

Performance Comparison of Schedulers in MmWave Communication using NS-3

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Abstract—Millimeter-wave (mmWave) has proven to provide the bandwidth requirement for the new radio (NR) on 5G. MmWave has been developed as a new technology to support enhanced mobile broadband (eMBB), massive machine-type communication (mMTC), and ultra-reliable low latency communication (URLLC). Since using a high frequency, mmWave also has some disadvantages that could not be avoided, such as small coverage, high signal attenuation, limited against some obstacles, and sensitive to the influence of signal quality. This paper discusses the effect of signal quality on 5G performance using mmWave while sending or receiving packet data by using three types of the scheduler, such as Round Robin, Proportional Fairness, and Max Rate scheduler. Signal quality will impact the value of modulation and coding scheme (MCS) that will be used. Our experiments using NS-3 based on the scenario showed that in the same location and number of UEs, performance throughput using Round Robin and Max Rate with excellent signal strength could reach the maximum throughput. The use of Proportional Fairness could lead only to reaching 50% of the maximum throughput. On the other hand, the use of the Proportional Fairness scheduler causes the weak signal to be unstable. Using Round Robin scheduler, the throughput is more stable. Different from the result using the Max Rate scheduler, the UE with the best signal quality compared to other UEs, was the only UE that get the resources allocation.

Keywords—mmWave, NR, 5G, schedulers, resource allocation

I. INTRODUCTION

The Internet's growth today and in the future is a challenge for the information and communication technology (ICT) industry to provide services with fast quality and low delay/latency. In overcoming the challenges, the ICT industry began to move into 5G technology [1]. The 5G technology appears at higher frequencies to accommodate increased internet usage. The mmWave is one of the waves transmitting large amounts of data to fit the future needs of the central 5G technology [2]. Millimeters wave has resources within the spectrum frequency of 30 to 300 GHz so that it can be used for high-speed wireless communication. Some examples of the application on wave millimeter waves are radar, backhaul, satellite, Wireless Local Area Network (WLAN), and Wireless Personal Area Network (WPAN) Communications [3]. In addition to the high wireless communication needs, the other requirements required are low delay/latency, in which the 5G standard has a delay/latency of less than 1 ms [4].

In order to cope with high-speed demand and low delay/latency required experiments on the physical layer and all layers of communication [5]. Meanwhile, based on Ruseld Fold to overcome this, there are several experiments in the Core Network Architecture, Medium Access Control (MAC) Layer, and Low-Latency MmWave mac. In both studies, there is the same focus slice that is research on MAC Layer [4].

There are several disadvantages by using mmWave that could not be avoided, such as small coverage, high signal attenuation, limited against some obstacles, and sensitive to the influence of signal quality [2]. These issues might give the users have different quality of signal due to differences in location. Moreover, the user experience is determined by the scheduler that is defined by the system as well. This paper aims to get the information on performance comparison based on the scheduler used by the system while the users are in the same or different locations using NS-3 simulator.

In the next section, this paper will provide some necessary information about mmWave, Adaptive Modulation and Coding, Scheduler, and NS3 in Section II. In Section III, this paper shows the simulation scenario. Section IV presents the result and analysis of simulation of two scenarios, and in Section V, the conclusion and suggestion for future work will be provided.

II. MMWAVE AND SCHEDULERS

Several experiments result and some effort to redesign in MAC try the time transmission interval (TTI)-based variable alteration of the TDMA structure [6]. TDMA is a type of channelization techniques on the MAC. The reason for the variable TTI-based conversion experiments on the TDMA structure is due to the TDMA has a weakness in the number of resource restrictions that use one TDMA frequency band. If it is not limited, the frame period will be too long and, consequently, potentially serial communication interferes with the conversation [5]. Other reasons for this experiment are that the data allocation for small shipments on the TDMA scheduler LTE Systems is inefficient because the transmission process is sent at a 1 ms transmission time interval [8]. Therefore, the appropriate scheduler is required to measure the performance at mmWave. It performed end-to-end (E2E) simulation by using Long Term Evolution (LTE) topology architecture and LTE modules (LENA) in NS3. With all necessary Service Access Point using Evolved Packet Core (EPC), the protocol was provided by LENA in LTE protocols [5][6]. In the mmWave module, beamforming, propagation

