Vol.7, No.1, 2024, pp. 22-27
DOI: https://doi.org/10.32698/02112

Contents lists available at Journal Global Econedu

Journal of Educational and Learning Studies
ISSN: 2655-2760 (Print) ISSN: 2655-2779 (Electronic)

Journal homepage: http://jurnal.globaleconedu.org/index.php/jels

An investigation study of 5G NR V2X Mode 2 in aperiodic traffic

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Article Info

Article history:

Received Aug 25th, 2024
Revised Sept 26th, 2024
Accepted Oct 03rd, 2024

Keywords:

Aperiodic traffic
Sensing base semi-persistent scheduling (SB SPS)
5G NR V2X mode 2

ABSTRACT

The rapid advancement of digital technology has fueled growth in vehicle networking, enabling wireless communication between vehicles. More vehicle use cases for networked vehicles have recently been planned but are not concerned with road safety. To serve advanced use cases for connected autonomous driving applications demanding reliability and latency requirements, 5G NR Vehicle to Everything (V2X) developed as a major enabler. This paper aims to investigate the aperiodic data traffic types in 5G NR V2X resource allocation in Mode 2 using the Sensing Base Semi-Persistent Scheduling (SB SPS). A thorough simulation-based analysis was conducted to collect the results, specifically focusing on the correlation between the Packet Reception Ratio (PRR) and the dual factors of traffic density and distance. The simulations showed that higher vehicle density led to more traffic, increasing the risk of collisions and interference. As a consequence of this, PRRs dropped across the range. Hence, a suggestion for further research involves utilizing machine learning algorithms to analyze traffic patterns and demands, which can help in allocating resources more proactively.

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Introduction

Through the circulation of the digital age of today's technology, one of the fastest-growing areas of technology is vehicle networking which has been a field of study for several years to facilitate wireless interfaces for communication between vehicles. The vehicle network's primary goal is to improve user road safety while increasing traffic efficiency. More vehicle use cases for network vehicles have recently been planned that are not restricted to road safety. Statistical reports from the World Health Organization (WHO) have reported 1.19 million deaths due to motor vehicle collisions worldwide and according to this report, it is also found that 20 to 50 million individuals have suffered non-fatal injuries and disabilities (WHO, 2023). This equates to almost one fatality and one injury every two minutes due to traffic crashes. This clearly shows that traffic collisions are a significant global problem, taking thousands of lives each year.

Due to global issues, most cases are used to support autonomous driving research and development, a growing trend in the automobile sector. Furthermore, network vehicle users can now experience infotainment applications that need high throughput and low latency communications. Thus, the 5G NR V2X was studied with an emphasis on the capability of designing autonomous vehicles. Radio access technology (RAT) is used in 5G cellular networks. This standard, known as 5G NR, was developed by the 3rd Generation Partnership Project (3GPP) to provide enhanced data throughput, lower latency and connectivity than the legacy 4G networks (Garcia et al, 2020). One of the different services and applications the 5G NR air interface was specifically designed for is enhanced mobile broadband (eMBB), massive machine-type communications (mMTC), and ultra-reliable low-latency communication(URRCL) (Kim et al, 2020).

5G NR V2X is a technology to address advanced safety and autonomous driving applications using 5G NR Rel-16 for vehicle-to-everything (V2X) communication. The technology is a critical element of the 5G ecosystem and will transform the way vehicles communicate with each other, pedestrians, network and infrastructure. One of the most important innovations in 5G NR V2X is ultra-reliable low latency communication (URLLC) with a target of as low as 1 ms latency and up to 99.999 percent reliability (3GPP TR 38.913,2016). This feature is critical for advanced safety applications such as collision avoidance, where every millisecond counts. It also supports sidelink communication, which enables direct communication between vehicles and other devices without the need for a cellular network.

