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Research Article

Opportunistic Scheduling Algorithms In 5G/6G

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ABSTRACT

Wireless networks have experienced rapid growth in recent years, which evaluates the importance of scheduling algorithms in the development and optimization of wireless networks. Opportunistic scheduling algorithms take channel condition as one of the factors when transmitting packets. The number of bytes which can be carried within a time or physical slot is determined by the channel condition which significantly impacts the throughput of wireless networks. This study aims to focus on the uplink and downlink schedulers and channel conditions which contribute to optimizing resources utilization, enhancing network throughput, and minimizing delays in network communication. In addition, this study also aims to compare and analyze existing scheduling algorithms and their impact on network throughput. In this paper, several existing opportunistic scheduling algorithms in 5G will be compared.
Index Terms–5G/6G, Opportunistic Scheduling algorithms, Quality of Service, Wireless Network

1. INTRODUCTION

The rapid development of cloud and online services has immensely increased the wireless cellular network's QoS demand. 4th Generation Broadband Cellular Network (4G) was introduced to overcome the shortcoming of 3rd Generation Wireless Cellular Network (3G). The Multiple Input and Multiple Output (MIMO), for example, allows multiple data to simultaneously transfer between the transmitters and receivers. The 4G is classified as a huge improvement from its predecessor 3G. In 2016, the 5th Generation Broadband Cellular Network (5G) was introduced by the 3rd Generation Partnership Project (3GPP) which significantly improved user experience of web browsing, and the quality of video and voice calls. Due to the increasingly high demand of the 4G, it causes several issues such as the possibility of increase the blocking rate or dropping rate due to the high traffic during peak hour. The QoS mechanism was then introduced to measure the overall performance of the network services in order to fulfill the networks standard requirements as predefined for each type of broadband cellular network.

While wireless network continues to evolve, the sixth-generation wireless network, or known as 6G is introduced and yet functional. 6G network is under extraordinary development with a promising factor which is to outperform its predecessor. The promising key factors are lower latency, higher reliability, increment in network capacity and enhancing overall performance. With the promising factors being said, it is expected that 6G wireless network will have the potential in enhancing the experience in our daily lives and leveraging the interest in researchers for upcoming evolutionary of technologies.

However, each wireless network generation will encounter challenges which is related to resource allocation. Resource allocation is also related to the development of scheduling algorithms for each of the wireless networks. Opportunistic scheduling is the scheduling algorithm that will be taken for a further discussion in this project.

Opportunistic scheduling is the factor which is the limitation of optimizing wireless network. It considers the channel condition as one of the crucial factors in transmitting packets. The number of bytes which can be carried in a time is determined by the channel condition in wireless network. As a result, the condition of the channel could be the potential factor which affects the performance of a wireless network. Hence, the uplink and downlink scheduler in wireless network will be the focus of this project.

As the functional realization of 6G network is still under development, the scheduling algorithms acts as a crucial role in outcoming the limitations for wireless networks to evolve. Hence, exploring opportunistic scheduling algorithm and comparing with other scheduling algorithms will be the main discussion onwards in this project.

The paper is written such that in Section 2, a brief overview of previous works is provided. In Section 3, the simulation tool used for the simulation of 5G networkis explored. Section 4 gives a simulation outcome of the simulated result. The comparison between several opportunistic scheduling algorithms are given in Section 5. The final section concludes the differences between the opportunistic scheduling algorithm simulated in the same environment.

