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Cellular Vehicle-to-Everything simulator for urban scenario

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Abstract

The automotive industry is constantly evolving, demanding advanced technologies for growth. Among these is cellular technology's long-term evolution (LTE), which 3GPP is pioneering to provide vehicle-to-everything (V2X) connectivity. It concentrates on vehicle-to-vehicle (V2V) direct communications, essential for safety applications like traffic management or infotainment. Something significant here is having a system that allows them to understand each other and cooperate. All vehicles should be able to do this by sending messages about what they are doing and where they are so that it will be safer for drivers moving through town where there may be several hurdles that break the signal lines or block them out completely. Still, before this goal can be reached, there is a need for clever ways of using packets to maximize radio channels while ensuring the service works correctly. This task poses a considerable challenge while constructing algorithms that can handle it, which is an open development question. To solve this development question, a simulator named LTEV2Vsim has been introduced. Written in MATLAB, this simulator uses straightforward models for managing vehicle movement or more complex ones based on realistic urban environment input files. This simulator is helpful for scholars interested in validating and designing LTE-V2V networks. The ability to simulate urban environment scenarios and give example results will help develop a better system for carrying packets and thus ensure that cooperative awareness services are successfully implemented in V2X communication.

Keywords: *C-V2X, V2V, urban, LTEV2Vsim*

Abstrak

Industri otomotif terus berkembang, menuntut teknologi canggih dalam perkembangannya. Di antara teknologi canggih yang dikembangkan adalah teknologi seluler long-term evolution (LTE), yang dipelopori oleh 3GPP untuk menyediakan konektivitas vehicle-to-everything (V2X). Teknologi LTE ini berkonsentrasi pada komunikasi vehicle-to-vehicle (V2V), yang

penting untuk aplikasi keselamatan seperti manajemen lalu lintas atau infotainment. Hal penting dalam pengembangan teknologi V2X adalah mengembangkan kemampuan sistem sehingga memungkinkan kendaraan untuk saling memahami dan bekerja sama. Teknik komputasi cerdas dibutuhkan untuk memaksimalkan sumber daya saluran radio sehingga memastikan layanan berfungsi dengan benar. Simulator LTEV2Vsim dikembangkan menggunakan MATLAB, simulator ini menggunakan model sederhana untuk mengelola pergerakan kendaraan atau model yang lebih kompleks berdasarkan masukan dataset perkotaan yang realistis. Simulator ini bermanfaat bagi akademisi yang tertarik dalam validasi dan desain jaringan LTE-V2V. Kemampuan untuk mensimulasikan skenario lingkungan perkotaan dan memberikan hasil yang akurat akan membantu mengembangkan sistem komunikasi C-V2X yang lebih baik.

Kata kunci: C-V2X, V2V, perkotaan, LTEV2Vsim

Introduction

Recent days have seen an increasing public interest in vehicular short-range communications, the approval of which often concerns various scholars as well as members of the industries. The latest news is that this kind of technology will soon be applied to them, which will help communicate with neighboring autos. The innovation is believed to completely alter our perception of driving safety while at the same time enhancing speed since it ushers us into an era of more secure roads. IEEE 802.11p has been the only standard designed for this field for many years [1]. However, the V2X scenario has recently become a matter of interest for 3GPP, with the first V2V features released explicitly for car-to-car communications as a part of LTE Release 14 in September 2016 [2]. LTE-V2V, a contemporary technology, entails fundamental modifications to the LTE subframe for PHY and MAC layers to suit high mobility scenarios [3].

One of the critical services expected in vehicular networks of tomorrow, and it is also at the center of many services, is cooperative awareness, which involves vehicles sending out messages at regular intervals, otherwise known as beacons (ETSI documents refer to them as cooperative awareness messages (CAMs)), so they can inform their neighboring counterparts about where they are situated and their current actions. This data can also help us, for example, develop cooperative driving techniques and geographically route people to their intended destinations. Therefore, LTE-V2V's major concern is resource allocation in cooperative awareness, which necessitates thorough investigation and fresh optimizations [4]. Maximum spatial reuse must be employed when allocating the finite resources available to reduce the chances of no vehicle accessing a channel or high interference levels preventing intended receivers from properly decoding messages [5].

