Research of the V2X Technology Organization Model for Self-Managed Technical Equipment

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***Abstract*—The steady progression of information technology today is opening up opportunities for extensive automation across various sectors, including the automotive industry. The active development of IT systems has paved the way for V2X (Vehicle-to-Everything) technology, which enables communication such as "vehicle-to-vehicle" and "vehicle-to-road infrastructure". This article focuses on exploring the use of V2X technology to create "intelligent transportation". Currently, V2X technologies are not widely adopted due to the limited coverage of 5G networks. Although the existing 4G network is adequate for streaming HD content and playing online games, it cannot support the safer and smarter operation required for autonomous cars. Nevertheless, within the 4G network framework, it is possible to develop a comprehensive solution for automating car traffic. This would significantly reduce the number of road accidents and optimize traffic flow. This article explores the implementation of V2X technology in road traffic to achieve these goals.**

***Keywords*—V2X; V2V; autonomous vehicles; DSRC; scenarios; frequency spectrum**

I. Introduction

In recent years, there has been a trend towards the widespread adoption and development of Internet of Things (IoT) systems, which enable various smart devices to fully interact through data transmission networks [1-9]. Within the IoT framework, a notable trend is the development of V2X (Vehicle-to-Everything) technology. This technology allows for the automation of all traffic and ensures synchronization with road systems, traffic lights, and road signs. Examples of the implementation of this technology are presented in publications [10-15].

The relevance of this study lies in the fact that V2X technology has not yet been implemented in neighboring countries. For the widespread adoption of such solutions, it is important to thoroughly examine their advantages and disadvantages before project development. The V2X system can provide complete connectivity between all vehicle systems, optimizing many processes. As shown in study [16-19], such systems enhance road safety and reduce road maintenance costs. This technology enables vehicles to connect to all devices through data transmission networks, with real-time data exchange [20-25].

As demonstrated in study [26-29], a more optimal approach to vehicular communication technology is cellular communication. For this purpose, the 3GPP organization has developed a specialized solution known as C-V2X. This solution can utilize LTE technology. LTE-V offers low cost, rapid development, and high efficiency.

The data transmission network between vehicles can use unlicensed frequencies, increasing the frequency range. However, licensed frequencies can be used for transmitting video and audio information from subscribers. Cloud access can be provided based on a commercially licensed spectrum for information transmission. This technology ensures data transmission to the cloud using a commercially licensed spectrum. All objects in the C-V2X data transmission network exchange data through the PC5 Sidelink data channel interface. Data transmission is based on Rel.14 and Rel.15 technologies. Data can be transmitted with low latency in two modes: Mode 1 and Mode 2. Data transmission can occur both within and outside the coverage area. As shown in [30-31], the technology can work with both the LTE radio interface and the wireless data transmission interface. The two data transmission modes are demonstrated in Fig. 1 [32].

Another type of data transmission using V2X technology can be organized based on the LTE-Uu wireless communication channel - this is a type of wireless interface for organizing communication between subscriber devices and the base station. Data transmission over such a line occurs in both the downstream and upstream directions with the allocation of special resources to subscribers for various information transfer processes. Most of the data traffic on such a channel will be periodic and have the same packet volumes.

If we consider data transmission based on the PC5 wireless communication channel, then during such transmission security messages are also transmitted, which makes it possible to ensure data confidentiality. This standard was developed by the 5GAA Association and operates at a frequency of 5900 MHz.

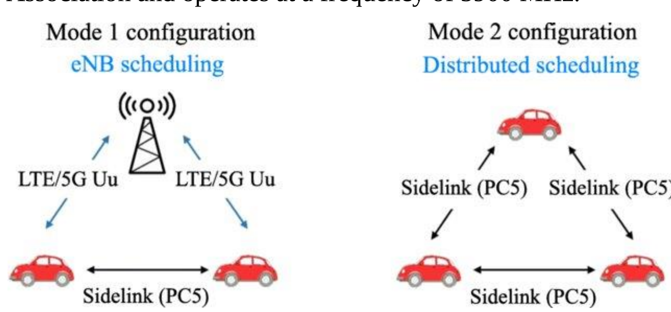

Fig. 1. Mode 1 and 2 data transmission in the V2X network.

Sidelink 1 mode provides scheduled data transmission when a base station is available. This mode uses three scheduling mechanisms: semi-persistent scheduling, UE message-based scheduling, and inter-carrier scheduling. The first mechanism is problematic when used on high mobility highways where all vehicles must be connected to a base station.

UE message-based scheduling mode operates regardless of the presence of a base station with direct communication between different devices. Interoperability can be achieved via PC5 interfaces at 5900 MHz. This means that this mode can be characterized as autonomous. Interaction is ensured within line of sight. This mode provides higher speed characteristics compared to the IEEE 802.11p protocol. In addition, the security of information in this mode is quite high.

Below in Table I we demonstrate the comparative characteristics of cellular communication technologies and DSRC.

TABLE I. COMPARATIVE CHARACTERISTICS OF CELLULAR COMMUNICATION TECHNOLOGIES AND DSRC

Options	DSRC	Cellular
Completion of technology	Fully developed	Versions 14 and 15 are fully developed, version 16 is under development
Data network	WI-FI standard	LTE/4G
Modulation technology	OFDM	CK-FDM
Relay technology	Not supported	HARQ
Communication model	Hybrid	Mixed
Support for network communication functionality	Limited functionality	Support available
Resource selection	CSMA-CS	Semi-permanent transmitter
Data transmission delay level	Low latency	Minor delay
Range of action	Short range	For long-term communication
Mobility	Up to 300 km/h	Up to 500 km/h
High traffic density	There will be losses	No losses
Security	Not much functionality	Have support

From Table I, it can be show that mobile communication technology has excellent characteristics for high traffic density and high reliability.

For roads with little traffic, DSRC technology is sufficient.

The modeling will be carried out on the basis of C-V2X, since Almaty can be classified as a city with high traffic density.

