# MCS Adaptation and its role in improving MAC Scheduling for Variable Packet Sizes in NR-V2X

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***Abstract*—This paper investigates the significance of assuming an adaptive Modulation and Coding Scheme (MCS) when scheduling packets of varying sizes in New Radio V2X (NR-V2X). It is envisaged that many existing and future event driven vehicular services will exhibit significant variance in packet sizes, both between applications and within the same application. To ensure a sufficient quality of service, NR-V2X and its predecessor Cellular V2X (C-V2X) must be able to effectively schedule these diverse packet sizes. As such, this paper analyses the impact of fixed vs adaptive MCS selection and shows that assuming an adaptive approach is preferable in all cases, especially when dealing with varying packet sizes. A fixed MCS is commonly assumed in literature and this paper shows that such an assumption can have a large negative performance impact on the MAC layer scheduler. We further evaluate that considering an MCS range exceeding that specified in the current standard is extremely beneficial and evaluate the performance of alternative MCS selection schemes that minimise disruption in the MAC layer grant mechanism. We find that the default standardised MCS selection mechanism still remains preferable.**

***Index Terms*—Cellular V2X, LTE-V, sidelink, NR-V2X, aperiodic, CAM, autonomous resource selection, 4G, 5G, SPS.**

## I. Introduction

NR-V2X [1] is the latest evolution of the C-V2X standard introduced by 3GPP in Release 14 [2]. In recent years, vehicular cellular standards have gone from definition to deployment, with FCC regulation of ITS frequencies driving significant developments in the US. In Europe the frequency bands are currently technology agnostic although a significant adoption of cellular standards is underway. With C-V2X and NR-V2X adoption becoming more widespread, a thorough examination of the standards effectiveness is necessary. This paper specifically considers the effectiveness when scheduling packets of variable size. It is expected that many vehicular services will generate variable sized packets as the payload will be dependant on the vehicle's situation and environment, with parameters that can change frequently. Furthermore packet headers may change based on the configuration of the C-ITS service e.g with respect to security. Examples of these services include Cooperative Awareness (CA) service, where vehicles broadcast their location and dynamics and Cooperative Perception (CP) to exchange information discovered by sensors e.g. a vehicle "discovering" a Non-Line Of Sight (NLOS) cyclist cooperatively from another vehicle or infrastructure. What is common amongst these applications and many others in a vehicular context is that the packets are typically event driven and their size is not fixed. However this is a challenge due to the nature of the standardised scheduling mechanism, where a grant is maintained for a number of transmission opportunities. As such, if packet sizes change dynamically, this may mean a grant has to be broken if the resources are insufficient.

This paper seeks to investigate the role and significance that an adaptive Modulation and Coding Scheme (MCS) mechanism plays in effectively scheduling packets in NR-V2X/C-V2X, especially when dealing with varying packet sizes. The majority of studies in literature that evaluate C-V2X and NR-V2X performance assume a fixed MCS for the duration of a simulation. This is not in accordance with the standards that specify an adaptive MCS selection scheme, where the MCS is chosen to maximise robustness while minimising subchannel occupation. While ignoring this is not ideal, it may be permissible if careful consideration is given to fixed packet sizes and the channel configuration. However it is the hypothesis of this paper that MCS adaptation is vital when conducting a study where the packets vary in size, indicative of many real world vehicular services. We further propose that the standard should consider a much wider range of MCS' that are currently specified and we investigate whether choosing alternative MCS selection strategies that minimise grant breaks in the scheduler improve overall system performance.

The rest of this paper is organised as follows. Section II gives an overview of the academic literature related to SB-SPS performance with varying packet sizes, with a specific focus on MCS selection. Section III provides a description of the standardised C-V2X & NR-V2X MAC scheduler and MCS selection mechanisms. A performance evaluation is carried out in Section IV with Section V providing concluding remarks.

## II. Related Literature

There has been limited work focused on MCS adaptation in the literature; most studies in the area of MCS assume it to be fixed and evaluate the impact of different MCS between simulation runs as opposed to adapting within the same scenario. In the same vein, there has been a somewhat limited focus on variable packet sizes in C-V2X and NR-V2X, with the majority of studies focusing on a single packet size.

