TCP Variant Simulation Performance in 5G mmWave Network

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***Abstract* - 5G millimeter wave (mmWave) is a cellular network technology that has a high frequency. This results in a wavelength of this small technology so that it results in a coverage area that is not too broad. This allows handover events to appear more frequently than usual technology. As a result, users who move at high speed will have each different performance. TCP as a transfer protocol will be affected as a result of users moving with high speed and in this hanndover condition. To treat this, a TCP congestion control algorithm is used that can optimize TCP under these conditions. In this study an analysis of the performance of variant TCP variants namely TCP CUBIC and TCP YeAH on a 5G mmWave network with varying User Equipment (UE) speeds using Network Simulator-3 (ns-3). The result from this paper is TCP CUBIC has 40,581 ms of average delay deviation and 6,012 Mbps of average throughput deviation. Meanwhile TCP YeAh has 37,996 ms of average delay deviation and 6,013 Mbps of average throughput deviation.**

Keywords - 5G Milimeter Wave, Handover, TCP Variant, Network Simulator-3

I. INTRODUCTION

The need for cellular data usage is growing rapidly along with the increase in cellular communication devices such as cellphones and tablets. In its implementation to implement fifth generation cellular technology is still difficult because it requires more cost and time. Therefore, before replacing the existing architecture completely with 5G, the Double Connectivity method is used when handover between 4G LTE and cellular technology 5G [1].

The fifth generation cellular technology (5G) is still very difficult to implement in the near future. Therefore, the connection with 4G is done first so that they can be connected to each other by using Dual Connectivity. 5G which has a high frequency (starting from GHz) causes it to have a short wavelength. This short wavelength affects the coverage area of 5G Base Station (BS). By using Dual Connectivity, the application of 5G becomes easier and does not require time and money to be implemented in the field because it can utilize 4G technology that is already available. But in its implementation, users themselves have different speeds when making movements. This will affect the handover process so that the performance obtained by the user depends on the user's own speed. This of course will also affect the transport layer, where the transport layer will experience problems in determining the data packet delivery system.

Transmission Control Protocol (TCP) is a transfer protocol that can guarantee 100 % data transmission to use the concept of acknoledgment (ACK). TCP itself will experience difficul-ties in handover conditions because the process of developing TCP communication is relatively long and traffic in high handover conditions. Moreover, with variations in the speed of different users. Of course this will affect the experience of users in conducting mobile communication. TCP itself uses a congestion control algorithm to regulate data flow and control errors caused by [2] data jams. By using congestion control on TCP, it is hoped that users will have a network with better TCP performance in overcoming Dual Connectivity with different variations of user speed. Differences in the use of TCP congestion control algorithms produce different QoS results.

II. TCP OVER 5G MMWAVE NETWORK

A. 5G mmWave

Cellular users now expect faster data rates and also more reliable services. The fifth generation cellular technology (5G) promises to realize the needs of these mobile users. 5G has to handle far more traffic at a much higher speed than the previous generation of cellular [3].

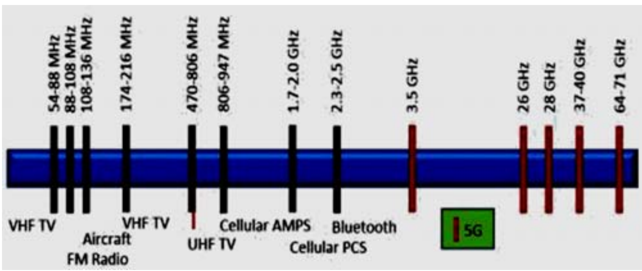

Fig. 1. 5G Frequency Band [5]

High frequency makes Millimeter Wave difficult to be applied on mobile broadband because it will cause high propagation loss and vulnerability to blockage such as buildings, vehicles, humans, and so forth [6].

