Simulation and analysis of C-V2X data transmission in different traffic scenarios based on MAC layer scheduling algorithms

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Abstract. With the rapid development of communication technology, vehicles are becoming more and more intelligent, and Vehicle to Vehicle (V2V) communication has become an important cornerstone for the future intelligence of vehicles. Because of the high-reliability and low-latency characteristics of 5G networks, many applications can be realized by using Vehicle to Network (V2N) communications. Different applications have different requirements for Quality of Service (QoS), which should be met by the network, and the base station can use different scheduling methods to satisfy these different requirements. This paper focuses on the scheduler at the MAC layer in 5G base stations. The scheduler must handle both video signals and other communication signals transmitted by the vehicle, and must also consider Hybrid Automatic Repeat reQuest (HARQ) retransmissions. We performed a C-V2X signaling network transmission simulation by using OMNeT++. We considered urban and motorway, two public transportation scenarios. Different types of data are set to be transmitted in two scenarios. We used different scheduling schemes for data scheduling, then investigated the performance of these scheduling schemes for transmitting data. The methods and simulation experiments mentioned in this paper are important for practical generalization.

Keywords: 5G, V2N, QoS, priority scheduling, OMNeT++

1. Introduction

The Third Generation Partnership Project(3GPP) has introduced C-V2X. C-V2X allows direct exchange of information between vehicles. It also has cellular mode and the pass-through mode. The cellular mode refers to the use of the Uu-interface for communication between terminals and base stations, and the use of the base station as a centralized control center and data and information forwarding center. Base station completes tasks such as centralized dispatch, congestion control and interference coordination, which can significantly improve the access and networking efficiency of C-V2X and ensure service continuity and reliability. The direct communication method refers to the direct communication between vehicle-vehicle, between vehicle-road, and between vehicle and pedestrian through PC5 interface, and this communication method meets the transmission requirements of low latency and high reliability of automatic driving, and node telling movement. Compared to Dedicated Short-Range Communication (DSRC), C-V2X uses partial bandwidth to send, with higher power spectral density. In addition, DSRC is a line-of-sight transmission technology, which means too many obstacles will affect the signal

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transmission efficiency. Instead, C-V2X uses Turbo code, with a high coding gain, which is more suitable for outdoor environments.

Therefore, this paper analyzes the network transmission simulation for vehicle networking based on C-V2X technology communication. Currently, vehicles use 5G mobile networks to accomplish parallel data services. Stable connection between vehicles and the Internet is the key to complete the stable transmission of these data, the application programs that generate video data and vehicle information data run simultaneously in the vehicle, competing for limited network resources, in this case, each base station has a very important role in controlling the flow by scheduling the program through the MAC, for the data streams with different performance requirements, the scheduling priority can be used to for data flows with different performance requirements can be prioritized by scheduling for traffic control. The 5G QoS model is defined in the 5G system architecture, in which the QoS flow is described as the finest QoS granularity in the 5G system. In QoS model, default priorities are defined for different applications. The scheduling of data transmission can be done by modifying the priority of the application.

At the same time, other information can be used to define the scheduling priority, such as the information of the packet, the channel quality, and the scheduled transmission time of the packet. We can use this information, or adjust the predetermined parameters to get different priority scheduling schemes, and determine which scheduling scheme is more effective through network simulation.

We set up Urban and Motorway, two scenarios in OMNeT++. Then we measured package delay under the scheduling of different algorithms in each scenario.

In the next section, the related work is summarized, the results of the simulation are analyzed and discussed. Finally, the research is summarized and future research is envisioned.

2. Related works

For the problem of Telematics communication in 5G network environment, many scholars have carried out extensive research in different aspects, and in this section, we will present some of the literature researches related to our work. S. Pusapati, B. Selim, Y. Nie, etal proposed a simulation framework for NR-V2X communication and used it in the OMNeT++ simulation environment to analyze the performance of VoIP data transmission in upstream and downstream V2N communication under two scenarios, NRCar and Lumsden, but did not consider the impact of multiple data transmission in parallel [1]. T. Deinlein, R. German and A. Djanatliev proposed a V2I/N network simulation framework for 5G network environments and utilized the model for simulation [2]. T. Deinlein, M. Roshdi, T. Nan, etal have carried out an analysis of scheduling algorithms at the MAC layer using the simulation framework in [2]. They have used different information to get different scheduling priorities and have drawn conclusions by simulating eight scheduling priorities [3]. M. A. Bin Mustaffa, H. Binti Zainol Abidin, L. B. Mazalan, etal, based on [3], collected the values of Signal to Noise Stem Ratio (SINR) and used the Maximum Carrier to Interference Ratio (MAX C/I) algorithm as scheduler for the simulation to illustrate that the proposed protocol uses heterogeneous transmissions to validate the performance in the C-V2X by the importance [4]. T. Deinlein, A. Brummer, R. German, etal used the framework in [2] to model and simulate the attenuation of Line of Sights (LOS) signals, which further improves the framework [5].

