On the Impact of priority-based MAC Layer Scheduling in 5G V2N multi-application Scenarios

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***Abstract*—The automotive market's ongoing shift towards connected and automated vehicles has enabled a multitude of new use cases enabled by Cellular Vehicle-to-Everything (C-V2X) communications. With the hyperconnectivity enabled by 5G, many new applications utilize Vehicle-to-Network (V2N) communications to deliver services with many objectives such as infotainment, advanced driving, etc. These different applications come with different configurations and Quality-of-Service (QoS) requirements that should be satisfied by the network. A base station could use the scheduler on the Media Access Control (MAC) layer to divide the available radio resources among all connected vehicles to satisfy these various requirements. In this paper, we focus on such MAC layer schedulers located in 5G gNodeBs. The scheduler has to handle four different application types of several connected vehicles simultaneously, considering new data packets and Hybrid Automatic Repeat reQuest (HARQ) retransmissions. For the prioritization of the different parallel services, we consider different approaches which all determine a scheduling priority differently and compare its impact on the application layer performance via network simulation in a real traffic scenario. One main part of our study is to integrate the 5G QoS model into the simulator to be able to use standardized values from 3GPP specification as a scheduling priority. We use the OMNeT++ framework 5G-Sim-V2I/N for this investigation. We present a detailed study on the performance of each of the various prioritization approaches and suggest a path forward on how to optimize the scheduler performance.**

***Index Terms*—5G, V2N, priority-based scheduling, 5G QoS model, OMNeT++**

I. INTRODUCTION

State-of-the-art vehicles use 4G/5G mobile communications technology for different parallel data services (e.g., infotainment, navigation, traffic optimization, over-the-air updates, etc.) [1]. Most of these applications rely on a steady connection between the vehicle and an Internet server (V2N), where vehicles are connected to a base station via the Uu-interface. These applications run simultaneously in vehicles and compete among each other for the usually limited resources of the network. The MAC scheduler in every base station is of great importance in this context due to its traffic steering role. It controls the data flow by sharing the available resources among all connected users in different ways. One scheduling approach for data flows with different performance requirements is using scheduling priorities. The main question is how the scheduler shall determine the priority of different application types. One option is to consider predefined values from specification tables. The 5G QoS model described in [2], Chapter 5.7, defines such default priorities for different application types in general, which defines the QoS characteristics of a QoS flow. A QoS flow is described there as the finest QoS granularity a 5G system could offer, and the question is whether its predefined performance parameters for a differentiation between several services is efficient enough.

Besides the predefined specification table, the scheduling priority could also be determined by individual packet related information like the packet size, the current channel quality, the number of retransmissions or the time the packet is already waiting for a transmission. It is of interest to find out whether using predefined parameters is efficient enough or a more enhanced priority metric calculated by a combination of different parameters leads to better performance results.

For such a hands-on evaluation, it would be hard to orchestrate a field test. One would need a fleet of vehicles and also access to the mobile communication infrastructure to measure relevant parameters. Thus, in this paper, we conducted a performance evaluation by using our OMNeT++ [3] simulation framework 5G-Sim-V2I/N [4]. We simulated a real highway V2N scenario in several runs with eight different approaches to define the scheduling priority and measured the packet delay and the reliability on the application layer in DL and UL separately.

In the next section, we summarize related work and point out differences to this study. Afterwards, we describe the preliminary work before we conducted this study, the modifications we implemented regarding the MAC scheduler and the traffic scenario. In the penultimate section, we focus on the simulation results and discuss the findings in detail. Finally, we summarize the findings and give an outlook for future studies.

II. RELATED WORK

Questions surrounding realistic evaluations of different resource allocation algorithms and their effect on network performance have long been studied across different use cases and wireless technologies. In this section, we present some of the recent studies in literature that are related to our work.

Starting with LTE networks, the authors in [5] examine the effects of different scheduling algorithms on the performance

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of different Voice over Internet Protocol (VoIP) traffic flows in an LTE advanced network. The findings show that the Maximum Carrier to Interference Ratio Scheme (MAXCI) achieves the highest throughput and the lowest frame delays among the evaluated schemes. Similarly, the authors in [6] utilize the OMNeT++ framework and the SimuLTE library to test VoLTE performance in a variety of realistic scenarios. The two studies, however, do not consider multi-application scenarios, the effect of HARQ retransmissions nor highly dense scenarios. The authors in [7] extend the SimuLTE framework to enable dedicated bearers by implementing the Traffic Flow Template (TFT) and the GPRS Tunneling Protocol (GTP). Their results show considerable improvements of QoS by using the dedicated bearers, which enables the deployment of low latency applications such as smart time critical smart grids. The study, however, only focuses on static User Equipment (UE) terminals. The work in [8] also utilizes the OMNeT++ and SimuLTE frameworks to study the impact of utilizing different Quality of Experience aware policies and their impact on Packet Loss Rate (PLR) and End-to-End (E2E) delay. The results show a clear trade-off between the two metrics and a need for use case optimization to achieve needed results.