The rapid proliferation of connected vehicles in urban environments has created an urgent need for robust and efficient vehicle-to-vehicle (V2V) and vehicle-to-

infrastructure (V2I) communication systems. While LTE-V2X technology has emerged as a promising solution for vehicular communications, its performance in complex urban scenarios remains a critical area of investigation. The dense network of streets, high-rise buildings, and dynamic traffic patterns in cities pose unique challenges for V2X communications, particularly in terms of signal propagation, resource allocation, and network congestion. Furthermore, the coexistence of various transportation modes and numerous road users with varying speeds and trajectories add another layer of complexity to the urban mobility ecosystem. There is a pressing need to evaluate and optimize the performance of LTE-V2X Mode 4, which enables vehicles to autonomously select and manage radio resources without cellular infrastructure support, in urban intersections where non-line-of-sight (NLOS) conditions are prevalent [6]. Additionally, the integration of Day-1 V2I applications and message sets, which vary across different global regions, requires careful consideration to ensure seamless interoperability and maximize the benefits of connected vehicle technologies in improving road safety and traffic efficiency [7]. As urban areas continue to grow and evolve, addressing these challenges is crucial for the successful deployment and widespread adoption of V2X communications in smart-city initiatives.

Only a couple of simulation tools can be used to simulate LTE links and system-level scenarios, for instance, [8] and [9]. Such tools do not support the device-to-device (D2D) communication layer, whereas [10] incorporates it. [11] lacks an exploration regarding the V2V mobility scenario, unlike [10], which lacks the D2D communication layer. This simulation is done only on a heterogeneous network to evaluate the coexistence of 802.11p and LTE without including V2V since it does not encompass V2V. A MATLAB simulator was introduced to study the surroundings, propagation conditions, modulation and coding scheme (MCS), and vehicular traffic settings that can be varied. The simulators work with trivial mobility patterns or proper source texts, such as traffic traces [12, 13], providing genuine vehicle location over time. The simulator reassigns values such as blocking probability, packet error rate, and radio resources.

LTEV2Vsim, introduced in [14], is a MATLAB-based simulator explicitly designed to investigate resource allocation in LTE-V2V networks, focusing on cooperative awareness services. Unlike other simulators, such as ns-3-based models for LTE D2D communications or 802.11p and LTE-V2X tools, LTEV2Vsim offers unique capabilities for analyzing network-controlled and autonomous resource allocation in vehicular scenarios [15]. In contrast to simulators like ms-van3t, which integrates ns-3 with SUMO for mobility management, LTEV2Vsim can handle both simple mobility models and complex, realistic input files for vehicle positions [15]. While simulators such as the one presented by Ali et al. for NR V2X at mmWave frequencies focus on specific aspects of 5G V2X communications, LTEV2Vsim

provides a comprehensive platform for evaluating LTE-V2V performance under various conditions [15]. Furthermore, unlike commercial simulators with restrictive licenses, LTEV2Vsim is openly available to researchers, allowing for modifications and inspections of the source code, which is crucial for fostering innovation in the field [15]. The simulator's ability to model both LTE-V2V and IEEE 802.11p/ITS-G5 technologies in a single framework also sets it apart from many other simulators, enabling direct comparisons between these competing standards for vehicular communications [16]. This comprehensive study aims to evaluate the performance of Cellular Vehicle-to-Everything (C-V2X) communication technologies in complex urban environments using LTEV2VSim [14], an advanced open-source simulator designed for LTE-V2X and IEEE 802.11p.

Methods

The research focuses on two representative European urban scenarios: Bologna, Italy (1.6 × 1.3 km², average 670 vehicles) and Cologne, Germany (1.85 × 1.85 km², average 1000 vehicles), chosen for their distinct urban characteristics and traffic patterns [17]. The primary objectives are to assess the performance of C-V2X technologies, including LTE-V2X, compare various resource allocation strategies in challenging urban settings, and analyze the impact of urban-specific factors on C-V2X communication efficiency.