Regarding scheduling algorithms, A. K. Rai and C. Mahobiya first compare different data traffic scheduling techniques such as First-In-First-Out (FIFO), Priority Queuing (PQ) and Weighted Fair Queuing (WPQ) in a 5G network environment, and then consider minimum delay maximum Throughput (mDmT) scheduling scheme for Worldwide Interoperability for Microwave Access (WiMAX) connections [6]. While comparing the existing scheduling algorithms, the advantages and disadvantages of each algorithm are analyzed. In [7], the authors focused on reviewing the work of several authors on metrics-based fog node scheduling for various types of tasks. These metrics are compared and analyzed with other scheduling algorithm metrics. The impact of one metric on the other is identified so that researchers can focus on optimizing metrics during scheduling of various tasks with fog nodes. Z. Wang, J. Duan and A. Yao proposed a QoS fairness guaranteed scheduling algorithm by using Q-Learning's which balances the relationship between fairness and delay to effectively guarantee the QoS requirements of different traffic flows [8]. A. Abdulazeez, A. S. Tijjani and A. Mohammed, proposed a QoS-Aware EDDF scheme, which prioritizes the scheduling of the allocation and transmission of user traffic by prioritizing the signaling state and QoS requirements of the user traffic, which reduces the traffic and packet loss rate based on the original scheme [9]. Y. Tang, Y. Yang, H. Huang, etal studied the uplink transmission resource scheduling mechanism by analyzing the QoS requirements of different services in the smart grid and proposed a 5G uplink radio resource scheduling algorithm with guaranteed QoS by combining 5G uRLLC technology [10]. While ensuring the system throughput, it effectively reduces the transmission delay of delay-sensitive services in the system and improves the transmission satisfaction of services in the smart grid. In the article [11], the authors propose reception control and scheduling of QoS-aware video streams, which utilizes transcoding of video streams using cloud resources, and the scheduling system is based on admission control judgments of the opening time of each transcoding server queue. A nice balance between price and quality of service is provided. C. Zhang, G. Zeng, Z. Ren, etal proposed an information entropy based multi-QoS driven hierarchical scheduling architecture for IoT resources. The approach consists of two main processes: categorized request scheduling and precise selection scheduling, which enables personalization and optimal utilization of resources [12]. N. K. M. Madi and M. Madi have focused by considering a promising scheduling algorithm (EDC), this work further analyzes the impact of CQI and other queue-based parameters in terms of providing throughput guarantees or latency-aware behavior in the algorithm and proposes a solution that bridges the gap between the two main QoS metrics (throughput and latency) for real-time services [13]. S. Wang, K. Liu, P. Liu, etal formulated the packet scheduling problem as an optimization problem and theoretically analyzed the impact of slot wastage on system performance. Then they propose a traffic aggregation-based QoS-sensitive scheduling (TAQS) algorithm to improve the throughput of the system [14].

3. Simulation experiment design and realization

The 5G network is mainly composed of two main parts: the User Plane (UP) and the Control Plane (CP). The UP is responsible for carrying data traffic and realizing fast and efficient data transmission, while the CP is responsible for processing network control information to ensure network security and stable operation. The protocol architectures of user plane and control plane are shown in Fig.1&2 respectively. Among two pictures, the control plane adds an AMF node relative to the user plane, and AMF is a key node in the 5G network, responsible for access and mobility management functions to support the user access process and seamless switching.

In Fig2, the protocol can be divided into physical layer, MAC layer, RLC layer and PDCP layer. Among them, the user layer uses the SDAP protocol to perform QoS streaming network, while the control layer protocol uses the radio resource control (RRC) protocol used for UMTS, LTE, and air interfaces for mobile communication systems and NAS.