2. Literature Review

Nguyen et al. (2020) has proposed scheduling algorithms which are conducted to resolve the problems related to scheduling for heterogeneous service in 5G networks. The first algorithm that Nguyen et al. (2020) proposed is Resource Partitioning Based Algorithm (RPA) and its objective is to divide the resources and users into different groups and improve the resource allocation with the groups that have been divided. The second algorithm that Nguyen et al. (2020) proposed is Iterative Greedy Algorithm (IGA) which it is used to assign resources to users according to the weight of the assignment such as the amount of data that is spread and the latency of the physical resource block which is assigned. Li et al. (2021) conducted research on the two scheduling algorithms which are Resource Block (RB) reservation algorithm and a scheduling algorithm which is related to Quality of Service for 5G network slicing. A new algorithm is proposed from the RB reservation algorithm which differentiates the resource ratio into dedicated, priority and maximum to multiple slice groups. The resource ratio of resource block is the lowest resource ratio that is allocated to different slice groups while the maximum resource ratio of resource blockis the maximum radio allocated by the network to the slice group. The prioritized RB resource ratio is the prioritized radio resource ratio apportioned to different slice groups. The second algorithm which is taken into research is QoS algorithm. Instead of reserving resources for individual slices, spectrum resources are shared for different slice services in a differentiated manner with the configuration of target rates. As 5G experiences explosive growth in traffic volumes, the demand for diverse Quality of Service (QoS) standards has become irresistible. In this study, Salman et al. (2021) has proposed a hybrid scheduling scheme which is the combination of co-existence and non co-existenceover resource blocks for extending the full potential of connectivity to meet the requirements such as latency and reliability of multi-user equipments (MUEs). Besides, there are two multi-user scheduling algorithms that have been proposed which is check requirements before scheduling (CRBS) and check requirements after scheduling (CRAS). The CBRS is to form groups of users according to the channel conditions and reliability requirements while CRAS is separate users into two groups which are having either strong or poor channel condition. Proportional Fair (PF) is one of the scheduling techniques that has been used in existing 5G networks. In this study, L. Li et al. (2021) has proposed a new scheduling algorithm which aims to improve the existing PF algorithm in case of performance and network throughput. The newly proposed algorithm allocates ratio resource by taking the quality of the channel, average transmission rate and packet transfer delay into consideration and maximizes the network throughput while also ensures the fairness among scheduled User Equipments (UEs) in a short amount of time. Al-Ali et al., (2020) proposed a dynamic approach which applied on heuristic scheduling algorithms and its objective is to achieve optimizations in uRLLC traffic while maximising the throughput of User Equipment and maintaining fairness of resources among UE. The proposed approach also aims to emphasize the effectiveness of heuristic algorithms by dividing the schedulers according to the condition of channel and QoS requirements when the process of resource allocation is performed. It also lowers the effect caused by uRLLC traffic in data rate, efficiency, and fairness.Karimi et al. (2019) has proposed a novel resource allocation algorithm which takes the network traffic, latency, and the channel control into consideration. The algorithm that Karimi et al. (2019) proposed aims to emphasize the performance of network traffic by enhancing network capacity while ensuring that the requirements of latency, reliability and throughput are achieved. In addition, the proposed algorithm prioritizes the scheduling for uRLLC and schedules the traffic more efficiently with the remaining resources. The benefits of frequency-selective multi-user scheduling is obtained through the proposed algorithm and unnecessary portioning of uRLLC payloads on numerous transmissions are also avoided.The overall experience for end-users in networks is always one of the concerns when developing wireless networks. Gatti et al. (2022) proposed a scheduling algorithm based on utility resources which is used to optimize cell boundaries in resource schedulingfor heterogeneous 5G wireless networks. The users in the cell boundaries are divided into two groups and based on cell centre users (CCUs) and cell end users (CEUs). There is a problem stated in the study is the need for efficient resource allocation between different cells. Hence, the objective of the proposed algorithm is to ensure that the requirements of Quality of Service (QoS) have been met in User

