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DEVELOPMENT OF HETEROGENEOUS SERVICES INTEGRATION CAPABILITIES FOR CHANGING TOPOLOGY VEHICULAR COMMUNICATION NETWORKS

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VILNIAUS UNIVERSITETAS

MINDAUGAS KURMIS

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INTRODUCTION

Scope and Topicality of the problem

Intelligent Transportation Systems (ITS) require development of the advanced information and communication technologies. It also requires development of interaction means and applications to the transport infrastructure based on wireless communication networks technological solutions. Results of wireless and embedded systems research and breakthrough of commercial applications allowed developing dedicated fast growing ITS area – vehicular communication Ad-Hoc networks. It is expected that this technology will greatly improve traffic safety, will reduce congestion, and improve travel comfort and the opportunity to preserve a cleaner environment.

Vehicular Ad-Hoc Networks – VANET can be implemented through long range communication (based on cellular 3G or 4G networks) or through short range technologies (Wi-Fi or DSRC). These types of communications allow users to provide road safety services by sharing safety information in order to avoid accidents, accident investigation afterwards, or to avoid traffic congestion. Other groups of services are a kind of services for passengers which are not related to security.

Application of communications technologies in vehicular transport has specific requirements and do not have strict restrictions on energy consumption. It can be equipped with powerful processing system equipment, wireless transmitters and various sensors. One of the most important requirements for communication systems is that the system must not distract the driver's attention from the road. The system should provide the necessary services to the user in the right place at the right time and it should be adapted in the right way to the user's needs without any intervention. One of the ways to increase autonomy and effectiveness of the user-vehicle interface is to understand the current and the past situations of the user, and predict the future situation.

A variety of vehicle, human and environmental sensors and information sources can be used to perceive the context. Sensor system generates large quantities of different types of information as the source of information. It includes the physical sensors of environment and the vehicle: GPS, speed, acceleration, temperature, radar, video, and so on. Also, virtual sensors are used including traffic condition information, hazard warnings, interactions with other cars, calls and etc. In the area of intelligent systems development research, several solutions for the adaptive services system have been proposed (Bielskis et al., 2012; Drungilas, Bielskis, 2012; Dzemydienė et al., 2010; Dzemydiene, Dzindzalieta, 2010; Gricius et al., 2015). Further development of intelligent adaptive services providing systems requires integration of immediate environment recognition and data management methods.

Recently, particular attention has attracted the area of changing topology mobile communication networks. In vehicles drivers are faced with the ever-increasing flow of information, thus, a major challenge becomes extraction of useful knowledge from data sources and appropriate presentation of it to the service support systems. An important question is how to adapt (adjust according to the user's needs) the services in real time, according to the knowledge gained from the context. By providing such services some questions arise:

- which information related to the subject area is important, or more important (prioritization issue),
- what services a user is interested in (the service support and adaptation according to the needs of the user question),
- which safety services should be provided automatically.

Relevance of the problem

The effective information collection from environmental and dissemination problem arises when developing adaptive systems for dynamic environments (Kakkasageri, Manvi, 2014). Context awareness and proper understanding as well as interpretation of this information require new methods which allow to collect the right information, to understand it (or aggregate) and disseminate it to other nodes. This information has to be directly attributed to the higher abstraction level of knowledge exclusion, that is the concept of environmental situations. By these situations there should be carried out the respective service selection, adaptation and improvement of the process automation quality.

One of the main research issues in the vehicular communication networks is the connection assurance. The research was carried out by some authors (Bazzi et al., 2015; Cespedes et al., 2013; N. Cheng et al., 2014; Kiokes et al., 2009; Li et al., 2014; Mumtaz et al., 2015; Shen et al., 2013; Sukuvaara et al., 2013). Most research focuses on the quality of communication protocols for heterogeneous network access, adaptation and management these protocols for vehicular communication networks. There is no detailed examination of configuration of the infrastructure channels, a different type of service priorities. The other area of the research is flooding based on Ad-Hoc network routing protocols and algorithms for data communication networks management and data dissemination. Last year’s research performed by authors (Annese et al., 2011; Bazzi, Zanella, 2015; de Oliveira Barros et al., 2013; Omar et al., 2015; Soares et al., 2014; Tian et al., 2015). These investigations consist of two parts: V2V and V2I communication and interaction aspects.

In addition to hardware and software development problems, computer engineering has to deal with the increased flow of acquired information, it has to avoid flooding the network. There is a lack of data dissemination methods for more effective integration of heterogeneous service support. There is a lack of methods and techniques that will enable a more accurate assessment of enriched and distributed context information according to a consumer preferences and transport system communication network configuration options. It has to be directly linked with quality of intelligent service support process of improvement. As much important are the IT communication methods as the foundation for the network configuration decisions for data transmission and network shaping that directly adapt the services provided in the subject area of dynamic nature. In this paper, their selection and integration techniques are presented. New methods and systemic platforms must allow to use the enriched context information in general, taking into account specific user requirements and traffic flow dynamics. Such heterogeneous service support in the complicated environment with growing traffic flows a need to evaluate conditions of communications network overload and to use the newly created resources for the new projects.

Object of Research

The intelligent methods and software and systematic means for context data acquisition, aggregation and dissemination in vehicular communication networks enable to develop a heterogeneous service support and adaptation systems for vehicle communication based systems.

Aim of Research

To develop a prototype system for vehicle communication network infrastructure configuration that integrates context information dissemination methods based on multicriteria data utility evaluation.