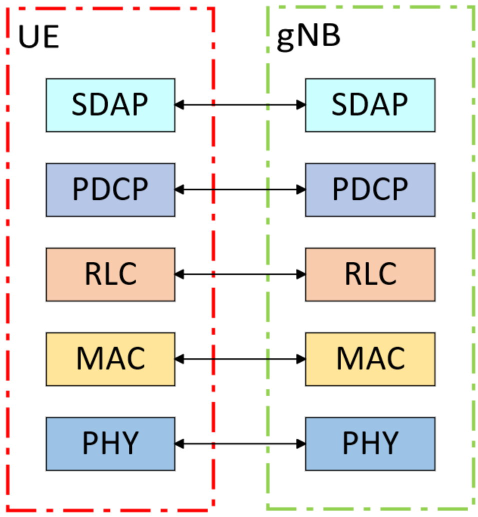

Figure 1. User-Plane Protocol.

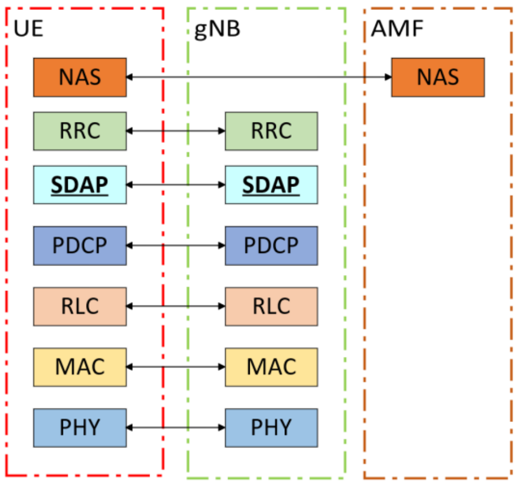

Figure 2. Control-Plane Protocol.

We focus on V2N communication in vehicles, i.e., communication between the vehicles and the 5G base station. A brief description of the 5G model is given below.

3.1. 5G QoS Model [15]

The purpose of 5QI is to prioritize the communication based on the resource type. The traffic classification and mapping sketch of user layer in 5G communication network is shown Fig3.

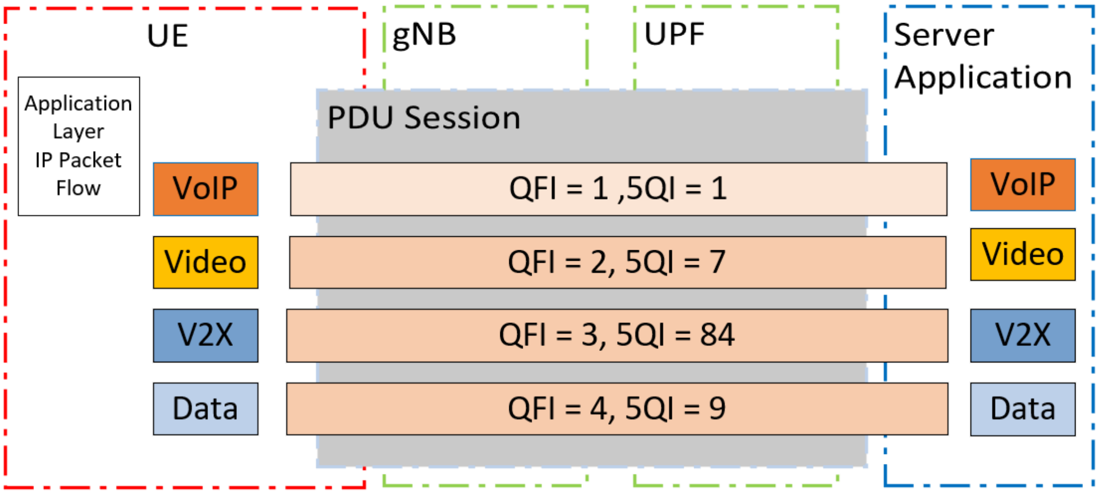

Figure 3. General 5G QoS Flow Identifier.

We are more concerned with the MAC layer scheduling method. In downlink, the MAC layer scheduling method is illustrated in Table1&2. The downlink (DL) scheduling workflow is shown Table1. After receiving the packets sent by the RLC layer, the MAC layer first stores the packets in the virtual buffer MAC-Buffer, and calculates the packet priority corresponding to each packet, and stores the packets in the message queues of the corresponding UEs according to the user terminal information UE type, and the message type information, and finally the MAC layer re-calculates the scheduling priority of these queues, and assigns each packet a priority according to its priority order. The MAC layer recalculates the scheduling priority of these queues and allocates resources according to the priority order of each packet, and selects only one terminal for allocation within a transmission time interval (TTI).