In the context of 5G new radio, the higher level of flexibility in the network and the variety of supported applications generate an abundance of research on the effect of QoS based scheduling. For example, in [9] the authors perform a comparison between different data traffic scheduling techniques such as First-in First-out (FIFO), Priority Queuing (PQ) and Weighted Fair Queuing (WFQ). Their findings show that PQ is the most appropriate queuing technique in case of supporting multiple priority data flows. The findings, however, are not supported with detailed system level simulation and are only constrained to machine-to-machine scenarios. Moreover, in [10] a new mechanism is introduced which considers the network in the context of different traffic type requirements to differentiate the treatments of data delivery in heterogeneous multi-applications networks. Despite evaluating the expected heterogeneity of 5G networks, the evaluations are done relying on the LTE user plane.

The authors in [11] propose a new joint scheduling algorithm that exploits the channel conditions perceived by different users to achieve either a guaranteed or a non-guaranteed bit rate service whilst maintaining fairness. The study however only investigates the performance of the proposed algorithm in a scenario where each UE is only using a single application and without considering the delay aspect for time-sensitive applications. The work in [12] takes a closer look into scenarios where a heterogeneous network builds on the aggregation of the LTE-V and NR-V2X networks. These scenarios require an adaptive scheduling algorithm capable of managing radio resources across different bands to satisfy the QoS of different UEs. The authors proposed a QoS guaranteed scheduling algorithm which takes into consideration the traffic loads, buffer queue length, and the users' fairness index to perform dynamic scheduling. The study, however, assumes also only one application type per UE and simulates the proposed scenario over a very short period of time of 2 seconds, which fails to give a full overview of the network performance.

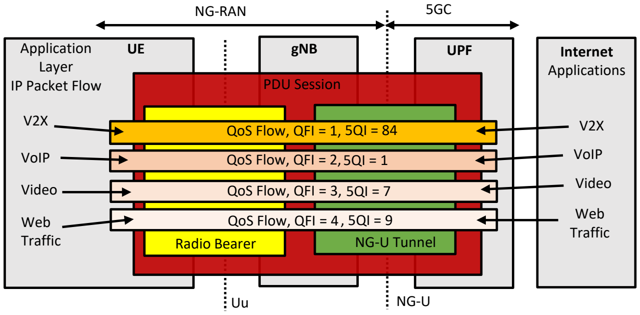


Fig. 1: General QoS model simulation setup

III. PRELIMINARY WORK AND SIMULATION SETUP

In this section, we describe in more detail the preliminary work regarding the modifications of the simulation framework we used for this study (focusing on the MAC layer scheduling). We used version v0.3.4 of the OMNeT++ [3] framework 5G-Sim-V2I/N [4] as a basis and enhanced the MAC layer to enable the usage of the 5G QoS characteristics from [2] in the scheduling procedure.

A. Integration of the 5G QoS Model

The 5G QoS model described in [2] was added to the simulation framework to be able to use standardized QoS characteristic values from Table 5.7.4-1 as a scheduling priority. We focused here on the default priority value and the packet delay budget (PDB). The first characteristic defines a priority among different QoS flows, where the lowest numeric value corresponds to the highest priority.

We implemented QoS flows in a simplified way because the simulator does not cover the control plane. Every data packet is categorized by its type, and each packet type is added to a QoS flow. We enhanced the framework in such a way to configure the application-specific QoS flows by setting the corresponding parameters in the `omnetpp.ini` file: The QoS Flow Identifier (QFI) has to be set to the values as shown in Figure 1. The QFI values remained the same during the simulation and needed to be combined with a 5G QoS Identifier (5QI) value. The 5QI is a pointer to a standardized QoS characteristic from the specification table mentioned before [2].

We consider a QoS profile to be a unique combination of a QFI and a 5QI. For four different applications, we defined a QoS profile with different values for the default priority and the packet delay budget. In Table I the considered QoS profile for this study is summarized. The reason we also considered the packet delay budget, which defines an upper bound for the time between a packet generation till its successful reception, was that a 5QI with a low priority value does not automatically have a low packet delay budget.

