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# Performance Analysis of C-V2X Resource Allocation in an Urban Vehicular Network

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**ABSTRACT**

This paper discusses the performance of a Cellular-Vehicle to Everything (C-V2X) in an urban vehicular network focusing on the Fifth Generation New Radio (5G NR). Urban areas with high volume of vehicles not only cause traffic jams and accidents but also affect the C-V2X communication. It requires a lot of resources and sometimes causes problems if resources are not well allocated. Limited resources need to be allocated efficiently to meet different needs and avoid congestion such as, Quality of Service (QoS), latency, and data rates. The main goal of this paper is to investigate the performance of C-V2X schedulers in the vehicular network. The objectives include developing a model of C-V2X network that includes Resource Allocation (RA) schedulers, assessing the schedulers in the model, and validating the performance of the RA schedulers. The system-level simulator has been deployed to evaluate the performance of the C-V2X communication with different schedulers for RA. The performance was analysed in terms of throughput and delay which were studied through simulation work conducted using OMNET++ with Simu5G framework. The results show that Deficit Round Robin (DRR) is better than Maximum Carrier to Interference Ratio (MAXCI) and Proportional Fair (PF) with 1.345% throughput and 0.033% delay. Therefore, it can be concluded that DRR scheduler has the best performance in terms of throughput and delay for VoIP traffic.

***Keywords:***
5G NR; C-V2X; OMNET++; resource allocation; schedulers; Simu5G

## 1. Introduction

Cellular-based Vehicle to Everything (C-V2X) communications have become more popular because of recent improvements in mobile network technology which was intended to work with the New Radio (5G NR). It is based on the 3GPP New Radio (NR) standard and be brought in gradually that coexist with the existing 4G (LTE/LTEAdvanced) infrastructure for an extended period of time [1]. The use cases for Cellular V2X (C-V2X) communications in the context of 5G include those outlined in 3GPP, such as advanced driving scenarios. These involve applications like ranging or positioning,

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extended sensors, vehicle platooning, and remote driving [2]. Using V2X technology, any automobile may connect with a range of communication entities, such as pedestrians, Road Side Unit (RSU)s, satellites, the internet or cloud, and other vehicles. C-V2X technology enables communication across conventional Up Link and Down Link (UL/DL) interfaces in addition to direct communication over the Side Link (SL) channel [3]. The development of effective and Intelligent Transportation Systems (ITSs), and ultimately safer, greener, and more efficient modes of transportation and smarter roads, resulted in the development of C-V2X [4]. In urban areas, the availability of 5G poses a revolutionary opportunity for urban mobility, allowing cities to modernize and make their transport systems more efficient. With access to 5G, cities will increase their ability to improve public transport operations and planning, even introducing dynamic transport planning—potentially reducing traffic congestion or reallocating space for cyclists and pedestrians.

There are several challenges of Resource Allocation (RA) in 5G C-V2X communication. The swift growth of urban areas has led to an increase in the volume of automotive traffic leading into and away from major cities. As a result, huge socioeconomic issues are caused by the fact that roads and highways in urban areas are plagued by both traffic congestion and road accidents. The high mobility and density of vehicle users in C-V2X communications may lead to additional signalling costs if resources are allocated centrally, while resource collisions caused by unilaterally incorrect judgments by User Equipment (UE)s could occur if resources are allocated randomly [5]. The purpose of this work is to develop the urban C-V2X network model, assessing the schedulers in the model, and validating the performance of the RA schedulers.

## 2. Related Work

Numerous research and development works conducted addressing the issues of network configuration. A study by Ramesh *et al.,* [6] provided an overview of RA techniques for cellular-based vehicle networks and its challenges and potential benefits of allocating resources in today's vehicle networks. They highlight that C-V2X has gained a lot of interest due to its wide coverage, high capacity, high quality of service, and multicast/broadcast capability. The study discussed the key element of 5G and future communication systems which is the ability to accommodate a wide range of vertical applications and use cases. The authors stated that the challenge is to efficiently construct a network that guarantees quality of service for C-V2X while also meeting the data needs of other vertical applications. Another study by Nardini *et al.,* [7] showed how the choice of the scheduler affects network performance, such as throughput, latency and fairness index, in a substantial manner. It is found in their study that Round-Robin (RR) outperforms Proportional Fair (PF) in terms of throughput, latency, and fairness index. Therefore, it is concluded that RR scheduling is the best option for voice traffic.

Md Zain *et al.,* [8] compared the performance of several scheduling algorithms in an LTE cellular network. Their findings show that rather than maximizing system capacity without respect for user fairness, Max throughput and Best Channel Quality Indicator (CQI) are used to maximize system capacity. In addition, it has been discovered that the proportional fairness algorithm degrades both system fairness and throughput. McCarthy *et al.,* [9] presented a new scheduling method that considers a trade-off between throughput and user fairness by merging the metrics of the Best CQI and PF schedulers. The authors have improved the performance of the PF scheduler by employing novel averaging approaches, notably median, range, and geometric mean, for calculating the average throughput, which is then utilized to establish the scheduling priority. The results demonstrated that the performance of the proposed scheduler with the new averaging methods in PF is superior to that of other schedulers.

