Performance Evaluation of Round Robin and Proportional Fair Scheduling Algorithms on 5G Millimeter Wave for Node Density Scenarios

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Abstract – Numerous imminent challenges face 5G technology, mm-Wave is a potential alternative technology for future networks. This happens because it offers greater bandwidth, multi-gigabit and low latency wireless links. With these advantages, a MAC scheduler is needed at the base station to allocate radio resources available for applications in high-speed and real-time data. The right scheduling algorithm greatly affects network performance. In our research reported in this paper, we compare round robin and proportional fair algorithm on NS3.27. We determine how the choice of the scheduler has a significant impact on network performance such as throughput, delay and fairness index. Our results show that round robin is better than proportional fair: it has better performance than proportional fair in terms of: a 3.65% throughput, 18.29% delay and 0.1% fairness index. We conclude that round robin is a better choice scheduler for voice traffic.

Keywords - Millimeter Wave, MAC layer, Scheduling Algorithm, Round robin, Proportional fair.

I. INTRODUCTION

The growth of internet users is increasing rapidly and indirectly will lead to an increase of channel capacity. Based on that, a higher frequency spectrum is required to accommodate data usage. The Millimeter wave (mm-Wave) is a wave that work at a frequency range of 30-300 GHz. It is making Millimeter wave as the central technology in 5G system because of its potential to achieved massive throughput required by the future. Nowadays, mm-Wave has become a key focus of the 3rd Generation Partnership Project (3GPP) NR1 effort and currently under development [1]. In accordance with its characteristics, research on mm-Wave generally uses the 28 GHz band, 38 GHz band, 60 GHz band, and E-band (71-76 GHz and 81-86 GHz) [2]. One of the requirements for METIS 2020, the target of E2E latency should be below 10ms, cannot be reach if still using the previous technology [3]. Therefore, to design of End-to-End (E2E) cellular systems that can fully utilizes the high-throughput, low-latency capabilities of mm-Wave network, innovation will be needed on several layers, such as the MAC layer. In [4], to support highly directional transmission, high latency, and high peak level the MAC layer was redesigned with several developments.

In the current LTE system, the transmission process sent at a fixed Transmission Time Interval (TTI) of 1ms. On TDMA scheduling, data allocation becomes inefficient for small packet.

Therefore in the study [5], a variable TTI-based TDMA structure has been proposed, also known as flexible TTI. This scheme allows for varying slot sizes and very suitable for diverse traffic. In addition, the TTI variable system also has flexibility in scheduling resources, which can handle the characteristics of various networks efficiently. The concept of flexible TDMA is a solution, considering 5G has various types of services with very diverse traffic, ranging from applications, devices and usage.

Figure. 1. Flow chart of proportional fair algorithm [7]
The scheduler has a role in the allocation of resource blocks in transmission between the users with different types [6]. The main purpose of the packet scheduler algorithm is to maximize throughput and fairness index.

Figure 1 shows the sequence of how the proportional fair algorithm works. Channel Quality Indicator (CQI) values are mapped according to the type. Then the proportional fair algorithm calculates based on the value of the average data rate and throughput in the previous matrix calculation. Then it is selected with the user who has the highest CQI value. A schedule is performed on the first user until the slot was full and continued until the next slot is available.

When managing the user priority on a resource block, this algorithm stated on m matrix and for user i on a resource block k as [8]:

\[
m_{i,k} = \frac{d_{i,k}(f)}{R_i(f)}
\]

With \( R_i(f) \) is average throughput of user i computed in sub frame f, and \( d_{i,k}(f) \) is Achievable throughput user k in m resource block and f sub frame which is a Shannon expression for the channel capacity as:

\[
d_{i,k}(f) = \log\left(1 + SNR_{i,k}(f)\right)
\]

The user’s matrix value above will be compared by another user’s matrix. User that has a bigger value will be served first.

Figure 2 shows the sequence of how the round robin algorithm works. This algorithm works by rotating the queue process. Each process has the same time allotment that is equal to time quantum (q). If this quantum time runs out, the server will handle the next process.

When managing the user priority on a resource block, this algorithm stated on metric m and for user i on a resource block k as [8]:

\[
m_{i,k} = w_i(t - t_i)
\]

Where notation on the metric (3) known as:

\( w_i \) = priority value for every service for user i
\( t \) = current time
\( t_i \) = last time when user i was served.