Table 1. MAC Scheduling package in Downlink workflows.

MAC Scheduling package in Downlink workflows
Step 1: Receive data packages from RLC-Layer. Step 2: In MAC-Layer, store packages in MAC-Buffers. Step 3: In MAC-Buffers, calculate priority and schedule packages, send packages to MAC-Scheduler. Step 4: In MAC-Scheduler, each UE, has its corresponding Queue Area, which contains Video Package Queue, V2X Package Queue, VoIP Package Queue, H-ARQ Queue. Step 5: In MAC-Scheduler, calculate the schedule priority for each package, then allocate resources, send the ordered package to the corresponding UE.

The workflow of the uplink (UL) of the MAC layer is shown in Table2. During the uplink process, each vehicle itself executes multiple parallel application programs, and the application packets generated by each program are placed in a queue as shown in the figure below. Before the vehicle transmits the data to the base station, it has to request the scheduling authorization from the base station. In each vehicle, the priority scheduling of its own information is calculated first, which determines which packet is sent for the scheduling request. At the base station side, the scheduling requests sent by all end devices are calculated and packet authorization is given to the vehicle that is given by the highest priority, similarly, the base station ensures that at each TTI it wants to send packet authorization with the highest priority to only one vehicle.

Table 2. MAC Scheduling package in Uplink workflows.

MAC Scheduling package in Uplink workflows
Step 1: For each UE, receive data packages from UE. Step 2: In MAC-Layer, store packages in MAC-Buffers. Step 3: In MAC-Buffers, calculate priority and schedule packages, send packages to MAC Scheduler. Step 4: In MAC-Scheduler, it has a Queue Area, which contains Video Package Queue, V2X Package Queue, VoIP Package Queue, H-ARQ Queue. Step 5: In MAC-Scheduler, calculate the schedule priority for each package, then allocate resources, send the resource allocation request to the MAC Scheduler in gNodeB. Step 6: In MAC-Scheduler in gNodeB, it receives many allocations request from different UEs in a same time. Step 7: In MAC-Scheduler in gNodeB, it calculates the highest scheduling priority for all connected UE for the highest priority package, then send scheduling grant to the corresponding UE.

For C-V2X technology, the allocation of communication resources is mainly dispatched by the base station (mode 3) and the terminal autonomous allocation (mode 4). In mode 3 as shown in Fig4, the scheduling of communication resources is mainly carried out by the base station, and the networked vehicles send the information to the base station through the Uu-interface, and after base station receives the information, it carries out the allocation of communication resources to the different vehicles through the specific resource allocation method. Communication resource allocation. Realize the communication transmission. In mode 4, as shown in Fig5, the vehicles are directly connected to each other through the PC5 interface without relying on the base station, which can improve the efficiency of the connected vehicles communication system in the case of dense vehicles and bad weather.

Two scenarios are as follow: Motorway and Urban, because in the general case of the Motorway, the density of vehicles is small, so consider the use of mode 3 application scenarios, and the networked vehicles and the base station communication in addition to Video and web Traffic two kinds of information, but also need to upload the V2X information; in the Urban, because of the high density of vehicles, consider the use of mode 4 In Urban, because of the high density of vehicles, mode 4 is considered for vehicle-vehicle communication, and the V2X information is directly transmitted to each other through the PC5 port, which is more efficient, only two kinds of data are transmitted between the networked vehicles and the terminals in the case of traffic in Urban.