One of the first papers that looked at both aperiodic arrival rates and variably sized packets was by Molina et al. [3]. This study highlights some of the challenges with variable packet sizes and how it can introduce increased reselection events in the MAC scheduler as a result of the change in packet size. This change ultimately results in grants being unable to accommodate changes in packet size, and this can negatively impact performance. However this study considers a fixed MCS throughout, which does ultimately does not reflect how the standard is meant to operate (i.e. with MCS adapting to packet size). Qualcomm published a rebuttal of such approaches arguing that if adaptation is not enabled, the performance of C-V2X is artificially degraded [4], which this study will corroborate. A similar study for NR-V2X was completed in [5], though with the same limitations as [3].

A recent study by Harri et al. [6] evaluated variable packet sizes in NR-V2X, with realistic packets ranging from 200 to 1500 Bytes. This study ultimately concludes that using the highest-order MCS, specifically 64 QAM MCS 24, is the best choice for scheduling these packets. Section IV will corroborate this, showing improved performance from higher-order MCS. One aspect which is not considered is adapting within those higher MCS'. This paper will ultimately show that while allowing for selection of higher MCS' beyond the current standard specification is better, it is the adaption of the MCS within the scheduler that will provide the most improved performance in all cases.

Similarly, the authors in [7] provide a comparable study. This is interesting as it provides results from real-world experimentation involving two vehicles to provide validation against simulated results. The final conclusion is the same as [6] i.e. a higher MCS and reduced subchannel usage will improve the performance of C-V2X/NR-V2X. Notably, the MCS remains fixed for each test and as such exhibits the same limitation as the previous study.

## III. MCS ADAPTATION IN THE C-V2X & NR-V2X SIDELINK

While NR-V2X Mode 2 adopts the same general MAC layer scheduler as C-V2X i.e. Sensing-Based Semi-Persistent Scheduling (SB-SPS), there are two significant differences. The first is the introduction of a re-evaluation technique, which enables vehicles to reschedule when a higher priority packet is deemed to have reserved the same transmission resource. The second is that potential transmission resources, referred to as Candidate Single Subframe Resources (CSRs), are no longer filtered based on RSSI. This means that any resource that is deemed to not be reserved, i.e. no sidelink control information message (SCI) has been received and there is a sufficiently high RSRP, will be available for selection. This was introduced to address issues with aperiodic packet arrival rates and frequent grant reselection.

Within SB-SPS resources are maintained for a period known as a grant which is typically 5-15 transmissions. This is the basis upon which the scheduler operates. SB-SPS accommodates packets size variability in two ways. It schedules grants of different sizes i.e. occupied subchannels, based on the size of the packet. These are the resources that are reserved for the duration of the grant. The second aspect is the use of an adaptive MCS selection mechanism within the grant on a per packet basis. The MCS determines how efficiently data is encoded in RBs, with a higher order MCS allowing an RB to hold a greater number of bytes. This comes with a trade-off; higher order MCS' exhibit less error redundancy in the encoded packet, and as such transmitted packets will be more susceptible to errors and ultimately loss. Lower order MCS allow for more robust transmissions but have large RB occupancy. As such there is a tradeoff between efficiency of resource usage and effective communication.

Thus, SB-SPS determines the size of the grant i.e. minimum number of subchannels required, based on the initial packet size and the available MCS'. On initial and subsequent transmissions within this grant, it will then select the optimal MCS i.e., using the fewest subchannels and the lowest MCS that accommodates the packet size, balancing resource usage with transmission robustness.

However if subsequent packets are too large, it may force grant breaking and resource reselection. The negative impact of grant breaking as a result of aperiodic arrival rates was evaluated in [8]. A similar challenge exists for varying packet sizes which causes a significant performance degradation as shown in Section IV. Therefore, considering that variable packet sizes are common in event driven vehicular services and that once the grant is generated, the allocated subchannels cannot be increased, adapting the MCS becomes the primary means by which the grant is maintained.

