Research Article

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Loss Estimation in VANET Communications

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Abstract
Vehicle Ad Hoc Networks (VANETs) provide efficient and secure communications between vehicles and infrastructure. Reliable data exchange between vehicles and Roadside Units (RSUs) is the main objective of the Intelligent Transportation System (ITS). One of the main tasks associated with automotive communications is the development of methods for predicting the behavior of VANET communication channels in critical conditions. This article explored data transfer between service provider, vehicles, and infrastructure in ITS. Since VANET requires communication channels with low packet loss, minimal message travel time and high Quality of Service (QoS) with the least number of bit errors, we simulated the simplest wireless communication channel in VANET and obtained data about possible packet losses at the RSU unit, message travel time over the network, the load of the vehicle communication link with the infrastructure, as well as information about the effect of the packet loss in the Internet and the influence of bit errors. The importance and usefulness of the performed numerical simulation lies in the ability to set traffic parameters and observe the resulting channel load, packet loss, message travel time, the number of bit errors and QoS in VANET under certain transmission modes.

Keywords: Data Traffic, Dropped Packets, Transaction Size (TS), Travel time (TT), Bit Error Rate (BER), Packet Fail Chance (PFC)

1. Introduction

Information and communication technologies have created a new paradigm for the information exchange between vehicles and infrastructure in Intelligent Transportation System (ITS). Modern vehicle designs incorporate and use applications for safety, traffic efficiency, driver assistance, infotainment and urban sensing systems. The automotive industry has entered a new era of digitalization in the areas of human mobility and transport infrastructures. This convergence of automotive and information technology is resulted in the Vehicular Ad-Hoc Network (VANET), a type of mobile peer-to-peer network.

Many reviews have already been published on VANET scientific research, such as applications and services of VANET, general characteristics and VANET parameters, routing protocols, security, congestion control, network topology and architecture, data transmission, wireless communication, and various technologies deployed in automotive networks [1-9].

The need to create and develop VANET was because the traditional content delivery in the automotive environment, based on a stationary network infrastructure, has such disadvantages as difficulties in delivering large content to several moving receivers at the same time and the absence of an appropriate stationary infrastructure on most roads [3]. VANET has become the basis of the ITS and helps effectively automate the traffic monitoring system. In this context, building a safer transport infrastructure requires knowledge of the critical facilities location such as gas stations, healthcare facilities, food centers, as well as traffic jams, accidents, dangerous road conditions, possible detours and weather conditions. Improving efficiency means increasing the capacity of the road network, reducing congestion and pollution.

It is important to have the tools to determine shorter travel times, lower vehicle operating costs and logistics that are more efficient [4]. All this is impossible without the availability of the necessary information in VANET, the existence of reliable communication between all network components for data transmission, as well as Internet access. The vehicles themselves are used to collect, analyze and share knowledge about the area of interest in ITS applications. Advances in computing technology and communication protocols provide real-time traffic information and vehicle routing.

VANET includes various types of vehicles that move and change direction, creating an unpredictable and dynamic road network infrastructure [6]. This circumstance can lead to frequent communication failures and breaks in the network topology. When deploying VANET in an urban environment, existing obstacles limit the line of sight between vehicles, which degrades wireless transmission.

VANET is a special case of Mobile Ad-Hoc Network (MANET) where mobile nodes are moving vehicles [1]. Network nodes do not have a fixed infrastructure and are therefore constantly self-tuning. VANET is a wireless network that does not depend on any central administration and provides communication between on-board units in nearby vehicles, between on-board units and the nearest fixed infrastructure (roadside units). The movement of vehicles in VANET is characterized by such fixed factors as the road network and traffic rules. VANET integrates next-generation wireless communications and is used as a reliable technology for the adoption of self-driving vehicles [3].

This work was done to explore a new paradigm for the information exchange between vehicles and infrastructure. For reliable operation, VANET requires minimal packet loss, short network transit times with the least bit errors. The operation of VANET communication channels was studied using the original model. Data were obtained regarding packet losses at the roadside unit, message travel time, and the load on the vehicle communication channel with the infrastructure. Critical information about the influence of the probability of packet loss in the Internet and the influence of bit errors allowed us to draw conclusions regarding the necessary modes for information transmission in VANET.

The rest of the paper is organized as follows. *Section II* reviews related work. *Section III* presents the theoretical approach, modeling algorithm, and calculation method. *Section IV* discusses the VANET model architecture. The results are presented in *Section V,* and *Conclusions* are discussed at the end of the article.

2. Related Works and Aim of the Work

Here we consider only works related to the general characteristics of VANET, architecture, data traffic and network modeling, leaving aside security issues, interaction with drones and satellites.

The review presents the main technologies used in transport networks for communication, control, vehicle safety, comfort and entertainment [1]. The main aspects of automotive peer-to-peer networks, communication protocols between and within automotive communications, as well as differences from MANET are considered.

Review discusses some of the key automotive wireless access technology standards, such as 802.11p, P1609, Cellular System, CALM, MBWA, WiMAX, Microwave, Bluetooth, and ZigBee protocols, which serve as the basis for supporting both security and non-security applications [2]. Wireless standards are analyzed and compared in terms of bandwidth, ease of use, initial cost, maintenance, availability, signal coverage, signal interference, and security. Review studies data communication in VANETs [3].