II. RESEARCH INTO POTENTIAL V2V WORK

The basis is the section of roads around Energo University, where numbers 1-5 are base stations (Fig. 2).

This is only a theoretical calculation, since at the moment leading telecom operators have just begun to launch 5G networks. As we know, the current 4G network is fast enough to stream HD content and play online games, but it cannot support safer and smarter autonomous cars.

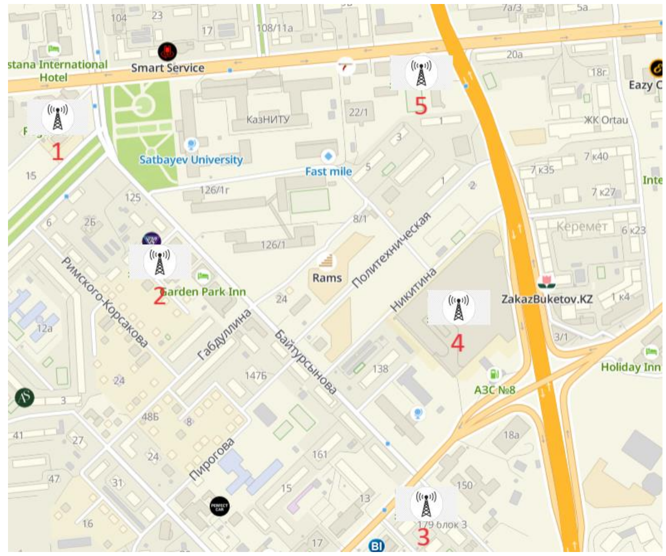

Fig. 2. Location of base stations.

Vehicles move in groups in two divided lanes down and up, respectively. It is assumed that the direction of propagation of messages is N, and the vehicles are moving at a constant speed c [m/s].

To integrate existing network infrastructure (V2I) with vehicle-to-vehicle (V2V) communications with lower transmission latencies, we use time latency as a key performance indicator to evaluate the effectiveness of this protocol switching mechanism. In particular, we measure the propagation rate of time latency when vehicles transmit warning messages via V2V or V2I protocols [33].

The time delay d for a message propagating within a group of connected machines can be expressed as the difference between the reception timestamps of the message at the destination and source machines. Specifically, if a message is sent from machine A and received by machine B, the time delay d is calculated using the reception timestamps T_B and T_A recorded at machines B and A, such as:

$$d = T_B - T_A \quad (1)$$

This measurement assumes that the clocks on machines A and B are synchronized. If the clocks are not synchronized, additional methods, such as clock synchronization protocols or time-stamping with a common reference, may be needed to accurately determine the time delay.

The time interval d(i,j) required for the successful end-to-end transmission of a message of length L (bits) between a pair of vehicles i and j, where the i-th vehicle transmits the message to the j-th vehicle, can be expressed using the data transfer rate f(i,j) (Mbit/s), such as:

$$d(i,j) = \frac{L}{f(i,j)} \quad (2)$$

L= 1024. As you know, in 5G networks the speed can reach 20 Gbit/s, but let's take only 1000 Mbit/s.

Respectively: d_{IJ}=0,128 s.

In vehicle communication systems, ensuring high throughput and low latency is critical, particularly for safety and emergency prevention. The total delay D within a group of vehicles is influenced by the propagation speed and the time delays across individual links between pairs of vehicles. For the entire a group of vehicles, the total delay D is the sum of the delays across all links (i,j) in the path of communication:

$$D = \sum_{i,j} d(i,j) = L \sum_{i,j} \frac{1}{f(i,j)}, \tag{3}$$

If we assume a constant data rate f for each link (i,j) in the a group of vehicles, and denote d(i,j) as the propagation delay for the communication channel between vehicle i and vehicle j, the total delay D for transmitting a message of length L across the cluster can be reformulated, Eq. (3) becomes:

$$D = \frac{L*h}{f} \tag{4}$$

This equation highlights the total delay as a combination of the constant transmission delay and the cumulative propagation delays in the network. This is crucial for evaluating the performance and reliability of vehicle communication networks, especially in scenarios requiring low latency.

To incorporate the role of roadside units (RSUs) in the overall communication delay within a vehicular network, we consider the propagation delay dRSU specifically associated with the network infrastructure. This delay is defined as the time required to transmit a message of length L between two consecutive RSUs, denoted as the m-th and (m+1)-th RSUs, at an effective data rate fRSU. The formula for the propagation delay dRSU is given by:

$$d_{RSU} = \frac{L}{f_{RSU}} \tag{5}$$

This consideration of RSUs is critical in vehicular communication networks, especially in scenarios of low traffic density where vehicle-to-vehicle (V2V) communication may not always be reliable. By integrating RSUs, the network can ensure more consistent and uninterrupted communication, enhancing the overall communication potential and resilience of the system.

Eq. (5) describes the propagation rate of the time delay within the existing network infrastructure in a VANET, focusing on both uplink and downlink communications between vehicles and roadside units (RSUs). The propagation rate of the time delay can vary depending on the direction of communication uplink (vehicle to RSU) or downlink (RSU to vehicle):

$$d_{UP} = \frac{L}{g(i,m)}, d_{DOWN} = \frac{L}{g(m,i)} \tag{6}$$

Uplink Delay is the time delay for a message sent from a vehicle to an RSU. It depends on the message length L and the effective data rate g (i,m) for uplink communication.

Downlink Delay is the time delay for a message sent from an RSU to a vehicle. It similarly depends on the message length L and the effective data rate g (m,i) for downlink communication.

In practical scenarios, factors such as network congestion, signal interference, and infrastructure capacity can impact these delays, influencing the overall performance of the vehicular communication system.

The propagation rate of the time delay d_{V2I} for communication between vehicles and RSUs via Vehicle-to-Infrastructure (V2I) depends on the effective data transmission rates in both the uplink and downlink channels, as well as within the RSU itself. These delays can be denoted as d_{UP} and d_{DOWN} for the uplink and downlink, respectively, and d_{RSU} for the internal RSU communication delay.