## IV. PERFORMANCE EVALUATION

The experimentation in this paper is conducted using the OpenCV2X model [1] for OMNeT++, which is a Mode 4 model that has been extended for Mode 2 MAC scheduling of Rel. 16 NR-V2X [9]. The parameters used in the investigation are described in Table I. The ETSI standard [10], specifies an MCS range from 0 - 11 at speeds below 160 Km/h. The default configuration of 5 subchannels with 10 RBs each is assumed and will form the basis for this evaluation.

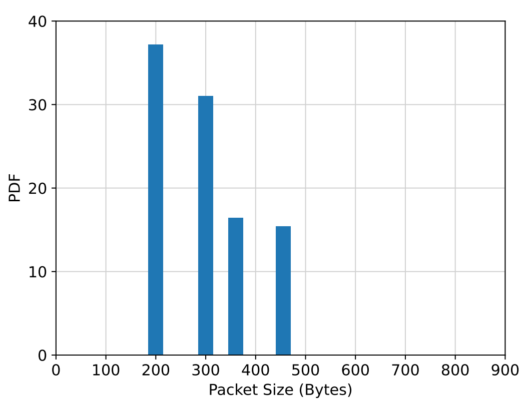
### A. Modelling of Packet Size Variability

Packet sizes are generated by the analytical model provided by Molina-Masegosa et al. [11], which is based on empirical data gathered from two vehicular manufacturers (Volkswagen & Renault) across three environments (Highway, Urban and Hybrid) [12]. As the study in this paper investigates the impact of MCS adaptation on the scheduling of packets of variable size, we consider a fixed transmission rate of 10Hz to avoid the negative impact of aperiodic transmissions on the scheduler, as studied in [8]. Fig. 1. shows the distribution of packet sizes across both vehicle models. For Volkswagen, most generated CAMs range from 200-455 Bytes in size, with more than 85% under 400 Bytes. The Renault model experiences a

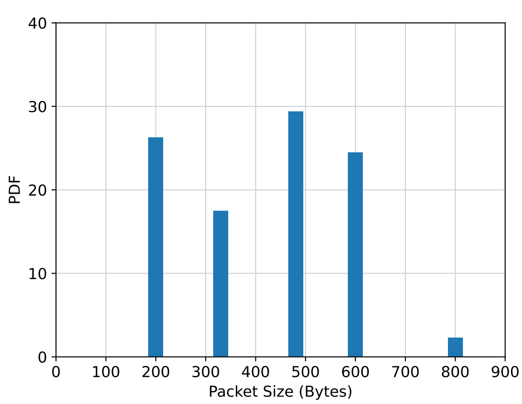
[1] https://www.cs.ucc.ie/cv2x

TABLE I: Simulation Parameters.

| Parameter | Value |
|---|---|
| **Vehicular scenario** | |
| Vehicular density | 0.2 veh/m |
| Road length | 2km |
| Number of lanes | 3 in each direction (6 in total) |
| Vehicle Speed | 40km/h |
| Vehicle Mobility | SUMO (step-length = 10ms) |
| **Channel settings** | |
| Carrier frequency | 5.9 GHz |
| Channel bandwidth | 10 MHz |
| No. subchannels, Subchannel size | 5, 10 Resource Blocks (RBs) |
| **Application layer** | |
| Transmission frequency | 10 Hz |
| **MAC & PHY layer** | |
| Resource keep probability | 0 |
| RSRP threshold | -126 dBm |
| RSSI threshold | -90 dB |
| Transmission power | 23 dBm |
| Propagation model | Winner+ B1 |
| Noise figure | 9 dB |
| Shadowing variance | 3 dB |




(a) Volkswagen.




(b) Renault.

Fig. 1: Distribution of empirical CAM packet sizes for the highway scenario.

significantly larger distribution in packet sizes, with packets of up to 800 Bytes occurring. As discussed in [12], CAM sizes can vary depending on the number of optional fields configured and the size of the payload. We also consider a fixed packet size of 190 Bytes in the performance evaluation, which is a commonly assumed packet size in the related literature.