Objectives of Research

1. To analyze and summarize methods for the heterogeneous services support in vehicular communication networks assessing the network configuration specifics.
2. To perform analysis of the existing adaptive software and hardware platforms enabling to carry out contextual data collection, aggregation and dissemination processes for heterogeneous service support and to determine how to perform a rational context data management, estimating quality of enriched context data in vehicular communication networks.
3. To propose systemic and software platforms, allowing integrated simulation of movement of the vehicles and likely predicate values of network mobility and to determine their suitability for the design and verification of context data acquisition and dissemination system (prototype).
4. To develop a management prototype for the heterogeneous service support in changing topology vehicle communication networks, allowing control of network infrastructure load, according to the information acquired from the environment and cooperating devices enriched context by evaluating its utility and performance of data dissemination between other nodes in multicriteria.
5. To experimentally evaluate the developed vehicular communication network infrastructure management system prototype for adaptively reducing useless context information in a network with different network traffic and mobility conditions.

The research methods

For the dissertation information retrieval, organization, analysis, comparative analysis and synthesis techniques were used. The object and the problem of investigation are concretized by analyzing the latest scientific literature in scientific databases, thus evaluating the settlement level of objectives proposed in the work.

In order to create a new method for real-time integration of context knowledge, information extracted from the environment and cooperating devices, multicriteria knowledge performance evaluation and dissemination of knowledge among the nodes, the work analyses the techniques for context data acquisition, aggregation, dissemination and transformation into a heterogeneous service support levels. For the development of a prototype, the qualitative research method of construction is applied which comprises of theoretical multiple criteria and machine learning methods and their applications. Also, new context data acquisition and dissemination models and constructed prototype system are proposed. In order to experimentally evaluate the developed cooperative context data acquisition and dissemination system behavior and performance under different traffic conditions and network mobility, it was created simulation models in NCTUns, ESTINET, LabVIEW and RapidMiner environments. The experiment results were assessed using statistical methods.

Results

Models for the context data storage and exchange were developed allowing to reduce the volume of the transmitted data and to use the resources of the channel in the cooperative manner. The models were specialized to store data in local DB, exchange with other cars and exchange with VANET hybrid cloud. The evaluation of context data dissemination quality was based on methods and indicators for the quality of context determination. It is confirmed that for the development of adaptive systems to user requirement for highly dynamic subject areas, it is purposeful to apply the specially adapted context data dissemination in real-time methods to determine their capabilities at the lowest possible cost and time and to assess the system's response to changes in the environment as accurately as possible.

Methodic for developing situation aware vehicular communication was developed based on systems enabling to evaluate data acquired from the environment and cooperating nodes in real time, including multiple criteria utility evaluation and dissemination of knowledge among the other nodes.

A new adaptive context dissemination method, based on the transmitted information multicriteria performance assessment, enabling significantly to reduce the amount of useless context information in vehicular communication network was created.

Scientific Novelty

By preparing thesis it was introduced these new results for the Informatics Engineering scientific area:

- The proposed methods and their application methodology extends heterogeneous services support, systems design and development capabilities and their integration in vehicular communication networks. Unlike the currently available context data dissemination systems, the proposed method allows to adapt the data flows depending on the different areas of context, thus reducing the load on the wireless network and allowing to effectively provide services in subject areas with the dynamic nature.
- The proposed methodology, based on multicriteria information dissemination performance assessment process is designed for distribution, heterogeneous data collection subsystems integration by transforming their generated data to the highly dynamic intelligent transport systems context awareness. Each element of this intellectual transport system runs as a separate component having a specific environmental monitoring and control elements. Evaluation of context information utility allowed to realize the methods and algorithms that adaptively reduce the load on the wireless channel, and the transmitted and stored data volume without losing the enriched contextual information quality, which allows to develop more complex, heterogeneous services. It is believed that the obtained scientific results will affect the future development of intelligent transport systems, especially for context awareness and service adaptation systems.
- The developed prototype of changing topology vehicular communication network management system for the situation awareness based on real-time enriching context information, multiple criteria evaluation of the utility of the information and dissemination of knowledge among the nodes, provides opportunities not only to facilitate and speed up the heterogeneous service support, but also allows more efficient use of wireless technologies and ensures the compatibility and scalability of the system.

Defended Propositions

1. It is appropriate to apply context information utility evaluation algorithms taking into account enriched environment context information for adaptive heterogeneous service support in vehicular communication systems.
2. Developing network management system prototype for complex communication conditions in vehicular communication networks it is appropriate to design three special context data management algorithms: locally stored, transmitted to other nodes and data directed to cloud computing system.
3. The developed system prototype is efficient and proposed software and system tools solutions allow to decrease the amounts of useless transferred data in

changing topology vehicular communication network, without losing quality of context data.

Practical Importance

The developed management prototype for changing topology vehicular communication network was designed for the situation-aware vehicle communication based systems design, which evaluates and enriches context information in real-time. The 3 context data storage and exchange models for the management of locally stored, transmitted to other nodes and cloud computing systems data were proposed. This led to adaptively reduce the volume of transmitted data and the cooperative use of the channel resources.

The methodology of situation-aware vehicle communication based systems design were created allowing to evaluate the acquired information from environment and cooperating nodes in real time. Multicriteria evaluation of this information utility and dissemination of knowledge among nodes enable to create more efficient new situation-aware systems and to expand the current traffic flow management, consumer information, monitoring and other intelligent transport systems.

Methods proposed in this work for data acquisition, aggregation and dissemination were used by the following research and development projects: VGTU-KU-KTU-LEI project "Development and Application of Innovative Research Methods and Solutions for Traffic Structures, Vehicles and their Flows", 2013-2015; project "Lithuanian Maritime Sector's Technologies and Environment Research Development", 2013-2015; project "Application of Smart Technologies for Cargo Handling Process in Klaipeda Port Companies in order to Increase Cargo Handling and Energy Efficiency", 2014; "LLII-215 JRTC Extension in Area of Development of Distributed Real-Time Signal Processing and Control Systems", 2012-2014; LLII-061 "Development of Joint Research and Training Centre in High Technology Area", 2010-2012; "Mobility ICT technologies", 2011-2012.

Approbation and publication of the research

The main results of this dissertation were published in 10 scientific papers: 1 article in journal abstracted in *ISI Web of Science* database with Impact Factor, 6 articles in peer reviewed periodical journals, 3 in the proceedings of scientific conferences.