Equipments (UEs) while remaining minimum delays for the CEUs. URSA also provides improvement in network throughput, proportional fair, and efficiency in 5G networks.Nomeir et al. (2021) proposed an algorithm which aims to provide improved outcome to solve the problems of scheduling relatedto real-time. Near-optimal outcome is to balance the Quality of Service (QoS) requirements regarding different types of traffic. The proposed algorithm also maximizes the rate of traffic while achieving the requirements of uRLLC devices in reliability and delay and the minimal rate guaranteed for every user in eMBB remained.Bag et al. (2019)came up with a dynamic resource allocation scheme which adopts multi numerologies and Shortened Transmission Tune Interval (TTI) to reduce the latency in schedulingfor 5G New Radio (NR) network. The proposed scheme aims to show improvements in latency for scheduling among high priority requests. Scheduling latency is the time it takes to assign resources to a user, and while reducing it further emphasized the performance in retransmissions and round-trip times. In addition, the proposed scheme aims to provide better reinforcements and services in the reduced delay application in 5G networks compared to LTE networks. The proposed algorithm also avoids direct control of Inter-Numerology Interference (INI).Rasied et al. (2023) proposed a modification in packet scheduling algorithm which Modified version of Maximum-Largest Weight Delay First (M-MLWDF). The proposed modification of packet scheduling algorithm aims to provide support on more users with greater efficiency in 5G network. The proposed algorithm adapted the five packet scheduling algorithms which are Max-Rate (MR), Proportional Fairness (PF), Round Robin (RR), Maximum-Largest Weighted Delay First (MLWDF) and Exponential- Maximum-Largest Weighted Delay First (EXP-MLWDF). The adaptation of algorithms to the proposed algorithm allows better reinforcementin the QoS of uRLLC and eMBB requirements. Rasied et al. (2023) conducted experiment with different packet scheduling algorithms and with Modified-MLWDF having the most number of users which satisfied the uRLLC Packet Loss Ratio (PLR) approach. Besides, the proposed modification is expected to benefit users to receiving better mobile multimedia services.Karimi et al. (2018) proposed two l algorithms for emphasizing the performance of 5G network. The first algorithm that Karimi et al. (2018) proposed is it schedules through a cell with the highest channel state information (CSI) and provides the available numbers of cells within the physical resource block. The second algorithm is to enable segmentation across cells with the quantity of remaining PRB after executing the first algorithm which Karimi et al. (2018) proposed. This ensures the conditions of the segmentations are achieved and allows the effectiveness of transmission in uRLLC payloads across 5G networks. Furthermore, Karimi et al. (2018) also conducted experiments between the proposed algorithm and traditional distributed solution and it has a 60% higher latency performance compared to traditional distributed solutions.The paper discusses the importance and the challenges of low latency in 5G networks. Hadar et al. (2018) mentioned that the combination of beamforming and scheduling can further improve the performance of multi-user Muti-Input and Multi-Output (MIMO) systems. Furthermore, Hadar et al. (2018) proposed a scheduling algorithm which is Maximal Utility with Dropping (MUD) algorithm. MUD algorithm which is the proposed algorithm, takes the priority and deadlines of the data packet when user is allocated to resource blocks and spatial beams. The proposed algorithm is used to achieve maximal rewards by scheduling packet transmission and the usage of resource elements.Husain et al. (2020) came up with a scheduling algorithm which is designed for 5G network, which is crucial for 5G and beyond networks. Husain et al. (2020) proposed a scheduling algorithm wchihighlights the packet basedon the weighted delay metric, focusing on enhancing the latency and reliability in downlink data transmission. The paper firstly introduces the proposed scheduling algorithm, then compares it with existing scheduling algorithms and Exponential Proportional Fair scheduling algorithm. The proposed scheduling algorithm focuses on some key metrics such as packet drop probability, delay and user throughput. The proposed algorithm enhanced the PF metric, taking the packet in the queue of delay as one of the considerations. The paper also indicates the importance of efficient scheduling mechanisms for developing and improving URLLC in future works.

3. Methodology

3.1. Network Simulation Tools

Network simulator is a software tool that allows researchers to perform tasks such as modelling, simulation, and analysis of networks. Researchers could observe the behaviour of different network components, conduct study between different elements and evaluate the performance of networking protocols, algorithms, and application. Network simulators are widely used in not only industries, but also in education for various purposes such as research, development of network applications, algorithms, or protocols, and education.

There are two favored network simulation tools which are Network Simulator 2 (NS-2) and Network Simulator 3 (NS-3) which are used in various purposes such as academic and research purposes. Both simulators allow researchers to perform simulations on different networking scenarios in a virtual and replicable environment.

Network Simulator 3, which is known as NS-3, is an open-source network simulation tool and a discrete event network simulator which will be the tool for simulation in this project. Networking experiments usually require a few devices such as computers and routers if it is a real-world experiment, and the cost would be expensive to build a network with the number of devices for experiment purposes. The use of Network Simulator 3 can eliminate the drawbacks of building a real-world network to simulate any network experiments.

Conducting network simulation with NS-3 requires several steps which includes setting up the simulation environment, defining the simulation scenario, clarifying the simulation parameters, running simulations, and analyzing the results such as performance metrics. The efficiency and throughput of the network algorithm, protocol and application can be evaluated after performing network simulation and the result could be used for comparison with the performance of other similar algorithms, protocols, and applications.

PointToPoint, Wireless, Carrier Sense Multiple Access (CSMA) and connections between nodes could be created with the use of NS-3. A Point-to-Point connection resembles a Local Area Network (LAN) established between two computers. A Wireless connection is comparable to a WiFi link connecting multiple computers and routers. CSMA connection is like a bus topology which links between computers while establishing the connections. In addition, the next step involves installing Network Interface Cards (NIC) on each node to authorize the network connectivity.

The languages which are used for NS-3 are C++ and Python. The use of C++ is to implement network simulation models. NS-3 also uses Python which allows user to interact and control the simulation environment by using Python scripts. The C++ is wrapped by the interface of python which provides a more user-friendly interface for the users to work with NS-3.