LTEV2VSim will be meticulously configured to simulate C-V2X technologies, encompassing direct vehicle-to-vehicle (V2V) communication via the PC5 interface and network-based communication through the Uu interface. The simulation parameters are carefully chosen to reflect real-world conditions: a 50-second simulation time to capture diverse traffic scenarios, a 100 ms beacon period for frequent updates, a 300 Bytes beacon size to accommodate essential vehicle data, a 10 MHz channel bandwidth typical for V2X applications, 23 dBm transmission power to ensure adequate range, 3 dB antenna gains for both transmitter and receiver, a 9 dB noise figure of the receiver to account for urban interference, and the WINNER+ B1 channel model specifically designed for urban microcell scenarios. Additional C-V2X specific parameters will be incorporated to enhance the simulation's fidelity, including spectrum usage simulations in both the 5.9 GHz dedicated Intelligent Transportation Systems (ITS) spectrum and conventional cellular bands, ultra-low latency settings crucial for safety-critical applications, and adjusted signal propagation models to accurately reflect C-V2X's superior range and non-line-of-sight performance in urban canyons [18].

The methodology includes scenario implementation, technology configuration, performance metrics measurement, simulation execution, data collection and analysis, and optimization and refinement. Special attention will be given to C-V2X Mode 4

communication, which has shown significant enhancements compared to traditional LTE systems [19]. The methodology is structured into six comprehensive steps:

1. **Scenario Implementation**: This phase involves importing detailed road layouts for Bologna and Cologne, meticulously configuring vehicle densities and traffic patterns to mirror real-world conditions, implementing urban features such as buildings, intersections, and traffic signals, and adding C-V2X specific elements, including cellular base stations and roadside units. Special attention will be given to accurately representing the unique urban topographies of each city, including Bologna's historic narrow streets and Cologne's mix of old and modern urban planning.
2. **Technology Configuration**: In this step, simulations for C-V2X will be set up, encompassing both LTE-V2X and 5G-V2X variants. Advanced resource allocation algorithms specific to C-V2X will be implemented and configured, focusing on adapting to the dynamic urban environment. PC5 (direct) and Uu (network-based) communication modes will be modeled to analyze C-V2X performance across various communication scenarios comprehensively.
3. **Performance Metrics**: A wide array of metrics will be measured to provide a holistic view of C-V2X performance. Standard metrics include Packet Reception Ratio (PRR) to assess communication reliability. Additional C-V2X-specific metrics will be incorporated, such as the system's scalability as the number of C-V2X-equipped vehicles increases.
4. **Simulation Execution**: The simulation will be conducted in multiple iterations, with a minimum of 30 runs to ensure statistical significance. Key parameters will be systematically varied, including vehicle density to simulate different times of day, beacon frequency to test network load, and the ratio of C-V2X-equipped vehicles to model various adoption scenarios. This comprehensive approach will provide robust data across various urban conditions.
5. **Data Collection and Analysis**: Extensive performance metrics will be collected for each simulation run, followed by a thorough analysis of the impact of urban features (e.g., building density, intersection complexity) on C-V2X communication performance. A detailed LTE-V2X performance will focus on reliability and scalability in urban environments. The effectiveness of C-V2X will be evaluated across various use cases supporting autonomous driving features in complex city environments.
6. **Optimization and Refinement**: Based on the analysis, performance bottlenecks specific to urban C-V2X deployment will be identified. Resource allocation strategies will be fine-tuned to improve urban performance, focusing on adapting to the unique challenges of dense urban environments. The balance between PC5 and Uu communication modes will be optimized to achieve the best overall system

performance. The simulation process will then be iterated with these optimized parameters to validate improvements.