The total time delay d_{V2I} for V2I communication can be expressed as the sum of these individual components:

$$d_{V2I} = d_{UP} + d_{RSU} + d_{DOWN} = L\left(\frac{1}{g(i,m)} + \frac{1}{f_{RSU}} + \frac{1}{g(m,i)}\right) \tag{7}$$

Similarly, we define the propagation speed with time delay for communication via V2V (i.e., d_V2V [s]) as:

$$d_{V2V} = d + \Delta T \tag{8}$$

As defined in Eq. (3), d represents the time delay within the group of vehicles, which includes the message length L, data transfer rate f, and the propagation delays d(i,j) between vehicles in the cluster. The average value of d is approximately 0.128 seconds.

The time interval ΔT can be calculated using as:

$$\Delta T = \frac{\Delta x}{c} 50 \text{ км/ч} = 15 \text{ м/с} \tag{9}$$

$$\Delta T = \frac{3}{15} = 0{,}2 \text{ с}$$

To calculate the average transmission time delay davg in a vehicular network, we consider various communication scenarios including Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) communications, as well as the impact of traffic density and vehicle speed.

In the proposed model, the entire system is considered as an alternating update process, where the vehicle connection cycles through three distinct phases:

- Phase 1: No connection, where a vehicle moves alone in the vehicle grid, indicating a completely disconnected scenario. This can occur in low-density areas or in remote regions due to the lack of network infrastructure such as roadside units (RSUs).

- Phase 2: Short-range communication, where vehicles form clusters when the distance between vehicles is below a certain threshold, which typically favors V2V communication. The effectiveness of V2V communication depends on the distance between vehicles being within the upper communication bound (e.g. ⩽ 125 meters). It is assumed that V2I communication is not available either due to the lack of infrastructure or due to a preference for using V2V in a cluster.

- Phase 3: Long-range communication, where vehicles enter a wireless cell, allowing them to connect to an RSU via V2I. This phase typically occurs in areas with established network infrastructure. V2I communication is available, allowing vehicles to communicate with the network infrastructure. V2V communication is not considered in this phase, possibly due to network policies or infrastructure-based communication priority.

In Phase 1, where a vehicle is initially isolated, the likelihood of establishing a multihop connection to another vehicle depends on the occupancy of cells in its path. For a vehicle to connect to the next vehicle via multihop V2V communication, each of the cells along the intended path must be occupied by at least one vehicle.

To calculate the average transmission time delay davg in a vehicular network based on the alternating phases of connectivity, we use the characteristics and assumptions defined for each phase:

$$d_{avg} = p(\tau = 1)\Delta T + p(\tau = 2)d + p(\tau = 3)d_{V2I} \quad (10)$$

Since Almaty is taken as the starting point, R will be taken as 10 m (Figure 3).

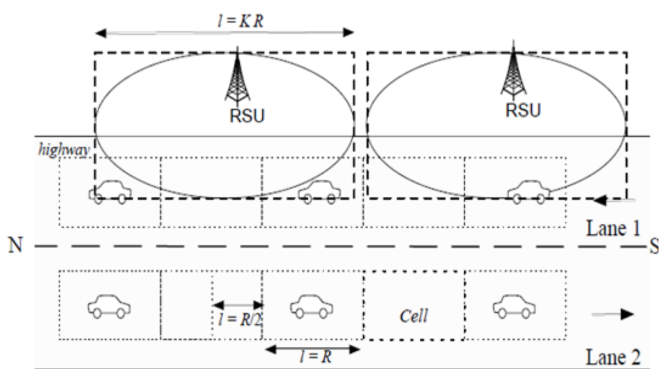

Fig. 3. Vehicle mesh.

Fig. 3 shows a vehicular network model where the coverage area is divided into cells shaped like honeycombs, each with a diameter L of 500 meters, we consider the connectivity of vehicles moving within these cells. Each cell can be occupied by one or more vehicles, and this occupancy affects the probability of establishing multihop communication, as:

$$(p_{e,w})^N = (1 - \exp(-\lambda_{e,w}R))^N, \quad (11)$$

where, λ(e,w) is represents the density of cars per meter, indicating how vehicles are distributed along a particular direction (e.g., east-west); G is denotes the gap or distance between vehicles. In this context, G is set equal to R, the minimum inter-vehicle distance required for communication.

N = 1: The number of cells, N, is set to 1 because we are considering only the immediate gap (or cell) between two vehicles for determining connectivity.

In the scenario described, we are focusing on a situation where vehicles are distributed across a grid of cells, and the connectivity between vehicles is determined by the occupancy of these cells.

This equation reflects the likelihood of establishing a connection based on vehicle density and the minimum inter-vehicle distance required for communication:

$$p_{e,w} = (1 - \exp(-\lambda_{e,w}R)) \quad (12)$$

$$\mathrm{N} = \frac{\mathrm{G}}{\mathrm{R}} \quad (13)$$

$$\mathrm{p_{e,w}} = 0{,}99$$

This equation reflects the likelihood of establishing a connection based on vehicle density and the minimum inter-vehicle distance required for communication. The model highlights that higher vehicle densities (larger λe,w) increase the probability of occupied cells, thereby enhancing connectivity within the vehicular network.

Density is taken as 0,2 auto/m according to Almaty statistics [33].

In Phase 3, the focus is on Vehicle-to-Infrastructure (V2I) communication, where vehicles rely on roadside units (RSUs) to establish and maintain connectivity. The probability that a vehicle moving in a specific direction (e.g., up/down) will connect via V2I to the next vehicle depends on the presence of RSUs within the network, then where in this case the number of cells N is:

$$N = \frac{G}{K * R} \quad (14)$$

N=0,002.