loss, bandwidth allocation, range frequency, Orthogonal frequency-division multiplexing (OFDM), multiple-input multiple-output (MIMO.) subframe, and symbol have been considered as the input to compute and perform the mmWave function. The E2E simulation had been performed using different schedulers. In this paper, the simulation using different schedulers is performed using the Adaptive Modulation and Code (AMC) to perform the mmWave with the user experience approach. AMC is performed as the quality that is possible to be received by the User Equipment (UE) in any location since mmWave has weaknesses of not too strong to avoid the obstacle and has high signal attenuation. MmWave module is also sensitive to attenuation in this simulation. The attenuation is simulated based on a beamforming antenna. The sensitivity of the signal is affected by the performance that could impact the user experience. Otherwise, the coverage that is covered by the antenna is small. The location with a slight difference in the distance might have big gaps in signal quality. All the flaws are calculated based on the measurement report from UE. The result is useful in finding the solution when the UE has the same problem or defining the scheduler that will be implemented with the available resources to optimize the resource allocation. With the big allocation resource, the resource allocation must be optimized so the end-users could receive the best performance experience. All the resources have to spread to the UE optimally based on the strategy and purpose of the communication.

A. Millimeter-wave

A new challenge to wireless communication is the use of frequencies. Frequency resource limitations trigger researchers to find solutions. Millimeter-wave is a solution offered in the development of communication technology called New Radio (NR). NR itself needs a big bandwidth to operate the new technology. All wireless communications are currently using the frequency below 6 GHz that could give long-range propagation and low loss of penetration. That made the frequency allocation below 6 GHz to be fully occupied. Therefore, the new solution to proceed with the NR is to mitigate the frequency and find a very large bandwidth slot.

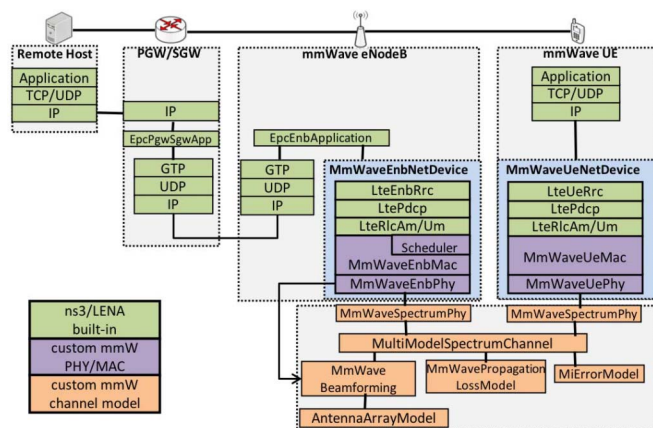


Figure 1. Class diagram of the end-to-end mmWave module [5]

The spectrum of mmWave will use 30 and 300 GHz frequencies, and it could provide a large bandwidth of more than 1 GHz [13]. With the weak penetration and weak propagation, mmWave will be penetrated by high-gain

antennas with the directive smart antenna. The smart antennas will perform the MIMO beamforming technique with multi-element antennas arrays as the solution for high attenuation. By using a millimeter-wave, the antenna size will be small, and it makes it possible to array the small element into the small cell station equipment that can reduce the possibility of UE to lose its connectivity. Figure 1 shows the class diagram of the end to end mmWave module.

B. Adaptive Modulation and Coding

Adaptive modulation and coding is a mechanism to make the system adapt the modulation scheme and coding that will be applied is based on the index quality of the channel (CQI)[5]. The CQI is generated based on the mapping of signal to interference noise ratio (SINR) computed based on the signal power received, interference, and noise [14]. Generally, SINR will be formulated as

$$\text{SINR} = \frac{S}{I+N} \quad (1)$$

S = Strength power, I = Interference, N = Noise

The CQI value will be mapped into the modulation and coding scheme (MCS) to compute the size of the available transport block (TB) for the subframe given by the MCS. The signal quality report will also be used to schedule resource allocation. It will be used by the scheduler to perform radio resource allocation management.