A comprehensive sensitivity analysis will be conducted on key parameters to ensure the robustness of the findings. Where possible, results will be correlated with real-world urban C-V2X testbed data to ground the simulations in practical reality. The expected outcomes of this study include a detailed, quantitative analysis of C-V2X performance in realistic urban scenarios, identification of optimal resource allocation strategies for dense urban environments, a nuanced understanding of how urban-specific factors impact C-V2X communication and evidence-based recommendations for improving C-V2X communication in challenging urban settings. The study will also provide valuable insights into the potential benefits and challenges of large-scale C-V2X deployment in smart cities, contributing to the ongoing evolution of intelligent transportation systems.

While this method provides a comprehensive approach to studying C-V2X in urban environments, it does have limitations, primarily the reliance on simulated environments and the focus on two specific urban scenarios. Future work could address these limitations by expanding the study to include a wider range of urban scenarios with varying characteristics, incorporating more extensive real-world testbed data, and investigating the impact of emerging 5G and beyond 5 G V2X technologies on urban mobility.

This rigorous research method will significantly contribute to the ongoing development and improvement of C-V2X technologies for urban environments. By providing a comprehensive, data-driven evaluation of C-V2X performance in realistic urban scenarios, this study will pave the way for the development of safer, more efficient, and increasingly autonomous transportation systems in the cities of the future.

Short-range LTE-V2X or sidelink is a fascinating technology introduced in Release 14. Unlike the traditional uplink and downlink, direct communication between devices is possible (it allows). Release 12 had a concept of D2D communication that dispenses with the cellular network as a requirement. PC5 is the communication interface used by short-range LTE-V2X that makes only a few moments, if any, possible between connections, hence highly reliant [20].

LTE-V2X covers a variety of application scenarios. It employs several modulation coding schemes offering different modulations and coding rates for each. 4-QAM and 16-QAM modulation schemes provide the highest possible flexibility from minimum to maximum coding rates in modulating signals. LTE-V2X applies the equivalent single carrier frequency division multiple access (SC-FDMA) in LTE uplink at the PHY and MAC layers. The spacing of subcarriers is 15 kHz in the frequency

domain. There are 12 subcarriers within each set, and the total bandwidth available for use on frequency is 180 KHz. A subframe lasts only one millisecond in the time domain, equivalent to transmission time intervals (TTI) of 14 symbols. These symbols are designed to embody nine data symbols, four demodulation reference signal (DMRS) symbols, and a blank symbol that serves as an auxiliary for shift and timing calibration between transmitter and receiver. Different modulation coding schemes (MCS) are present in LTE-V2X, which involve various modulations and coding rates designed to serve diverse use cases. One of the MCSs is 4-QAM, and another is 16-QAM, with almost limitless coding rates, thereby giving users freedom of choice.

LTE-V2X uses the exact subchannel multiple of 12 subcarrier groups in the frequency domain and TTI in the time domain as the least resource for assigning messages; usually, every packet in a single TTI consumes at least one or many subchannels. Orthogonal designs were planned for resources so that no two sending units could interfere with each other, apart from in-band emission (IBE), because of differing frequencies sharing an equivalent TTI. Due to the resources' orthogonal nature, interference between transmitters is either negligible or non-existent. However, IBE might still happen and should be planned to affirm trustworthy communications.

Regarding the upper layers, LTE-V2X is compatible with the ETSI-Intelligent Transportation System (ITS), ISO, SAE, and IEEE standards. Given the time-frequency structure with orthogonal resources, the resource allocation algorithm is crucial in optimizing spatial reuse. Since LTE-V2X was mainly designed to enable the cooperative awareness service, which transmits periodic messages by each vehicle to inform about its status and movements, resource allocation is normally associated with a semi-persistent scheduling (SPS) mechanism. 3GPP defines two approaches for reserving resources, namely Mode 3 and Mode 4, depending on the entity in charge of the allocation [21].