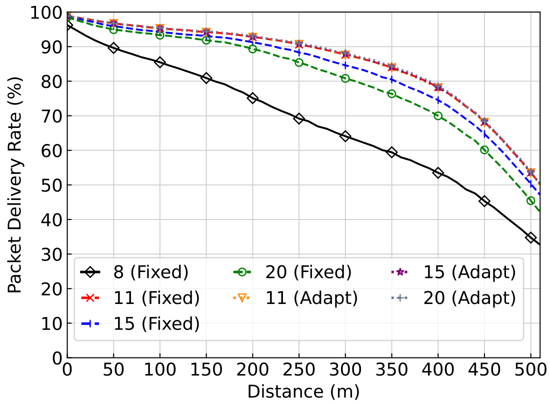
ETSI recommends a default configuration of 5 subchannels, composed of 10 RBs each, assuming a total channel bandwidth of 10 MHz [10]. Given this configuration and the 8 packet sizes collected in the empirical Volkswagen and Renault datasets, Table II shows the minimum subchannel occupation, the default MCS chosen, and the maximum byte capacity for all the packet sizes that occur in the empirical datasets. It is clear that a significant number of subchannels are required for the larger packet sizes, e.g. 4 subchannels are necessary for packet sizes of 600 or 800 Bytes. All packets for the Volkswagen model can be transmitted using 3 subchannels or less.

TABLE II: Default MCS & subchannel allocation for the Volkswagen & Renault empirical data sets.

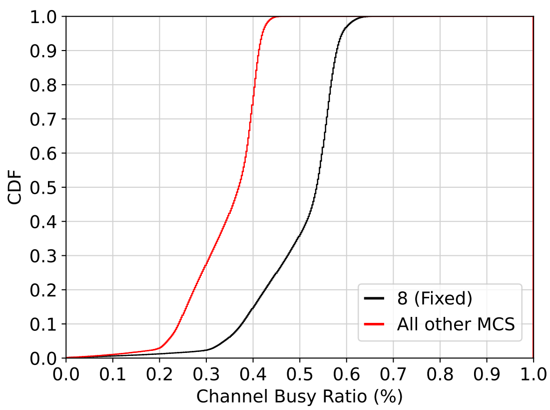
| Vehicle Model | Pkt Size (B) | Subchannel Occupation | Default MCS | Max Capacity (B) |
|---|---|---|---|---|
| Fixed | 190 | 1 | 11 | 201 |
| Volk & Ren | 200 | 1 | 11 | 201 |
| Volkswagen | 300 | 2 | 8 | 310 |
| Renault | 330 | 2 | 9 | 350 |
| Volkswagen | 360 | 2 | 10 | 390 |
| Volkswagen | 455 | 3 | 8 | 483 |
| Renault | 480 | 3 | 8 | 483 |
| Renault | 600 | 4 | 8 | 656 |
| Renault | 800 | 4 | 10 | 824 |

### *B. Adaptive versus non-adaptive MCS performance*

The first set of results, shown in Fig. 2a and Fig. 2b, set out to evaluate the significance of utilising the adaptive MCS scheme set out by cellular vehicular standards when conducting C-V2X and NR-V2X experiments. A fixed MCS is commonly assumed in related literature. To highlight the significance of sub-optimal MCS choices, a scenario with a 190 B fixed-size packet is initially considered. Based on this, it is known that MCS 11 is the optimal choice based on Tables 7.1.7.2.1-1 and 8.6.1-1 provided in [13]. This is because it allows a packet to be transmitted in a single subchannel. Fig. 2a shows that choosing MCS 11 (red dashed line) performs significantly better than configuring a sub-optimal MCS such as MCS 8 (black diamond line) which is used here as a comparison. The reason for this becomes obvious in Fig. 2b. MCS 8 exhibits a significantly higher CBR, as it requires two subchannels instead of the single subchannel that MCS' 11 and above will occupy. However it is also not simply a case of arbitrarily using a higher order MCS indiscriminately. While MCS' 15 and 20 (Fixed) also only occupy a single subchannel, the PDR declines as the MCS increases. This is because it cannot further reduce subchannel occupation, yet