During the PhD studies it was prepared 8 other publications in Informatics engineering area: 4 papers in journals abstracted in *ISI Web of Science* database, 4 papers in other peer reviewed journals.

The main results of the work have been presented and discussed in 8 international and 2 national conferences:

1. NOSTRADAMUS 2014. International conference on prediction, modeling and analysis of complex systems, Ostrava, Czech Republic, 2014 23rd - 25th June.
2. Jūros mokslai ir technologijos – 2014, Klaipėda, Lietuva, 2014, Balandžio 23-25d.
3. 13th International Conference on Knowledge in Telecommunication Technologies and Optics KTTO 2013, Ostrava, Czech Republic, 2013 September 4th - 6th. (Best Paper Award)
4. 2nd International Scientific Conference Baltic Applied Astroinformatics and Space Data Processing, Latvia, Ventspils, 2013 May 15 – 16.
5. International Conference Social Technologies '13 Development of Social Technologies in the Complex World: Special focus on e-Health, Lithuania, Vilnius, 2013 October 10-11.
6. XVI tarptautinė mokslinė kompiuterininkų konferencija Kompiuterininkų dienos – 2013, Šiauliai, Lietuva, 2013 rugsėjo 19–21 d.

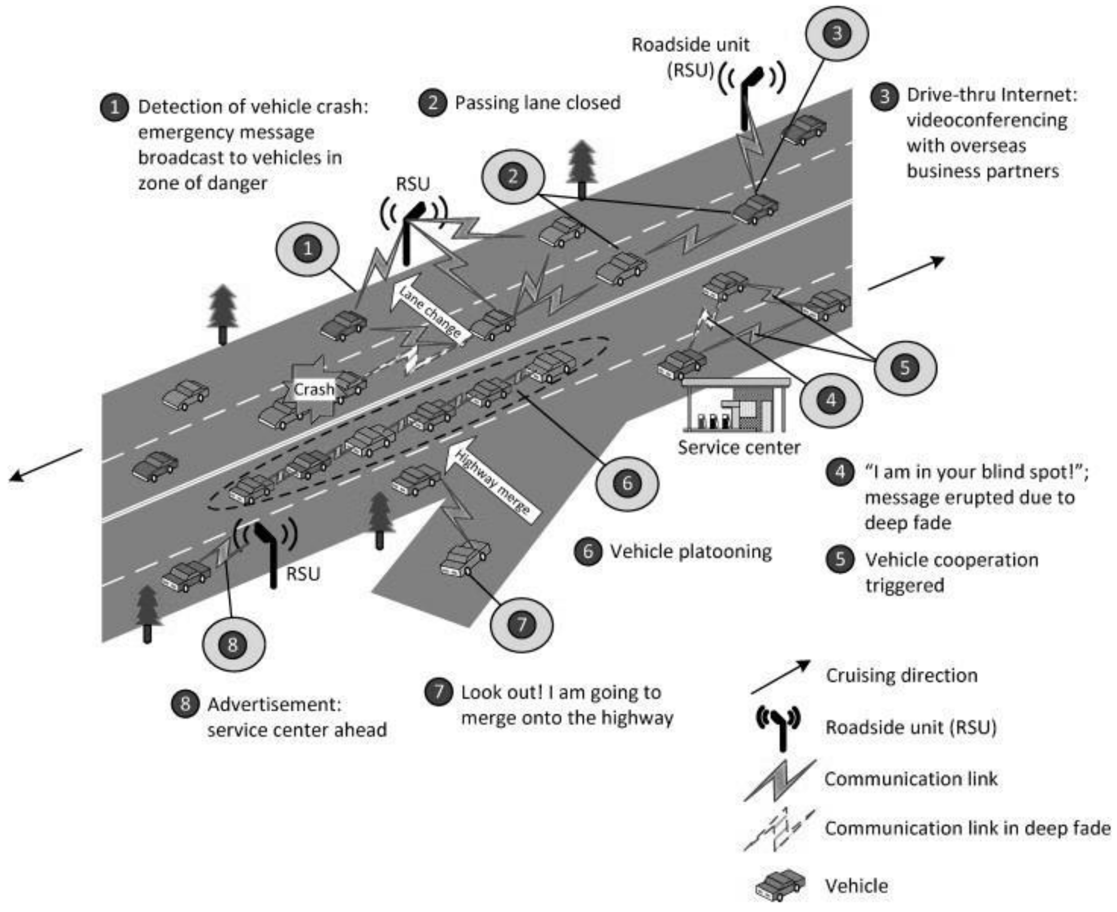
7. 7-oji mokslinė – praktinė konferencija Jūros ir krantų tyrimai – 2013, Lietuva, Klaipėda, 2013 balandžio 3-5.
8. Tenth International Baltic Conference on Databases and Information Systems. Vilnius, 2012.
9. International Scientific Conference Baltic Applied Astroinformatics and Space Data Processing, Latvia, 2012.
10. Technologijos mokslo darbai Vakarų Lietuvoje VIII, Klaipėda, 2012.
11. Mokslinė konferencija Socialinės Technologijos '11, Vilnius, 2011.
12. New electrical and electronic technologies and their industrial implementation: NEET 2011: 7th international conference, Zakopane, Poland, June 28 - July 1, 2011.

The scope of the scientific work

The work is written in Lithuanian. It consists of 5 chapters, and the list of references. There are 127 pages of the text, 53 figures, 7 tables.