Nsiri *et al.,* [10] presented a performance analysis of three scheduling algorithms in the Long-Term Evolution-Advanced downlink transmission system for an urban macro cell scenario using a realistic channel model. The evaluation is based on throughput, frame delay of Voice over Internet Protocol (VoIP) using simulations run on an OMNET++ simulator. The results show that the maximum carrier to interference ratio scheme provides the highest value of throughput and mean opinion score index among all schemes evaluated in the network scenario. Aji *et al.,* [11] conducted a comparison between the RR and PF schedulers within the NS3 simulator, specifically focusing on the 5G network realm. Remarkably, the findings showcased that the RR algorithm outperformed the PF algorithm across key metrics such as throughput, delay, and fairness index.

Barbecho Bautista *et al.,* [12] compared the performance of downlink transmission scheduling algorithms including RR, PF, Best CQI, and Maximum throughput in LTE cellular networks. These algorithms approaches may be evaluated for their fairness and throughput. The RR scheduler does not consider system throughput because it prioritizes fairness for all users. Rather than maximizing system capacity without respect for user fairness, Max throughput and Best CQI are used to maximize system capacity. In addition, it has been discovered that the PF algorithm degrades both system fairness and throughput.

The previous research in [13-15] have dealt with the performance of RA algorithms. However, they do not properly address issues and that develop in urban vehicle networks. Numerous vehicles and other obstructions can have a significant negative impact on the reliability and quality of communication in such networks. In this work, three schedulers will be analysed which are DRR, MAXCI, and PF in the urban vehicular network.

The rest of the paper is organized as follows. Section 3 describes the methodology on the analysis of RA schedulers using discrete event simulator called OMNET++ with Simu5G module to simulate 5G NR environment. Section 4 explores the simulation study and finally, Section 5 concludes the paper.

## 3. Methodology

### *3.1 Simulation Model*

The scenario of the C-V2X network is modelled using OMNet++ simulator that comprises of numerous modules with Simu5G. The system-level simulator has been created in order to inspect the performance of the C-V2X communication for performance evaluation. A based configuration has been defined where the design parameters were modified across different scenarios during the simulation. The design parameters that varied is the number of vehicles. The performance parameters that were observed are throughput and delay.

The flowchart of the performance analysis of the resource allocation is depicted in Figure 1. It starts with the development of network topology and the configurations of simulation parameter. Three different algorithms were examined known as DRR, MAXCI and PF. The results of the simulation were analysed to identify the throughput and delay of each scheduler.