In the context of vehicular networks partially covered by a wireless network, the mesh size L is defined as L=K−Rl = K - Rl=K−R, where K is a constant greater than zero, and R represents the minimum inter-vehicle distance. This setup suggests that the wireless network has larger coverage cells compared to the vehicular network's inter-vehicle communication range.

Given these parameters, we can state the following theorem regarding the average time delay dV2I for transmitting a message of length L from a vehicle in a vehicular network to another vehicle via a wireless network (V2I communication).

Theorem: the average time delay required for a vehicle moving in a vehicular network, which is partially covered by a wireless network, to transmit a message of length L is:

$$d_{avg} = p_{e,w}(N = 1) * \Delta T + p_{e,w}\left(N = \frac{G}{R}\right) * d + $$
$$+ p_{w,e}\left(N = \frac{G}{K * R}\right) * d_{V2I} \quad (15)$$

$$d\_avg = 0{,}99 * 0{,}2 + 0{,}99 * 0{,}128 + 0{,}002 * 0{,}128 = 0{,}324\ s$$

This theorem implies that, under the given conditions, the average delay for transmitting a message from a vehicle to the infrastructure is approximately 0,128 seconds. This delay is assumed to be consistent across different scenarios, possibly due to uniform network conditions, standard data rates, and minimal variation in transmission distances.

The average delay of 0,128 seconds is an idealized constant, likely based on empirical data or theoretical models. In practice, this value may vary depending on factors such as network congestion, data rate variability, and environmental conditions.

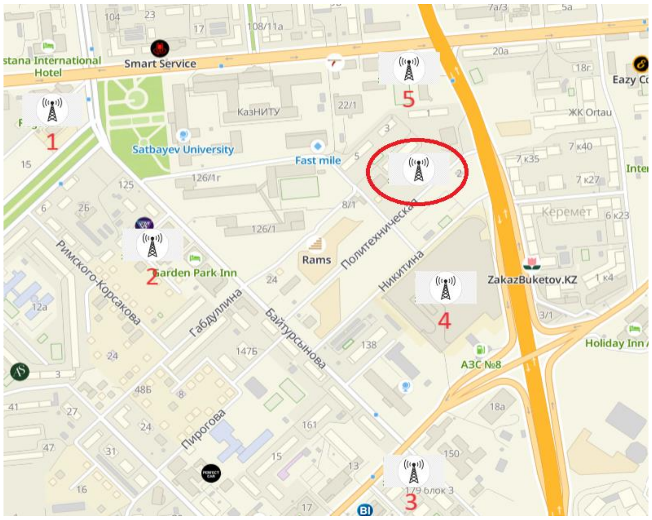

Fig. 4. Proposed location of BS.

This theorem provides a simplified model for understanding the delay characteristics in a vehicular network with partial wireless coverage, offering insights into the expected performance in terms of latency.

At a car speed of 15 m/s. This result complies with all V2X safety standards (3gpp rel.14).

In heavy traffic: the length of the selected section is 2500 m. Let's say there are 4 rows on each street, then it comes out to 10 000 m. The average length of a light car is 4 m. 2500 cars / 10 000 m = 0,25.

During traffic jams, the density reaches 0,25 cars/m. Accordingly, the speed will be lower - 20 km/h = 6 m/s. The distance between cars will also decrease to 1 m: d_avg ≈ 0,6 s.

Vehicle communication requires high throughput and low latency. Any delay can affect the prevention of an emergency. This is the result of 5G not being at its full potential.

BS are located around the perimeter of the block, but BS are located along the main roads. By placing the base station as in Fig. 4, it would be possible to solve two problems: reduce the delay for those driving along the streets (Fig. 5) and raise the level of customer service for students living in hostel #1.

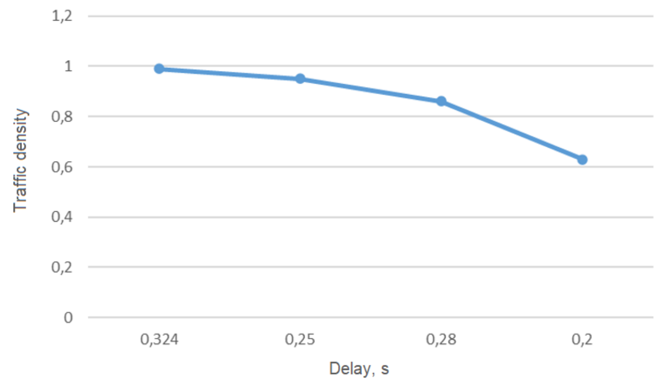

Fig. 5. Dependence of delay on traffic density.

III. SOFTWARE MODELING

With the advent of 5G solutions for automotive networks, the range of radio technologies is expanding to include the millimeter wave spectrum. This expansion is also supported by the recent move towards radar communications (RADCOM), which involves the integrated use of the 77 GHz band for both communications and sensing. The capabilities of existing programs for use in a transportation environment are being explored. Examples include WinProp, which uses deterministic ray tracing techniques, and NYUSIM, which relies on stochastic channel modeling.

Both modeling platforms have their unique advantages and disadvantages. WinProp provides results that closely match individual scenarios but requires more effort to model each scene accurately. On the other hand, NYUSIM is highly flexible and can be quickly adapted, although justifying a specific channel model parameterization can be challenging. The parameters were taken from the transmitting part (Fig. 6).