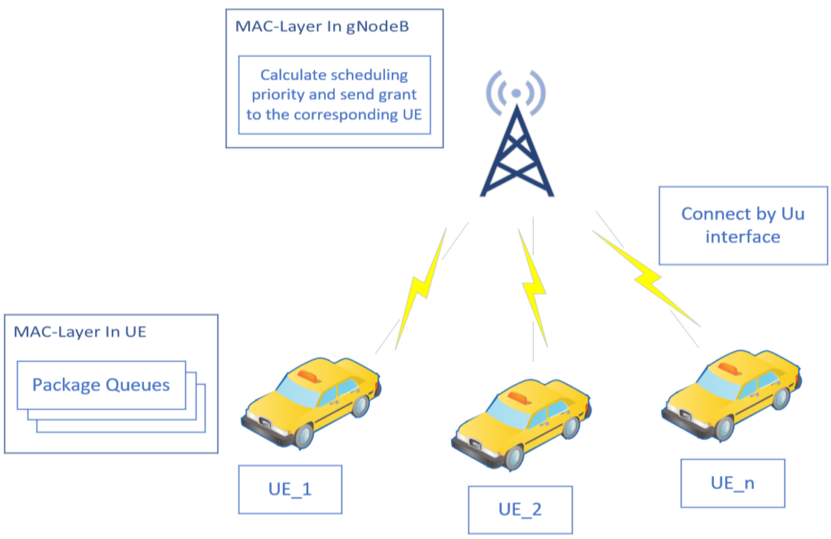

Figure 4. C-V2X mode3 Communication

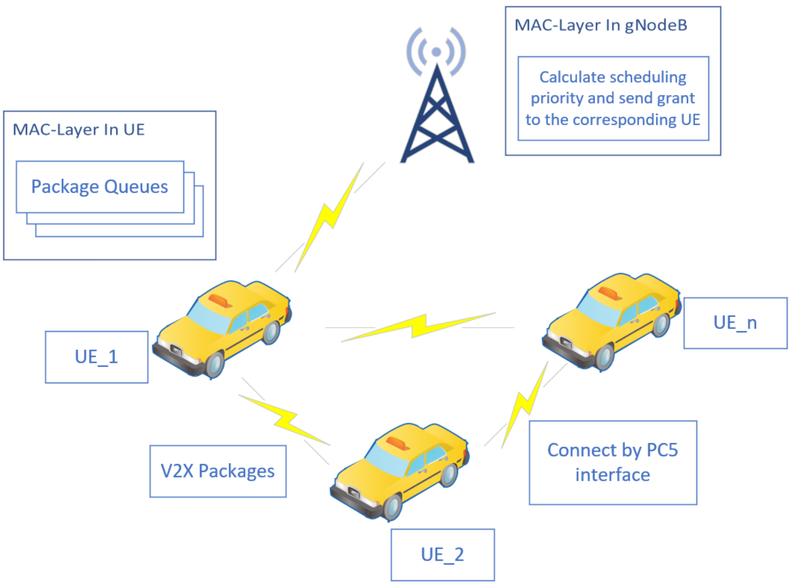

Figure 5. C-V2X mode4 Communication

3.2. Scheduling Algorithms

Scheduling algorithms include three classical algorithms: Proportional-Fair Scheduling (PF), BESTFIT, and Deficit Round Robin (DRR)

3.2.1. PF. The PF algorithm fully utilizes the properties of channel. It will first schedule users with good channel conditions, while considering users with bad channel conditions as much as possible. A compromise between throughput and fairness can be achieved.

If the immediate rate that user i can be assigned at moment t is $r_i(t)$, and the average rate is $R_i(t)$, then the scheduled user is the highest priority user at the current moment, and the priority formula is:

$$k = \arg\max_{i=1,\dots,N} \left\{ \frac{r_i(t)}{R_i(t)} \right\} \tag{1}$$

After the scheduling at time t is complete, update the average rate $R_i(t)$ for each user,

$$\vec{R_i}(t) = \begin{cases} \left(1-\frac{1}{t_c}\right)\overline{R}_i(t-1)+\frac{1}{t_c}r_i(t) & i=k \\ \left(1-\frac{1}{t_c}\right)\overline{R}_i(t-1) & i\neq k \end{cases} \tag{2}$$

In the above equation, t_c is the update time window function, which represents how long the average rate contains information about the channel conditions in the past. When the average user rate t_c is larger, the average user rate refers to the rate value of more previous moments, and the long-term fairness becomes better, on the contrary, when the average user rate t_c is smaller, the average user rate refers to the rate value of the most recent moments, which will lead to the sudden change of the user's channel and more likely to affect the scheduling result of the peripheral algorithm. According to the PF algorithm, if a user is communicating all the time, $R_i(t)$ will become bigger and bigger, and the user's priority will decrease; if the user is not scheduled for a long time, $R_i(t)$ will be small enough to increase the user's priority, so that the user can get the chance to be scheduled.