1. SYSTEM INFRASTRUCTURE FOR THE HETEROGENEOUS SERVICE SUPPORT IN VEHICULAR COMMUNICATION NETWORKS

Currently, one of the most attentions attracting mobile communication technology is vehicular wireless communication networks. They offer the potential to develop and produce safer, more reliable, economic and comfortable vehicles. These networks are gaining more and more commercial relevance, since the adoption of DSRC (Dedicated Short-Range Communication) / IEEE 802.11p (Wireless access in vehicular environments (WAVE)) standards in both the EU and the U.S., has given the possibility to reach an entirely new level of service in a vehicle, covering many areas, including road safety, traffic management, comfort applications. Vehicles do not have strict restrictions on power consumption, and therefore, can be easily equipped with powerful computing devices, wireless transmitters, sensors, complex systems - GPS, photo / video cameras, vibration, acoustic, chemical sensors and, etc. Practices of vehicular communication network's deployment, research and scientific projects are developing in two directions: direct vehicle-vehicle (V2V) communication and vehicle-to-infrastructure (V2I) communication. Example of the infrastructure components and capabilities of the vehicular communication network is shown in Fig. 1.



Source: (Cheng et al., 2011)

Fig. 1. *Example of infrastructure components and capabilities of the vehicular communication network*

The communication between vehicles and the Road side unit (RSU) and the infrastructure form three types of domains. In-vehicle domain consists of an on board unit (OBU) and one or multiple Application units (AU)). Ad hoc domain is composed of vehicles equipped with OBUs. Vehicles communicate with other vehicles forming a MANET, which allows communication between vehicles in a fully distributed manner with decentralized coordination. In Infrastructural domain the RSU can connect to the infrastructural networks or to the Internet, allowing the OBU to access the infrastructure network(*CAR 2 CAR Communication Consortium Manifesto*, 2007, “IEEE Std 1609.3-2010 (Revision of IEEE Std 1609.3-,” 2010).

Specifics of Vehicular Communication Networks

Vehicular communication networks have special characteristics and features that distinguish it from other kinds of mobile communication networks. The main unique characteristics (Lee, Gerla, 2010; Moustafa, Zhang, 2009):

- High energy reserve,
- Huge mass and size of the vehicle.
- Moving by the templates.

The vehicles have much bigger reserve of the energy compared to ordinary mobile device. The energy can be obtained from batteries and it can be recharged by the gasoline, diesel or alternative fuel engine. The vehicles are many times larger and heavier compared to ordinary mobile networks clients and it can support much larger and powerful computational and sensor components. The computers can be provided by powerful processors, huge amount of memory and fast wireless connections (3G, LTE, WiMAX, 802.11p and etc.). Vehicles can move at high speed (160 km/h) or even more so it is difficult to maintain constant V2V or V2I connection and to provide necessary services. However, existing statistical data about traffic such as moving together by some templates or moving in the rush hours can be used to identify some types of situations and sequences of situation occurrence. The situation identification is also influenced by the scenario of vehicles movement. In the rural areas there is less obstacles and interferences but the driving speed is higher and the number of information sources is lower. In the city there are high level of interference and obstacles, however, the driving speed is lower and number of information sources is higher.

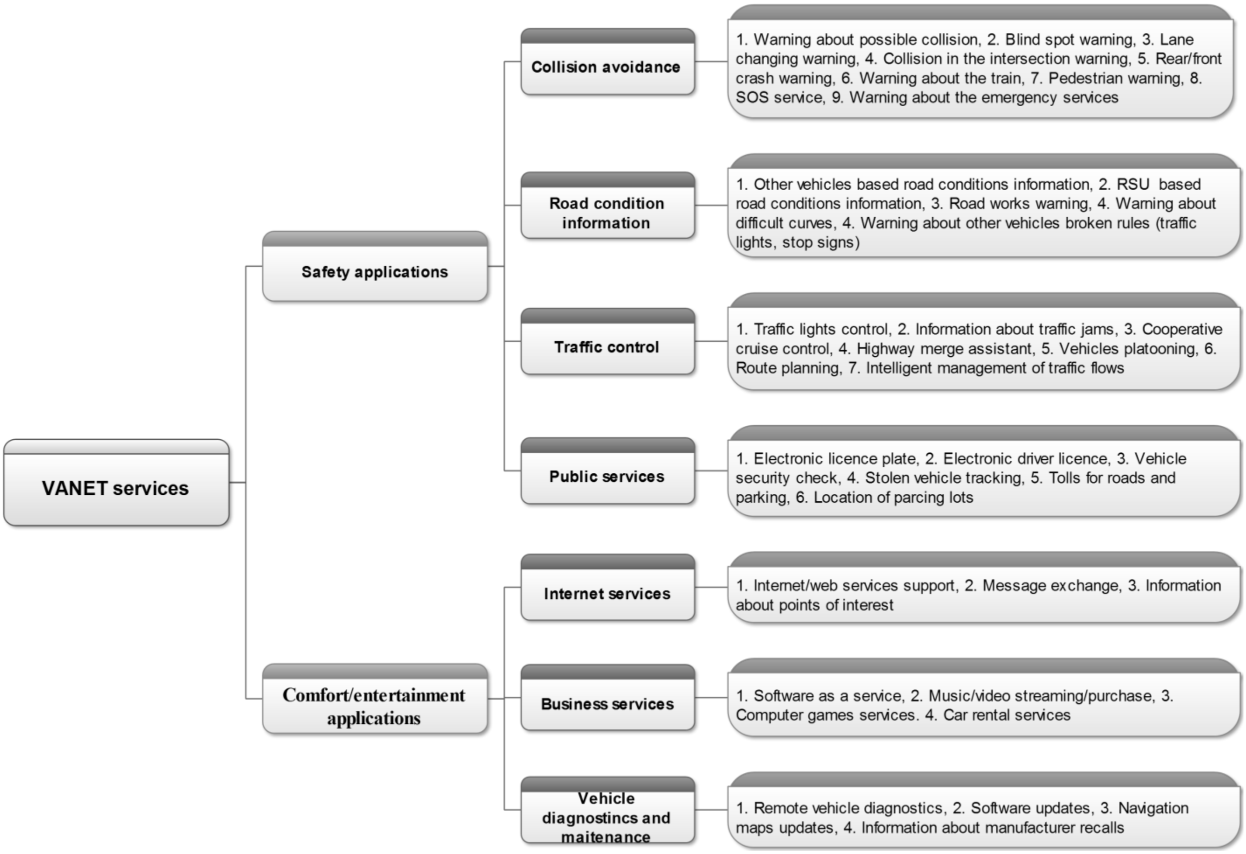
Analysis of heterogeneous services in vehicular communication networks

The VANET applications can be categorized in two categories: safety applications and comfort/entertainment applications:

The safety applications enhance the protection of passengers by sending and receiving information pertinent to vehicle safety. Generally, these alerts, such as cooperative collision warning, lane change warning, emergency video streaming, and incident management, are directly sent to the drivers or are received by the automatic active safety system.