The user’s metric value above will be compared by another user’s metric. User that has a bigger value will be served first. If the network only has one same service then the user will be served like First Come First Served User when the user that comes first will be prioritized. Metric from this algorithm will be:

\[
m_{i,k} = \left(t - t_i\right)
\]

In this experiment, we compare scheduler algorithm between Round Robin (RR) and Proportional Fair (PF) with variable TTI multiuser cell. The purpose of this research was to analyze the effect of scheduler on network performance such as delay, throughput, and fairness index.

Furthermore, network performance using the results generated by Network Simulator 3 version 3.27 with the mm-Wave module developed by [9]. The goal of this research is to analyze the QoS parameters such as throughput, delay, and Fairness index.

II. RELATED WORK

Scheduling on cellular technology has been applied to the LTE system. Some of them propose and compare between scheduler algorithms. In [10], Mohnish Jha compared the performance of three schedulers such as Round Robin, Priority Set Scheduler and Proportional Fair scheduler by transmitting real-time voice packets with a various channel conditions of the UE for observing the performance of each scheduler using NS3.24. The simulation results show that the round robin scheduler is better compared to the other two in terms of throughput, delay and jitter at uplink as well as downlink.
Research about 5G mm-Wave can be done to evaluate cross-layer and end-to-end performance. In [9], a research has been conducted on the implementation and validation of the mm-Wave module in NS-3. They redesigned several layers because mm-Wave will require innovation not only in the physical layer, but also across all layers of the communication protocol stack to fully utilize high throughput, low latency capabilities and maximum performance.

In [5] a TTI-based design analysis was conducted and focused on flexible TTI-based designs, in terms of how well they utilized the allocated radio resources, and found that flexible frame structures exceed fixed structures in all traffic scenarios discussed, especially for small burst traffic. So it can be concluded that the flexible TTI scheme will be very suitable to be applied on mm-Wave communication.

R. Ford analyzes the benefits of variable TTI over fixed TTI on [3]. The simulation is done using ns-3 full-stack simulation model for mm-Wave cellular networks with 1 GHz bandwidth. They evaluate latency performance and found that flexible TTI has lower latency value than fixed TTI. This happens because on the fixed TTI, all subframes are allocated to one user, but for the flexible TTI, schedulers can allocate a data symbols in a subframe that matches for each user.

Several studies about scheduling on 5G networks also have been researched before. K. Gomez on research [11], provided a comparative study of a different scheduling disciplines that can be used in future 5G especially on emergency communications for public safety. In addition to proposing a new disciplinary scheduler, simulation results show that the proportional fair scheduler can be the beneficial for both cell throughput and fairness when serving an emergency communication and commercial users at the same time.

In this research, two scheduler algorithms that have been adjusted to the flexible TTI scheme in the NS3 mm-Wave module will be compared. The parameters to be analyzed are network performance in terms of throughput, delay, and fairness index.

III. RESEARCH METHOD

The simulations on this research were performed on the Network Simulator 3.27 with an additional mm-Wave module. The mm-Wave module is designed for end-to-end simulations of 3GPP style cellular networks. In general, this research will discuss about the effect of scheduler algorithms on network performance with density changes using voice traffic.

The number of packet size and data rate used in the simulation is adjusted to the characteristics of the packet size and data rate on one of the VoIP codecs G.729. Voice traffic is simulated by adding OnOffHelper. The constant packet is transmitted periodically as long as the time is ON when the user speaks. Packages are not sent during OFF time and the user stops talking. The UDP Transport Protocol was chosen because it is in accordance with the need for data transmission in VoIP communications where data delivery time is important [12].
Figure 4 shows the flowchart system. After designing the module in the NS3 environment, the simulation design is adjusted to the scenario. The scheduling algorithm is implemented and simulated alternately. Changes on the number of nodes are set gradually from 20, 40, 60, 80, and 100 nodes. If the simulation is failed, the simulation scenario design will be reconfigured. If it is successful, the output that will be analyzed are throughput, delay, and fairness index.