B. Handover

Handover is the process of changing the relationship of User Equipment (UE) that moves Base Station (BS) in such a way that it is able to be served by the BS properly. A simple rule to determine which BS has the best service is based on Received Signal Strength (RSS). In other words, the EU can change associations if there are other BSs that are able to provide higher RSS than its serving base station, which might occur when the EU moves its location from serving base station to another base station. With the growing level of heterogeneity in cellular networks, there are other criteria developed to determine the best BS during handovers other than RSS, namely load balancing, delay and throughput [7].

Handover is carried out in three stages, namely initiation, preparation and execution. During the initiation phase, the user reports the results of the interference signal from the neighboring BS to the serving base station. In addition to the results of interference signals, handover can also be started based on the measurement report downlink and uplink signals.

In the next phase, which is the preparation phase, the signaling signal exchange will take place between serving base station and target base station. In this phase, the UE also synchronizes to the target base station using the Random Access Channel (RACH). After synchronization with the target base station is complete, the UE sends a confirmation message to inform the network that a handover is in progress.

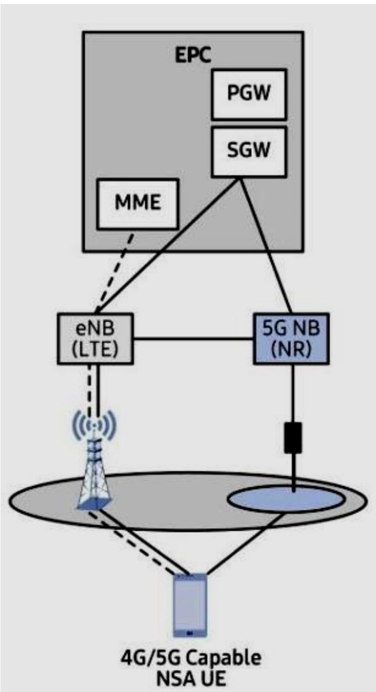

Fig. 2. Handover Dual Connectivity System [7]

Figure 1 shows the Dual Connectivity handover scheme which can be ascertained from its Radio Access Netwrok (RAN) which consists of two types of BS, namely eNB LTE and 5G eNB. The scheme shows that the core network used is still an Evolved Packet Core (EPC). Where EPC itself is 4G LTE technology. In the EPC block there are 3 sub-block systems that have different functions such as Mobility Management Entity (MME) function to manage, authenticate and track UE on a network. Packet Data Network Gateway (PGW), which functions to connect LTE networks with other packet data networks or to connect with Remote Hosts. Finally, the Serving Gateway (SGW) is used to forward data packets from PGW to RAN [8].

C. TCP CUBIC

TCP CUBIC is a TCP algorithm that is implemented in Linux operating systems. CUBIC is designed more concise and updated control window from BIC. The main feature of CUBIC is that the window growth function is defined in real time so that growth will be independent of Round Trip Time (RTT). The CUBIC period is determined by the packet loss rate. If the packet loss rate is high or the RTT value is low then CUBIC operates in TCP mode [11].

TCP CUBIC shows friendly nature during a short RTT when the window in TCP CUBIC increases based on real-time computing. This is because CUBIC does not increase its window based on the RTT it receives from ACK like other congestion control algorithms. When other TCP reaches an aggressive stage, then CUBIC will not change, short RTT will make CUBIC more friendly. On short RTT networks, CUBIC window growth will be slower compared to other algorithms.

Raising the window on CUBIC based on real-time comput-ing can also show friendly if the flow is short RTT. Because CUBIC did not raise its window based on the RTT received from ACK. When other TCP reaches an aggressive stage, then CUBIC will not change, short RTT will make CUBIC more friendly. On short RTT networks, CUBIC window growth will be slower compared to other TCP.

D. TCP YeAH

TCP YeAH itself is a combination of TCP Newreno and TCP Scalable. This causes TCP YeAh to have different prop-erties and can adapt in two environments that have different RTTs. Thus, TCP YeAh is classified into high-speed type TCP. The use of RTT is a cause because in TCP there is an Acknowledgment (ACK) process which is feedback from previous data transfers that the data has been successfully delivered and sent. TCP YeAH works with dual operating modes that can be used based on queue backlog and network congestion level [9]. TCP YeAH uses two modes on its connection those are Slow and Fast mode.