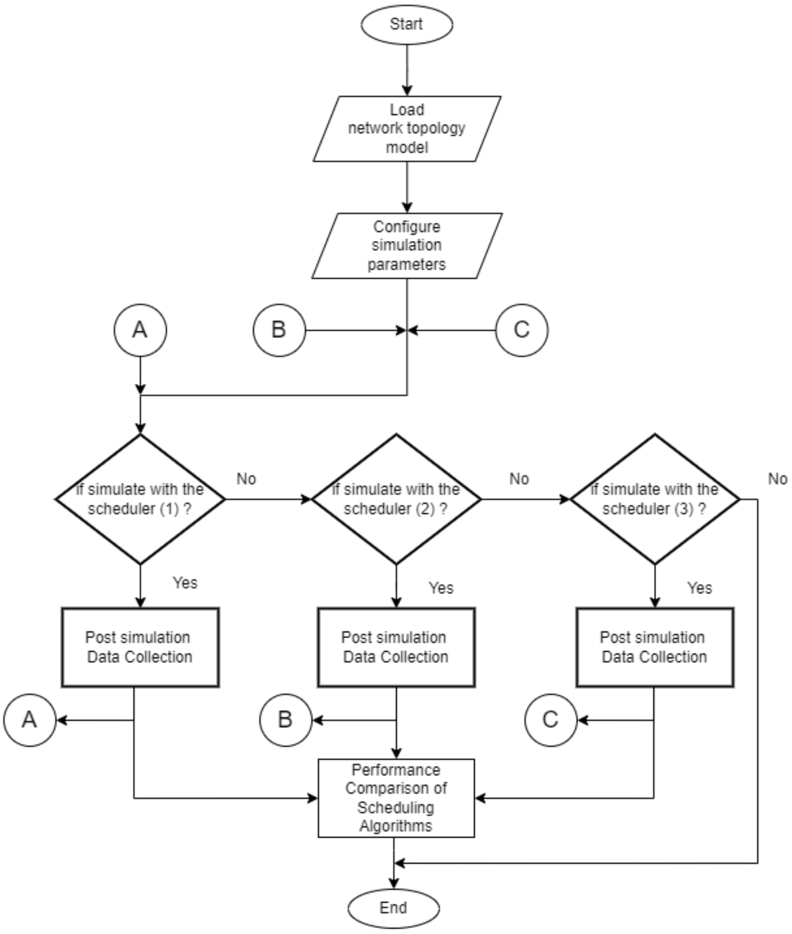

**Fig. 1.** Flowchart of the performance analysis

### *2.2 Scheduling Algorithms*

### *2.2.1 Deficit round robin (DRR)*

The DRR scheduling approach is a queuing algorithm which divides the different data flows into FIFO sub-queues and dequeues from these respective queues in an iterative manner [16]. During each iteration the DRR enabled node uses variables which are corresponding to the sum of the number of allowed bits to transmit and the number of deficit bits from last iteration. The deficit variables give the DRR enable node a higher degree of fairness since it reduces the impact of different packet sizes from different sources.

### *2.2.2 Maximal carrier to interference ratio (MAXCI)*

The MAXCI achieves the maximum sum-throughput by scheduling the user with the best channel in each scheduling block [17]. This can improve the overall performance of the system by reducing interference and increasing the capacity for data transmission. The scheduler typically uses techniques such as power control, frequency scheduling, and adaptive modulation to achieve optimal resource allocation. Therefore, the scheduling block is assigned to the user that supports the maximum throughput i.e., the user that has reported the highest CQI.

### *2.2.3 Proportional fair (PF)*

The PF has a role in the allocation of resource blocks in transmission between the users with different types [18]. The main purpose of the packet scheduler algorithm is to maximize throughput and fairness index. Channel Quality Indicator (CQI) values are mapped according to the type. Then the proportional fair algorithm calculates bandwidth needed 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.

## *2.3 Simulation Parameters*

The simulations of this research were performed on the OMNET++ framework with an additional Simu5G-1.2.1 module. The module is designed for end-to-end simulations of 5G NR cellular networks. The simulation network model was developed based on the network topology depicted in Figure 2. UE represents the vehicles while GNodeB is the base station. The server node has a function as the sender and connected to the Router node in point-to-point mode. Router node was connected to GNodeB using the NR core network, which indicates that the network to be simulated is a standalone 5G network. The RA among users is based on availability of Physical Resource Blocks (PRB) assignment.

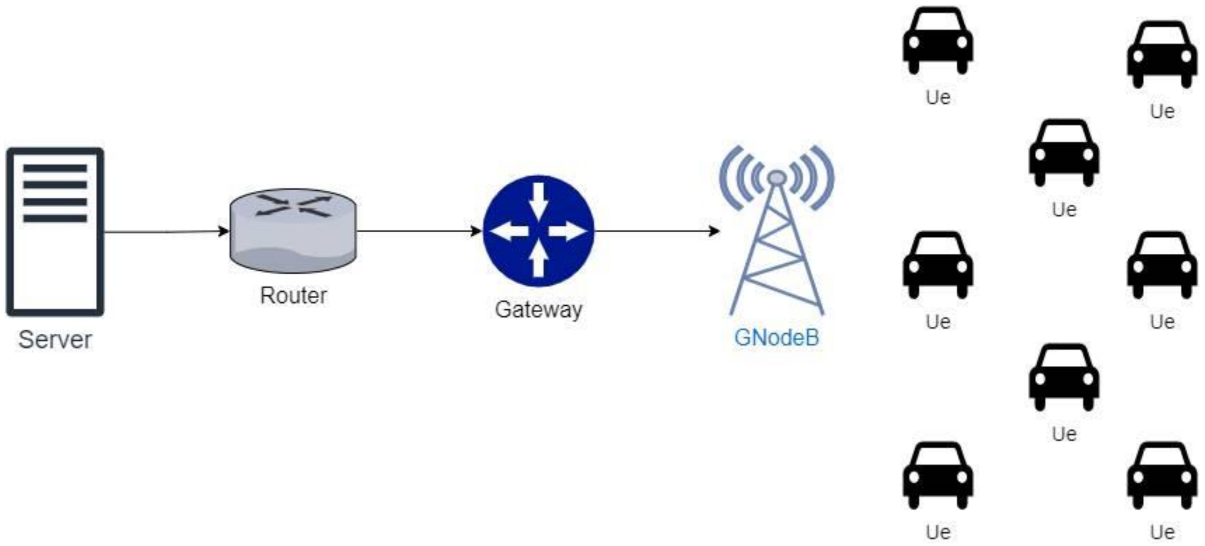

**Fig. 2.** Network topology

The simulation parameters and its values are tabulated in Table 1. Here, the values are adopted from Aji *et al.,* [11]. The author compared the performance of RR and PF schedulers and conclude that RR is the better algorithm in 5G network. However, the author did not examine MAXCI scheduler which was determined to be the best scheduler by Ibraheem *et al.,* [19] in LTE-based network. Therefore, in this simulation were analysed the DRR, MAXCI and PF schedulers.