C. Scheduler

Scheduling is a process by which gNodeB decides which UE should be given the resource block (RB) and resources that should be given. Since the NR is using LTE strategy, scheduling is conducted per subframe basis, and the scheduler will govern the schedule. The scheduler will manage the resource based on the type of scheduler that is configured into the system. There are several types of schedulers in terms of signal quality conditions. The signal quality will be measured by the SINR, which is generated from UE feedback. It had been converted to the CQI value. The MCS dan the buffer will be computed based on CQI or the SINR value [7][9]. There is a pro and con for each type of scheduler, as shown in Table 1.

Table 1. Advantage and Disadvantage of the Schedulers

Scheduler Type	Advantage	Disadvantage
Round Robin (RR)	The resource is shared in an equal manner	The cell throughput will not be optimum due to resources allocation
Proportional Fairness (PF)	The throughput will be traded off between fairness and cell throughput	Complex to implement, and overall throughput will not get the highest.
Max Rate (MR)	Cell throughput will be maximum	Users in the cell edge will suffer from the limitation of resources.

Besides CQI and SINR generated from UE Measurement, there are QoS Information and system configuration computed by the scheduler, as shown in Figure 2.

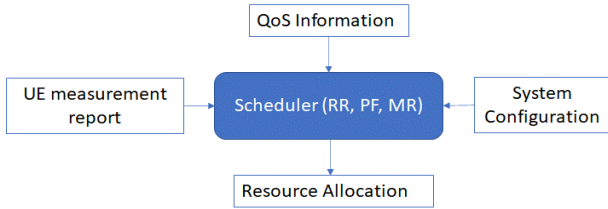


Figure 2. Scheduler Scheme

D. Throughput Performance

Several key performance indexes are used to evaluate network performance. The throughput is defined as the number of packets passing through the network in the time unit [10]. The values are expressed in the following formula:

$$\text{Throughput: } \frac{\sum Rx \text{ File Size}}{\text{Transmission Time}} \quad (2)$$

E. NS-3

NS3 is an open-source simulator tool designed to simulate network. The development carried out on NS3 [12] has the following focus:

- new software core: designed with a C++ and an optional Python scripting interface for improving scalability, modularity, coding style, and documentation
- software integration; supporting the integration of open-source software such as kernel protocol stacks, routing daemons, and packet trace analyzers
- attribute system: ns-3 provides an attribute system that integrates the handling and documentation of default and configured values
- tracing architecture: ns-3 is building a tracing and statistics gathering framework using a callback-based design that decouples trace sources from trace sinks

In this paper, NS-3 conducted the simulation using the mmWave module in the LENA LTE architecture. The mmWave module is performed in the MAC and PHY layers. The result is the end-to-end performance of LTE design using mmWave as MAC and PHY layer. The scheduler will be computed in the MAC layer, using a report given by the mmWave measurement report.

III. SIMULATION SCENARIO

This research uses NS3 simulation based on Mezzavilla's Research and advanced by New York University (NYU) mmWave Researcher. In this paper, we made two scenarios by defining the position of 6 UEs (User Equipment) from Next Generation NodeB (gNB). In Scenario 1, all UEs were placed in one location to know the difference in the resulting throughput. In Scenario 2, all UEs were placed in different locations, as shown in Figure 3, in order to find out the difference in throughput experienced by the UEs.