The key characteristics of automotive networks, architecture details, protocols, applications, and future perspectives are discussed. Particular attention is paid to communication and applied problems. The protocol stack of this network type is discussed and a qualitative comparison between the most common protocols is given. Review provides an overview of broadcasting in automotive networks and discusses various performance and QoS metrics related to broadcasting issues [4]. A comparative study of broadcasting protocols considering QoS was carried out, classifying them according to different taxonomies. QoS requirements and performance metrics for VANET services were defined. Article is an overview of Vehicle-to-Vehicle (V2V) communication in VANET [5]. A description of recent research in the field of V2V communication is given, focusing on the characteristics, problems and future trends of research. Article provides an overview of research papers on the architecture, characteristics, applications, security, and security issues of VANET [6]. Modifications, enhancements, secure communication, data protection and V2V communication are discussed.

Paper uses macroscopic fluid flow models to predict connectivity behavior in networks between vehicles [7]. Vehicle density determines radio communications in light traffic conditions and can even contribute to radio interference in heavy traffic conditions. Analytical solutions have been developed for estimating the density of vehicles based on the method of solving traffic flow equations. Under general infrastructure conditions, one can find the density evolution at any place and at any time for given initial conditions. It is possible to include path losses between vehicles and interference from situations with heavy traffic in line-of-sight and non-line-of-sight conditions. The method is parameterized using Bluetooth and IEEE 802.11a radio technologies.

The article compares the characteristics of VANET with the attributes of big data indicated in the literature [8]. The performance of the algorithm used for routing in automotive networks is evaluated on an autonomous distributed platform, as well as on a multi-node cluster with 2, 3, 4 and 5 nodes, respectively. The obtained results confirm that with an increase in the number of nodes, the processing time of the algorithm is significantly reduced.

The article presents the implementation of Multiple Input and Multiple Output (MIMO) and Adaptive Modulation and Coding (AMC) methods in VANET based on WiMAX (Worldwide Interoperability for Microwave Access) [9]. The developed system provides several radio channels between the transmitter and receiver for transmitting and receiving data using the concept of MIMO technology. AMC also provides a choice of different modulation methods depending on the signal-to-noise ratio. These two methods provide a significant increase in throughput, delay, jitter, packet delivery rate, and packet loss rate.

In most previous work, the quality of routing protocols was analyzed with a change in topology. The work considers not only topology changes, but also different distances between vehicles and other RSUs, which is also an important aspect of protocol reliability and efficiency [10]. In simulation using IEEE 802.11p, the topology around Farid Gate (Bahawalpur) was established, and QoS parameters (bandwidth, delay, loss and routing overhead) were estimated using Omnet++, SUMO, JOSM.

Special attention is paid to communication and applied problems of VANET [11]. In particular, the protocol stack of this network type is discussed and a qualitative comparison is made between the most common protocols in the literature. A detailed discussion of the various categories of VANET applications is provided.

The study presents a new distributed strategy aimed at optimizing traffic congestion in real time based on VANET communication system and Ant Colony Optimization (ACO) methods [12]. ACO methods are used to calculate the shortest path a driver can take to avoid congested routes. The proposed system is based on a multiagent architecture in which all agents work together. The simulation results show that the proposed method can reduce the total distance traveled and the time required to reach the destination, compared to the classical "shortest path method" based only on a distance.

Paper proposes a context-sensitive border-forwarding scheme for VANET [13]. The proposed scheme uses a fuzzy logic edge node selection protocol for a decentralized search for the best edge nodes. A reinforcement-learning algorithm is used to optimize the last two-stage communications in order to increase the adaptability of communication routes. The proposed scheme selects different edge nodes for different types of links with different contextual information. Simulations have been performed to evaluate the proposed scheme by comparing it with existing broadcast protocols and unicast protocols for various network conditions and traffic patterns.

The article proposes an emerging super network model with Inter-Vehicle Communications (IVC), which consists of two layers: a traffic network and a communication network [14]. The IVC model includes the key parameters of wireless devices (characterized by their transmission ranges and throughputs). The influence of these parameters on the topological structure of the model is revealed and verified by modeling using a modified vehicle-following model with vehicle-to-vehicle communications.

The appearance of the first VANET simulators dates back to the early 2000s. Due to the difficulty of using a real test bench to evaluate research results, several simulators were developed at that time. Recently, autonomous vehicles and new 5G technologies have emerged. Article provides an updated overview of VANET simulators, showing their status and opportunities for evaluating new scenarios in VANET research [15].

One of the main goals of automotive communications is to develop an efficient routing mechanism for distributing data from node to node. The article presents a comparative analysis of existing routing protocols with propagation models [16]. The study optimizes routing and propagation models for reliable packet transmission. The work uses a realistic scenario from Open Street Map (OSM) for simulations with SUMO. Trace files generated from SUMO are used for further modeling in NS-3. The results show that the Two-Ray Ground and FRIIS propagation model outperforms the compared models, and the OLSR routing protocol outperforms AODV and DSDV.

The Objectives of our Paper are

➢ To develop original model for simulation data exchange in VANET using NetCracker software;
➢ to obtain and analyze dependences for: a) the number of lost packets at the roadside unit on the transaction size, b) the travel time on the transaction size, c) the loading of the communication link “RSU - Vehicle” on the transaction size for various laws of statistical distribution for the time between transactions;
➢ to study dependences of: a) the bit error rate of the communication link “RSU - Vehicle” on the load and the transaction travel time; b) the travel time and the “RSU - Vehicle” channel loading on packet fail chance in a wide area network.