**Table 1**
Simulation parameters

| Parameters | Values |
|---|---|
| No. of gNodeB | 1 |
| No. of Vehicles (UE) | 20,40,60,80,100 |
| Mobility | Uniform (3mps,13.85mps) |
| UeTx power(mW) | 26 |
| gNodeBTx power(dB) | 40 |
| No. of Resource Blocks (RBs) | 270 |
| Simulation time | 250s |
| Scheduler Algorithms | DRR, MAXCI, PF |

The scheduling algorithm was implemented and simulated alternately. Changes on the number of vehicles were set gradually from 20, 40, 60, 80, and 100 on a single cell tower. The speed of the vehicles was varied from 3 miles per second (mps) to 13.85 miles per second (mps) and the simulation time was set to 250 seconds [11].

## 3. Results

### *3.1 Performance Study*

The performance parameters that were analysed are throughput and delay. Throughput is defined as the effective ability of a network in sending data which is determined using Eq. (1) as follows [20]:

$$Throughput = \frac{\sum RxPacket\ Size}{Delivery\ Time} \tag{1}$$

Delay is the time taken for a packet to reach the destination from the source which is calculated by using Eq. (2) [21]:

$$Delay = \frac{Trx - Ttx}{\sum Rx} \tag{2}$$

where the Trx is the time of received packet on destination, Ttx is the time of packet sent on source, ∑Rx is the total received packet size.

### *3.2 Throughput Results*

In the first analysis, performance of the network traffic is analysed based on the average throughput of multiple UEs. The throughput decreases as the number of vehicles increases, as depicted in Figure 3, due to the available bandwidth being split among all of the vehicles.

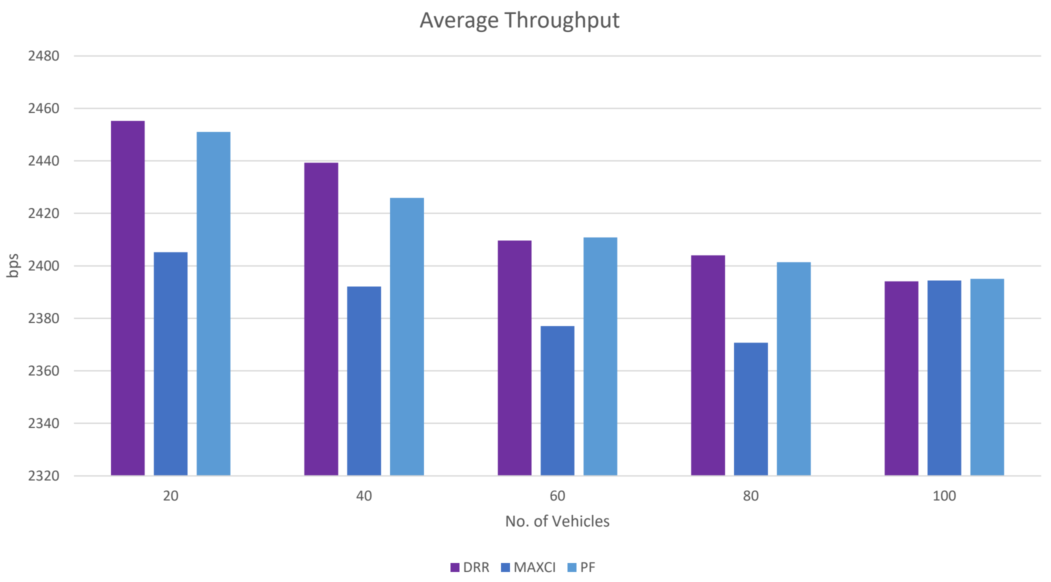

**Fig. 3.** Average throughput

The chart clearly shows that DRR exhibit the highest throughput as compared to the other schedulers. The MAXCI scheduler is responsible for determining the lowest possible throughput by giving priority to the channel that the vehicles have determined to be the best. The PF scheduler is the second-best algorithm in terms of throughput, this is due to the scheduler distributing the workload fairly among the blocks. The percentage differences are depicted in Figure 4.