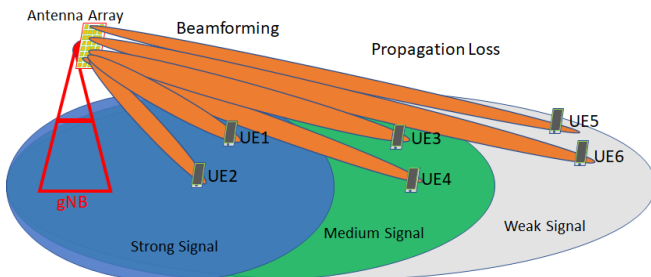


Figure 3. Simulation Scenario 2

The scenario will be performed using LENA architecture that will use mmWave in the channel class. UE will start the transaction to evolved Node Base (eNB) by sending signaling by performing the mmWaveUeRrc and will be responded by mmWaveEnbRrc. LENA architecture is added in the LTE system, and gNB uses the eNB in the simulation. The RRC module in the simulation still uses LENA LTE since either LTE or 5G has the same RRC characteristic. Before the UE sends a request to the eNB for resource allocation, eNB will request information (MIB and SIB) to allow UE to find and sync into the network. Then the UE will send the random-access preamble as the information requested by the eNB. After getting the UE information, the eNB will respond to allow the UE to send further messages. Afterward, the UE will request for RRC connection. The connection will be completed after the eNB setup connection. After the RRC connection is completed, the UE will attach request Packet Data Network (PDN) and initialize the attach procedure as non-access stratum (NAS) to MME through the eNB using the S1-AP interface. MME will do authentication for verifying all the rules, and after all, the MME would create session request to SGW using S11 interface, SGW will create the default bearer request to PGW. PDN GW user plane address, control plan, EPS bearer Identity, and QoS that was received from PCRF to SGW will respond. SGW will send an acknowledge message to MME that indicates the establishment of GPRS Tunneling Protocol Control (GTP-C).

Then MME will send eNB initial context setup message containing S1 interface context setup request, NAS attachment accepts, and activate default bearer request. Afterward, the eNB will reach the UE using a secure RRC connection. UE will send an acknowledge message that UE uses the newly activated keys to encrypt and integrate protection. eNB will send reconfiguration of RRC to activate the default radio bearer. Then UE will send an acknowledgment to eNB that the RRC has been completed, and UE has successfully established a connection to the network. Data will be passed to the data radio bearer (DRB) using GTP-U to Remote host as an emulator for the Internet [13]. In the scenario, the RRC process will be emulated by NS-3. The NS-3 will compute mmWave as a channel class. The scheduler will be computed in mmWaveEnbMac after getting information from PGW (QoS), UE (CQI), and system configuration, as shown in Figure 4.

The CQI report is calculated according to SINR of the receive signal level in each subband and calculate with the path loss, frequency-selective fading, and MIMO beamforming gains. CQI report sent to gNB to be translated to be Modulation and Coding Scheme (MCS) and used as a resource probability of error model calculation to decide the packet should be dropped and retransmitted by HARQ while the good packets forward up to the MAC layer. The MCS computes and gives the size of Transport Block (TB) for a subframe, and it is used by the scheduler to conduct the radio resource management.

Table 2. Parameter for mmWave MAC and PHY Configuration

Parameter Name	Default Value	Description
SubframPerFrame	10	Number of Subframe in a frame
SubframLength	100	Length of a subframe in μs
SymbolPerSubFrame	24	Number of OFDM Symbol per subframe
SymbolLength	4.16	Length of an OFDM symbol in μs
NumSubbands	72	Number of Subbands
SubbandWidth	13.89	Width of a subband in MHz
SubcarriersPerSubband	48	Number of subcarriers in each subband
CenterFreq	28	Center of carrier frequencies in GHz
NumRefScPerSymbol	864 (25% Total)	Reference subcarriers per symbol
NumDICTrlSymbols	1	Downlink control symbols per subframe
NumUICtrlSymbols	1	Uplink control symbols per subframe
GuardPeriod	4.16	Guard Period for UL-to-UL mode switching in μs
MacPhyDataLatency	2	Subframes between MAC scheduling request and scheduled subframe
PhyMacDataLatency	2	Subframes between TB reception at PHY and delivery to MAC
NumHarqProcesses	20	Number of HARQ processes for both DL and UL

*Channel model support only 28 and 73 GHz

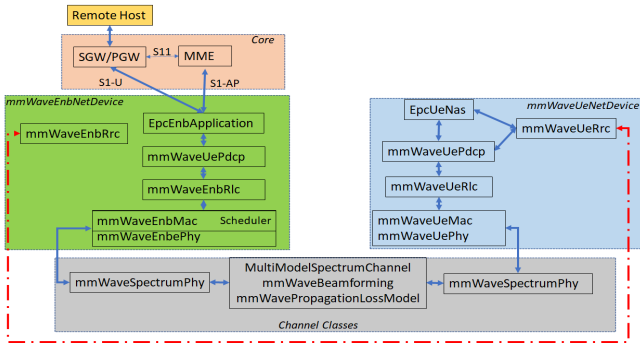


Figure 4. Block diagram end-to-end 5G scenario Remote host to mmWaveUeNetDev [11]