3. Theoretical Approach

This article uses NetCracker for the structural-logical design and simulation of VANET. NetCracker provides real-time “what-if” interactive simulations and uses mathematical equations to predict network performance. The quality of predicting data traffic parameters using the NetCracker software was tested in our publication, where the dependences of the message travel time on the number of satellites and aircraft were obtained [17]. Our calculated data were later experimentally confirmed in [18].

The internal characteristics of the communication channel, which was simulated in this study, were the Average Load (AL), the Travel Time (TT), and Dropped Packets. The external characteristics, affecting the internal – the Transaction Size (TS), the Time Between Transactions (TBT), the Bit Error Rate (BER), the link Bandwidth, the Packet Fail Chance (PFC).

When calculating the characteristics of the VANET communication channel, it is necessary to know the distribution law of the transmitted packet lengths $\omega(x)$ and the distribution law of time intervals between them $\omega(t)$. In the proposed model, the following probability distribution laws were used: Const law - $\omega(x) = const$, *Exponential* law - $\omega(x) = \lambda e^{-\lambda x}$, and *LogNormal* law - $\omega(x)=$ $\frac{1}{x\sqrt{2\pi\sigma^2}}\exp(-\frac{(lnx-a)^2}{2\sigma^2})$.

Formulas for calculating the average length of transmitted packets, the average time interval between two adjacent packets, the average channel load and the average packet travel time are the following:

$$TS = \int_{-\infty}^{\infty} x\varpi(x)dx.$$

$$TBT = \int_{-\infty}^{\infty} t\varpi(t)dt.$$

The average utilization of the communication channel is given by the formula:

$$AU = TS/TBT = TS/\mu, \quad (5)$$

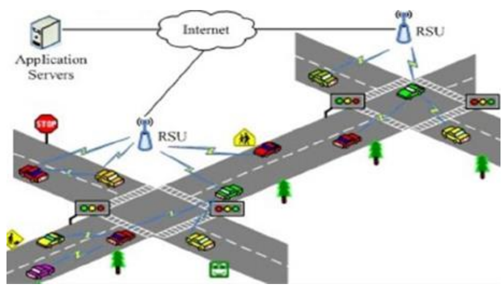
where $\mu = 1 / TBT$ is the packet transmission rate over the communication channel. The utilization of the communication channel depends both on the size of the transmitted packets and on the intensity of their generation. If the value of the AU parameter is greater than the maximum data transmission rate of the communication channel, then some of the transmitted packets will be lost with the probability:

$$P = 1 - \frac{AU_{link}}{AU}. \quad (6)$$

The average packet travel time through the communication channel is determined by the formula:

4. VANET Communication Channels

VANET typically contains such main components (Fig. 1): Service Provider (SP), Wide Area Network (WAN), Roadside Units (RSUs) along roads, On-Board Units (OBUs) on vehicles, and a link that can be wired (between RSUs) or wireless (from Vehicle OBUs to RSUs). In order to exchange traffic and entertainment information, vehicles communicate with each other via OBUs using broadcast messages. RSUs have network interfaces for connection with OBUs, other RSUs, and internet-providers. The main VANET components (Fig. 1b) are described in Table 1.



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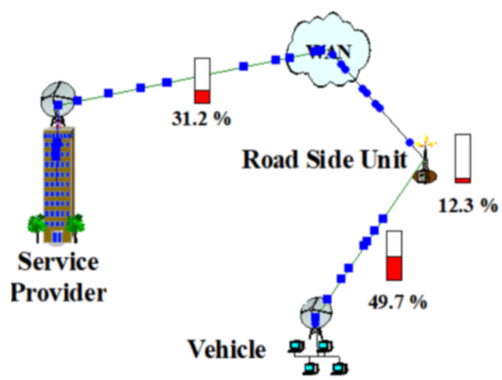


b)

Figure 1: a) VANET Architecture [20]; b) “SP – WAN – RSU - Vehicle” Communication Channels

Parameters → Model elements ↓	Bandwidth (Mbps)	Length (m)	BER (%)
Model "SP – WAN – RSU – Vehicle"			
Service Provider			
Data Server	2	-	-
Server – Antenna link	1.544	10	0
Antenna	2	-	-
SP – WAN wireless link	1.544	50000	0
WAN	Latency - 0 s; Packet Fail Chance - (0 – 0.8)		
WAN – RSU wireless link	1.544	10000	0
RSU	2	-	-
RSU – Vehicle wireless link	1.544	10000	(0 – 0.7)%
Vehicle			
Antenna	2	-	-
Antenna – Server link	1.544	1	0
Server	2	-	-

Table 1: Model Parameters

The model architecture presented in this paper is simple in sense that it contains the minimal necessary set of elements for communication simulation in VANET. This simple model may serve as a basis for further study of data transmission in VANET with complex structure, Radio Access Networks and the Internet of Things. VANET communication channel (Fig. 1b) was designed using Net Cracker Professional 4.1. Model characteristics were simulated considering the data transfer protocol, statistical parameters of transactions, and the time between transactions. The number of dropped packets was estimated for the specified traffic parameters.