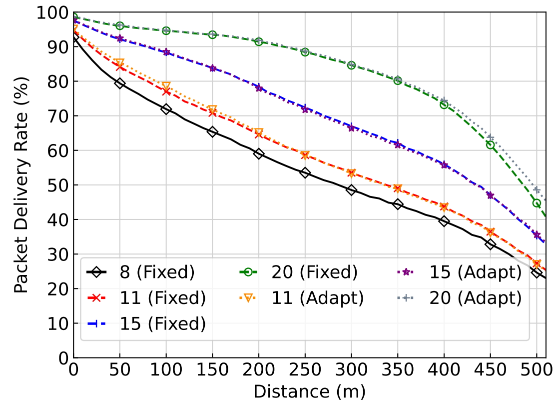



(a) PDR.

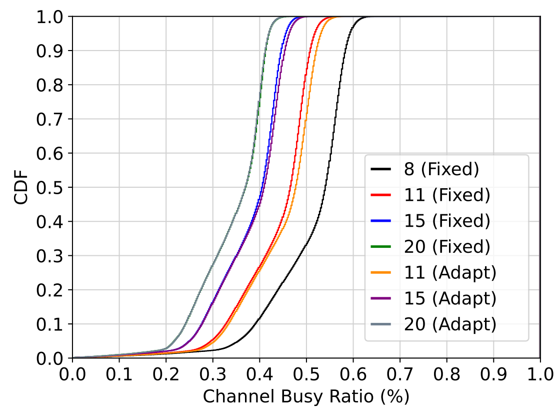



(b) CBR CDF.

Fig. 2: Performance considering a fixed packet size of 190 B.




(a) PDR.



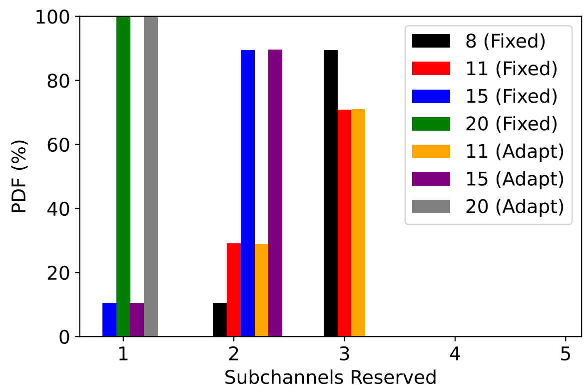

(b) CBR CDF.

Fig. 3: Performance considering the Volkswagen packet size distribution.

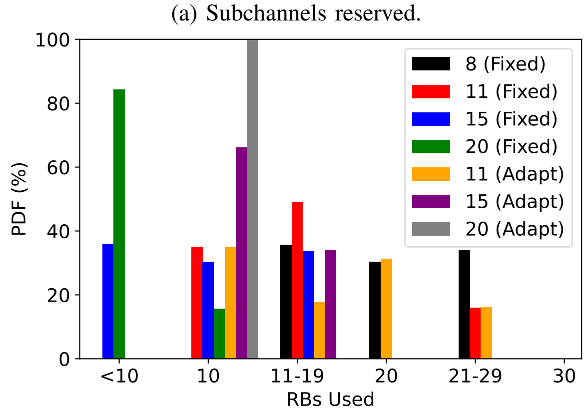
increasing the MCS impacts the robustness of transmissions resulting in increased packet loss. Swapping to an adaptive approach, allows the system to choose the optimal MCS based on the packet size. In this case, as the packet size is fixed, the optimal MCS will always be MCS 11 and as such we can see that MCS 15 (Adaptive, purple star) and MCS 20 (Adaptive, grey bar) both exhibit the same high PDR as MCS 11 (Fixed) and MCS 11 (Adaptive). This is because it automatically conforms to the optimal MCS for the fixed packet size. Thus, this introduces an important tenet of the operation of standardised MCS adaptation; the MCS should be increased such that subchannel occupation is minimised as much as possible to improve channel utilisation while ensuring the MCS is kept as low as possible so as to not degrade robustness of transmissions.