Throughput, defined as the effective ability of a network in sending data. Throughput is the number of packets received in bits divided by the amount of delivery time [13].

\[
\text{Throughput} = \frac{\sum \text{Rx Packet Size}}{\text{Delivery Time}}
\]  

(5)

Delay, defined as the time it takes for a package to deliver from source to the destination. The delay value starts calculated when the source starts sending packets and ends when the destination actually receives the packet.

\[
\text{Delay} = \frac{\text{Trx} - \text{Tx}}{\sum \text{Rx}}
\]  

(6)

Where notation on the formula (6) known as:

\[\text{Trx} = \text{Time of received packet on destination} \]
\[\text{Tx} = \text{Time of packet send on source} \]
\[\sum \text{Rx} = \text{Received packet} \]

Fairness Index, defined as the level of fairness of scheduling algorithms in schedule packages and allocation of resources to be sent. The theory and formula regarding the fairness index was revealed by [14]. Metrics of the formula are known as Jain's Fairness Index. Maximum value of this metrics is 1, where it indicates perfect fairness among the users in the system.

\[
f(x) = \left(\frac{\sum_{i=1}^{n} x_i}{\left(\sum_{i=1}^{n} x_i^2\right)^{1/2}}\right)^2
\]  

(7)

Where notation on the formula (7) known as:

\[f(x) = \text{fairness index} \]
\[n = \text{number of user} \]
\[x = \text{Throughput user i} \]

IV. RESULT AND ANALYSIS

After simulating voice and video traffic from the 5G mm-Wave network in NS3, we obtained performance results such as throughput, delay and fairness index, then be analyzed. The analysis divided into two parts for voice and video traffic to find out which better scheduler for the two services.

A. Delay Evaluation

Figure 5 shows the effect when increasing the number of users to the delay obtained from the voice traffic simulation. The lowest delay in round robin occurred on 20 UE with 1.023ms, for proportional fair lowest delay occurred on 20
UE with 1.285ms. On 100 UE, round robin and proportional fair generating the highest delay with 1.321ms and 1.755ms.

Average delay obtained from round robin is 1.215ms. This is 18.29 % lower than proportional fair with average delay of 1.487ms. Based on figure 5, it can be conclude that delay for both scheduler increase, due to increase of number of UE make waiting time for each users to be served is getting longer.

Round Robin has a better delay because for small packages, users queuing don’t to take long time, different with Proportional fair which must take consider the channel quality.

Proportional fair has higher delay because this algorithm is considering the Channel Quality Indicator (CQI) value when deciding its algorithm matrix. In this case, UE has a different channel condition, and on the other side this algorithm has to serve all UE while maintaining its fairness so the delivery took a longer time.

B. Throughput Evaluation

Figure 6 shows effect the when increasing the number of users to the throughput obtained from the voice simulation. It show that the increase number of users, throughput decreased due to the bandwidth capacity will be shared with all users.

Round robin gets average throughput of 0.137 Mbps. This is 3.65 % better than proportional fair with average throughput of 0.132 Mbps. The lowest throughput in proportional fair occurred on 100 UE with 0.131 Mbps, and for round robin occurred on 100 UE with 0.132 Mbps.

Round robin has a higher throughput because this algorithm not consider the channel condition and has main purpose to balance between throughput and fairness among all the users. The proportional fair’s delay has higher delay, that makes the packet received is less than round robin.

C. Fairness Index Evaluation

Figure 7 shows the effect when increasing the number of users to fairness index in each scheduling algorithm for voice simulation. The average of fairness index obtained from the simulation of adding the number of users to the proportional fair algorithm is 0.994. It is lower than the round robin’s fairness index that has 0.995. The value obtained by the round robin algorithm is greater because this algorithm does not consider channel conditions so that it offers a higher fairness value.

![Fairness Index on change number of users for voice traffic](image)

Round robin and proportional fair have a decreasing fairness index value against the increase in the number of users. This happened because of the increasing number of users, more users were served which reduced the value of fairness. Both schedulers show fairness due to the fairness index being close to 1.

V. CONCLUSION

In this paper, our work focused on scheduling in a 5G mm-Wave network with a new MAC layer structure that was proposed in previous studies. Based on simulation results, the choice of scheduling algorithm has an effect on network performance. Evaluating the use of a scheduler, on a flexible TTI scheme applied to a 5G mm-Wave network using VoIP traffic, shows that the round robin algorithm is better in terms of throughput, delay and fairness index than the proportional fair algorithm. For the delay, Round Robin algorithm obtained 1.215ms on average. This is 18.29% lower than proportional fair average delay with 1.487ms. For throughput, Round Robin algorithm obtained 0.137 Mbps on average. It is 3.65% better than the proportional fair’s throughput which has 0.132 Mbps. For fairness index Proportional fair algorithm obtained 0.994 on average, and round robin has 0.995. Both schedulers show fairness due to the fairness index close to 1.

REFERENCES