3.2.2. BESTFIT. The idea of the BESTFIT algorithm is to find the free partition from all free zones that can satisfy the requirements of the job and has the smallest size, and this method makes the fragmentation as small as possible. To accommodate this algorithm, the free partitions in the free partition table (chain of free partitions) are sorted from smallest to largest, starting from the header of the table to the first free partition allocation that meets the requirements. The algorithm retains large free partitions but causes many small free partitions, the main flow of the algorithm is shown in Fig6.

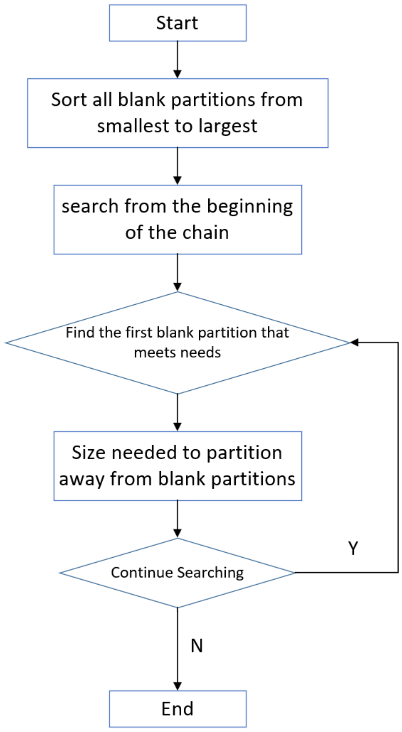

Figure 6. The workflow of BESTFIT Algorithm

3.2.3. DRR. Polling is used to schedule multiple queues. The difference with RR scheduling is that RR scheduling is done according to the number of messages, while DRR scheduling is done according to the length of messages.

DRR sets a counter Deficit for each queue, which is initialized to the maximum number of bytes allowed for one scheduling, and each time a queue is polled, the queue outputs a message while the counter Deficit is subtracted from the message length. If the message length exceeds the scheduling capacity of the queue, DRR allows Deficit to go negative to ensure that long messages are also scheduled, but the queue will not be scheduled the next time it is polled. Stop scheduling the queue when the counter is 0 or negative, but continue scheduling other queues with positive counters. When the Deficit of all queues is 0 or negative, add the Deficit counters of all queues to the initial value and start a new round of scheduling.

This section describes in more detail our simulation work using the framework. In our study, we focus more on two types of data, Video, and Data generated in Web Traffic. In our simulation, we use the simulation parameters for these two types of data as shown in the table below. The values in the table are derived from Table 5.7.4-1 in [15].

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Table 3. QoS profile values

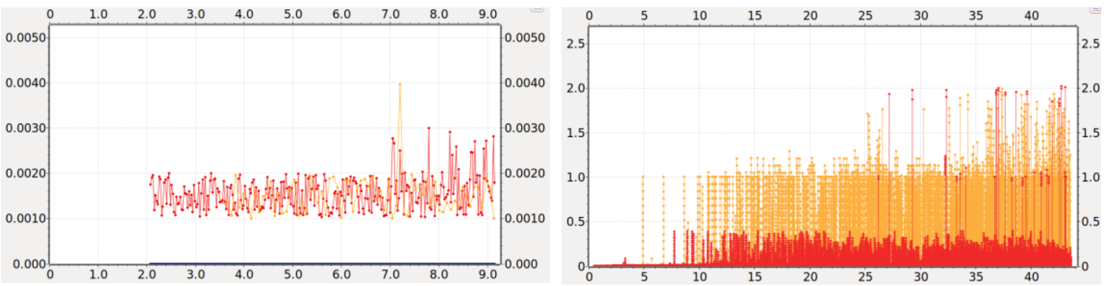
Application	V2X	Video	Data
5QI	84	7	9
Default priority	24	70	90
P. delay bud.(PDB) (ms)	30	100	300
Packet size(B)	400	15000	2000
Packet interval (ms)	100	25	80

Table 4. QoS profile values

Parameter	Value/Configurations
Simulation Time(s)	300
Channel model	RMa_A
Fading Type	Jakes
P. delay bud.(PDB)(ms)	300
Packet size(B)	2000
Packet interval(ms)	80
Bandwidth	50MHz
Height cars	1.5m
Height gNodeBs	35m
Tx mode	Single port antenna

3.2.4. Urban Scenario (2 Apps). The red line represents the package delay of Video, the yellow line represents the package delay of Data.