The second set of results, shown in Fig. 3, focus on the Volkswagen empirical data and set out to explore whether higher order MCS should be considered beyond the maximum range (MCS 0 - MCS 11) set out by the ETSI standard [10]. Fig. 3 provides clear motivation for this, showing that utilisation of MCS' up to 64QAM MCS 20 should be considered, further corroborating research by Harri et al. [6]. As shown in Fig. 3a, selecting MCS 20, whether adaptive or not, shows the most significant improvements in performance. This is due to the reduction in collisions due to the reduced CBR, which is a direct result of reduced subchannel occupation, as shown in Fig. 3b. Even MCS 15, which is 16QAM, results in significant performance improvements.

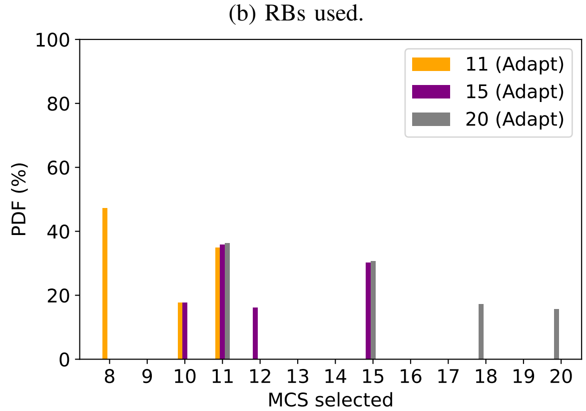
Fig. 4 provides deeper analysis on the performance of each MCS configuration with a focus on the reserved subchannels, the RBs used, and the MCS selected given adaptation for variable packet sizes. In Fig. 4a it is worth noting that MCS 8 and 11 (Adapt and Fixed) can use up to 3 subchannels, while MCS 15 will use a maximum of two, and finally MCS 20 will only require one subchannel to transmit each packet size. Fig. 4b shows a PDF of the RBs used for each transmission. It can be observed that MCS 20 (Adapt) will always use the full 10 RBs, while in the case of MCS 20 (Fixed), the RB usage can drop below 10. However, this RB reduction does not have a PDR benefit, as we observed in Fig. 3a, with a minor drop in performance at distances beyond 400m as a result of the reduced robustness of the transmission. To reiterate, this signifies that there is little point in RB reduction if subchannel occupation cannot be reduced further. Fig. 4c shows a PDF of how often a particular MCS is used, given the range of MCS that could pitentially be used for a particular packet size. Fixed MCS is not shown as no change in MCS will occur. It can be observed that an adaptive MCS scheme can exhibit significant variation in the MCS used e.g. for MCS 20 (Adapt), the MCS used can range from MCS 10 to MCS 20 itself. This echos earlier observations that performance can be significantly positively influenced by utilising a wider availability of MCS within an adaptive approach.




(a) Subchannels reserved.

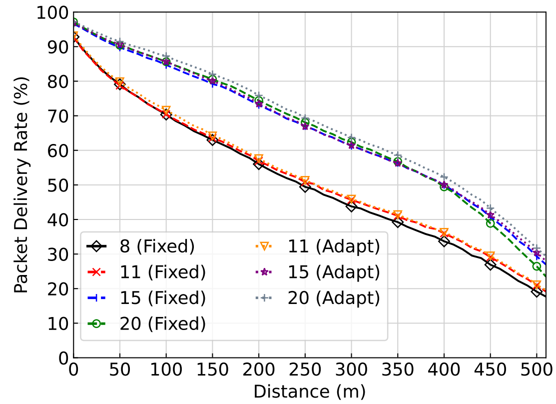



(b) RBs used.

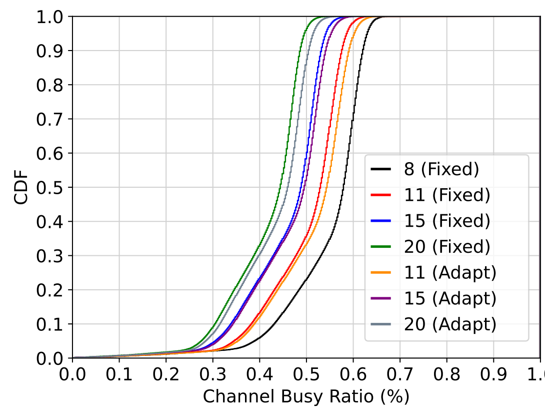



(c) MCS used.