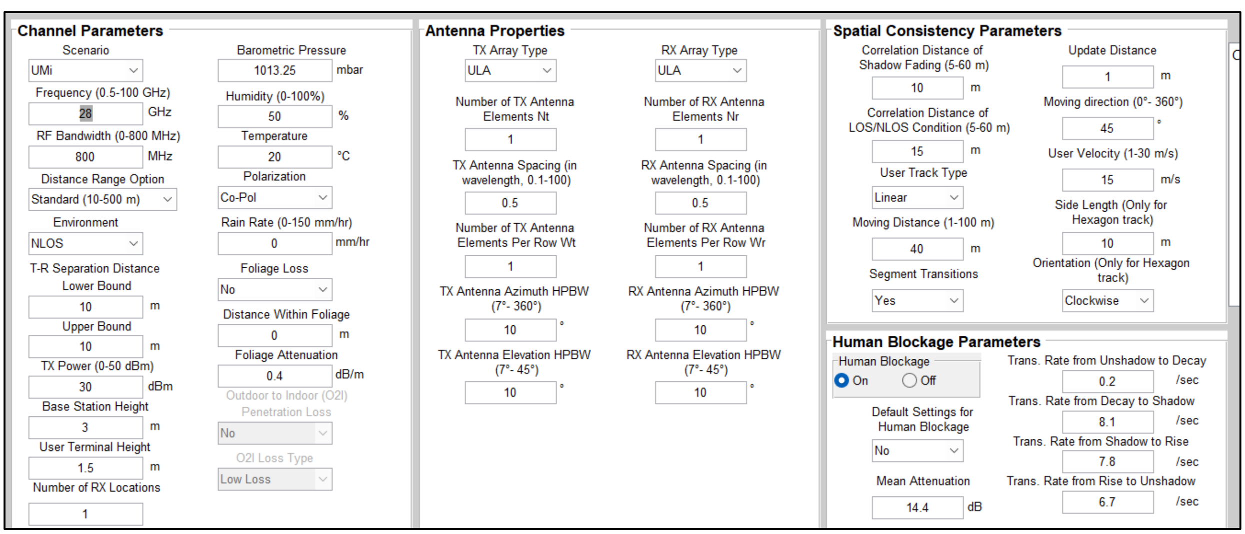

Fig. 6. Input parameters.

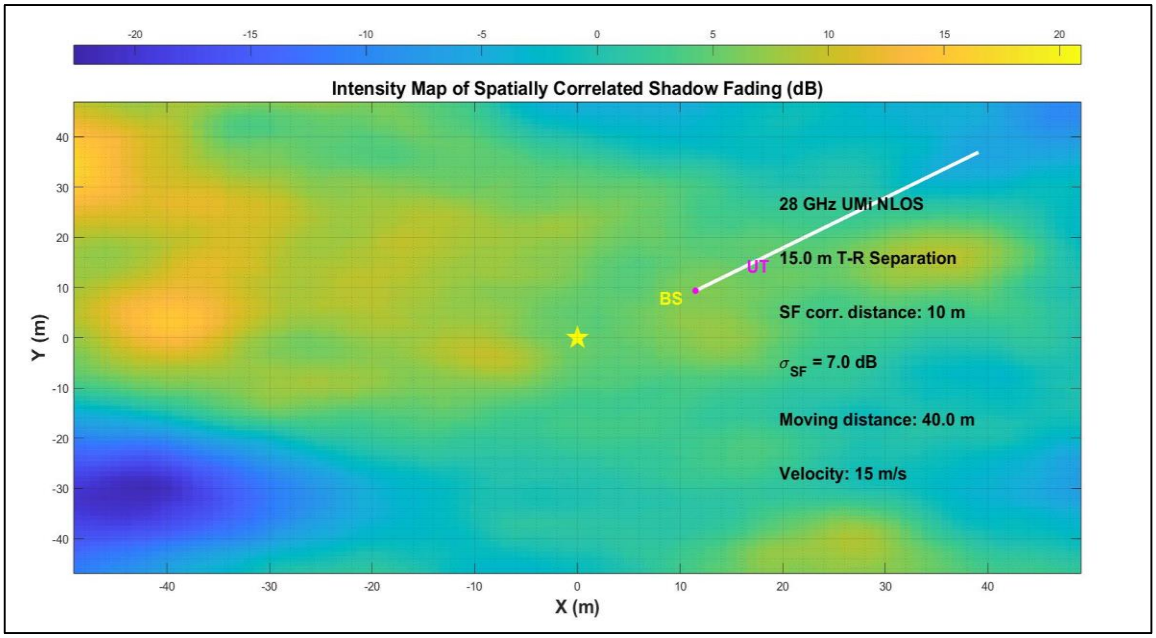

Fig. 7. The intensity map of spatially correlated shadow attenuation (dB).

User speed – 15 m/s (≈50 km/h). The intensity map of spatially correlated shadow attenuation (dB) is shows in the Fig. 7.

5G will operate at 28 GHz and it is important to consider signal attenuation when calculating the system's energy budget. Based on the graph, it can be seen that as the distance from the base station (BS) increases, the signal level decreases, and at the end the client receives an attenuation of 7 dB.

Signal attenuation (path loss) is measured in decibels (dB) and is usually expressed by the formula:

$$PL(dB) = 20\ log_{10}(d) + 20\ log_{10}(f) + C, \quad (16)$$

where d - distance between transmitter and receiver, f - signal frequency, C –constant.

Therefore, you can use this formula to calculate the signal attenuation over the distance to the end. Knowing that the client receives 7 dB of attenuation, given that SF (shadow fading) varies continuously from -20 dB to 20 dB, this parameter can be included in the energy budget calculation.

The energy budget of a system is defined as the difference between the transmitted power and the signal attenuation, taken into account by various factors such as losses in cables, amplifiers and others.

This information allows you to evaluate how effectively the signal transmission system copes with environmental conditions and how much power must be transmitted to ensure an acceptable signal level at the end (Fig. 9).