TABLE I: QoS profile values

Application	**V2X**	**VoIP**	**Video**	**Web Traffic**
5QI from [2]	84	1	7	9
Default priority	24	*20*	70	90
P. delay bud. (PDB) (ms)	*30*	100	100	300
Packet size (B)	400	70	15000	2000
Packet interval (ms)	100	20	25	80
Total data rate (Mbit/s)	5.06 Mbit/s (consumed by each vehicle)			

A ranking from the highest to the lowest priority would consider VoIP applications first, V2X second, Video third and Web Traffic would be considered as the application with the lowest priority. Using the packet delay budget values (the lowest value means the highest priority) for ordering would consider V2X packets first, followed by VoIP and Video packets, and Web Traffic packets would be considered with the lowest priority.

Within OMNeT++ all relevant protocol layers of the 5G user plane are considered and simulated. The data flow in the DL direction begins at an Internet server on the User Datagram Protocol (UDP) based application layer. Every time when a vehicle appears in the simulation, the application layer of the server is notified and the UDP data flow for this vehicle and four application starts. All relevant parameters regarding the different applications are summarized in Table I. A V2X application here represents a message service, which sends status information about the vehicle to an Internet server (”beaconing”) where the data could be merged with the data of other vehicles to detect traffic jams. VoIP represents a phone call during the drive, and Video addresses a typical video streams application. Finally, Web Traffic addresses best-effort data of different kinds of services which retrieve data via an Internet browser (e.g., e-mail, web search, etc.).

In the `omnetpp.ini` file, the sending interval and the UDP packet size is configured (likewise in UL direction). The server uses these parameters to create a constant and steady data flow of UDP packets. We only consider UDP applications (even for web traffic) to ensure that the TCP flow control does not affect the results. The packets are transmitted to the gNodeB where the corresponding vehicle is connected. The packet size and the message generation rate of each application remained the same for all vehicles during the simulation. The Service Data Adaption Protocol (SDAP) in vehicles and gNodeBs ensures that every packet is marked with the corresponding QoS flow and the corresponding 5QI. On the MAC layer, the scheduler prioritizes the buffered packets by using the values from the corresponding QoS profile of each packet. In Figure 2 the DL scheduling flow is shown graphically.

Every application which sends data to a vehicle has its own buffer. During the scheduling, all buffers with packets of different applications from different vehicles are considered and prioritized. The scheduler also takes into consideration all packets in the HARQ buffers which are ready for retransmission. The scheduler guarantees that only one packet for each vehicle is scheduled during the same transmission time interval (TTI).

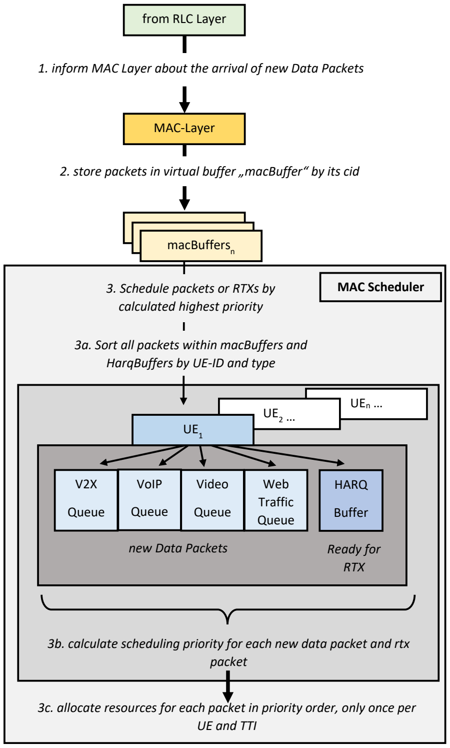


Fig. 2: MAC scheduling workflow in DL (within gNodeBs)

In the UL, the data flow is conversely orchestrated. Each vehicle executes four running applications in parallel and creates packets in an individual and periodic interval. On MAC layer, a scheduling grant has to be requested first before a transmission to the connected base station can be conducted. The procedure is shown in Figure 3.

The priority value is used first on the vehicle side to choose for which packet in any of the macBuffers a scheduling request should be sent. In section III-B, we describe in detail which different prioritization techniques we considered in this study. Within the scheduling request, all necessary information is transmitted to the gNodeB and considered there for scheduling transmission grants. Here, also HARQ buffers are considered. It could be possible that a vehicle receives a grant for a HARQ retransmission even though no grant was requested (for a new transmission). The scheduler in the gNodeB ensures that only one grant for the packet with the highest priority is sent back to the vehicle per TTI.