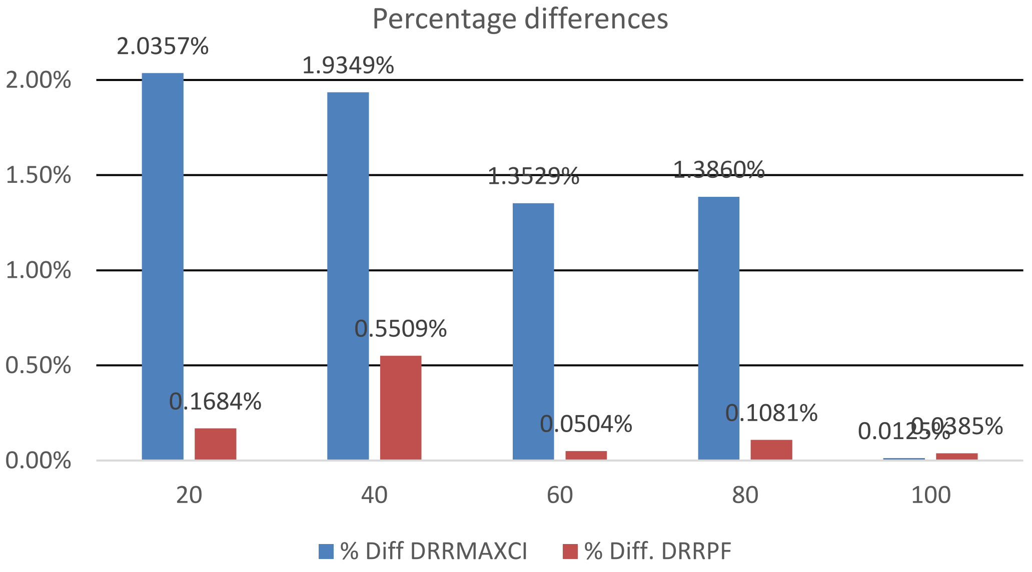

**Fig. 4.** Percentage differences

The second analysis is focusing on just one vehicle as a primary UE which is UE5 while the other UEs are the background data traffics that flood the network. The focus on optimizing the performance of the DRR scheduler in terms of allocating the highest single UE throughput continues, as shown in Figure 5.

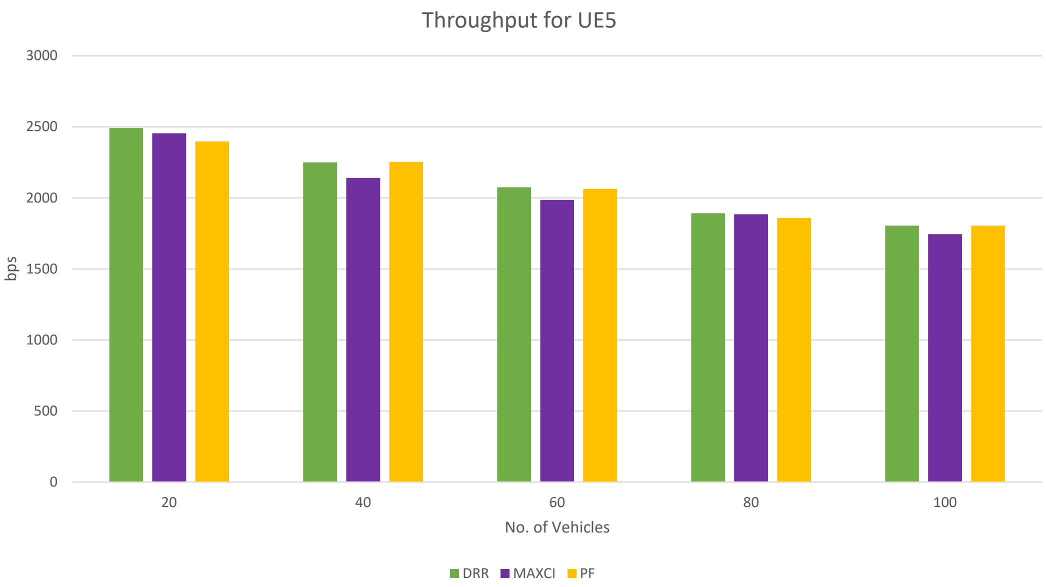

**Fig. 5.** Throughput for UE5

The PF scheduler comes next, then the MAXCI scheduler. The pattern is varied with 40, 60, 80, and 100, where the performance of the MAXCI scheduler between DRR and PF is seen to have declined. The performance of DRR, MAXCI and PF algorithms in terms of throughput decreases as the number of vehicles increases in a vehicular network. This is because when the number of vehicles increases in a network, the amount of available bandwidth becomes scarce. This leads to more congestion and collisions occur, resulting in a decrease in the overall throughput of the network. In the case of DRR, as the number of vehicles increases, the number of flows also increases, and the deficit counter of each flow becomes smaller, which leads to more collisions and higher delay. As a result, the overall throughput of the network decreases. MAXCI, as a rate-limiting algorithm, assigns a maximum credit value to each flow. As the number of vehicles increases, the credit value becomes smaller, and the flow is blocked more often, which leads to a decrease in the overall throughput of the network. PF algorithm aims to maximize the throughput while maintaining fairness among flows. However, as the number of vehicles increases, the bandwidth available for each flow decreases, and it becomes harder for the algorithm to maintain fairness among flows. Consequently, the overall throughput of the network decreases. Therefore, as the number of vehicles increases in a vehicular network, the performance of DRR, MAXCI and PF algorithms in terms of throughput decreases. The percentage differences are depicted in Figure 6.