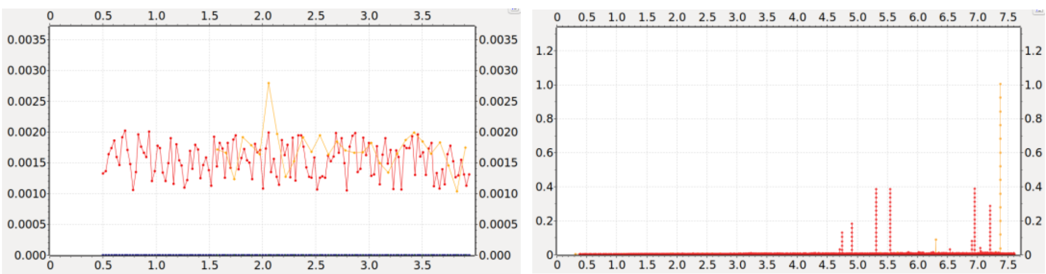
3.2.4.1. Scheduling algorithm is PF



(a)package delay in DL (b) package delay in UL

Figure 7. package delay in PF algorithm Urban Scenario

3.2.4.2. Scheduling algorithm is DRR



(a)package delay in DL (b) package delay in UL

Figure 8. package delay in DRR algorithm Urban Scenario

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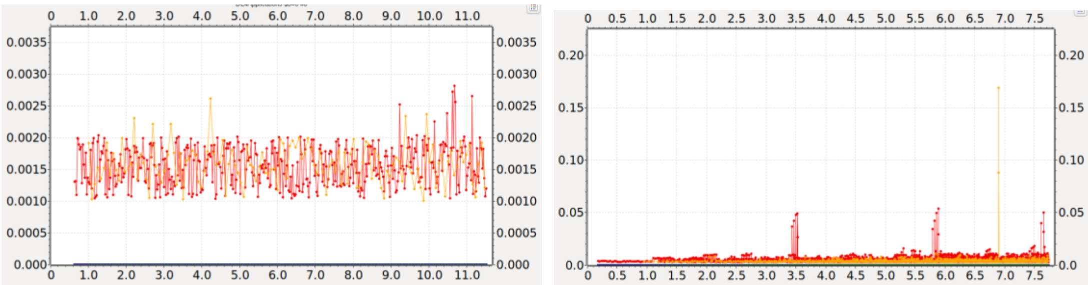
3.2.4.3. Scheduling algorithm is BESTFIT

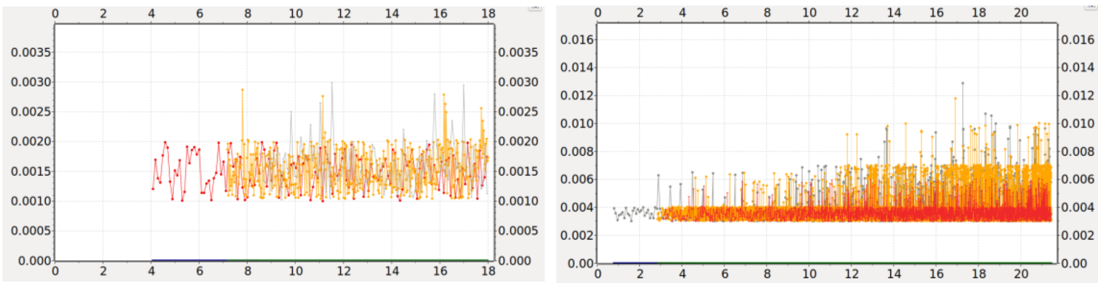


(a)package delay in DL (b) package delay in UL

Figure 9. package delay in BESTFIT algorithm Urban Scenario

3.2.5. Motorway Scenario (3 Apps). The red line represents the package delay of V2X, the yellow line represents the package delay of Video, and the grey line represents the package delay of Data.