Fig. 4: Radio resource usage considering the Volkswagen packet size distribution.




(a) PDR.




(b) CBR CDF.

Fig. 5: Performance considering the Renault packet size distribution.

The empirical Renault data set, which exhibits much larger differences in CAM size is considered in Fig. 5a. It is once again clear that MCS 11 (fixed) limits the performance of the model, and increasing this to MCS 15 allows for significant performance improvements. Furthermore, it can be observed in Fig. 5b how the CBR decreases in steps once the MCS is increased. Notably, adaptive MCS 20 is once again the best performing, but performance improvements are more marginal than for the Volkswagen dataset. This highlights the fact that packet sizes, the number of subchannels and RB configuration have a significant impact on the performance benefits that these mechanisms can gain. Ultimately, the optimal MCS will depend on the specific configuration of the scenario. However, what is important is that enabling a high MCS such as MCS 20 and allowing adaptation within that wider range ultimately result in the best performance. As such, it is paramount that within any study assuming variable packet sizes, common to almost all realistic vehicular applications, the simulation model should implement MCS adaptation as per the C-V2X and NR-V2X standards.

### C. Grant Optimisation

As stated, the default adaptive MCS selection process in C-V2X and NR-V2X chooses an MCS so as to occupy as few subchannels as possible while ensuring the lowest possible MCS for robustness. The challenge is that packet sizes are variable and thus can change over the course of an SB-SPS grant. If a packet is too large to transmit, the grant is broken and the grant selection process commences again.

This section seeks to investigate different MCS selection approaches to investigate the trade-off between the current default approach where the grant is determined based on the packet at generation time vs an approach that could seek to optimise MCS selection based on possible distribution of packet sizes incurred by a given application.

To do this we evaluate the following:

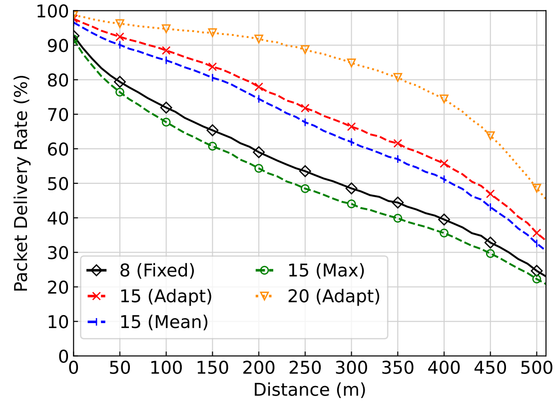
- **SPS grant generation using the Default C-V2X/NR-V2X MCS Selection Scheme:** This is the approach adopted so far in the investigation and described in Section III.
- **SPS grant generation using an MCS Selection Scheme to minimise grant breaking:** By examining typical distribution of packet sizes, an MCS will be selected based on the largest possible packet. In the case of Renault, this is an 800Byte packet. This approach will eliminate the need for grant reselections at the cost of increased subchannel occupation. This is labelled *(Max)* in Fig 6.
- **SPS grant generation using an MCS Selection Scheme based on mean packet size:** This selection scheme is a tradeoff between the first two where the MCS will be selected such that it fits most of the packet sizes that occur, with the exception of rare larger packets. This will balance the subchannels occupied while reducing the number of reselections. This is labelled *(Mean)* in Fig 6.

It is clear from Fig. 6 that adopting an approach other than the default MCS selection scheme is not beneficial. On the contrary, it can have a serious negative impact on performance even if it reduces the number of SB-SBS grant reselections. This is highlighted by the performance of the MCS 15 (Max) configuration for both Volkswagen and Renault. The negative impact for MCS 20 is less pronounced, but ultimately still does not offer any benefit.