Our model contains the SP, the WAN cloud, the RSU, and the Vehicle OBU. Only two parameters, "Packet Latency" and "Packet Fail Chance," can be user defined in the WAN cloud. A traffic with LAN (Local Area Network) peer-to-peer profile was specified for the created model with the topology according to Fig. 1b. This means decentralized network based on the equal rights of participants. There are no dedicated servers in such a network, and each peer is both a client and acts as a server. Such an organization allows to maintain the network's operability for any number and any combination of available nodes, which are understood here as Vehicles. Modeling was provided until "saturation" of calculated parameters, when they stop their changing.

5. Results of Vehicle Channel Simulation

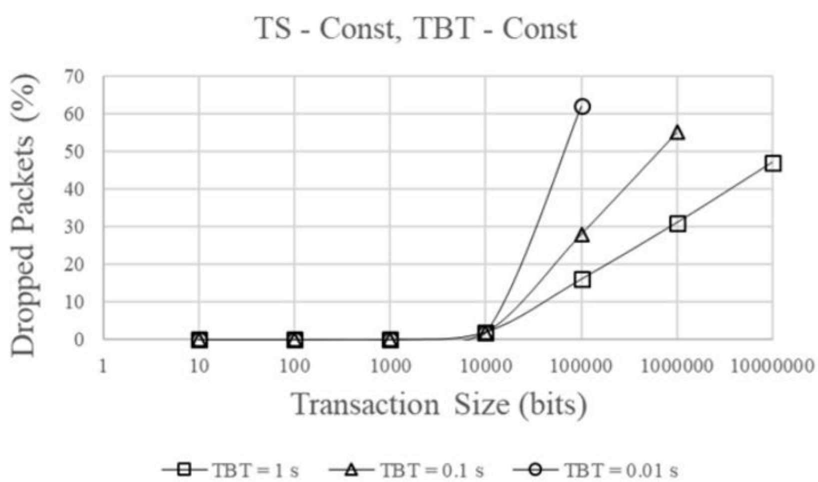
Problems associated with intermittent connectivity in VANET arise due to the high mobility of nodes and the heterogeneity of the network. The network is more resilient for communications in areas with fewer vehicles. In urban environments, the network suffers from frequent outages, long delays, and lost messages. Such problems have a particularly significant impact on time-sensitive applications.

Content delivered in VANET serves purposes such as safety, security, entertainment, and news delivery. The main reason for deploying VANET from a safety point of view is the long reaction time (up to 1.5 s) for any driver to apply the brake after an emergency occurs. The potential damage from such a prolonged reaction of an individual driver is very great, especially when there are many vehicles on the road moving at high speeds. Therefore, the time of message transmission in VANET communication channels is critical. VANET applications, especially those related to security, are very sensitive to delays and have specific performance and QoS requirements - the number of lost packets per RSU, the number of bit errors, and the probability of packet failure in the Internet.

The biggest challenge in expanding VANET connectivity to the Internet is the need for a ubiquitous, fully networked roadside infrastructure. Such a requirement is difficult to meet at the initial stage of the deployment of road networks, as well as in areas where there is no roadside infrastructure. In this regard, of particular interest is the study of the traffic features in the data exchange between the service provider and the Vehicle via the Internet. The task here is to find out the conditions for minimizing packet loss, reducing end-to-end delay in message transmission, and improving the average load of communication channels.

Fig. 2 shows the dependences of RSU dropped packets on the transaction size, the time between transactions, and the type of statistical distribution law. The general distribution law (*Const*) is selected for the TS parameter, and three different laws are used for TBT parameters — *Const* (Fig. 2a), *Exponential* (Fig. 2b) and *LogNormal* (Fig. 2c). The values of the TS parameter varied from 10 bits to 10 Mbits, and the TBT parameter took values of 1 s, 0.1 s, and 0.01 s. This allowed the change in channel operation to be simulated and critical situations to be determined in terms of information loss during data transfer.

For TBT parameters with *Const* (Fig. 2a) and *LogNormal* (Fig. 2c) distribution laws, no packet loss is observed up to TS = 10 Kbits, and with *Exponential* distribution law (Fig. 2b), up to TS = 1 Kbits. At TBT = 1 s packet loss with distribution law *Const* is less 50% at TS = 10 Mbits; for *Exponential* distribution law < 20% at TS = 1 Mbits; and for *LogNormal* distribution law < 10% at TS = 10 Mbits. Using these data, it is possible to optimize packet loss by choosing the right transmission mode, namely by choosing the appropriate transaction size and time between messages. The common thing in this case is that there is a region where there are practically no losses at all, and there is a limit on the size of TS, after which the losses begin to increase sharply.



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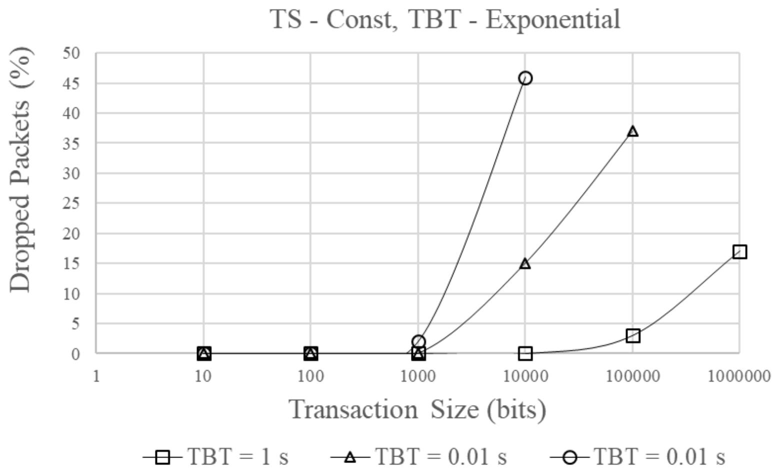