B. Calculation of scheduling priority variants

Our main goal of this study was to evaluate the application performance by using the default priority values and the packet delay budget values from the 5G QoS model specification [2], which are addressed in the scheduling priority variants 1 and 2. We wanted to compare these variants with other approaches for determining a priority value for each packet. Variants 3, 4 and 5 consider information about the channel quality, the retransmission status and the packet size. As it is

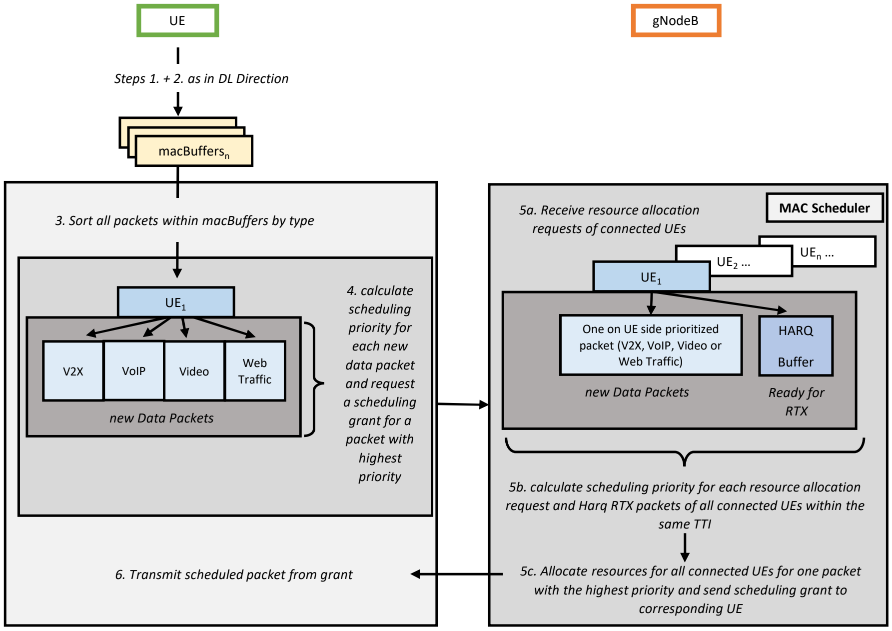


Fig. 3: MAC scheduling workflow in UL

not only sufficient to study the individual performances, we also analyze different combinations of these variants. Table II lists all eight different variants considered, which are going to be described in more details in this section. The calculated priorities of all approaches are normalized values (0 to 1) and are ranked in ascending order, i.e., a value of 0 has the highest scheduling priority.

- The default approach is *variant 0*, which represents a FIFO approach. The scheduler does not calculate an individual priority value and treats all packets (and HARQ retransmissions) identically. The application of each vehicle which started the transmission process first is always scheduled first in this approach. The start of each application is randomized.
- *Variant 1* refers to the default priority value from the QoS profile (Table I). The smallest value represents the highest scheduling priority of a packet. The value is calibrated to a value between 0 and 1 by the following formula:

  $$sPrio_1(n) = \frac{defPrio(n)}{max(allDefPrios)}, \tag{1}$$

  where $sPrio_{DefP}$ is the calculated scheduling priority of a single packet n, $defPrio(n)$ is the default priority value taken from the QoS profile, and $allDefPrios$ is a list of all default priority values of all 5QIs within the specification table from [2] (90 is the highest value).
- *Variant 2* uses the packet delay budget from the QoS profiles to derive a scheduling priority. Here, not the pure numerical value in milliseconds is used, but the remaining delay budget is calculated. For this purpose, the current delay of each packet is calculated first. The calculated delay is subtracted from the packet delay budget and the result is used for the calculation, where also the lowest value represents the highest priority. The calculation is done by the following formula:

  $$sPrio_2(n) = \frac{PDB(n) - (cT - tBuf(n))}{max(allPDBs)}, \tag{2}$$

  where cT is the simulation time the scheduling procedure is executed, $tBuf(n)$ is the timestamp a packet n was sorted into the corresponding MAC buffer, $PDB(n)$ is the packet delay budget value taken from the QoS profile, and $allPDBs$ is a list with all PDBs of all 5QIs within the specification table from [2] in seconds (0.5 is the highest value).

The following three variants do not use standardized values, but live information about each data packet.

- *Variant 3* uses the status information of the channel quality. For this, the Channel Quality Indicator (CQI) is retrieved, which is calculated during a repeating feedback mechanism. A value of 15 represents the best channel quality, a value of 1 the worst. The scheduling priority in this variant is calculated as follows:

  $$sPrio_3(n) = \frac{1}{cqiValue(n)}, \tag{3}$$

  where $cqiValue(n)$ is the latest updated CQI value for the connection between the vehicle and the gNodeB to which the packet n belongs to.
- *Variant 4* uses the number of HARQ retransmissions, which are counted individually for every packet. The higher the number of retransmissions for a single packet, the higher the scheduling priority of the packet. Retransmissions are thus always scheduled preferentially in this method. The scheduling priority is calculated as follows:

  $$sPrio_4(n) = \frac{1}{(1 + numberHarqRtx(n))}, \tag{4}$$

TABLE II: Scheduling priority variants

Scheduling variant	**Priority value**
0	FIFO
1	Default priority from QoS profile
2	Remaining del. budget
3	CQI
4	Number of RTXs
5	Packet size
6	1 & 2 combined
7	1 & 5 combined

where $numberHarqRtx(n)$ is the value which represents the already conducted retransmissions for this packet (0 for new data packets).