The parameter that was used for the simulation is based on the configuration of the Centre Technologic de Telecommunications de Catalunya (CTTC) and New York University (NYU) team, as shown in Table 2. The configurations are appropriate to perform the scenario. The experiment is conducted two test scenarios. The first scenario aims to evaluate time to start the transaction between UE and Remote Host since the inputs used by each scheduler are different. Otherwise, this scenario also will evaluate UE's performance and find out the differential for each UE. In the second scenario, as shown in Figure 3, UE will be in three different locations representing the signal condition. The aim of performing the scenario is to see the performance of each UE in a different location. Through these scenarios, there will be a suggestion that might be useful in the future to define the scheduler based on signal condition.

IV. SCHEDULER PERFORMANCE AND COMPARISON

The experiment was conducted using the scheduler type that had been provided in the source code. The data was generated every ten μs by 500 Bytes in 2 seconds. UEs were located in the same position in all experiments per scenario. Those scenarios were done using the mmWave channel. The

UEs were simulated to get a signal quality based on the mmWave channel's computation, which means that the signal quality will be affected by beamforming and propagation model computation. The UE quality might not be constant in the same location at a different time. It was caused by the matrix of model propagation and beamforming of array antennas.

A. Performance Comparison Scheduler on the Same Location

This experiment aims to evaluate the function of schedulers that will be affected by user experience when the signal condition is the same in all UE. We set 6 UEs located 30 meters from gNB. By the distance, we assumed that the UE would have a strong signal level and a good quality of the signal. The purpose of this scenario is to find out the scheduler application in a proportional state.

The result from Figures 5,6,7 shows that there is different user experience in the same quality of signal with the same number of UE. The RR scheduler in figure 5 shows that the user experiences are divided to be two. Half of UEs have very good throughput experience with an average throughput of 400 Mbps, and the other has half of the good experience with the average throughput of 200 Mbps. By this result, the throughput is not divided equally to all UEs. The resources are divided become two parts. The three UEs that were first attached got the most allocation resources and could get the maximum throughput while the other three got the remaining resources allocation. The remaining allocation resources are scheduled to UE3, UE4, and UE6 that made the throughput is not stable.

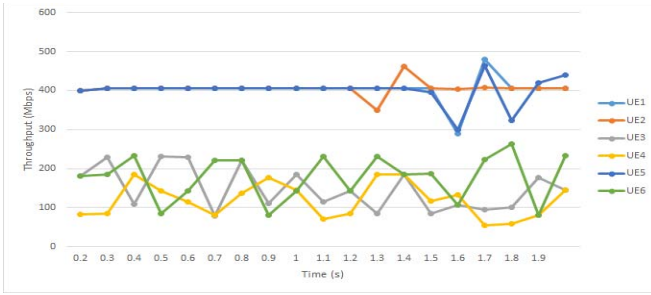


Figure 5. Throughput Using Round Robin Scheduler based on Scenario 1

The second experiment uses proportional scheduler. Figure 6 shows that the UEs have varied experiences, but there is no UE with throughput as big as RR scheduler throughput. The resources are allocated to all UEs based on portions. Since the simulation did not consider QoS for the UE, the PF scheduler's input was only based on CQI feedback from UE. Resources allocation is scheduled for all UE and given as the portion of the UE signal quality and capability. In this simulation, the PF scheduler gives UE1 and UE5 as the first attached sequence scheduling resource more stable than the other UEs. The scheduler gave the resource to the first attached UE and gave the rest to the other UEs until the resources being fully occupied, and the first attached UEs get the remaining unallocated resources to the next sequence.

