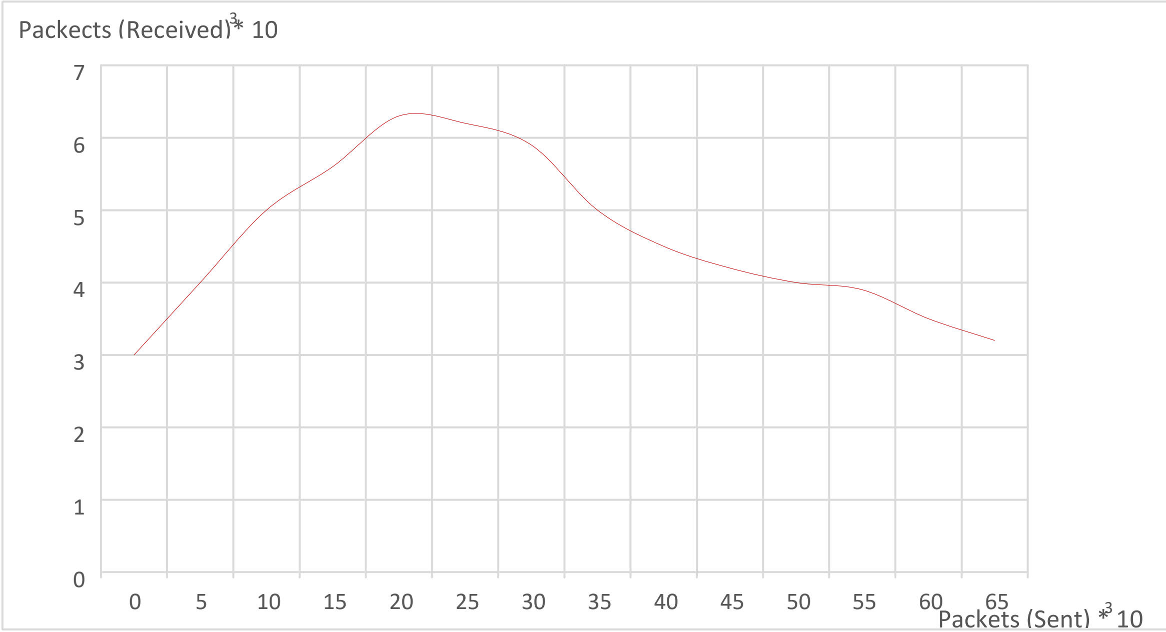

Figure 8: Packet Delivery Ratio Analysis of Simulated Long-Term Evolution Network Environment

Figure 8 shows how the Packet Delivery Ratio in Long-Term Evolution Networks is affected by congestion. As traffic increases the packet delivery ratio drops, it shows that the network cannot keep up with the inflow of packets coming into the network and therefore the time taken for packets to be delivered to the destination node is significantly high.

V. Conclusion and Recommendations for Further Studies

Today the Internet is very much built on TCP and its application in Long-Term Evolution Networks shows how ineffective it can be. We have been able to show from the simulation results that TCP is a contributing factor to congestion in Long Term Evolution networks and this can pose a huge problem if it is continued to be deployed on Long Term Evolution networks. Further studies should be carried out to look for methods to solve this problem.

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