- *Variant 5* calculates a scheduling priority based on the packet size. We considered this approach because the packet sizes of our applications differ largely. During our tests, we figured out that this parameter influences the performance severely. For this variant, we assume that the larger the packet, the higher the scheduling priority. With reference to Table I, this means that Video packets are given the highest priority and VoIP packets the lowest. The priority is calculated by the formula:

$$sPrio_5(n) = \frac{min(pSizeAllPackets)}{packetSize(n)}, \qquad (5)$$

where $packetSize(n)$ is the size of the packet n in Bytes, and $pSizeAllPackets$ is a list with all packet sizes of the four different applications used during the simulation (see Table I).

- *Variant 6* is a combination of variant 1 and variant 2 and is calculated as follows:

$$sPrio_6(n) = sPrio_1(n) + sPrio_2(n), \qquad (6)$$

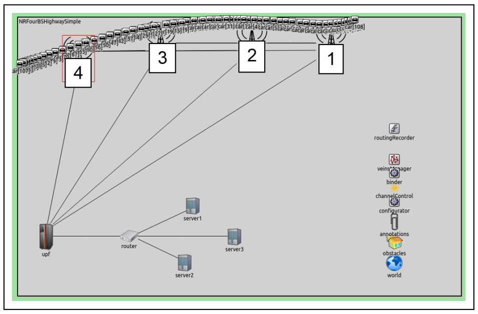
- *Variant 7* is a combination of variant 1 and variant 5 and is calculated as follows:

$$sPrio_7(n) = sPrio_1(n) + sPrio_5(n), \qquad (7)$$

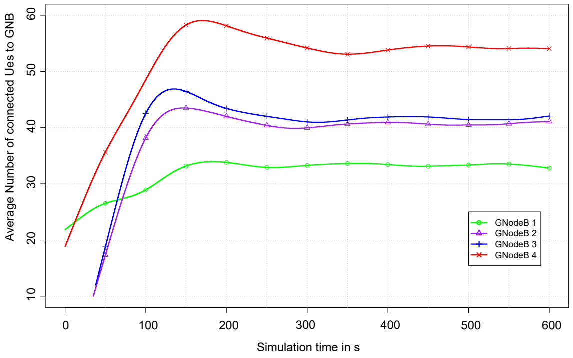
With variants 6 and 7 the calculated priority value can be between 0 and 2.

C. Traffic scenario and simulation setup

In our simulator, the OMNeT++ framework is coupled with the traffic simulator SUMO [13] for an online exchange of all relevant vehicle mobility data (e.g., speed, position, etc.). All different scheduling approaches were simulated in a highway traffic scenario, which represents a part of the German highway A6 and has two lanes in both directions. Vehicles start from the left- and right-hand side at the beginning of a simulation, and drive along the whole lane. Both lanes are filled with cars after a hundred seconds of the simulation time has elapsed, and about 200 vehicles are simulated simultaneously until the simulation finishes. Figure 4 shows a screenshot from the OMNeT++ GUI and also illustrates the average number of vehicles connected to gNodeBs during the simulation.



(a) OMNeT++ GUI screenshot (with IDs of all gNodeBs)



(b) Average number of vehicles connected to gNodeBs

Fig. 4: Highway simulation scenario

Most relevant simulation parameters are summarized in Table III. Under the best channel conditions every gNodeB could provide a maximum data rate of about 310 Mbit/s and under the worst channel conditions only about 9 Mbit/s. These data rates can be calculated with the formula of the calculation of the transport block size (TBS) in [14]. The simulator uses the Modulation and Coding Scheme (MCS) Table 5.1.3.1-2 from [14] and under the best channel conditions the index 27 of the mentioned table would be chosen. With a total number of 270 Resource Blocks (RB), one MIMO-layer, a subcarrier-spacing of 15 kHz and 14 scheduled symbols a maximum TBS of 311 368 bit would be available in a TTI of 1 ms. In the worst case, the index would be 0 and with the same values for all other parameters a maximum TBS of 9744 bit would be available. Theoretically, the scenario should therefore provide sufficient bandwidth for the constant data rate of 5 Mbit/s for each vehicle. However, no flow control was implemented, which means that on application layer all applications continued the packet generation, even when the channel quality was impaired due to interference or other disruptive factors (e.g., long distances between sender and receiver).