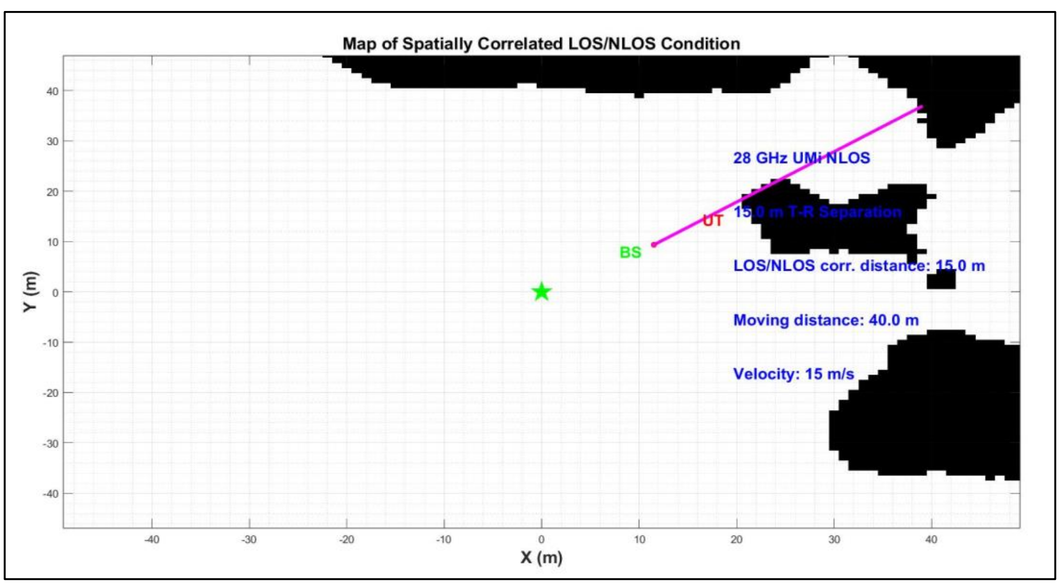

Fig. 8. Map of spatially correlated LOS/NLOS state.

The model clearly accounts for NLOS (non-line of sight) conditions, which are typical in urban environments. Urban areas often feature obstacles such as buildings and other structures that can create shadows and block signals.

Given that 5G utilizes millimeter waves, which have a higher frequency than previous generations of networks, these waves are more susceptible to attenuation when passing through obstacles. Consequently, a denser placement of base stations along roads is required to ensure reliable coverage in urban areas.

These base stations, placed along roads, will help improve signal availability for moving objects, reducing the effects of shadows and blocking. However, it is always important to consider specific characteristics of the urban environment, such as geography, building height, population density, and other factors, when designing and deploying a 5G network.

The power delay profile (PDP) is a crucial parameter for characterizing a multipath channel. PDP represents the intensity of the signal received through a channel with different time delays (Fig. 9).

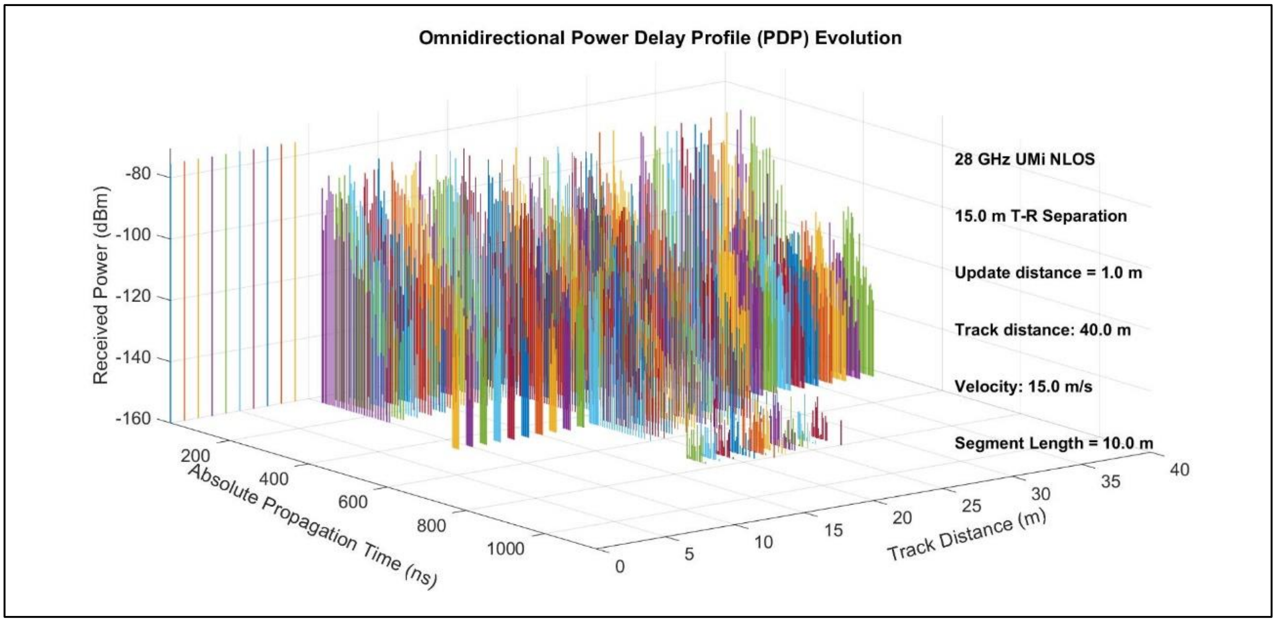

Fig. 9. Omnidirectional Power Delay Profile (PDP) (average values).

Recommendation ITU-R P.1407 specifies that the shape of the delay profile depends on the propagation parameters associated with the conditions under which the waves travel through the medium. The profile is created by multiple waves with different amplitudes and time delays. Waves with long delays have lower amplitudes due to propagation along a longer path.

From Fig. 9, it can be observed that an object located at 20-25 meters experiences maximum delay and minimum power. This may be attributed to the characteristics of the wave propagation path in the given medium, such as reflections and diffractions, which lead to multipath propagation of the signal. This observation is further supported by Fig. 8.

IV. CONCLUSION

The model of such a network represents a high-quality and expensive solution. Implementing it in Kazakhstan requires significant investments of both time and money. Discussions on the implementation of such networks are ongoing. To implement this solution, complete coverage of all highways and roads is necessary. Given the current challenges with full coverage in our country, the issue remains unresolved.