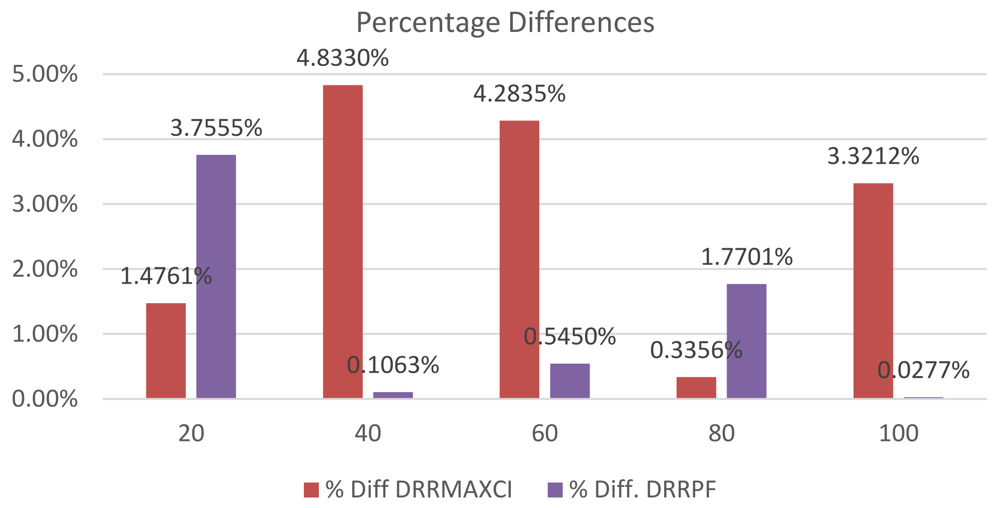

**Fig. 6.** Percentage differences for UE5

These results were compared to the work presented by Nardini *et al.,* [14] and the findings are quite different. It shows that MAXCI has the best throughput while DRR is the worst compared between the three algorithms. One of the factors may be due to the different type of data transferred in this paper which uses VoIP data type. DRR can handle variable-sized packets, unlike MAXCI which is only suitable for fixed-sized packets [15]. This means that DRR can handle different types of traffic and adapt to changing network conditions more efficiently. It ensures that each flow gets its fair share of bandwidth, and allows for a more efficient use of resources, which makes it more suitable for a wide range of network environments, including delay-sensitive traffic.

### *3.3 Delay Results*

In the first analysis, the delay of is based on the average delay for multiple UEs. As depicted in Figure 7, the average delay for all algorithms is almost similar when there are 20 vehicles. As the number of vehicles gradually increases from 40 to 100, the average delay increases.

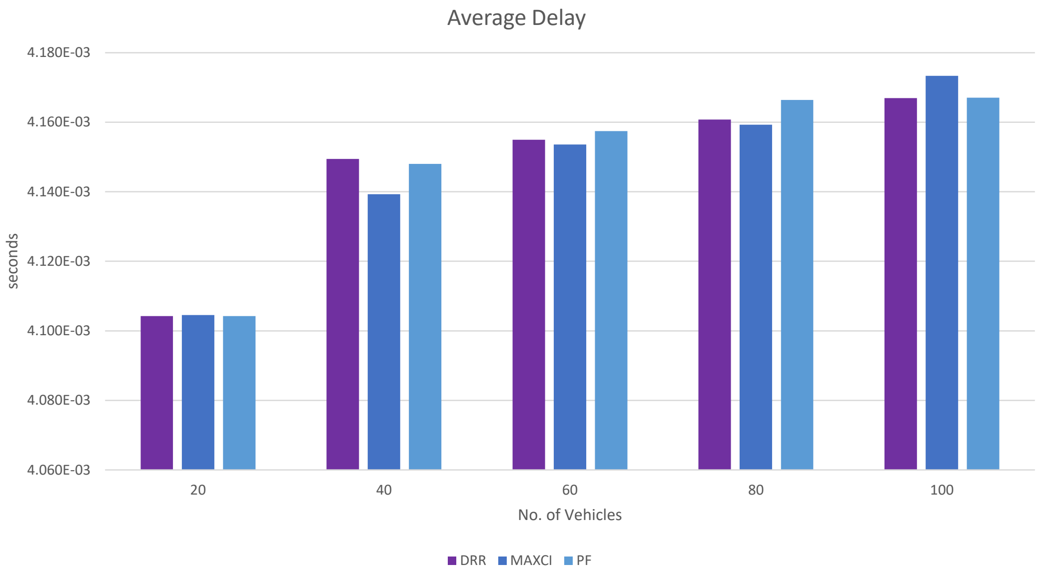

**Fig. 7.** Average delay

The scheduler with the highest average delay is the MAXCI scheduler, followed by the DRR scheduler, and the PF scheduler. In contrast to PF, which must take into account the quality of the channel, DRR has a more manageable delay because it requires less time for users to queue up when their packages are relatively small. The proportional fading algorithm considers the value of the Channel Quality Indicator (CQI) which results in a longer delay than other fading techniques. As each UE in this scenario possesses a unique channel condition and this algorithm is required to provide service to each UE while preserving its integrity, the delivery process requires more time. The percentage differences are depicted in Figure 8.