Mode 3, also called scheduled or controlled, is a networking strategy that permits every vehicle to be given fixed resources for short-range communications so that all the cars can receive equal power requirement levels. Therefore, depending on the distance, each car will have an increasing and decreasing power requirement, which makes sense to accomplish until one reach all over the desired range band. Mode 3 extracts great computing power and deeper insight into network status for improved performance. As it appears, the modes for Mode 3 do not offer predetermined algorithms based on the specifications, making it the duty of operators to implement them according to their particular interests. In this case, software-defined networking (SDN) would also play a crucial role by enabling more efficient and effective management of networks [21].

An autonomous Mode 4 is where nodes can autonomously select network resources. Based on sensing and scheduling procedures, its algorithm is provided in 3GPP. In this mode, all that happens is that at the MAC layer, a node selects a random resource from among those received from the PHY. After retaining the same resource for some time, packets are delayed for a duration that is 5-15 times the usual packet generation interval. This interval could be determined randomly, with a probability value P_{rk} retained by the same resource. The operator bounds P_{rk} between 0 and 0.8. It is changing to another resource value if retention fails [22].

Resources in the PHY layer are checked upon continuously within a window of 1 second by comparing received power measurements with a predetermined threshold and reading sideline control information (SCI) messages, which notify about the availability of future reservations. The least interfered among these resources that are supposed not to be used in the next packet interval (or any fractional part thereof) are then chosen and sent to the MAC unit. If the available resources are estimated at less than 20%, the mentioned threshold increases by 3 dB and the process is repeated.

It has been demonstrated that the way P_{rk} is set is the most significant factor affecting its performance despite several parameters being included in the algorithm. Most situations in which P_{rk} is chosen involve a compromise between dependability and time taken to react: this is because choosing small values more often results in bookings being changed, which makes it difficult for the censoring process to correctly tell whether they will be taken or not in forthcoming periods while choosing higher ones may lead to very prolonged errors [23].

One evaluates beacon reception errors by calculating the signal-to-noise and interference ratio (SINR). Narrowly, any packet that a vehicle sends to another vehicle would not be received accurately using the BR n due to the fact that the SINR, illustrated as Γ_{ab}, is below some minimum requirement Γ_{min}ust as follows, Γ_{ab} is gotten from [14],

$$\Gamma_{ab} = \frac{\frac{P_{tx_{RB}} \times G_r}{L_0 \times d_{ab}^{\omega}}}{\left(K_{si} \times P_{tx_{RB}} + P_{n_{RB}}\right) + \sum_{\substack{c \in V_n \\ c \neq b}} \left(\frac{P_{tx_{RB}} \times G_r}{L_0 \times d_{cb}^{\omega}}\right)}, \quad (1)$$

where in (1) transmission power per resource block is described as $P_{tx_{RB}}$, antenna gain at the receiver is represented as G_r, loss at 1 m is shown as L_0, the distance between vehicles a and b is denoted by d_{ab}, ω is loss exponents and other notations like noise power over a resource block are $P_{n_{RB}}$. Among other components, V_n is the BR n used by some selected cars.

The self-interference cancellation parameter K_{si} allows the simulation of full-duplex (FD) radios. Its value can be modified over a binary channel such that zero indicates total removal of the self-interference while one implies no removal. In the event of standard half duplex (HD) radios, Ksi will be zero. The numerator in (1) symbolizes the useful received strength. At the same time, the denominator comprises the sum of the residual self-interference (for FD radios), the noise power contribution, and the received power from all interferers, if any.

This study uses a MATLAB-based simulator to simulate a cellular vehicle-to-everything communications environment. We ran the simulation using MATLAB version R2023a. Table 1 explains the detailed configurations; these configurations will be executed to create the LTE-V2X environment within the simulator named LTEV2Vsim [14].