The comfort/entertainment category of applications is referred to as non-safety applications, and aim to improve drivers and passengers comfort levels (make the journey more pleasant) and enhance traffic efficiency. They can provide drivers or passengers with weather and traffic information and detail the location of the nearest restaurant, petrol station or hotel and their prices. Passengers can play online games, access the internet and send or receive instant messages while the vehicle is connected to the infrastructure network. The investments by the vehicle manufacturers show that these applications are becoming extremely popular.

The taxonomy of vehicular communication networks (VANETs) applications is shown in Fig. 2.



Source: prepared by author based on (Baiocchi, Cuomo, 2013; Campolo et al., 2015; C.-M. Cheng, Tsao, 2015; Dias et al., 2014; Emara et al., 2015; Florin, Olariu, 2015; Golestan et al., 2015; Hussain et al., 2015; E. Lee et al., 2014)

Fig. 2. *Taxonomy of VANET services*

2. CONTEXT DATA AND PROCESSING METHODS FOR VEHICULAR TRANSPORT MANAGEMENT

For the vehicle to adapt to human needs and to provide the necessary services at the right time and the right place it is essential that the system is aware of the surrounding environment and to identify the current, past and likely future situation. A variety of sensors data can be used for situational awareness, but the data are extremely complex (different modalities, huge volume, with complex dependencies between sources), dynamic (real-time updates, critical aging) and different accuracy(Ye et al., 2012). However, the system does not have to evaluate individual sensor data, but instead - this information must be transformed to the next level of domain concept, called the situation, which can be used in applications as input, in order to adapt the software to a user needs (Costa et al., 2006).

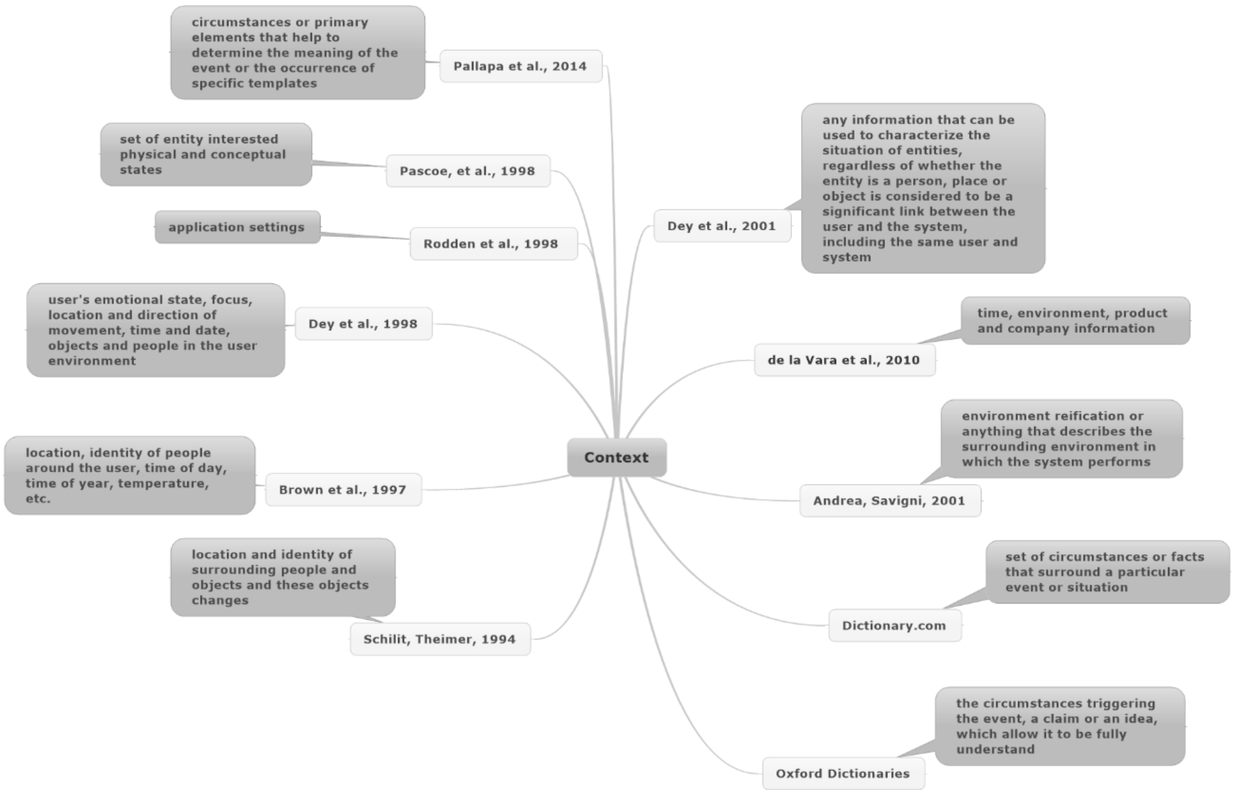
Situation identification system must be able to identify a number of different situations, to understand the relationship between them, their context and manage these situations, because otherwise, the system can operate incorrectly and improperly adapt to user needs. The system should be aware of several situations simultaneity or the fact that they cannot occur simultaneously, e.g., the car at the same time cannot be parked and ride on the highway. Given the complexity of the system operating conditions, a high level of dynamics, sensors heterogeneity, sensor inaccuracy and other circumstances, to achieve a high accuracy of situations identification is a difficult task. Situation identification is highly influenced by the vehicles movement scenarios: if it rides the highway, city, country, highway or it is parked. The summary of different scenarios analysis is shown in Table 1.