3.2. Simulation parameters

Parameters	**Value**
Application type	Streaming Application
Packet generation interval	Random
Simulation time	20 seconds
AMC mode	Piro
Bandwidth	5 MHz
Cell radius	1.5 km
Transmission power (eNB)	30dB
Transmission power (UE)	20dB

Table 1: Simulation parameters

Husain et al. (2020) conducted an LTE Downlink Transmission Simulation with the parameters above. The simulation consists of one eNB which is the base station, 1 packet data network gateway (PGW) with default evolved packet core (EPC) point to point link with eNB, 2 remote host as the servers to generate the data packets to the UEs through the PGW and a number of UE starting from 50 to 100 in an interval of 10. The first simulation parameter is the application type that is used in the simulation which is streaming application. Next, the second simulation parameter is the packet generation interval, known as the packet generation time for UE, is randomly generated. The total simulation time is 20 seconds which is running the simulated network in 20 seconds.

The total simulation time of 20 seconds was chosen to provide a sufficient duration for capturing the data that are transmitted of the LTE downlink transmission while maintaining computational efficiency. A 20-second timeframe allows the system to reach a quasi-steady state where meaningful performance metrics such as throughput, latency, and packet loss can be measured effectively. Longer simulation times could provide more data but would significantly increase the computational resources and time required for the simulation, while shorter times might not capture enough data to be representative of the network's performance. Therefore, 20 seconds is a balanced choice to achieve reliable results within a reasonable simulation duration.

The AMC mode used in the LTE simulation conducted by Husain et al. (2020) is Piro which is on default. The bandwidth for the eNB Network device in Downlink is set to 5MHz while the transmission power for the enB is 30dB. The UE, which is known as the User Equipment, is set to 20 dB for transmission power. The flow for the simulation is there are 2 remote hosts that generate the data packet with random time interval and transmit the generated packet to the packet gateway. The packet gateway then transfers the received to eNB. Finally, the eNB performs radio resource scheduling while attaching the UE to the eNB to transmit packets.

3.3. Proportional Fair Scheduling algorithm

The first scheduling algorithm will be discussed in proportional fair (PF) algorithm. The key characteristics of the PF used in LTE network is it aims for maximizing the system throughput and ensuring fairness among users. PF algorithm prioritizes user that has a good condition of channel to maximize its potential throughput. Besides, it also ensures that the resources are shared equally over time, while also prevents users that are having poor channel condition from sharing the resources. The equation of PF scheduling algorithm is written below.

$$S_{i,t}^{PF} = S_{i,t}^{MR} \cdot S_{i,t}^{BET} = argmax \left\{ r_i(t) \cdot \frac{1}{R_i(t)} \right\}$$

3.4. Round Robin Scheduling algorithm

The Round Robin (RR) scheduling algorithm is one of the simplest scheduling algorithm among the other scheduling algorithm that existed for LTE simulation. The key characteristics of RR used in LTE network is it targets simplicity, fairness and time quantum. RR ensures that each user in the network get an equal share of the resources available. Besides, RR scheduling algorithm is simple since it cycles through all the users in a fixed and repetitive order. Lastly, the time quantum of RR is a fixed period which allows user to utilize the allocated resources. After the period ends, it continues to the next user in the list.

3.5. Maximum throughput scheduling (MT)algorithm

The MT scheduling algorithm is a resource allocation algorithm that is widely used in LTE network. The aim for MT scheduling algorithm is maximizing the overall throughput of the network with prioritizing users with the best channel conditions. Although MT algorithm can maximize the potential throughput, it cannot ensure the fairness of each user which are sharing the resource. The user that are having poor channel condition will be neglected by the MT scheduling algorithm. The equation for MT scheduling algorithm in achievable rate is shown below.

$$R_i(k,t) = \frac{S(M_{i,k}(t), 1)}{\tau}$$

Firstly, the i and j in the equation represents the generic users. The t in the equation is the subframe index, k is resource block index and $M_{i,k}$ is the MCS that are usable by the users in i on resource block k as subframe t. Lastly $S(M,B)$ represents the transport block size as in bits.

The τ represents the TTI duration. At the beginning of each subframe, a certain number of users are assigned to a resource block. In short, the index $\hat{\imath}_k(t)$ to which resource block is assigned at time t can be the equation below.

$$\hat{\imath}_k(t) = argmax\ (R_j(k,t))$$

4. RESULTS AND DISCUSSION

With the scheduling algorithms being discussed, the result of simulation is now discussed. The first result that will be taken into discussion is the total system throughput. The parametersare taken from the parameters stated in Section 4 which is provided by Husain et al. (2020). The result of the simulation in system throughput over number of UEs is shown in the chart below.