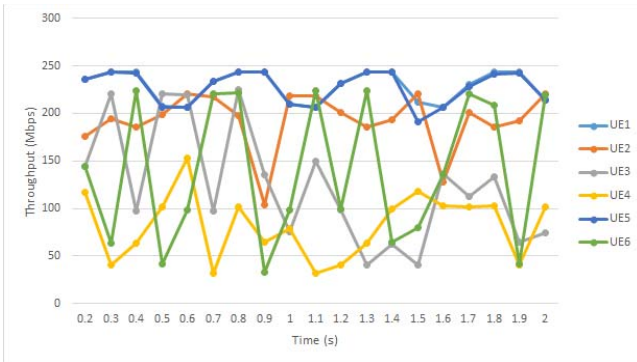


Figure 6. Throughput Using Proportional Fairness Scheduler based on Scenario 1

The result from Max Rate in figure 7 shows that the service only could be used by two UEs that first attached the mac layer. The resources are not allocated to other UEs. Otherwise, even those UEs got the resources, the number of resources is different. The first attached UE has the maximum resources, and if there are resources that were not being used, it would be allocated to the second attached UE. That would be done until all the resources being allocated. The resources would be assigned to other UE after the transaction between UE2 finish or handover due to the time set in the scheduler configuration to the remote host. The scheduler would re-compute the UE input based on its quality. All the resources would be allocated to the users to optimize cell throughput. Using this scheduler would make the cell resources to be fully occupied all the time but would make the other UE's waiting until the attached UE finish.

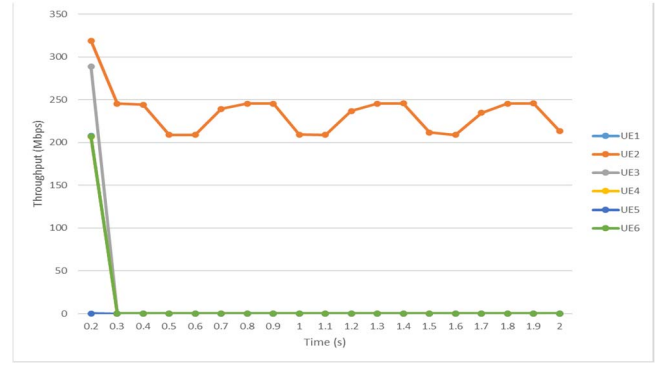


Figure 7. Throughput Using Max Rate Scheduler based on Scenario 1

B. Performance Comparison Scheduler on Different Location

In the second scenario, the location was categorized into three locations. Every location is put two UE. A strong signal is assumed the location has a great signal condition, UE1 and UE2 are located 30 meters from gNB. The medium signal assumes that the location has a middle signal condition where UE3 and UE4 are located 80 meters from gNB, and UE 5 and UE 6 are located on the weak signal, which are 160 meters from gNB.

Based on the experiment, the SINR results in line with MCS. The MCS was obtained based on the SINR calculation that was mapped to CQI. The CQI result will be mapped on the MCS table.

UEs, which had higher SINR got higher MCS, and the MCS allocate transport block size bigger due to the error probability is lower. The higher transport block size increases the packet size, and the throughput becomes higher. The RR scheduler allocated the resource equally while throughput is affected by the transport block size based on MCS calculation. In a proportional state, the throughput was divided into two parts, half is stable, and the highest throughput and the other half is the remain unused by resource allocation. By the result, one of the UE, which is far from gNB, gets higher resource allocation; however, the throughput did not get the highest throughput since the SINR is below 20 dB. Otherwise, UE with SINR greater than 20 dB could reach throughput up to 450 Mbps. Figures 8 and 9 as the result of the Round Robin Scheduler test show that the SINR for UE 1 and 2 is better than the other UEs. Since the SINR is good, the throughput experience in UE 1 and 2 are also good. The maximum throughput that could be reached by UE1 is 450 Mbps; however, the UE2 only could reach up to 250 Mbps. The throughput for UE3 could reach 350 Mbps, while UE4 could reach 300 Mbps. The throughput of UE6 could reach up to 300 Mbps with SINR 15 dB while UE5 only get SINR below 5 dB and throughput below 100 Mbps due to the resources are allocated to UE6 and affected the SINR of UE5.

The throughput for each UEs is not stable due to the throughput is defined based on the transport size portion that is given based on MCS value. The MCS mapped based on the CQI result is sent to gNB while the resources are given equally by the RR scheduler.