5G NR V2X defines two resource allocation modes for sidelink communication which are Mode 1 and Mode 2 (Bazzi et al., 2021). Mode 1 uses cellular networks to connect vehicles to infrastructure like roadside units (RSUs). This is network-based or infrastructure-based V2X communication. This mode delivers vehicle data to the RSU, which transfers it to the cellular network. The cellular network processes and delivers the data to another vehicle or traffic management centre (3GPP TR 22.886, 2018). Whereas for Mode 2, communication between vehicles or infrastructure does not use cellular networks. Vehicles or infrastructure communicate directly with each other using sidelink interfaces. This mode is also known as device-to-device (D2D) or sidelink V2X communication. In this mode, data transmission is directly to the recipient such as another vehicle or RSU by using the sidelink interface (3GPP TR 22.886, 2018). Therefore applications that require low latency and high reliability communication, such as autonomous driving and advanced safety applications are suitable to use Mode 2.

However, packet collision is one of the autonomous mode's most challenging problems. The autonomous mode relies on channel sensing for the operation to choose the resources. The incorrect Sensing of neighboring vehicles' radio resources causes packet collisions (Campolo et al., 2021). Inaccurate radio resource sensing happens when two vehicles cannot detect one another. So, a vehicle may utilize another's radio resource. The likelihood of packet collisions increases in a busy area with many vehicles travelling at high speeds. Therefore, a situation in which, when a vehicle chooses a source and goes at high speed, it may swiftly approach another vehicle accessing the same resource (Todisco et al., 2021). Therefore, this paper aims to investigate the aperiodic data traffic types in 5G NR V2X resource allocation in Mode 2 using the Sensing Base Semi-Persistent Scheduling (SB SPS).

Method

After outlining the key aspects of 5G NR V2X technology in the preceding section, this section focuses on the main part of the project. First, the purpose of this chapter is to describe the research design and framework selected to solve the issue and achieve the study goals. Second, it will detail how the chosen study design and simulation were implemented to carry out the data collection process. For this study, a simulation method was used to get the most accurate result. The simulation approach involves investigating the validity of previous work to enhance the project. The simulation method uses the open-source simulator WiLabV2Xsim written in MATLAB Software to analyse and validate the data for this study. All measurement parameters in this investigation are adopted from previous research (Todisco et al., 2021) and supplemented with other relevant parameters. The details of the flowchart, block diagram of WiLabV2Xsim procedure, and parameter are as Figure 1:

For performance evaluation in a simulation setting, this study uses highway scenarios. There is a 2-kilometre-long straight road with three lanes going in either direction. Each vehicle travels at an average speed of 70 km/h with a standard variation of 7 km/h, which is a Gaussian random variable. The vehicle traffic density estimation varies between 50, 100, 150, 200, 250, and 300 vehicles per kilometre. The UEs transmit data with a constant spectral power density of 13 dBm/MHz through a channel bandwidth of 10 MHz in the 5.9 GHz band. Both the transmitter side and the receiver side antenna gain are 3 dBi. The receiver's noise figure is set at 9 dB as a default. The path-loss model is based on the WINNER+, scenario B1 and comprises correlated log-normally distributed shadowing with a standard deviation of 3 dB and decorrelation distance of 25 m, as shown in (3GPP TS 38.201, Jan. 2020). Line-of-sight (LOS) circumstances are taken as given in the highway scenario. In the absence of any specification, the RSRP threshold is set at -126 dBm. Vehicle speeds vary from 240 km/h on average, with a standard deviation of the speed of 0 km/h. All UEs are assumed to generate packets that are 350 bytes long (McCarthy et al., 2021).