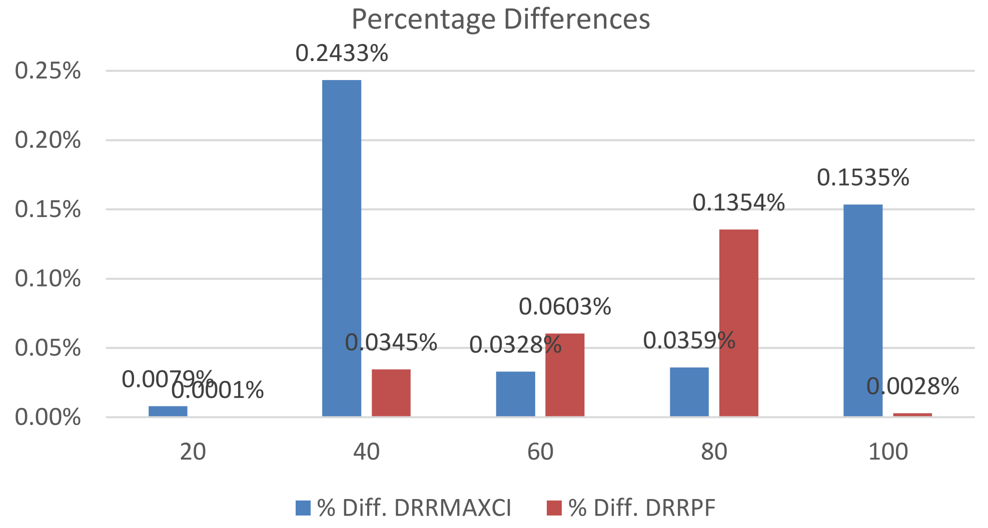

**Fig. 8.** Percentage differences

The second analysis is focusing on just one vehicle as a primary UE which is UE5 while the other UEs are the background data traffics that flood the network. Figure 9 shows that in comparison to MAXCI and PF, the worst delays are experienced by the DRR when 20 vehicles are used. The delay gradually increases when the number of vehicles rises from 40 to 100.

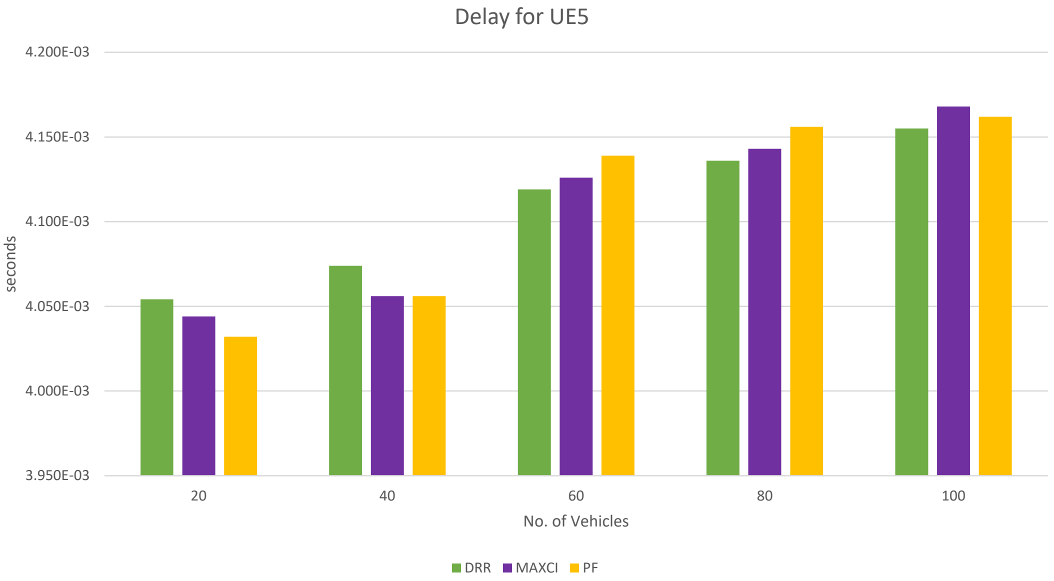

**Fig. 9.** Delay for UE5

The highest delay is experienced by the PF scheduler, followed by the MAXCI scheduler and the DRR scheduler. In terms of delay, as the number of vehicles increases in a vehicular network, the performance of DRR, MAXCI and PF algorithms also decreases. As the number of vehicles increases, the amount of available bandwidth becomes scarce, leading to more congestion and collisions. This results in increased in delay for the packets as they have to wait for their turn to be transmitted. In the case of DRR, as the number of vehicles increases, the number of flows also increases, and the deficit counter of each flow becomes smaller. This leads to more collisions and higher delay, resulting in an increase in overall delay. MAXCI assigns a maximum credit value to each flow. As the number of vehicles increases, the credit value becomes smaller, and the flow is blocked more often. This leads to increased delay for the packets, as they have to wait for their turn to be transmitted. PF algorithm aims to maximize the throughput while maintaining fairness among flows. However, as the number of vehicles increases, the bandwidth available for each flow decreases, and it becomes harder for the algorithm to maintain fairness among flows. This can result in increased delay for low-bandwidth flows, leading to a higher overall delay. As the number of vehicles increases in a vehicular network, the performance of DRR, MAXCI and PF algorithms in terms of delay also decreases. The scarcity of bandwidth leads to more congestion, collisions, and delay, which affects the overall efficiency of the network. The percentage differences are depicted in Figure 10.