IV. SIMULATION RESULTS

In this section, we discuss the simulation results. As metrics for the performance analysis, we measured the E2E packet delay on the application layer and also the reliability of each packet. In the DL direction, the delay was measured on each

TABLE III: Simulation parameters and characteristics

Simulation time	600 s
Channel model from [15]	RMa_A
Carrier frequency	2.1 GHz
Bandwidth	50 MHz (270 RB)
Subcarrier spacing	15 kHz
TxPower cars	23 dBm
TxPower gNodeBs	40 dBm
Height cars	1.5 m
Height gNodeBs	35 m
Antenna gain cars	0 dBi (omni-dir.)
Antenna gain gNodeB	8 dBi (omni-dir.)
Average vehicle speed	$80 - 180\,\mathrm{km/h}$
Tx mode	Single port antenna (1 layer)
MCS Table	Table 5.1.3.1-2 from [14]
OMNeT++ seed values	$0 - 4$

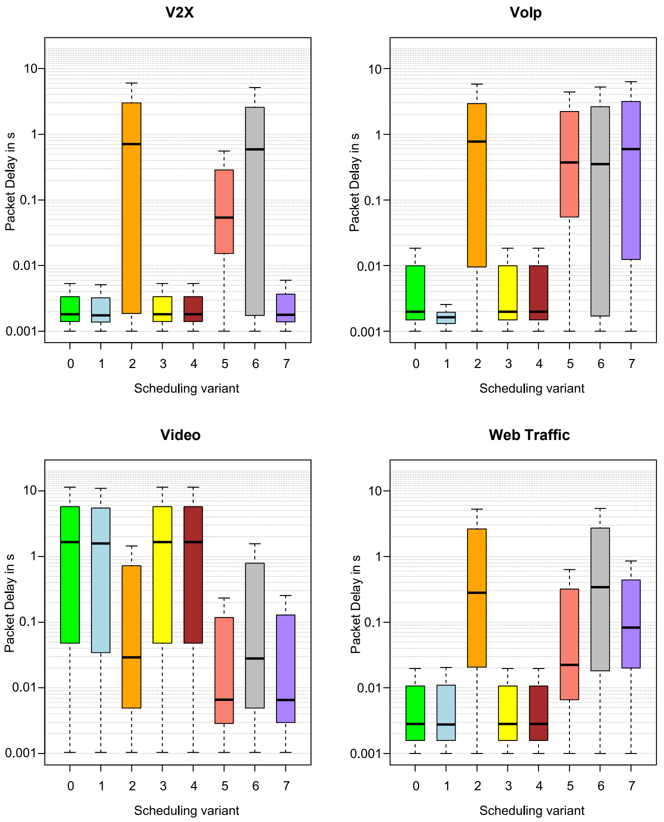


Fig. 5: Downlink delay results

vehicle which received packets for the corresponding application. All measurements on vehicles from all five different runs (with seed values 0 - 4) for each scheduling variant were collected and are shown in the following figures. These result graphs show all delay values as box plots for all four simultaneously running applications on the Y-axis and across different scheduling priority variants on the X-axis (see Table II).

The reliability is based on the packet delay and expresses the probability that a single packet was delivered to the application layer successfully within its default packet delay budget (PDB) from Table I. After the calculation of the packet delay, it was checked whether the corresponding delay budget was met or not. The results for these measurements are shown as box plots, and the reliability value on the Y-axis shows the percentage of all correctly received packets for the corresponding application.

A. Downlink results

In Figure 5 the results of the packet delay in DL direction are shown. The green box plots represent the default approach without any scheduling priority. That means during every TTI, all packets which competed for resources were allocated by a FIFO principle. It is interesting to see that only the Video application performs poorly with a median delay of about 1 s.

The box plots for scheduling variant 1 with the priority value from the QoS profile show a similar behavior like the scheduling variant 0 and it seems that the packet size of one single packet plays an important role. This can be explained by the behavior of the scheduler: After the calculation of the scheduling priority, packets with the same priority are collected in an unordered list and the scheduler only ensures that packets with a higher priority are sent first. Packets with the same priority value were treated without any further considerations and if the priority calculation leads to a limited range of different priority values, then applications with larger packet sizes suffer from this behavior because the needed bandwidth is already reserved for packets of other applications with the same priority.

We have to consider that profile 1 defines the highest priority value for the VoIP application and the lowest for Web Traffic. It is remarkable that the Video application performs as badly as with the default variant, although it does not have the lowest priority.