Table 1 Simulation Configurations

Parameter	Value
Simulation time (T)	10 seconds
Vehicle position update time (t_r)	0.1 seconds
Channel bandwidth	10 MHz
Transmission power (P_{tx})	23 dBm
Receiver antenna gain (G_r)	3 dB
SINR threshold (Γ_{min}	7.3 dB
Sensing interval	0.1 seconds
Beacon size	190 Bytes
Modulation coding scheme (MCS)	7
Probability resource keep (P_{rk})	0, 0.2, 0.4, 0.6, 0.8, 1

To investigate urban environment cases, we simulate two kinds of scenarios. These scenarios take the two major cities in Italy, Bologna and Cologne. We used these two cityscapes as examples since many related research studies also use them. The study in [4] utilizes Bologna and Cologne as representative urban environments to evaluate the performance of 3GPP C-V2X Mode 4 under varying conditions. Bologna, with an area of approximately 140 km² and a population of around 390,000, serves as a medium-density urban scenario with an average of 25.4 neighboring vehicles within a 100 m radius. In contrast, Cologne, spanning about 405 km² with a population exceeding 1 million, represents a larger urban setting with lower vehicle density, averaging 14.8 neighbors within the same range. These cities were strategically chosen to provide diverse urban landscapes for assessing vehicular communication protocols. Bologna's compact layout and higher vehicle concentration offer insights into protocol performance in congested environments. At the same time, Cologne's more expansive area allows for the evaluation of the system under less dense but more extensive urban conditions. This careful selection of urban environments enables a comprehensive

analysis of C-V2X Mode 4 across different city sizes and vehicle densities, contributing to a more robust understanding of the protocol's real-world applicability. The current LTEV2VSim is not limited by the size of the maps loaded into the simulator. The only limitation is the computational costs; since LTEV2VSim is built in MATLAB, most of the computational code is executed in a single CPU thread. Another drawback is that the dataset output tends to be large file size, hence consuming a tremendous amount of memory space.

The detailed description of the scenarios is as follows:

- **Bologna**: The described area is urban, 1.6×1.3 km2, and congested. It has jammed crossroads, which means queues can form here as well. Six hundred seventy cars move around most of the time, with 13.1 significant neighbors; however, their number may be higher in a few instances. Some streets are bustling—there is consistently heavy traffic along them, and occasionally, there can even be lines of cars without movement at all junctions within such a route.
- **Cologne**: This scenario is a 1.85×1.85 km² section of the urban map that is relatively dense with 1000 vehicles and 7.8 central neighbors within 100 m on average at 7:30, thus making it moderately dense.

The output metric used to measure the vehicle network performance is the packet reception ratio (PRR). We have observed a PRR performance of the vehicle within a distance of 10-100 meters. The maximum 100-meter observation distance is due to the urban scenario's many buildings and obstacles; hence, the current 100-meter area should be employed to interpret the near real-time conditions. It is possible to calculate the total PRR performance indicator as follows [24],

$$PRR = \frac{\sigma_s}{\sigma_t}, \tag{2}$$

where σ_s is the total number of packets successfully received, and σ_t is the total number of packets. Retransmission packets are also included in the total number of packets. It was found that the transmitting vehicle and the specified receiving vehicle were chosen randomly. The PRR statistical calculation based on (2) will be carried out after the simulation time (T) is reached. In order to calculate the vehicle communication precisely, the simulation will record the car movement every 0.1 seconds, symbolized by tr. The same time interval is also used in sensing interval configuration to allow a synchronized capture at 0.1 seconds. The sensing interval allows each car to detect its neighbors and determine their distances.

Results and Discussions

The following section discusses the overall simulation results. As mentioned in Table 1, the results will be shown for the Bologna dan Cologne scenario with different

Prk values. In this report, we still used a single MCS value at 7, based on the related works conducted at [24].