Fast mode force TCP YeAH to raise the congestion window each time before it reach to peak like TCP Scalable. While in Slow mode, TCP YeAH acts like TCP NewReno and using slow start method Mode selection decided based on an estimate of how many packages that coming trough the queue. RTT_{base} is the minimum RTT for TCP YeAh that measured by the sender from the general RTT that has been received and RTT_{min} is the minimum RTT in the current data window of the packet congestion window [12].

When data flow on a network connection increases, TCP YeAH reduces the number of windows in slow mode so that other streams on the network can increase the number of windows. While careful congestion algorithm itself is used to prevent excessive packet loss in buffer overflow conditions and to handle buffer overload at network capacity.

III. SCENARIOS

In this simulation using the network topology as illustrated by Figure 3. There are 1 BS 4G and 1 BS 5G. User Equipment (UE) will then move with a constant speed but with variations in the value that has been specified. The data connection from the user will go through the first BS namely mmWave nodeB and then it will be forwarded to the Evolved Packet Core (EPC) which is the core network to the SGW block. After that the data will be forwarded to the PGW block. The PGW block will then be forwarded to the remote host that the user is addressing. The MME block aims to determine whether the user will move or not by looking at the signal strength obtained from each BS. The simulation in this scenario uses the 5G mmWave module [13] which is a development of the LTE LENA [14] module and is implemented on ns-3 [15]. The script used for the simulation has been modified to fit the specified parameters.

This scenario is intended to determine the comparison of each type of TCP variant on the condition of the Single Connectivity handover and the Dual Connectivity handover. A description of this scenario is given by Table 1.

TABLE I. TCP VARIANT COMPARISON SIMULATION SCENARIOS.

No.	Scenario	Output	Parameter
1	User Speed Impact on TCP CUBIC Performance in Dual Connectivity	Delay, Through-put	UE Velocity: 1, 5, 10, 15, 20 m/s
2	User Speed Impact on TCP YeAh Performance in Dual Connectivity	Delay, Through-put	UE Velocity: 1, 5, 10, 15, 20 m/s

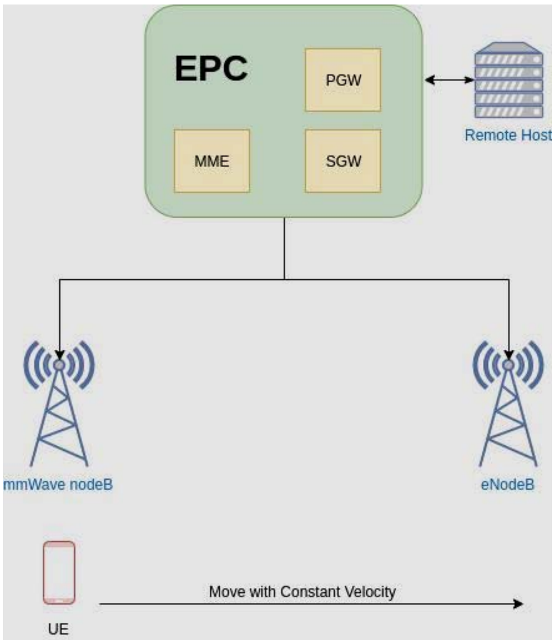

Fig. 3. Scenarios Topology.

IV. ANALYSIS

A. User Speed Impact on TCP CUBIC over Dual Connectivity Handover

This scenario aims to compare the performance of TCP CUBIC and TCP YeAH on the Dual Connectivity handover condition. In this scenario, a simulation with a large UE speed used is 1 m/s, 5 m/s, 10 m/s, 15 m/s and 20 m/s.