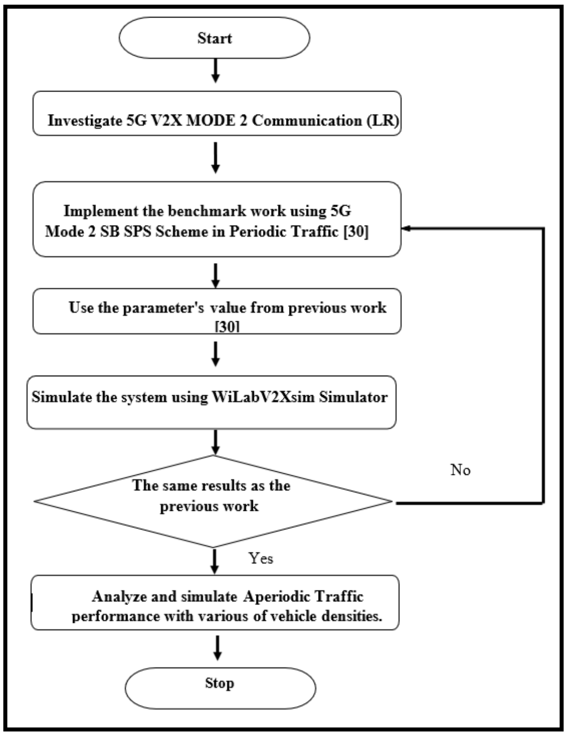

Figure 1 <Flowchart proposed for research Methodology>

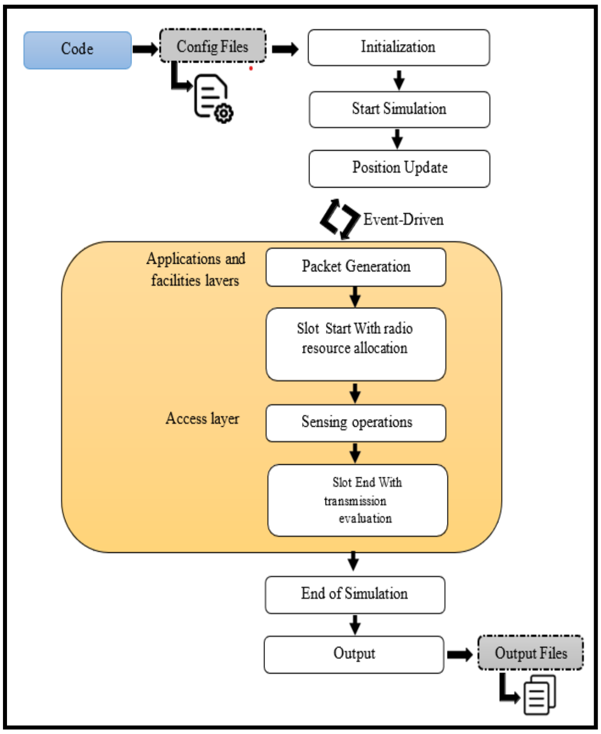

Figure 2 <Block Diagram of WilabV2Xsim when running the 5G V2X parameter (Todisco et al., 2021)>

The sub-carrier spacing (SCS) is assumed to be 15 kHz, 30 kHz, and 60 kHz, which results in slots of 1 millisecond. Within the 10 MHz channel, it is also expected that there will be ten subchannels, each consisting of ten Physical Resource Blocks (PRBs). The Modulation and Coding Scheme (MCS) 21 is used, which, given the bandwidth parameters that are taken into consideration, enables the allocation of 350 bytes in a single slot. By following the technique outlined in (Todisco et al., 2021), it is possible to determine whether or not each packet was correctly received based on a SINR threshold that has been set at 3.61 dB. In terms of the parameters for the SB-SPS, the keep probability has been calibrated to 0.4, the RSRP threshold has been calibrated to -126 dBm, and the delay budget has been confined to fall between 1 and 100 milliseconds.

To analyze the aperiodic traffic in a sensing base semi-persistent, the probability of resource reselection was kept at 0.4, with an RRI of 50 ms, generation Interval at 0.05, variability generation interval at 0, and generation interval average random part at 0.1. In this research, the outcomes in terms of the PRR were analysed. The packet reception ratio (PRR) is the average ratio of vehicles correctly decoding a packet to the entire number of vehicles, given a specified transmitter distance.

Results and Discussion

In this section, we present the analysis of the simulation results performed using the simulator using WiLabV2Xsim simulator. The results regarding packet reception ratio (PRR) over traffic density and distance are expressed. The dependent variable (Y) is PRR while the independent variable (X) is traffic density and distance.