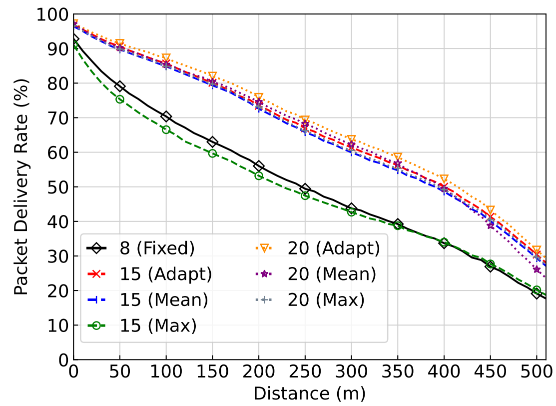
TABLE III: Grant Breaking due to packet size

| MCS | MCS adapt | Volkswagen | Renault |
|---|---|---|---|
| 8 | Fixed | 2544 | 2715 |
| 15 | Adapt | 2519 | 1496 |
| 15 | Mean | 0 | 475 |
| 15 | Max | 0 | 0 |
| 20 | Adapt | 0 | 1669 |
| 20 | Mean | - | 1694 |
| 20 | Max | - | 0 |

This is somewhat unexpected as it could be assumed that by reducing grant reselections, an improvement in PDR would be observed.




(a) Volkswagen.




(b) Renault.

Fig. 6: Performance based on alternative MCS Selection Strategies linked to packet size distributions i.e. deviating from the standard SB-SPS grant selection mechanism.

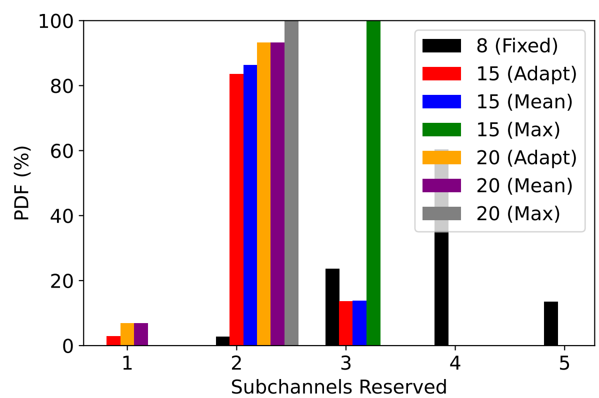



Fig. 7: Subchannel Occupation (Renault)

Table III shows that adopting the Max MCS selection approach eliminates all grant breaks due to size, eliminating the need to reschedule grants. Mean also reduces the number of rescheduling events, which generally would result in improved performance. However, the explanation for this is shown in Fig. 7, where subchannel occupation is compared for each scheme. In the case of MCS 15, adopting the Max approach results in 3 subchannels being used. With over half the subchannels being reserved for all transmissions, this results in increased interference as there will always be an overlap in subchannels if 2 or more vehicles transmit simultaneously. Clearly, while grant breaks can be reduced, the trade-off when increasing the subchannel occupation results in a degradation in performance greater than the benefit from increased grant duration.

## V. Conclusion

There are three main conclusions from this work; the first is that it corroborates recent research in the area i.e. higher-order MCS' should be utilised in the ETSI standards as they result in significantly improved performance for C-V2X/NR-V2X, when compared to the currently standardised MCS ranges.

The second conclusion is that it is vital to consider an adaptive MCS selection scheme in studies that consider variable packet sizes. Given that many vehicular services exhibit variable packet sizes, this is significant. If a fixed MCS is considered then depending on configuration of the subchannels, the performance may not be indicative of true performance. Also, given the variability in packet sizes, while an MCS may be initially optimal, this may not hold true throughout the course of a study. Choosing a sub-optimal lower order MCS can result in excess subchannel occupation and thus degraded performance. Choosing a sub-optimal higher order MCS may be inappropriate due to compromised robustness.

The final conclusion of this work is that the current approach where MCSselection is determined based on the current packet size is preferable. Adopting an approach based on typical or maximal packet sizes may reduce grant breaking and reselection occurring, but this comes at the cost of increased subchannel occupation, and thus degraded PDR performance.

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