The research theorem considered allows us to estimate the average time delay for transmitting a message in a vehicular network that is partially covered by a wireless network. The average transmission time delay davg for a vehicle moving in a vehicular network, which is partially covered by a wireless network, is stated to be 0,324 seconds. This delay value is significant as it aligns with the safety standards for Vehicle-to-Everything (V2X) communications, particularly those specified in the 3GPP Release 14 standards.

In a heavy traffic scenario where the density reaches 0,25 cars per meter, the average time delay increases to approximately 0.6 seconds. This underscores the importance of delivering high throughput and low latency in high traffic environments.

The study results indicate the significant potential of 5G technology to provide reliable communications in vehicular networks. However, to fully realize this potential, additional infrastructure improvements and optimization of base station placement are required.

Message delay is critical to road safety, and the proposed solutions comply with 3GPP Rel.14. However, higher throughput and low latency are emphasized as necessary for vehicle interactions in dense traffic conditions.

Thus, the article highlights the importance of further research and development in the field of 5G networks to ensure secure and efficient communication in vehicular networks, especially under heavy traffic conditions.

REFERENCES

[1] S. Kumar, P. Tiwari, and M. Zymbler, “Internet of Things is a revolutionary approach for future technology enhancement: a review,” *J. Big Data*, vol. 6, no. 111, 2019, doi: 10.1186/s40537-019-0268-2.

[2] M. Konyrova, S. Kumyzbayeva, T. Iliev, and K. Chezhimbayeva, “Effeciency Assessment Of Iot Devices Control With Teletraffic Theory,” *East.-Europ. J. of Enterpr. Tech.*, vol. 3, no. 9, pp. 49–59, 2023, doi: 10.15587/1729-4061.2023.281287.

[3] S.K. Jagatheesaperumal, S.E. Bibri, J. Huang, J. Rajapandian, B. Parthiban, “Artificial intelligence of things for smart cities: advanced solutions for enhancing transportation safety,” *Computat. Urban. Sci.*, vol. 4, no. 1, 2024, doi: 10.1007/s43762-024-00120-6.

[4] J.A.J. Alsayaydeh, M.F.B. Yusof, K.S. Mohan, A.K.M.Z. Hossain, and S. Leoshchenko, “Advancing Road Safety: Precision Driver Detection System with Integrated Overspeed, Alcohol Detection, and Tracking Capabilities,” *Int. J. of Adv. Comput. Sci. and App.*, vol. 14, no. 12, pp. 504 – 516, 2023, doi: 10.14569/IJACSA.2023.0141253.

[5] J. S. Yalli, M.H. Hasan, N.S. Haron, M. U.-R. Shaikh, N.Y. Murad, and A.L. Bako, “Quality of Data (QoD) in Internet of Things (IOT): An Overview, State-of-the-Art, Taxonomy and Future Directions,” *Int. J. of Adv. Comput. Sci. and App.*, vol. 14, no. 12, pp. 1075 – 1091, 2023, doi: 10.14569/IJACSA.2023.01412110.

[6] A.R.H. Hussein, “Internet of Things (IOT): Research Challenges and Future Applications,” *Int. J. of Adv. Comput. Sci. and App.*, vol. 10, no. 6, pp. 77-82, 2019, doi: 10.14569/IJACSA.2019.0100611.

[7] Cr. Turcu, and C. Turcu, “Internet Orchestra of Things: A Different Perspective on the Internet of Things,” *Int. J. of Adv. Comput. Sci. and App.*, vol. 8, no. 12, pp. 53-58, 2017, doi:10.14569/IJACSA.2017.081208.

[8] F. Kiani, and A. Seyyedabbasi, “Wireless Sensor Network and Internet of Things in Precision Agriculture,” *Int. J. of Adv. Comput. Sci. and App.*, vol. 9, no. 6, pp. 99-103, 2018, doi:10.14569/IJACSA.2018.090614.

[9] S. E. Bouanani, O.Achbarou, M.A. Kiram, and A. Outchakoucht, “Towards Understanding Internet of Things Security and its Empirical Vulnerabilities: A Survey,” *Int. J. of Adv. Comput. Sci. and App.*, vol. 10, no. 10, pp. 337 -345, 2018, doi: 10.14569/IJACSA.2019.0101048.

[10] K. Prabhakara, J. Kurunandana, A. Ala-Saleh D., and P. Prabu, “Highly secured authentication and fast handover scheme for mobility management in 5G vehicular networks,” *Comput. and Elect. Eng.*, vol. 116, May 2024, doi:10.1016/j.compeleceng.2024.109152.

[11] Nair, and S. Tanwar, “Resource allocation in V2X communication: State-of-the-art and research challenges,” *Physic. Commun.*, vol. 64, 2024, doi: 10.1016/j.phycom.2024.102351.

[12] L.L.F. Jahn, S. Park, Y. Lim, J. An, and, “Enhancing lane detection with a lightweight collaborative late fusion model,” *Robot. and Autonom. Syst.*, vol. 175, May 2024, doi: 10.1016/j.robot.2024.104680.

[13] Y.-B. Kim, and H. L.Lee, “Compact planar phased array antenna for extended V2X communication coverage,” *Alexandria Eng. J.*, vol. 94, pp. 226 – 234, May 2024, doi: 10.1016/j.aej.2024.03.054.

[14] G. Khekare, K.P. Kumar, K.N. Prasanthi, S.R. Godla, V. Rachapudi, M.S.A. Ansari, and Y.A.B. El-Ebiary, “Optimizing Network Security and Performance Through the Integration of Hybrid GAN-RNN Models in SDN-based Access Control and Traffic Engineering,” *Int. J. of Adv. Comput. Sci. and App.*, vol.14, no. 12, pp. 596 – 606, 2023, doi: 10.14569/IJACSA.2023.0141262.

[15] S. Yadav, and R. Rishi, “Joint mode selection and resource allocation for cellular V2X communication using distributed deep reinforcement learning under 5G and beyond networks,” *Comput. Commun.*, vol. 221, pp. 54 – 651, May 2024, doi: 10.1016/j.comcom.2024.04.015.