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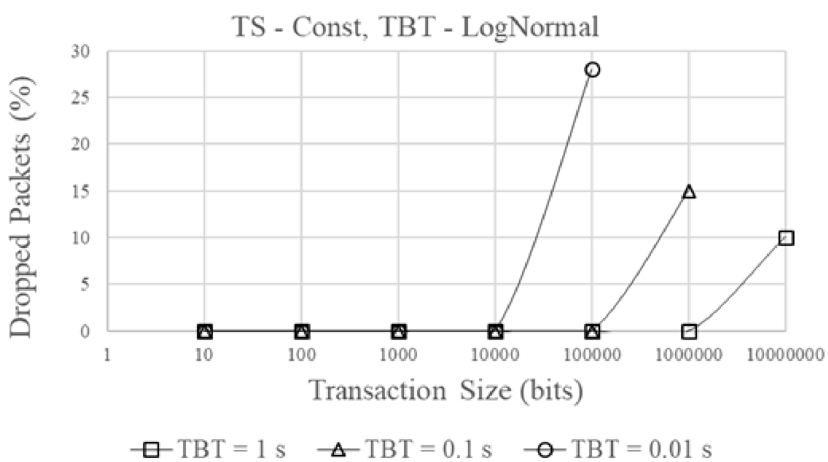


c)

Figure 2: Dependences of Dropped Packets on TS

Fig. 3 shows the dependences of message travel time on the size of transactions and the time interval between them for different statistical distributions. The same law (*Const*) is selected for the TS parameters in Fig. 3a, 3b, and 3c. The similar types of dependences are observed in Fig. 3 for all TBT distributions: with increasing transaction size, the time of their transmission via the channel increases.

Since the main thing is to ensure the minimum time for passing messages in the network with reasonable values of the parameter's TS and TBT, then based on the data of Fig. 3a, 3b, and 3c the following can be recommended. Choose the value of the parameter TS ≤ 1 Kbit, since for all the considered values of the parameter TBT, under any distribution laws, the parameter TT ≤ 0.4 s, and there are practically no packet losses based on the data from Fig. 2.