Validation of benchmark work

This analysis is important because, through the results of the simulation, it can determine the accuracy percentage of the subsequent analysis. Findings from simulations using the same simulator and parameters as the benchmarks' research papers have shown equivalent packet reception ratio (PRR) results. This simulation result demonstrates the accuracy and dependability of the simulator in predicting the performance of 5G V2X Mode 2 Sensing Base Semi-Persistent Scheduling. As a result, the re-simulated shows exactly the same result as the original work, as shown in Figure 3. Thus the benchmark finding was validated successfully. Therefore, this simulator gives a remarkable performance in simulation studies.

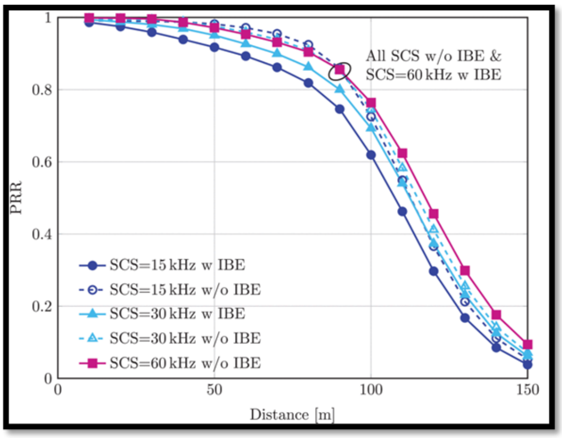

Figure 3 <The Original Graph from the Benchmark Paper (Todisco et al., 2021)>

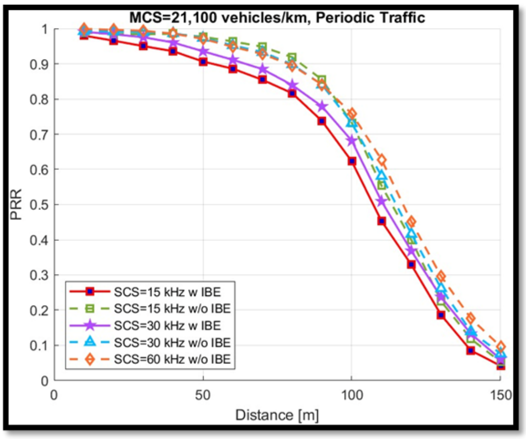

Figure 4 <Simulation Work Implementation from the Benchmark Paper>

The PRR comparison of the impact of periodic and aperiodic traffic for vehicle density = 100 vehicles/km using MCS 21.

(Modulation and Coding Scheme) MCS = 21 was chosen based on (Todisco et al., 2021), because it is the lowest MCS where an equivalent number of orthogonal users can be set, given that 350-byte packets are used.

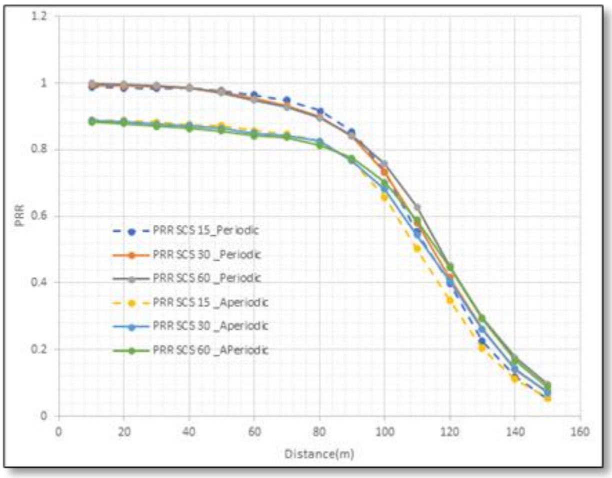

Figure 5 <The PRR Comparison of the Impact of Periodic and Aperiodic Traffic for Density 100vehicle/km, MCS 21>

Figure 5 shows the simulation results of the PRR in periodic and aperiodic traffic Mode 2 proposed SB SPS scheme. The results show the comparison in terms of SCS 15, 30, and 60 KHz. The aperiodic traffic performs worse than periodic traffic in Figure 5 since the maximum PRR result value decreases from 1.0 to 0.9. As we can see, compared to subcarrier spacing of 15 kHz, the performance of 30 kHz and 60 kHz subcarrier spacing is better due to the number of available slots per second being two times and four times greater than 15 kHz subcarrier spacing. At a 100m distance, it shows that both PRR periodic and aperiodic traffic degraded uniformly however the performance of SCS 60KHz is still higher than SCS 15KHz and 30KHz.