Table 1. *Characteristics of scenarios of traffic and network mobility*

Parameter / Scenario	Rural	Town	City	Highway
Average speed of node movement	Average	Low	Very low	Very high
Density of nodes	Low	Average	Very high	Average / Low
Interference	Low	Average	Very high	Low
Number of radio obstacles	Low	Average	Very high	Low

Context concept and representation

After analyzing works of pioneer of the ubiquity computing M. Weiser (Weiser, 1991), we can identify three main aspects of this type of communication: context-aware computing, intelligent environment and monitoring people and things. The author suggested paradigm has allowed the development of the ubiquitous computer systems which empower seamlessly to meet human needs. According to Caceres on Friday (Caceres, Friday, 2012), context awareness is a very important aspect of ubiquitous computing. Context analysis begins with the context definition and interpretation, widely discussed in literature. A Concept Map, a systematic information about the various scientific knowledge description given in Fig. 3, was made. Many scientists perceive and define context similar, but with a certain interpretation. This is understandable, because the concept is very wide, it combines different domains and it is used for various purposes. The first mention of the term “context-aware systems” were (Schilit, Theimer, 1994). They described context as location and identity of surrounding people and objects and the changes of these objects.



Source: sudarytas autoriaus, prepared by author based on (Andrea, Savigni, 2001; Brown et al., 1997; de la Vara et al., 2010; A. Dey et al., 2001; A. K. Dey et al., 1998; Pascoe et al., 1998; Rodden et al., 1998; Schilit, Theimer, 1994)

Fig. 3. *Concept map of context definition*

The analysis of our subject area question thus is context information acquisition, aggregation and dissemination in vehicular communication networks, the most appropriate term to describe the context is a definition by context-aware systems pioneer A. Dey who says that the context is “any information that can be used to characterize the situation of entities, regardless of whether the entity is a person, place or object is considered to be a significant link between the user and the system, including the same user and system” (Dey et al., 2001).

Context quality concept and management of context

The development of adaptive systems for ubiquitous computing environments encounters with problem of limited context information quality (Bu et al., 2006). In order to assess the context information collection, aggregation, and dissemination techniques, it is necessary to define the concept of quality of the context. Two units of context information belonging to the same entity in the same type and received at the same time may vary according to their degree of accuracy, and the likelihood of fairness. This type of quality is identified as Quality of Context – QoC (Buchholz et al., 2003). Authors, who first used the term, define the quality of context as "any information used to identify quality of context information”. It also states that the context is based on the quality of information, rather than a process or hardware component, potentially providing information. One of the recent definitions say the quality of context is “a set of parameters representing context data quality requirements and properties (Bellavista et al., 2012). According to these authors, the quality of context does not require perfect context information with the highest possible precision and novelty, but it needs the adequate data quality assessment. Despite a number of works, trying to define the context of the quality, the universally accepted definition of quality of context does not exist.

Understanding of the context in a mobile environment requires an interdisciplinary approach that combines programming paradigm, operating systems, embedded systems, computer networks, mathematical analysis and other fields of science. This creates a huge gap between the high-level requirements for mobile systems, services and operations complexity of working with context derived from the environment. Application requirements include various aspects such as: adaptability, flexibility, and ingenuity. Given the heterogeneity of devices, a high level of mobility and changing topology, the management of context information is extremely complex and can be significant to errors.

Applications face raw context in the context aware modules. Applications adapt their actions according to the changing context (Zhang et al., 2011). Management of context in environment with fast changing topology such as vehicular communication networks is a difficult task due to several factors (Wibisono et al., 2009):

- Context becomes obsolete due to the high mobility of nodes. Context information is closely tied to a physical location and a certain place, thus it may become less important or completely useless. It may be difficult to keep updated information on the context due to repeated disconnection of nodes from the context source.
- Temporary context relevance, caused by dynamic changes. Context can gain temporary importance of customer or supplier mobility. Temporary context relevance can change dynamically, depending upon the situation. This can lead to problems related to the uncertainty of the context.
- Context ambiguity and redundancy. Lack of coordination in V2V environment can lead to ambiguity and redundancy, whereas a similar context may be proposed by a number of units with different values and attributes.

In recent years, researchers have focused on various aspects of the context, including: the context middleware and tools, information acquisition and ontologies, which provides a description of the vocabulary of the context. The focus was on the context abstraction and sharing, in order to identify the relevant context abstractions and characteristics. However, the issue of uncertainty, which is one of the fundamental in the sensors based mobile environment was considered very low. Context related philosophy can be expressed in the context-situation pyramid which meant a three-level hierarchy of the concept abstraction. The first is the basic raw data. This information (possibly with certain preprocessing) is used to create the concept. For example, the context is the model used to describe real-world situations. Then, as a meta-level concept above context, we identify the concept of situations, which can be derived by analyzing context information.

Context Spaces use geometrical metaphors to describe context and situations as first-class objects of the model. We start by defining the application space – the universe of discourse in terms of available contextual information for an application. The application space comprises types of information that are relevant and obtainable to the system. An information type is termed a context attribute and is denoted by a_i. The value of a sensor reading at time *t* is the context-attribute value at time *t* and is denoted a_i^t. The application space is a multi-dimensional space made up of a domain of values for each context attribute, in which context can be sensed. Within it we perceive subspaces (possibly defined in fewer dimensions), which reflect real-life situations. These subspaces are called the situation spaces. Situation spaces are defined over regions of acceptable values in selected dimensions and represent collections of values that reflect real-life situations. The actual values of sensory originated information are defined by the context state, e.g., the collection of current sensor readings(Padovitz et al., 2008; Padovitz et al., 2006; Padovitz, 2006).