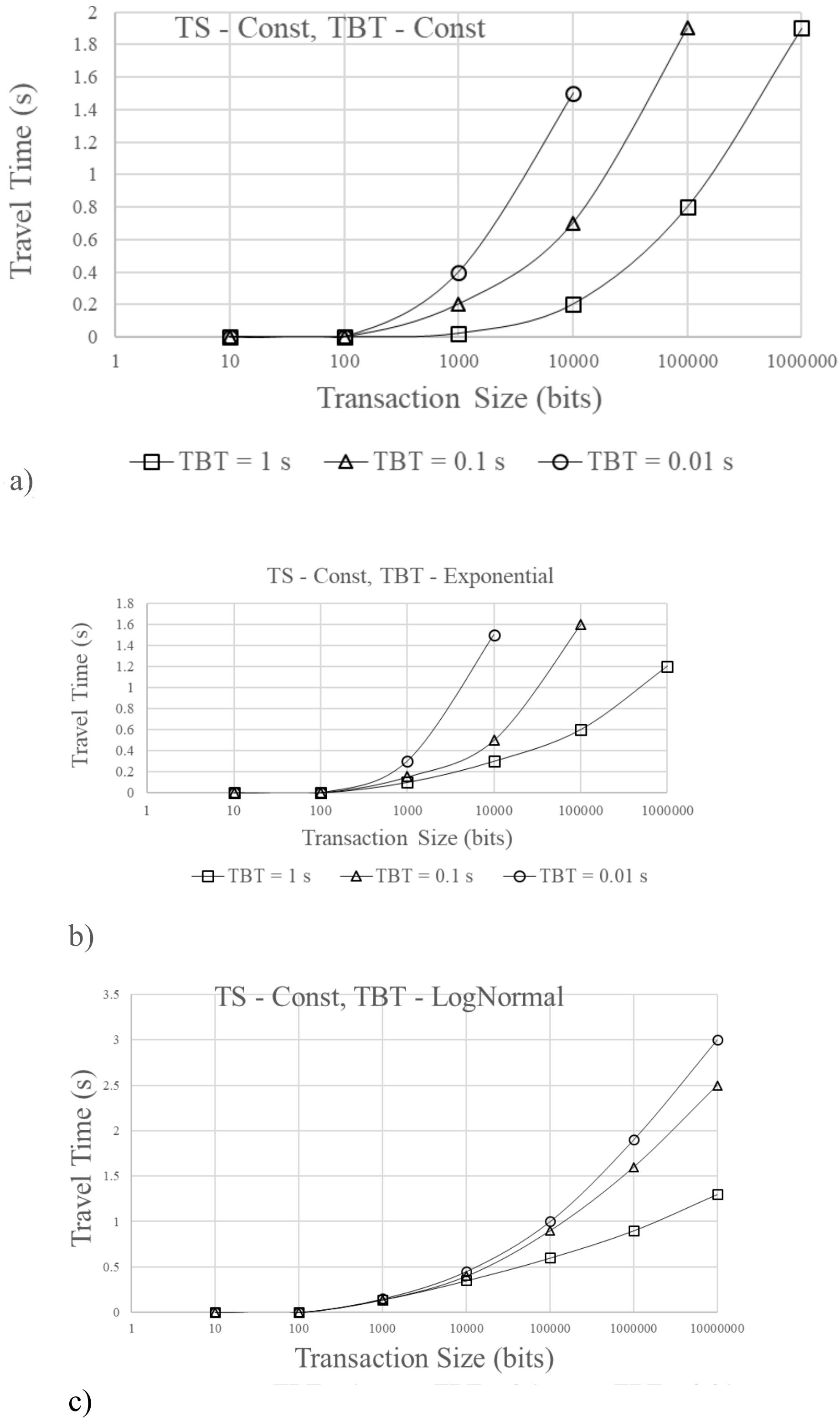
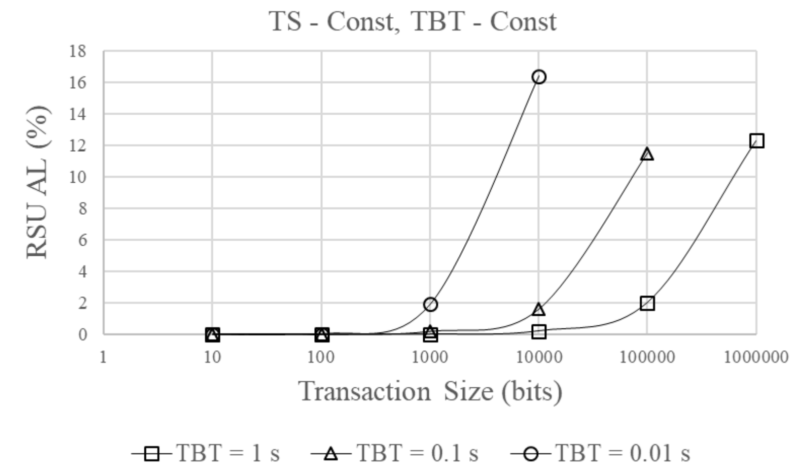
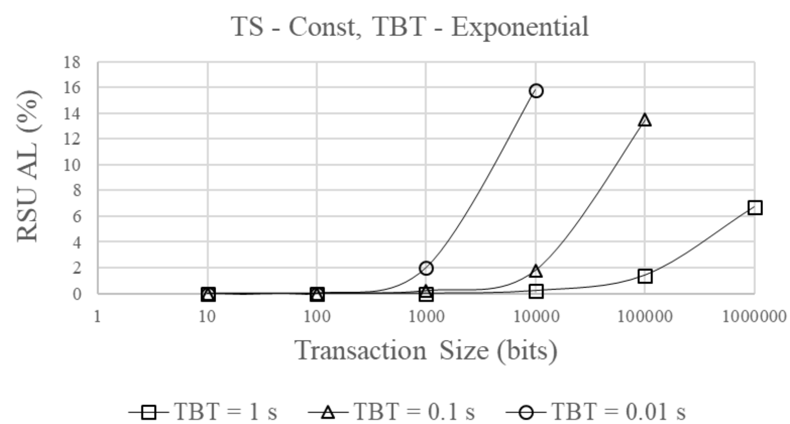


Figure 3: Dependences of Message TT on TS



a)



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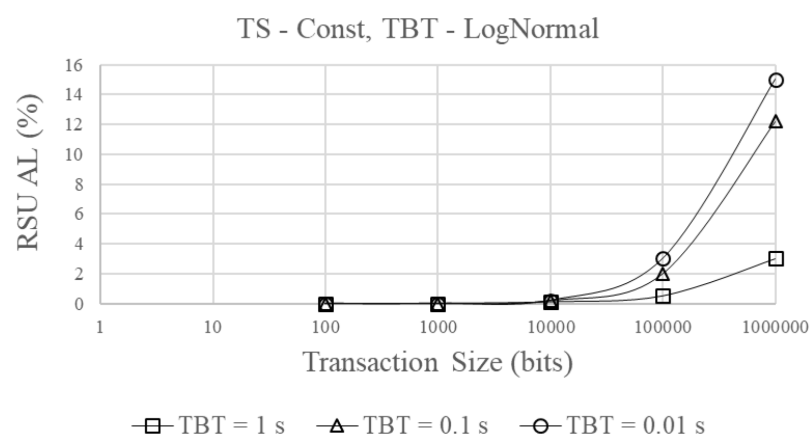

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Figure 4: Dependences of AL on TS

Fig. 4 gives the dependences of the RSU AL on the size of transactions and the time between them for different statistical distribution laws of the TBT parameters. The common Const law of the TS parameter distribution is selected in Fig. 4. The RSU AL parameter does not exceed ≈13% for Const, ≈7% for Exponential and ≈3% for LogNormal distributions for the TBT parameter at TBT = 1 s. The value of RSU AL increases quite significantly with decreasing TBT parameter for all distributions.

The dependences of the "RSU – Vehicle" channel load (Fig. 5) on its bandwidth are decisive for data transmission. As an example, we studied a transaction with TS=10 Mbits (*Const law*) at TBT=1 s with different statistical distribution laws. A channel with a bandwidth of 2.048 Mbps leads to an increase in the channel load up to ≈75% for the *Const law*, up to ≈54% for the *Exponential law*, and ≈22% for the LogNormal distribution law. The lowest channel load for all distribution laws is observed for bandwidths E3 = 34.368 Mbps and T3 = 44.736 Mbps.