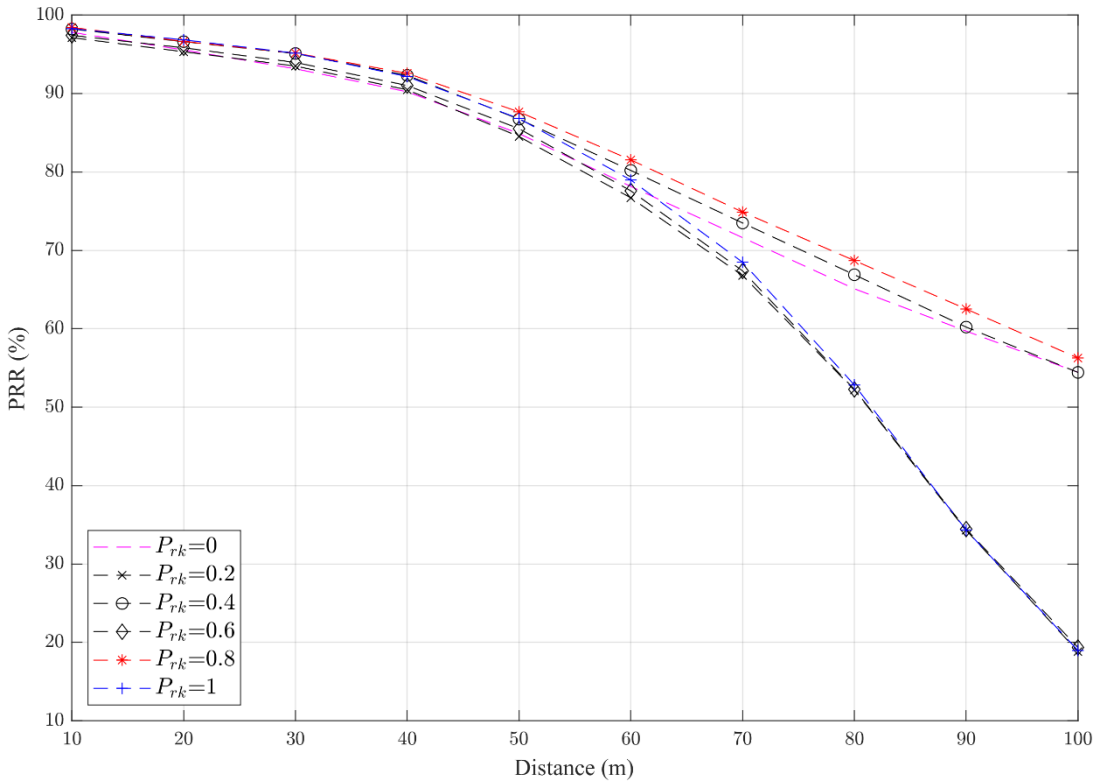

Figure 1 PRR performance result for the Bologna scenario

Figure 1 shows the PRR performance for the Bologna scenario. Figure 1 shows various P_{rk} effects, ranging from 0 to 0.2, 0.4, 0.6, 0.8, and 1. The red-colored line is the $P_{rk} = 0.8$; this value is the most used P_{rk} value in the related research and the highest value governed by 3GPP. In this study, we also include the P_{rk} value outside the 3GPPP standard, which is 1, and its curve is blue-colored. This P_{rk} value meaning is as follows: when the minimum P_{rk} value is applied, which is zero, the cars will try to find new radio resource blocks to send the payload.

On the other hand, when the maximum P_{rk} value, which is one, is applied, then the cars will most likely keep the same assigned resource blocks for the following payload transmission. As depicted in Figure 1, the P_{rk} value 0.8 outperforms all other P_{rk} values for the Bologna scenario. As for the P_{rk} value of 0, the magenta-colored line can barely keep up with the 0.8 result. A similar result is also shown by the P_{rk} value of 1; the performance plummeted starting at 60-meter vehicle distances, and using the same assigned radio resource does not satisfy the junction urban environment. Figure 1 also showed that utilizing a correct amount of probability value would produce the best results.