The impact of the number of vehicles in SB-SPS Aperiodic Traffic configuration.

The SB SPS aperiodic traffic in the 5.9GHz frequency band is shown in Figure 6 with a subcarrier spacing of 30 KHz. According to 3GPP Release 16, 30 kHz sub-carrier spacing with normal Cyclic Prefix (CP) is supported for 5G NR SL. The next evaluation of the SB SPS in aperiodic traffic is when aperiodic traffic SB SPS are varied for the vehicle traffic densities across 50, 100, 150, 200, 250, and 300 Vehicles/Km. Figure 6 depicts that the PRR result degrades when vehicles generate aperiodic traffic with varying vehicle densities. For example, looking at the PRRs at a distance of 50 m, 50 V/Km, 150V/km, and 300V/Km density, vehicle scenarios have a value of about 0.885, 0.833, and 0.804 where the values decrease, respectively. Furthermore, it was found that the PRR approached zero from 170m onwards because the signal was too weak to withstand the effects of further interference. Thus, the possibility of interference or congestion will rise as the vehicle density parameter increases. Therefore, it can be concluded that when there are more vehicles per unit distance, PRR performance is poor, and this effect rises with increasing distance.

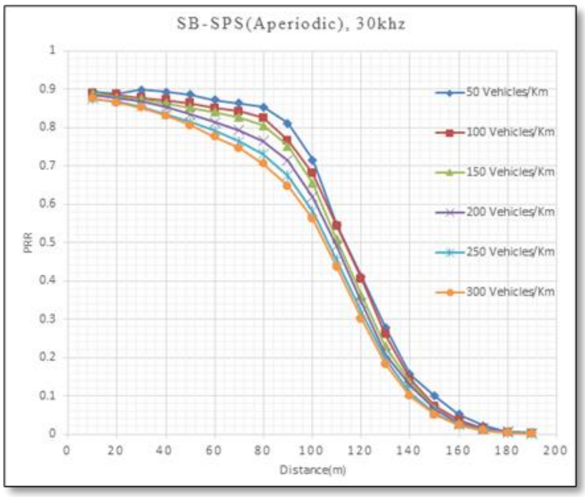

Figure 6 <Analyzing the impact of SB SPS Aperiodic traffic using SCS=30KHz with various vehicle densities from 50 to 300 Vehicles/Km>

Conclusions

Overall, this research contributes to the complete understanding of resource allocation in 5G NR V2X Mode 2 using the SB SPS scheme for aperiodic traffic with various vehicle densities from 50 to 300 Vehicles/Km. The findings of the simulations revealed that the scenarios with a larger vehicle density had higher levels of traffic, which led to an increased risk of collisions and interference. As a consequence of this, PRRs dropped across the range. Therefore, these issues lead to a worsening of the NR V2X mode 2's SB SPS scheduling system and a higher probability of packet collisions.Therefore, this research work has successfully produced an SB-SPS based on a resource allocation model for aperiodic traffic that can be used as a model for further studies and enhancement in 5G NR V2X.

For future work, the method based on current sensing, also known as long-term sensing, can potentially lessen the likelihood of a collision, hence increasing dependability with induced delay. In addition to improving dependability, 3GPP Rel. 17 strives to improve the distributed scheduling mechanism. Along with that, we will also investigate the coordination of user equipment between vehicles. This mechanism introduces coordination between vehicles, where UEs share their action of selecting sources with UE in their proximity. This approach is a potential solution that can reduce packet collisions. Further research involves utilizing machine learning algorithms to analyze traffic patterns and demands, which can help in allocating resources more proactively.

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