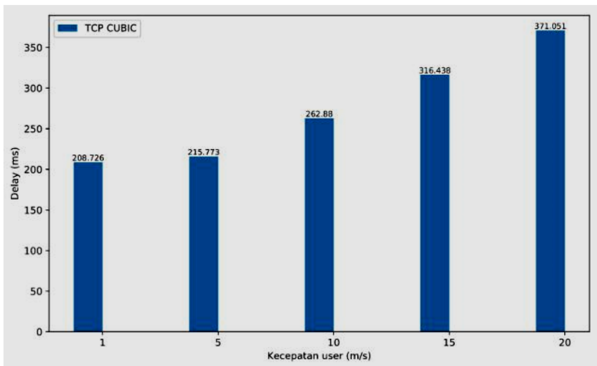

Fig. 4. TCP CUBICs Delay on Dual Connectivity Handover.

Figure 4 shows the results of the delay obtained in the scenario 2 simulation experiment. The graph of the simulation results shows that the moving EU with a speed of 1 m/s and 5 m/s has a small increase in delay. Whereas in the EU which moves at speeds of 10 m/s, 15 m/s, and 20 m/s experiences a fluctuating delay increase. This is caused by the increasing speed of the user so the process of sending data will be increasingly difficult. In addition, because the Dual Connectivity handover uses two different technologies

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(in this simulation 4G LTE and 5G mmWave) also affects the RTT connection thereby slowing down the delay experienced by the EU.

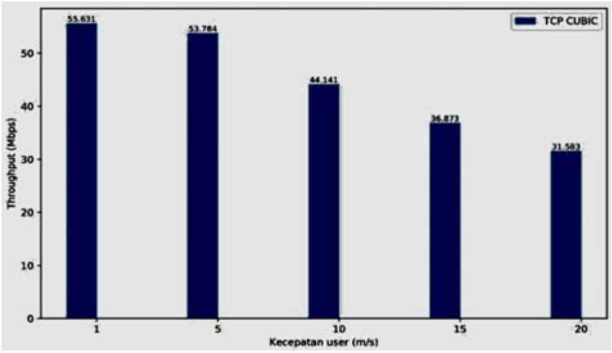

Fig. 5. TCP CUBICs Throughput on Dual Connectivity Handover.

Figure 5 shows the results of the throughput obtained in a scenario 2 simulation experiment. The graph of the simulation results shows that a moving EU with a velocity of 1 m/s and 5 m/s has an insignificant decrease in throughput. Whereas the speed of 5/ms to 10 m/s and so on has a fluctuating decrease in throughput.

The RTT needed by TCP CUBIC in transferring and receiv-ing ACK in this handover condition is somewhat difficult be-cause the EU that moves at high speed is difficult to control by MME which will provide initiation of the connection transfer from enodeB to mmWave nodeB. In Dual Connectivity, MME updating the path for each UE in S-GW requires adjustments at the PDCP sub-layer [17]. The nature of TCP CUBIC which when in a long RTT can adjust its window size so that the data sent has a relatively large and stable throughput even at the expense of a large delay.

B. User Speed Impact on TCP YeAh over Dual Connectivity Handover

This scenario aims to compare the performance of TCP CUBIC and TCP YeAH on the Dual Connectivity handover condition. In this scenario, a simulation with a large UE speed used is 1 m/s, 5 m/s, 10 m/s, 15 m/s and 20 m/s.

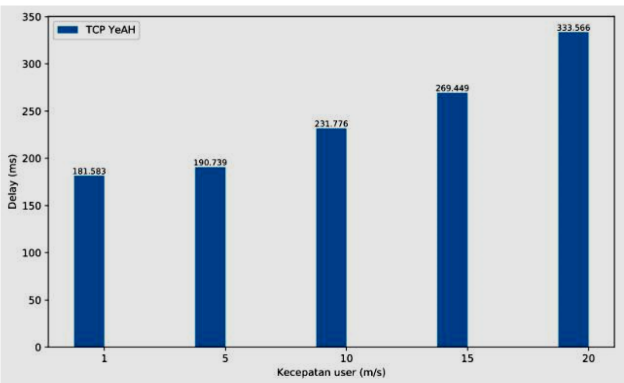

Fig. 6. TCP YeAhs Delay on Dual Connectivity Handover.