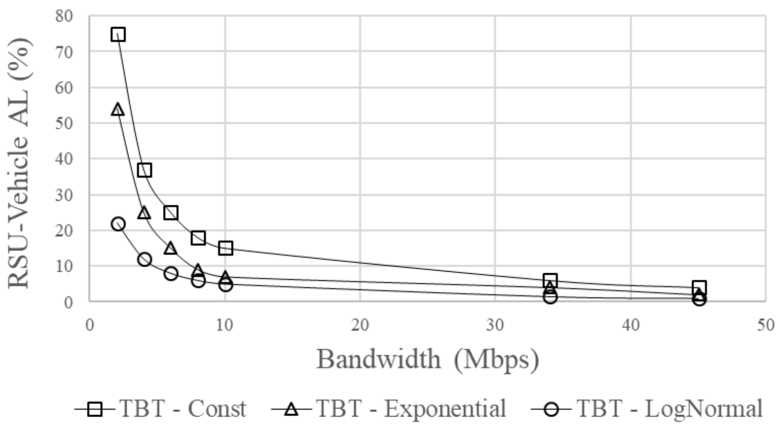
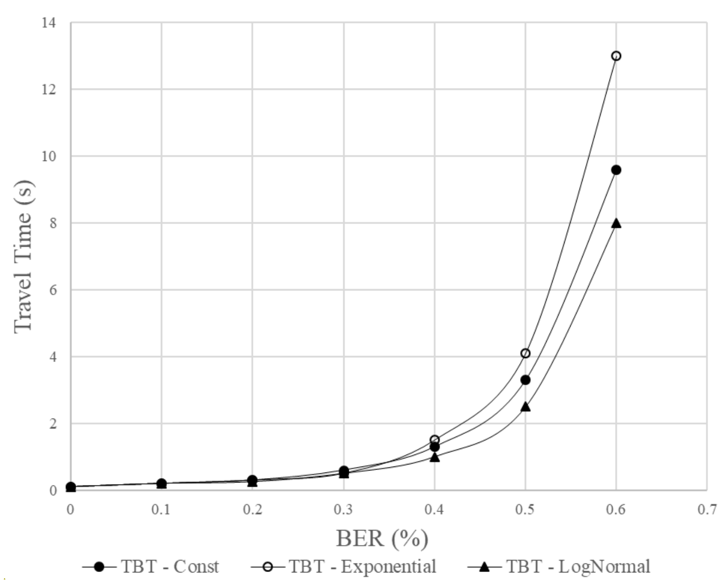


Figure 5: Dependences of Rsu-Vehicle Link Average Load on Bandwidth (TS=10 Mbits – Const Law, TBT=1 s)

The number of bit errors increases with traffic growth, which affects the transaction travel time and the "RSU – Vehicle" channel load. Fig. 6 demonstrates these processes on the example of a transaction with TS=1 Kbits (*Const la*w), and TBT=1 s for all considered statistical TBT distributions when changing the BER parameter from zero to 0.7%. The dependences of TT parameters on BER (Fig. 6a) are practically the same for all TBT laws up to BER = 0.3% and does not exceed 0.6 s. However, with a further increase in the number of bit errors, the message transmission time increases dramatically. From Fig. 6b it follows that the "RSU – Vehicle" channel load practically does not increase when transmitting the selected test messages up to BER = 0.3%, but then it increases and can reach ≈30% for the *LogNormal* law, ≈80% for the *Const law*, and ≈90% for the *Exponential* distribution law.



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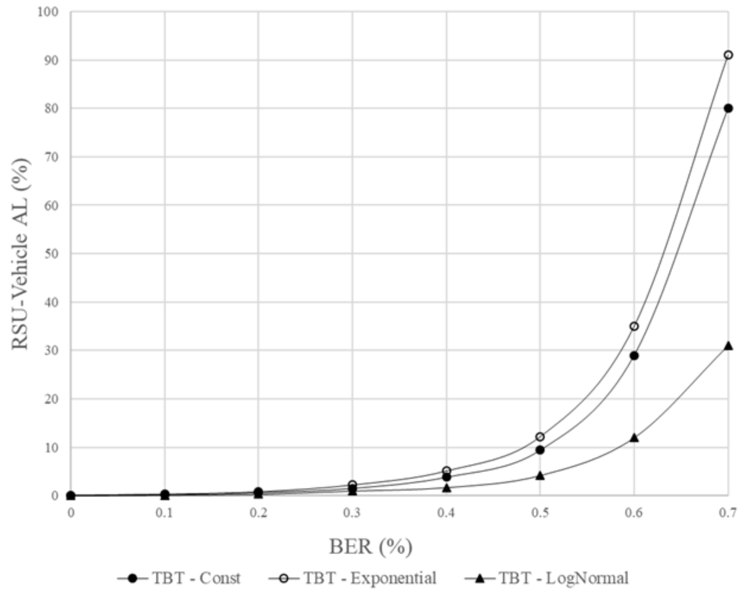
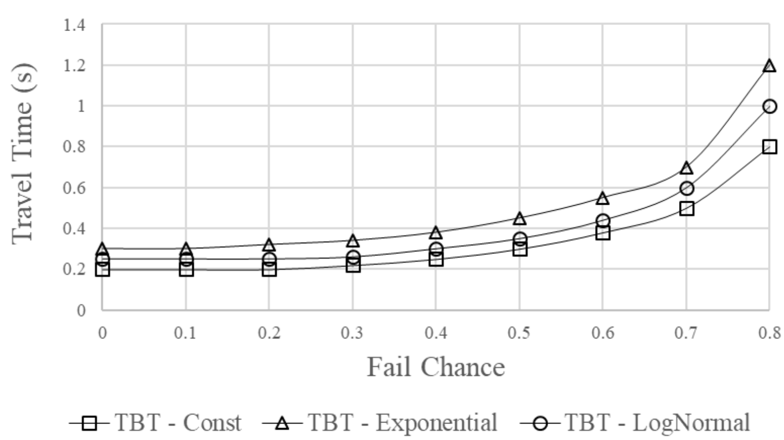