In order to reason about the context and situations represented by the context spaces with uncertainty, we can apply different reasoning methods. In particular, the proposed new reasoning, based on Multi-attribute Utility Theory (MAUT) (Dyer, 2005). In artificial intelligence, representation of heuristics rules, mostly based on the expert's experience and common sense, and is used as a guideline for solving the problem. It is proposed to use the MAUT as a way to integrate the heuristics of confidence in the measurement, reflecting the degree of confidence in the situation occurrence. In many cases, some types of information are more significant than others, describing the situation. To model the differences of significance between the attributes of a particular situation, the utility function is defined that assigns weights to the context attributes. The weights reflect what is important for each attribute (in comparison with other attributes) when describing the situation. In the utility function, relative importance between the situations of space attributes and in the contribution function is modeled, as well as individual elements of a specific contribution in the field, describing the situation. Instead of just knowing whether the value is in the field or not, it is evaluated in the same meaning. Such an approach is used in MAUT, which takes the information provided in the model (eg. status of the context and expressed situations space description) and calculates the degree of confidence that the situation is occurred. Estimated confidence is compared to a threshold of confidence (comparing the calculated confidence to the individual situation of a particular threshold, which allows comparison of results calculated for different situations).

The main requirements for the developing infrastructure management prototype

The literature analysis showed that traffic and different network mobility scenarios must be taken into account, the data is acquired and transmitted in a very dynamic and changing topology environment, the safety messages are not for the actual receiver, data from the environment must be collected accurately and on time, part of the collected data becomes insignificant after a certain period of time and the distance, data acquisition and dissemination algorithms must be fault tolerant and it must be ensured the data collection and dissemination, even if some nodes go offline, it must be taken into account that not all vehicles will be equipped with communications equipment.

The essential data dissemination characteristics were determined: information must be constantly updated, information exchange mechanism must operate effectively both dense and sparse VANETs, dissemination strategy must be resistant to the fluctuations in the level of the transmitted signal, information dissemination process has to be intelligent, to be able to identify the purpose of the dissemination eg., movement in the same direction, in opposite directions or in both directions.

It was showed that for the author research the context spaces and multi attribute utility theory general statements are only partly suitable. For the new solutions of this problem it is appropriate to apply the new algorithms for exchange of context information between the nodes and to integrate this information with enriched environmental context information.

3. SYSTEM AND SOFTWARE PLATFORMS FOR TRAFFIC FLOWS AND NETWORK MOBILITY MODELLING AND RESEARCH

The analysis showed a huge range of software platforms allowing to investigate and evaluate various accesses, routing and transmission protocols. Vehicular communication modeling is fundamentally different from the MANET simulation, whereas the automotive environment leads to new problems and requirements, such as: restricted road topology, roadside barriers, traffic flow models, variable speed of cars and mobility, traffic lights, traffic congestion, driver behavior, etc. Development and testing of vehicular communication networks uses a lot of time and financial resources, it is often appropriate to investigate the case of systems using simulation. Vehicular communication network modeling and simulation software has been divided into 3 different categories: (a) the vehicle mobility generators, (b) network simulation software, and (c) vehicular communication network simulation software. The classification of the software platforms is shown in Fig. 4.

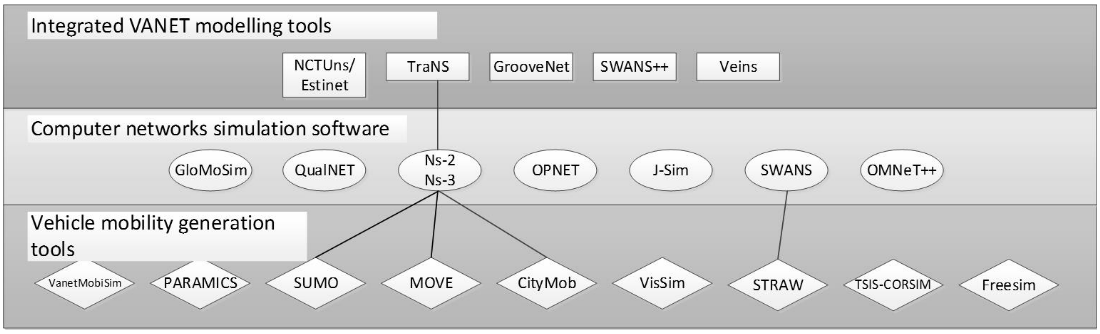


Fig. 4. *Classification of VANET simulation software*

The literature analysis showed that part of the research carried out using a specially designed modeling tools for the specific network element. Such modeling tools have serious shortcomings for repeated experiments, whereas some models details remain poorly defined or not disclosed and the tools are not open sources or available to the public. The qualitative comparison of integrated vehicular communications network modeling tools analysis is presented in the Table 2.

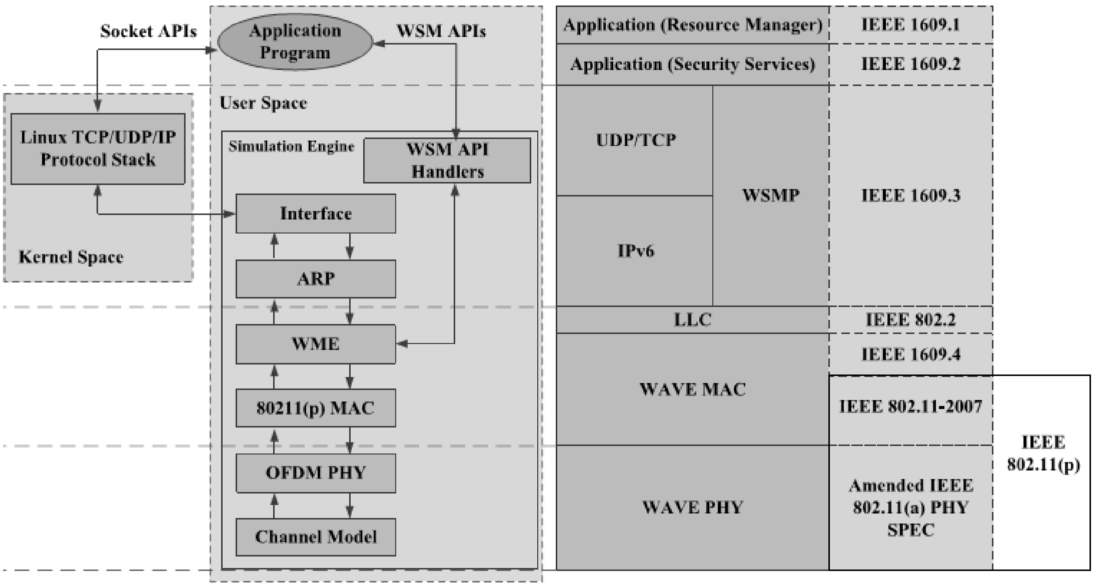
Table 2. *Comparison of integrated simulation software tools*