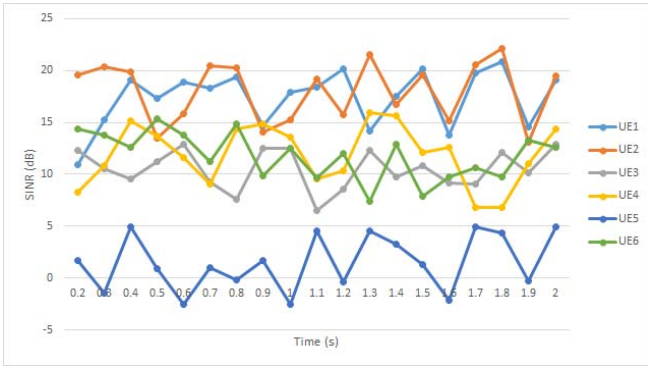


Figure 8. SINR Using Round Robin Scheduler based on Scenario 2

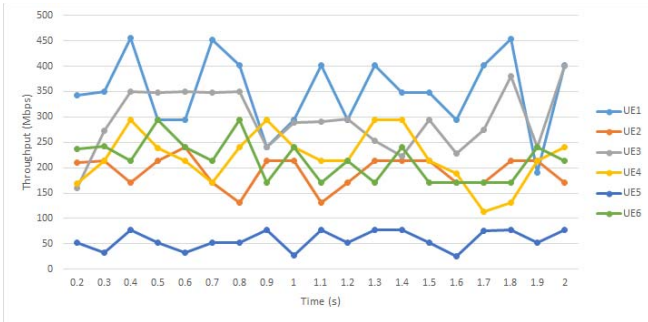


Figure 9. Throughput Using Round Robin Scheduler based on Scenario 2

In Figures 10 and 11, as the result of the Proportional Fairness test, indicates that SINR on UE 1 and 2 are more stable than SINR of UE 3 and 4, with average is almost the same. UE 5 and 6 show that the SINR is weak due to the location is far already from gNB. The SINR was mapped to the CQI to get the MCS result. The throughput for each UE in line with the SINR result. The average throughput for UE 1,2,3 and 4 almost the same, and there is no UE that has a very great experience by using the PF scheduler. All the resources are allocated based on the CQI measurement report that was sent to gNB, and then the gNB mapped the MCS to give the Transport Block size based on the quality of the signal. The TB size is affected by the throughput, while the PF scheduler also considers the portion of resources to each UE based on the quality signal received by the UE. The CQI report is sent periodically, and the TB size is not the same as the previous, and that made the throughput does not always have the same value. On the other hand, the lowest performance of SINR has a bad and unstable throughput experience. This scheduler is the representative of user experience based on the signal quality based on the measurement report.

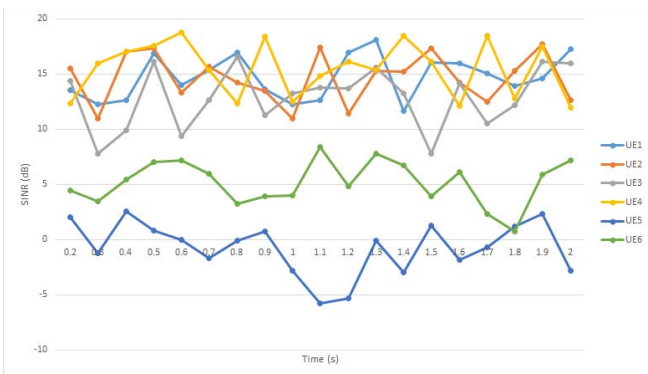


Figure 10. SINR Using Proportional Fairness Scheduler based on Scenario 2

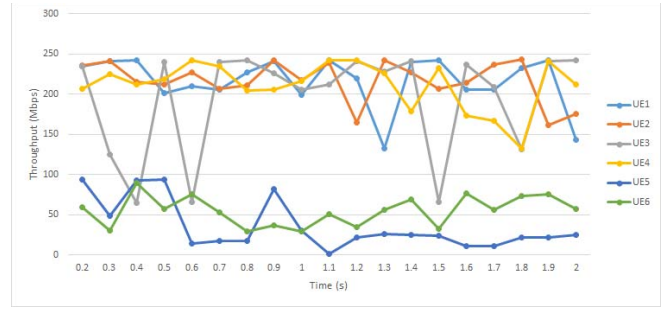


Figure 11. Throughput Using Proportional Fairness Scheduler is based on Scenario 2