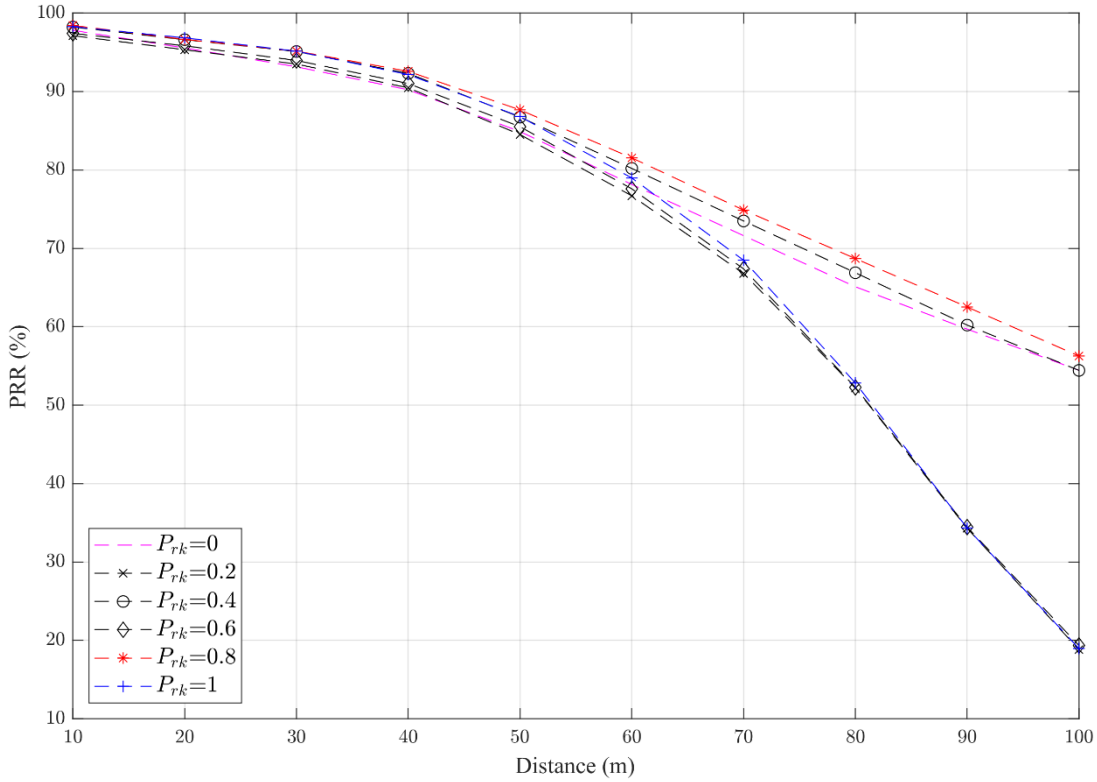

Figure 2 PRR performance result for the Cologne scenario

Figure 2 shows an interesting result. It is the PRR performance result for the Cologne scenario. Since the Cologne scenario is classified as moderately dense, the probability value returns opposite effects. As mentioned, the Cologne scenario is recorded during morning rush hour, during which as many as 1000 cars are simulated. The combination of the high number of vehicles in the area, which means more neighboring vehicles encounter, and also heavy interference from those neighboring cars, causing the use of the same last assigned radio resource, is the best choice to maintain communication performance. Keeping the same radio resources is proven to overcome the high vehicle density, as depicted in Figure 2, as the blue-colored line can perform better than the red-colored ($P_{rk} = 0.8$) and magenta-colored ($P_{rk} = 0$) lines. As shown in Figure 2, the 0.6 P_{rk} value achieves the best overall PRR performance for the Cologne scenario.

Conclusions

This study investigates the cellular vehicle-to-everything communications in urban scenario case studies. The scenario used in this study is based on typical related works, which are two cities in Italy, Bologna and Cologne. The packet reception ratio is an output metric used to measure network performance. One configuration parameter is also being investigated in this study. Namely, probability resources keep value. From the results, the P_{rk} value causes various effects in different scenarios. For the less dense

vehicle, Bologna, with around 600 cars, the 0.8 P_{rk} value outperformed the other P_{rk} values.

Conversely, in the high-density scenario, which is Cologne with approximately 1000 cars, P_{rk} values 1 and 0.6 achieve the best PRR performance. This study is considered an initial investigation since it still only considers the P_{rk} value to measure communication performance. Other parameters could be adjusted to achieve better results, such as adjusting the transmission power, modulation, and coding scheme and involving sophisticated machine learning in radio resource management.

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