[16] M. Saleh Bute, Muhammada, P. Fan, G. Liu, and L. Zhang, “Trust-Aware V2V Relay-Assisted Content Distribution in Cellular V2X Networks,” *IEEE Internet of Things J.*, vol. 11, no. 8, pp. 13452 – 13466, 15 April 2024, doi: 10.1109/JIOT.2023.3338190.

[17] J. Liu, C. Wang, and W. Zhao, “An eco-driving strategy for autonomous electric vehicles crossing continuous speed-limit signalized intersections,” *Energy*, vol. 294, 1 May 2024, doi: 10.1016/j.energy.2024.130829.

[18] A. Faareha, B. Alsamani, M. Alkhathami, A.Deafallahc, N. Alosaimi, B. Alenzi, and L. Nkenyereye, “Efficient content caching for 5G assisted vehicular networks,” *Scient. Rep.*, vol. 14, no. 1, December 2024, doi: 10.1038/s41598-024-54486-y.

[19] I. Khalid, V. Maglogiannis, D. Naudts, A. Shahid, and I. Moerman, “Optimizing Hybrid V2X Communication: An Intelligent Technology Selection Algorithm Using 5G, C-V2X PC5 and DSRC,” *Future Internet*, vol.16, no. 4, 2024, doi:10.3390/fi16040107.

[20] L. Jiao, J. Zhao, Y. Xu, T. Zhang, H. Zhou, and D. Zhao, “Performance Analysis for Downlink Transmission in Multiconnectivity Cellular V2X Networks,” *IEEE Internet of Things J.*, vol. 11, no. 7, pp.11812 – 11824, 1 April 2024, doi: 10.1109/JIOT.2023.3335233.

[21] R. Chen, S. Sun, Y. Liu, X. Hu, Y. Hui, and N.Cheng, “Proactive Effects of C-V2X-Based Vehicle-Infrastructure Cooperation on the Stability of Heterogeneous Traffic Flow,” *IEEE Internet of Things J.*, vol.11, no. 5, pp. 9184–9197, 1 March 2024, doi: 10.1109/JIOT.2023.3322867.

[22] A. Molina-Galan, L. Lusvarghi, B. Coll-Perales, J. Gozalvez, and M.L. , “On the Impact of Re-Evaluation in 5G NR V2X Mode 2.” *IEEE Transact. on Vehic. Tech.*, vol. 73, no. 2, pp. 2669–2683, 2024, doi: 10.1109/TVT.2023.3318235.

[23] M.-S. Pan, and S.-W. Kao, “Subchannel selection methods for 3GPP C-V2X networks by considering vehicular mobility,” *Telecomm. Syst.*, 2024, doi: 10.1007/s11235-024-01138-1.

[24] J. Clancy, D. Mullins, B. Deegan, J. Horgan, E. Ward, C. Eising, P. Denny, E. Jones, and M. Glavin, “Wireless Access for V2X Communications: Research, Challenges and Opportunities,” *IEEE Communicat. Surv. and Tutor.*, 2024, doi: 10.1109/COMST.2024.3384132.

[25] J. Akhter, R. Hazra, A. Mihovska, and R. , “A Novel Resource Sharing Scheme for Vehicular Communication in 5G Cellular Networks for Smart Cities,” *IEEE Transact on Consum Electr*, 2024, doi: 10.1109/TCE.2024.3392435.

[26] S.H. Alrubaee, S.K. Al-Jaff, and M.A. , “Optimizing Downlink Resource Allocation for High-Speed LTE-V Networks Through Intelligent Scheduling,” *J. of Communicat.*, vol.19, no. 3, pp. 133–142, 2024, doi: 10.12720/jcm.19.3.133-142.

[27] L. Nkenyereye, R.P. Naik, J.-W. Jang, and W.-Y. Chung, “Software-Defined Small Cell-Linked Vehicular Networks: Architecture and Evaluation,” *Electronics (Switzerland)*, vol.12, no. 2, 2023, doi: 10.3390/electronics12020304.

[28] S. Gupta, and V. Khaitan, “Reliability and Survivability Analysis of Long-Term Evolution Vehicular Ad-Hoc Networks: An Analytical Approach,” *J. of Netw. and Syst. Manag.*, vol. 29, no. 2, 2021, doi: 10.1007/s10922-020-09582-5.

[29] I.A. Kamil, and S.O. Ogundoyin, “A lightweight certificateless authentication scheme and group key agreement with dynamic updating mechanism for LTE-V-based internet of vehicles in smart cities,” *J. of Inf. Sec. and App.*, vo. 63, 2021, doi: 10.1016/j.jisa.2021.102994.

[30] M. Uzair, “Vehicular Wireless Communication Standards: Challenges and Comparison,” *Int. J. of Electr. and Comput. Eng. Syst.*, vol. 13, no. 5, 2022, doi: 10.32985/ijeces.13.5.6.

[31] A. Turley, K. Moerman, A. Filippi, and V. Martinez, “C-ITS: Three observations on LTE-V2X and ETSI-ITS G5,” *White Paper*, pp. 1-6, 2018.

[32] CY. Chen, JY. Chen, and P.R. Lin, “Adaptive Clustering and Scheduling for Dynamic Region-based Resource Allocation in V2V Communications,” *J. Sign. Process Syst.*, vol. 92, pp. 1349–1368, 2020, doi: 10.1007/s11265-020-01535-0.

[33] A. Mostafa, A. M. Vegni, R. Singoria, T. Oliveira, T. D. C. Little and D. P. Agrawal, "A V2X-based approach for reduction of delay propagation in vehicular Ad-Hoc networks," in Proceeding of 11th International Conference on ITS Telecommunications, St. Petersburg, Russia, pp. 756-761, 2011, doi: 10.1109/ITST.2011.6060155.