Figures 12 and 13 show that the UE 1 is the only user that has resource allocation. In the first 0.1 seconds, all UEs still have resource allocation, and on the 0.4 seconds, the only UE that has resource allocation is UE 1. The maximum rate scheduler allocates the resources in the first attached UE. The first 0.1-second experiment also shows that all UE has resource allocation based on the quality signal. The resource allocation was done based on a quality signal that was taken from the measurement report. The UE with the best quality signal will have all the resources. During the interval among all UE in the cell as configured by the scheduler. In this experiment, the transaction was conducted by concurrent UEs during the simulation, so UE1 will be the only UE that does the transaction.

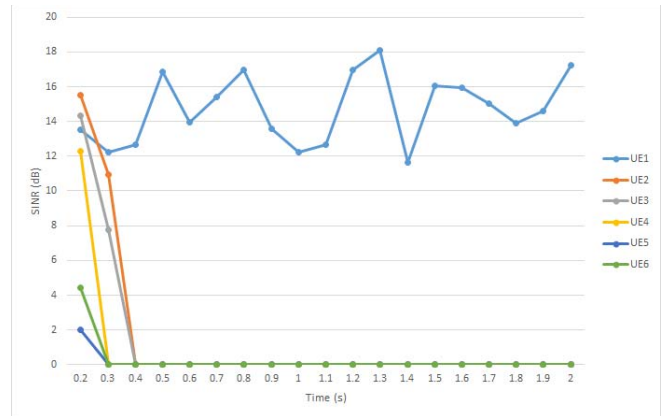


Figure 12. SINR Using Max Rate Scheduler based on Scenario 2

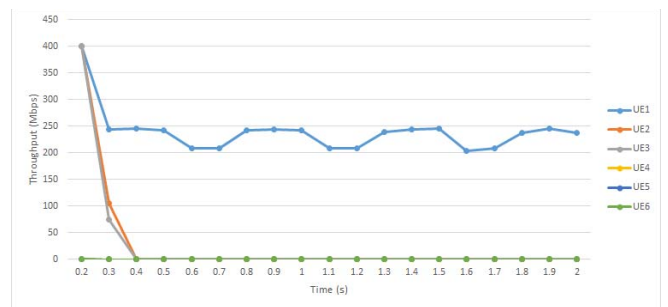


Figure 13. Throughput Using Max Rate Scheduler based on Scenario 2

V. CONCLUSION

This paper presented an overview of end-to-end 5G communication by using the mmWave module as a channel class in LTE architecture developed by CTC and NYU team. The scheduler is an important part of 5G communication that can manage resource allocation. The optimum resource allocation could make the system work maximum. Based on

the QoS function, the scheduler could be set to optimize its works depending on the QoS purpose.

Based on the simulation result, the experiment using Round Robin Scheduler in the same location divides the allocation of resources number to be two groups with maximum throughput (above 400 Mbps) and middle throughput (average 150 Mbps), and in a different location, the UEs experience is based on quality. The UE with low quality still could reach above 50 Mbps. This is different from the Proportional Fairness Scheduler. The resources were allocated to UE based on the portion. In the same location, there is no UE received a very good experience. All UE almost has a similar experience. Proportional Fairness in a different location with SINR above 10 dB achieve the throughput of 210 Mbps on average, and the average SINR of 5 dB could reach 54 Mbps. UE experience with the average SINR of 0 has unstable throughput. The UE still could reach the remote host with a throughput of 35 Mbps on average. Max Rate Scheduler shows that the resources were allocated based on the first UE attached to the best signal quality. The resources were allocated if the resources are not fully occupied with the next UE allocated. All the resources that were used kept occupied by the UE until the UE finishes to transmit or receive the data from or to the remote host. Using the same concept, UE in a different location also obtained the same experience. UE that has the best quality signal received maximum allocation resources. All the schedulers have their own purpose, depending on the target that will be achieved.

Further evaluation can be conducted using different numerology. It might be able to provide additional knowledge to the future development of 5G.

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