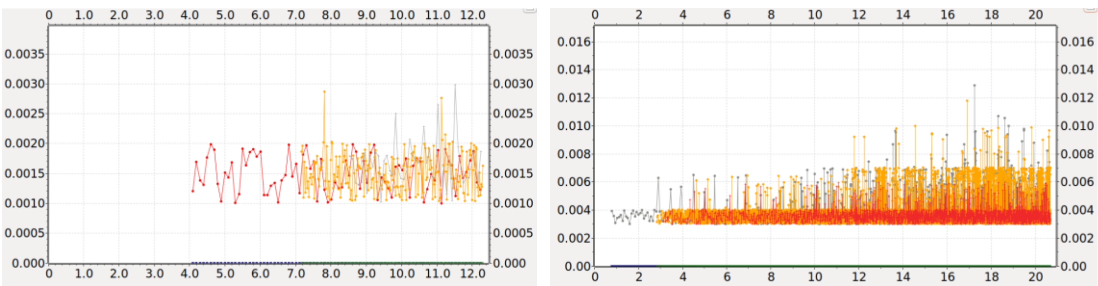
3.2.5.1. Scheduling algorithm is PF



(a)package delay in DL (b) package delay in UL

Figure 10. package delay in PF algorithm Motorway Scenario

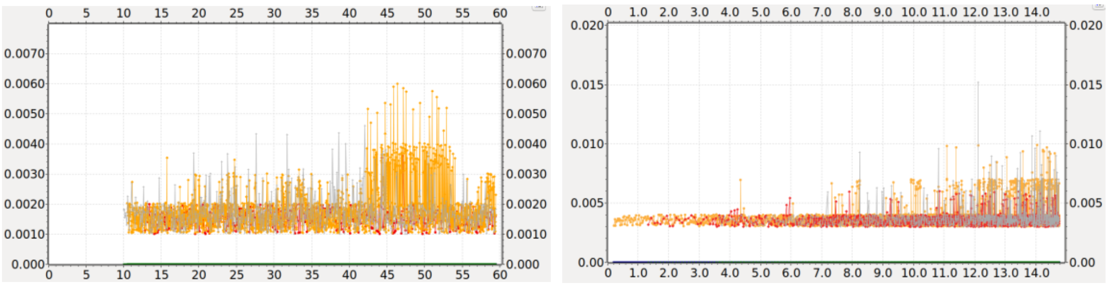
3.2.5.2. Scheduling algorithm is DRR



(a)package delay in DL (b) package delay in UL

Figure 11. package delay in DRR algorithm Motorway Scenario

3.2.5.3. Scheduling algorithm is BESTFIT



(a)package delay in DL (b) package delay in UL

Figure 12. package delay in BESTFIT algorithm Motorway Scenario

The impact of different scheduling algorithms applied to the MAC layer on the delay of different Apps in two traffic environments, Urban and Motorway, is shown in the above figure.

In the Urban case, we only focus on the delay situation of the two Apps, Video and Data, as can be seen from the figure, in DL, the data delay of the packets of the two types of data under the three algorithms is roughly stabilized in the same range, although the maximum delay of the V2X data is larger than that of the DRR algorithm in both the PF algorithm and the BESTFIT algorithm. In UL, there is a very clear difference between the three algorithms in terms of their impact on data latency. In the case of PF algorithm, most of the demo of Data packets are around 1s and most of the delay of V2X packets are below 0.5s, and they all have the same maximum delay. And the Data latency is much lower for most of the moments under the effect of DRR algorithm and BESTFIT algorithm. But the maximum delay of both V2X and DATA packets of DRR algorithm is higher than BESTFIT algorithm. Combining the DL and UL simulations, we conclude that the BESTFIT algorithm will be a better choice in the Urban case and in the V2N case where only two packets, Video and Data, are considered for transmission.

In the Motorway case, we focus on the delay of the three apps, V2X, Video and Data. In DL, it is clearly seen that with the BESTFIT algorithm, the latency of all three packets is higher than the latency with the other two algorithms. In UL, it can be seen that the effect of PF and DRR algorithms on the delay of the three packets is almost the same, and the maximum delay as well as the distribution of the delay of different packets are extremely similar, and the BESTFIT algorithm has a higher average data delay and a higher maximum data delay than the other two algorithms in this case. In the Motorway case, considering three packet transmissions V2X, Video and Data, it is better to use PF algorithm or DRR algorithm as compared to BESTFIT algorithm.

4. Conclusion

In the paper, we analyse the C-V2X technology in the 5G communication environment, and the 5G network structure and protocols. The impact of different MAC layer scheduling algorithms on data transmission in C-V2X in various scenarios is investigated. The data transmission in Motorway scenarios and Urban scenarios are simulated and analysed using mode3 and mode4 policies in C-V2X technology respectively. By setting different scheduling algorithms in the MAC layer, the latency of data transmission for each application under the two transmission scenarios is simulated separately. The simulation results are analysed and more applicable simulation strategies in different scenarios are proposed based on the simulation results. In the future, we will improve the scheduling algorithm and apply it in autonomous driving technology.

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