Remarkable is the performance of scheduling variant 2. Here, the remaining delay budget is used for the calculation of the priority. Considering the raw packet delay budget values from the QoS profiles in Table I, the V2X application should perform best and Web Traffic worst. This approach leads to a larger scattering of the delay results for V2X, VoIP and Web Traffic applications. The performance of these applications suffers tremendously, especially V2X and VoIP packets reached median delay values of about 1 s. Video packets perform really good (median delay about 30 ms). Once more, the packet size can justify this because the Video packets are the largest in size and have the second-highest packet generation rate, which results in video packets consuming most of the bandwidth leaving less resources for other applications to consume.

Variants 3 and 4 show similar results as variants 0 and 1. It seems that these variants are not good in combination with applications with large packet sizes.

The results of variant 5 confirm our assumptions. Here, the packet size of a single application packet was used for the calculation of the scheduling priority. The higher the packet size, the higher the priority of this packet was considered. The results show a much better performance of video packets,

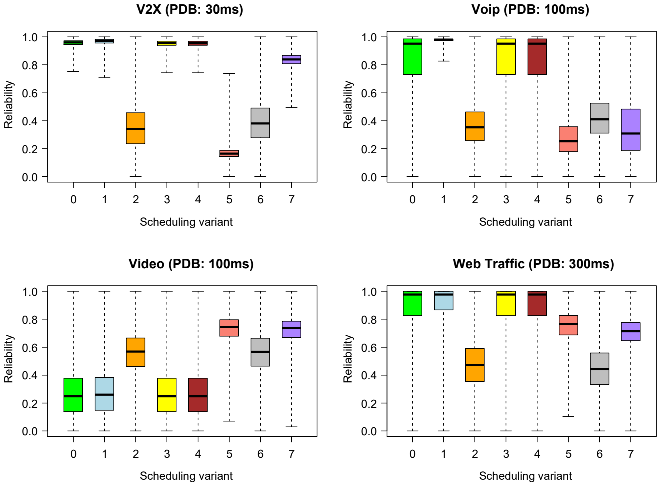


Fig. 6: Downlink reliability results

but led to a much worse performance for VoIP applications. Nevertheless, it leads to sufficient median delay values for Video and Web Traffic packets.

As detailed in the previous section, we also analyze the combination of these variants. Variant 6 combines variants 1 and 2. The delay of Video packets could be reduced largely, but all other applications lost performance dramatically. Nevertheless, in comparison to variant 2 one can see some reduction of the (median) delay of V2X and VoIP packets.

Furthermore, variant 7, a combination of variant 1 and 5, shows a performance boost especially for V2X and Video packets. On the other side, VoIP packets perform worse than in case of the variants based on the remaining delay budget.

The reliability results in Figure 6 confirm our findings from the pure delay values. Variants 0, 1, 3 and 4 guarantee reliability values of almost 100% for V2X, VoIP, and Web Traffic packets, but on the other hand lead to a weak Video performance (about 20%). Most promising with regard to a good performance of all four applications, seems variant 7, where only VoIP performs weakly with a reliability of about 40%.

Considering the overall performance in DL direction of all four application types, the usage of standardized priority values for scheduling packets does not seem to be sufficient to guarantee an adequate performance for all applications. A combination of the different variants seems to be most promising regarding better performance. Special notice should also be given to packet size as the larger the packet size the worse the performance. Using the packet size as a basis for the scheduling priority calculation affects the performance of applications with large packet sizes enormously.

B. Uplink results

In Figure 7, the results of the packet delay in UL direction are shown. The different scheduling procedure has to be taken into account in this direction. On the vehicle side, a calculation of the highest scheduling priority is done first. For that packet, a scheduling grant is requested from the connected base station and the base station only takes the already preselected packets into account for scheduling. Due to the reduced transmission power of a vehicle, the received signal strength of a transmitted packet is worse than in the DL direction and leads to higher delay values in general.