b)

Figure 6: Dependencies of Message TT and RSU-Vehicle AL on RSU-Vehicle Link BER (TS=1 Kbits – Const law, TBT=1 s, All Links with T1 Bandwidth)

Packet failure can be caused by network transmission errors or network congestion. Fig. 7 shows the role of the WAN cloud in data transfer. The dependences of the message travel time (Fig. 7a) and the "RSU-Vehicle" channel load (Fig. 7b) on the packet failure chance in the WAN cloud are investigated, when the packet failure varies in the range (0.0 - 0.8). As an example, a transaction with TS = 500 Kbit (*Const law*) and TBT = 1 s with different distribution laws was used.

The dependences of travel times on WAN Packet Fail Chance (Fig. 7a) are similar for all TBT distribution laws and show an increase in the TT parameter from ≈0.2 s to ≈(0.8-1.2) s with increasing packet fail probability from 0.0 to 0.8. The average load of the "RSU-Vehicle" channel increases (Fig. 7b) with an increase in WAN Packet Fail Chance. The smallest increase in load is observed for the *LogNormal* law, and the largest for the *Exponential* distribution law.



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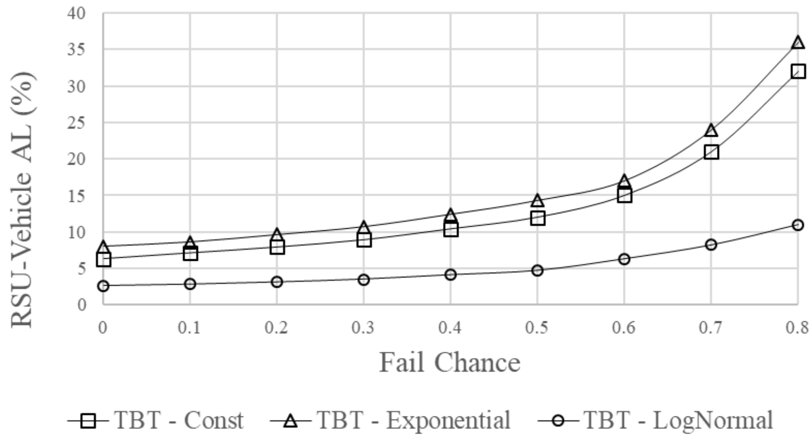

b)

Figure 7: Dependences of Message TT (a) and RSU-Vehicle AL (b) on WAN Packet Fail Chance (TS = 100 Kbits with Const Law, TBT = 1 s)

6. Conclusions

It still remains a difficult problem to create effective communication channels for the information exchange between vehicles in real time. Such information is necessary for the timely display of traffic conditions in urban areas and the estimation of time on a given route for dynamic path planning.

When creating communication channels for vehicles and choosing their modes of operation, it is important to know when a critical situation arises and communication becomes unreliable or completely interrupted. This is important when transmitting the necessary information, as such a situation can lead to a traffic accident. Therefore, when creating new VANETs, the theoretical foundations of their communication channels must be constantly developed, which is necessary to predict their behavior. The urgency of the problem is connected with the inclusion of both terrestrial and space networks in the communication channels of vehicles and the creation of integrated communication systems with drones.

Quantitative information on the loss of two-way traffic for VANET communication channels containing the terrestrial network is currently not available in the literature. In this paper, such information was obtained using the proposed model, for which the calculated traffic characteristics are presented. The dependences of the lost packets number in the roadside block on the transaction size and the "RSU-Vehicle" channel load are obtained and analyzed. The dependences of the bit error rate for the "RSU-Vehicle" channel on its load, the load of this channel on the probability of packet failure are studied.

The importance and usefulness of such numerical analysis lies in the ability to set traffic parameters and observe the resulting throughput, packet loss, bit error rate and QoS in the channel under certain transmission modes.

Authors' Contributions

Conceptualization, V.Kh.; methodology, A.G.; investigation, A.G.; resources, V.Kh., V.K.; writing — review and original draft preparation, A.G.; writing — editing, V.Kh., V.K.; project administration, V.K.

Availability of Supporting Data

All data generated and analyzed during this study are included in this article. The datasets generated during the current study are available from the corresponding author on request.

Declarations

Ethical Approval and Consent to Participate: Not applicable.

Consent for Publication: All authors have read and agreed to the published version of the manuscript.

Human and Animal Ethics: Not applicable.

Competing Interests: The authors have no relevant financial or nonfinancial interests to disclose.

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