Figure 6 shows the results of the delay obtained in the scenario 4 simulation experiment. The graph of the simulation results shows that the moving EU with a velocity of 1 m/s and 5 m/s has a small increase in delay as in scenario 2. Whereas the moving EU with speeds of 10 m/s, 15 m/s, and 20 m/s have increased fluctuating delays. This is due to the increasing speed at the user, so the process of sending data will be more difficult because there is an additional time for MME to do EU tracing and initiate its relationship with the SGW block. In addition, because the Dual Connectivity handover uses two different technologies (in this simulation 4G LTE and 5G mmWave) also affects the RTT connection thereby slowing down the delay experienced by the EU.

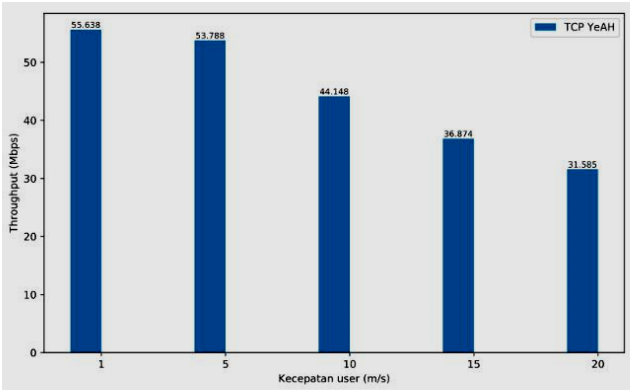

Fig. 7. TCP YeAhs Throughput on Dual Connectivity Handover.

Figure 7 shows the results of the throughput obtained in a scenario 4 simulation experiment. The graph of the simulation results shows that a moving EU with a velocity of 1 m/s and 5 m/s has a non-significant decrease in throughput as in scenario 2. Whereas from a 5 m/s user speed going to 10 m/s and so has a fluctuating decrease in throughput.

The RTT needed by TCP CUBIC in transferring and receiv-ing ACK in this handover condition is somewhat difficult be-cause the EU that moves at high speed is difficult to control by MME which will provide initiation of the connection transfer from enodeB to mmWave nodeB. In Dual Connectivity, MME updating the path for each UE in S-GW requires adjustments at the PDCP sub-layer [17]. TCP YeAH in handling this increase in speed and Dual Connectivity by entering slow mode is to reduce the increase in window but accelerate the pause of sending between packets.

V. CONCLUSIONS

As can be seen from the results of the data obtained and analyzed, it is known that TCP on each increase or adding in user speed, there is also a change in performance in terms of delay and throughput. If seen, the TCP CUBIC has increased with a fairly high difference between data with changes in the increase in the average delay of 40,581 ms and has a decrease in average throughput of 6,012 Mbps. TCP CUBIC has good performance in terms of throughput and less good in terms of delays. This is due to the nature of TCP CUBIC which adds windows so that the data sent has a large capacity so that it affects a large throughput. Whereas in TCP YeAh it was found that there was an increase in the average delay for each additional user speed of 37,996 ms and had a decrease in average throughput of 6,013 Mbps. This is because of the nature of TCP YeAH that first sees whether the network has a high or low RTT. In Single Connectivity, the performance of each TCP is quite stable because the handover process does not involve two different technologies. From the data comparison of the delay and throughput above, it can be taken to say that TCP CUBIC has the advantage of handling the decrease in throughput at every increase in user speed. Meanwhile, YeAH TPC has the advantage of handling increased delay at each additional user speed. Because handover is prioritized for user connectivity to remain stable without interruption, TCP YeAh is the right choice in handling the Dual Connectivity handover problem.

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