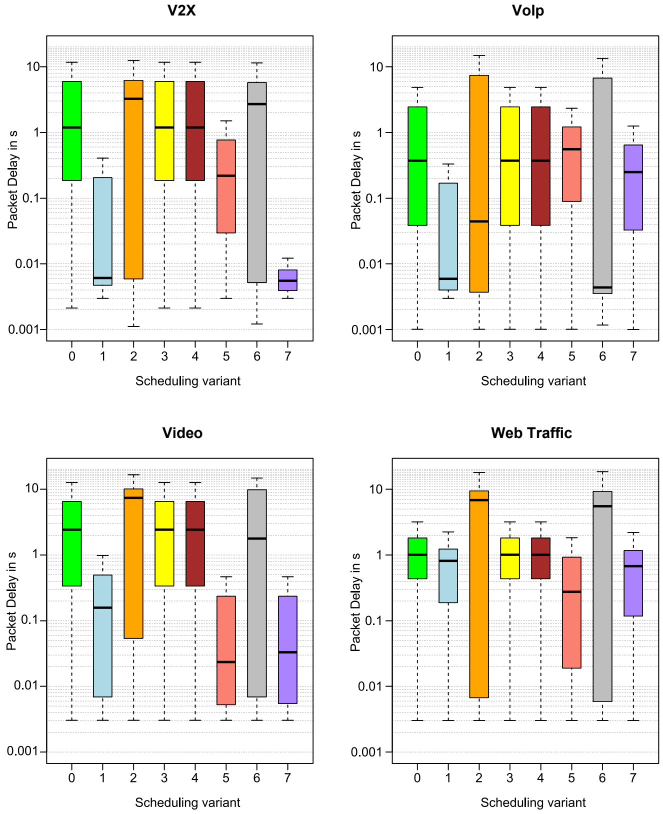


Fig. 7: Uplink delay results

Scheduling variant 0 shows a bad performance. All four applications reach a median delay of about 1 s.

Remarkable is the performance boost of variant 1 for all four applications. In DL direction, this variant only led to a better VoIP performance. Especially, the delay of V2X and VoIP packets can be reduced largely. Also, the results for Video and Web Traffic could be appropriate for most real scenarios (especially, if a buffered Video stream application is assumed).

The large scattering can also be seen in the DL direction with variant 2. The Video application also shows worse results than with the previous variant. Variant 2 seems to be inappropriate for the UL scheduling.

Variants 3 and 4 show similar delay values like variant 0 for all four applications and seem to be inappropriate likewise.

Interesting to see is that variant 5 led to a good performance for Video packets, and the median delay values of V2X and Web Traffic packets could also be sufficient enough. Only the median delay of VoIP packets is too high (about 1 s). So, considering the packet size for the scheduling priority affects the delay values also in the UL direction.

A combination of variant 1 and 2 led only for Video

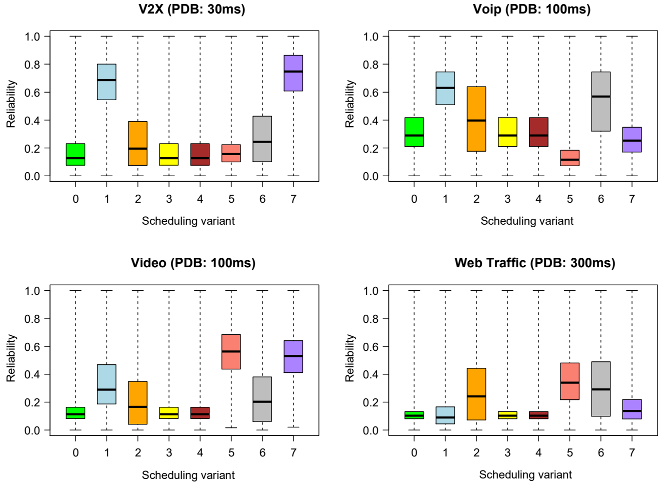


Fig. 8: Uplink reliability results

and VoIP packets to smaller median delays in comparison to variant 2. Therefore, this variant is also insufficient.

Variant 7, a combination of variant 1 and 5, shows good results for V2X and Video packets. Unfortunately, the performance of VoIP packets is decreased.

The reliability results in UL direction are shown in Figure 8. We can see a good performance for V2X and VoIP applications with variant 1. Variants 2, 3 and 4 seem insufficient for all applications. Variants 5 and 7 show the best reliability results for Video packets, but only variant 7 shows good results for the V2X application. Variant 6 shows insufficient results for all four applications.

In UL direction, sufficient results for at least two applications could be reached with variants 1 and 7. Like in the DL direction, considering the packet size in the scheduling priority calculation could lead to a better performance of several applications.

V. CONCLUSION AND FUTURE WORK

In this study, we investigated the effects of using different priority calculation mechanisms for a priority-based scheduler on MAC layer in a 5G V2N scenario, considering four different applications running in parallel by measuring the E2E packet delay and reliability in DL and UL for a performance evaluation. With an OMNeT++ simulation, we simulated a highway traffic scenario for all combinations. Some variants were based on standardized scheduling parameters from the 3GPP 5G QoS model [2], the other variants consider packet related values, e.g., the packet size, for the calculation of a scheduling priority.

The usage of standardized values does not seem to be sufficient to guarantee an adequate performance for all four applications. A combination of the different variants seems to be most promising regarding a better performance in both directions. The bigger the packet size, the worse the performance of the corresponding application. Using the packet size in the calculation of the scheduling priority affects the performance of applications with large packet sizes tremendously.

As future work, we want to investigate the performance of the standardized values in more specific V2N use case (e.g., remote driving). Finding the best combination of parameters for the calculation of a scheduling priority is also of interest, which could be investigated with machine learning approaches.

The source code of the modified framework used for this study will be published in the near future on GitHub [16].

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