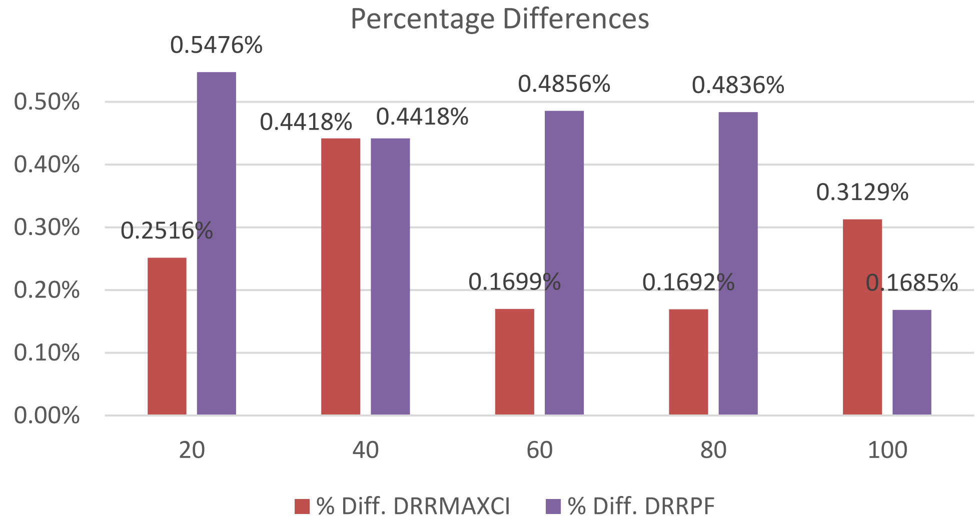

**Fig. 10.** Percentage differences for UE5

From the simulation results, MAXCI has the highest delay compared to DRR and PF as they have to wait for their turn to send packets. Additionally, MAXCI's simplicity can cause it to be less efficient in handling different types of traffic and adapting to changing network conditions, which can also contribute to high delay. On the other hand, DRR and PF are designed to be more efficient and fairer in their bandwidth allocation. DRR assigns a deficit counter to each flow and allows them to send packets based on their assigned weight and the remaining deficit counter. This ensures that each flow gets its fair share of bandwidth and allows for a more efficient use of resources. PF algorithm aims to maximize the throughput while maintaining fairness among flows, which can reduce the delay for low-bandwidth flows.

## 4. Conclusions

In conclusion, the performance analysis of RA in C-V2X communication in a high-density vehicular network is a crucial area of research. The growth of urban areas and the increase in automotive traffic have led to severe socioeconomic issues such as traffic congestion and road accidents. To address these issues, V2X technology is being studied and explored, but it presents challenges such as complexity, security concerns and safety risks. The high mobility and density of vehicle users in C-V2X communications may lead to additional signalling costs if resources are allocated centrally. To overcome these challenges, it is important to efficiently allocate the limited resources available in the network. Through the simulation study conducted in this paper, the most effective resource allocation method for optimizing performance in high-density vehicular networks was identified. The results show that DRR scheduler has excellent performance at maximizing the average system throughput in Vo-IP traffic with a percentage of 1.345% better than MAXCI and 0.149% better than PF. In term of delay, DRR scheduler has performance at the average system delay in Vo-IP traffic with a percentage of 0.0058% better than MAXCI and 0.033% better than PF. Hence, DRR scheduler has the best performance in term of throughput and delay.

This can be useful in an urban scenario where the goal is to balance the needs of both high and low traffic users in VoIP data traffic. The lack of sufficient bandwidth causes increased delay, congestion, and collisions, all of which reduce the network's overall effectiveness. These issues can be overcome by employing advanced algorithms and approaches, such as dynamic channel allocation. Examining a diverse network with a range of services and applications is a great area of study. Given this dynamic environment, it is necessary to investigate how scheduling strategies affect VoIP traffic performance. This investigation can provide a fundamental understanding of handling the dynamically changing dynamics seen in heterogeneous networks. Given the interaction between C-V2X and heterogeneous networks, a major step towards scheduling and strategically allocating VoIP traffic is the adoption of a suggested hybrid technique. This method not only closes the gap between simulation findings and actual situations, but it also establishes the foundation for a useful scheduling optimization technique.

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