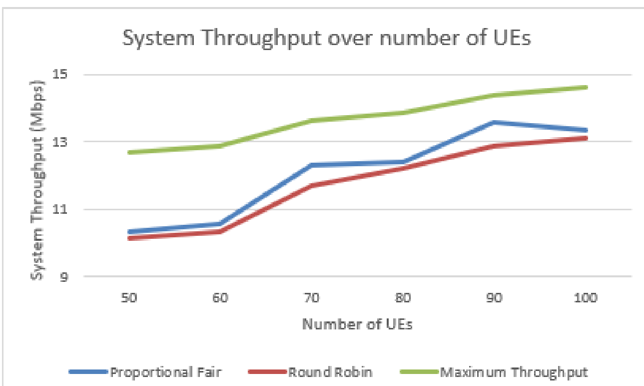

Figure 1: System Throughput

The simulation has gone through the UEs starting from 50 to 100. Throughout the observation from the chart above, it is observed that Maximum throughput has the highest system throughput, which is approximately 15Mbps, compared to the other two scheduling algorithms which are PF and RR scheduling algorithm. The reason that MT has the highest system throughput is that it prioritizes the users that have good channel conditions to maximize the overall throughput. The second highest scheduling algorithm that comes after MT scheduling algorithm is Proportional Fair scheduling algorithm. PF scheduling algorithm compared to RR scheduling algorithm; PF scheduling algorithm maximizes the system throughput while ensuring that the user have an equal share among the resources. The last algorithm that has the lowest system throughput is Round Robin scheduling algorithm. Since RR scheduling algorithm is rather simple compared to PF, the throughput between PF and RR are quite similar. At the number of 100 UEs, maximum throughput scheduling algorithm has the highest throughput which is higher than PF and RR, which is approximately 1Mbps higher.

The next result that is taken in discussion is the packet delivery ratio. The packet delivery ratio is the ratio of packet received by UE that is generated from remote hosts. The average delivery ratio is calculated and generate to a chart shown in the figure below:

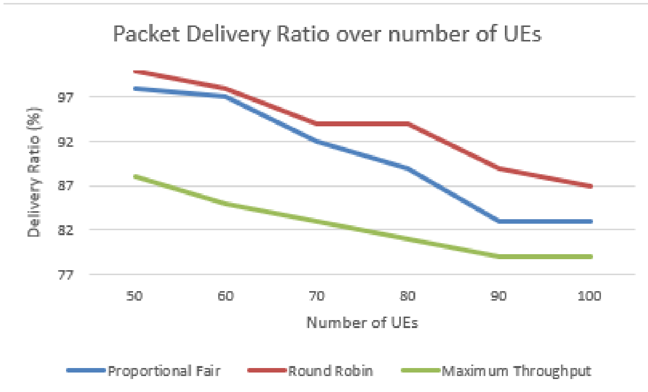

Figure 2: Packet Delivery Ratio (%)

With the chart shown above, the MT scheduling algorithm has the lowest packet delivery ratio, which is approximately around 79% but has the highest system throughput. This is because MT scheduling algorithm priorities maximum throughput but does not ensure the UEs that are having poor channel condition willreceive the packet generated from the remote host. The second algorithm is the PF algorithm. The PF algorithm has a relatively high packet delivery ratio which is around 98% approximately at the number of 50 UEs. As the number of UE increases, the packet delivery ratio drops. The reason behind the low packet delivery ratio as the number of UE increases could be limited resources, network congestion, interference and so on. At a number of 100, the packet delivery ratio for PF is around 83%. The last scheduling algorithm is RR algorithm. The round robin algorithm has a similar packet delivery ratio with PF algorithm but slightly higher. At the number of 50 UEs, the RR algorithm has approximately 100% packet delivery ratio which means all of the UE are sharing the resource equally. As the number of UE increases, the packet delivery ratio drops. At the number of 100 UEs, the RR algorithm has approximately 87% of packet delivery ratio, which is also slightly higher, approximately 4% compared to PF algorithm.

5. Conclusion

This paper summarizes the differences between opportunistic scheduling algorithms in 5G networks by evaluating their total system throughput and packet delivery ratio in downlink simulations. Three scheduling algorithms have demonstrated their significant characteristics in different simulations. It is notably important that each scheduling algorithm can be used in different scenarios. The results from the simulations indicate that each scheduling algorithm is best suited for specific scenarios. For example, Proportional Fair is better in environments where a balance between fairness and throughput is required. Maximum Throughput excels in scenarios where maximizing overall system performance is the priority, and Round Robin is ideal in situations where fairness among users is required. This paper also aims to contribute to the field of wireless networks and scheduling algorithms by providing insights that support future enhancements in the performance and capabilities of 5G/6G wireless networks. The NS3 simulator is utilized to obtain comparable results. For future work, scheduling algorithms could be designed and implemented to enhance the overall QoS and network throughput for future generations of networks.

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