Atribute	Swans++	GrooveNeT	TraNS	Veins	NCTuns/ Estinet
Mobility functions					
User graphs	*Supported*	*Supported*	*Supported*	*Supported*	*Supported*
Random graphs	*Random waypoint*	*Voronoi graphs*	*Grid based*	*Random waypoint*	*Figure files*
Maps based graphs	*Tiger DB*	*GDF*	*Tiger DB*	*OpenStreetMap DB*	*Figure files*
Multiple lanes	*Supported*	*Supported*	*Supported*	*Supported*	*Supported*
Start/end	*Random*	*AP,*	*AP, random*	*Random*	*Random*

position		*Random*			
Road	*Random waypoint*	*Random waypoint, Dijkstra*	*Random waypoint, Dijkstra*	*Random waypoint*	*Random waypoint*
Speed	*Constant*	*Depending on conditions, constant*	*Depending on conditions, constant*	*Constant*	*Depending on conditions, constant*
Intersection control	*Unsupported*	*Traffic lights, signs*	*Unsupported*	*Unsupported*	*Traffic lights*
Lane changing	*Unsupported*	*Supported*	*Unsupported*	*Unsupported*	*Supported*
Radio obstacles	*Unsupported*	*Supported*	*Unsupported*	*Supported*	*Supported*
Other functions					
GUI	*Supported*	*Supported*	*Unsupported*	*Supported*	*Supported*
Real TCP/UDP /IP stack	*Unsupported*	*Unsupporte d*	*Unsupported*	*Unsupported*	*Supported*
Repeatable simulation results	*Partial*	*Partial*	*Partial*	*Partial*	*Supported*

After the evaluation of the simulation software analysis results, it was found that the best suited research for the author is tightly integrated modeling platform NCTUns/Estinet, in particular for the use of real TCP/UDP/IP protocols and repeatable simulation results. Also, it can be used with any actual Unix application on a simulated node without additional modifications.

NCTUns/Estinet supports two types of IEEE 802.11 (p) / 1609 protocol nodes: 802.11(p) RSU and 802.11 (p) OBU. Both units use the same protocol stack configuration, which is shown in Fig. 5.



Source: (Wang, Lin, 2008)

Fig. 5. *Architecture of IEEE 802.11(p)/1609 protocol in NCTUns/Estinet environment*

It was established that there is no single platform covering all of the prototype development and verification phases, thus for the data collection and dissemination management system (prototype) design and verification within analyzed coverage the most appropriate means is:

- package – *NCTUns/ESTINET*, enabling to perform a finite micro traffic simulation using real Linux operating system's TCP/UDP/IP protocols to ensure the reliability and realism of the obtained results,
- for the System prototype design, the most appropriate is the National Instruments LabVIEW software and CompactRIO systemic platforms,
- for the design, testing and verification of the adaptive channel quality management and data stream reduction by creating clusters of vehicles it was chosen RapidMiner 6.5 tool.
- There is a need to create an algorithm for these software and system tools integration.

4. DESIGN OF INTEGRATION SYSTEM FOR HETEROGENEOUS SERVICE SUPPORT IN CHANGING TOPOLOGY VEHICULAR COMMUNICATION NETWORKS

Context information sources for situation identification

To identify situation in the vehicular environment various sensors and other sources of information can be used. The raw data can be acquired from physical sensors deployed in the vehicle: video cameras, GPS, microphones, movement dynamics, vehicle parameters, etc., and from virtual sensors: user preferences, data from Smartphone/tablet (calendar, reminders, social networks) and from other vehicles data (warnings, road information, etc.). This collected data makes vehicle user context. The context of an entity is a collection of measured and inferred knowledge that describe the state and environment in which an entity exists or has existed (Latré et al., 2013). This definition includes two types of knowledge: facts that can be measured by sensors (physical or virtual) and inferred data using machine learning, reasoning or applying other methods of artificial intelligence to the current of past context. Due to discussed specifics of vehicular communication networks sensors used in the vehicles cover much broader spectrum than used in the traditional ubiquitous environment. In the Table 2, the update rate of the data, information source and data exchange ways can be seen: inV (in vehicle), V2I (vehicle to infrastructure), V2M (vehicle to mobile device), V2V (vehicle to vehicle). Different sensors provide different data types: binary, numerical and features, therefore the software and hardware must be able to deal with all types of data.

Table 3. *Proposed sensors for the situation recognition in the vehicular communication networks environment*

Sensor	Update rate	Information source	Data exchange
Physical			
GPS	High	Vehicle	inV
Speed	High	Vehicle	inV
Accelerometer	High	Vehicle	inV
Temperature	Low	Vehicle	inV
Fuel quantity	Low	Vehicle	inV
No of passengers	Low	Vehicle	inV
Vision	High	Vehicle	inV
Voice commands	Average	Vehicle	inV
(Millimetre wave radar system)	High	Vehicle	inV
WSN	Average	Environment	V2I

Wireless interface info	Low	Wireless equipment	inV
Virtual			
Calls	Low	Smartphone	V2M
Calendar	Low	Smartphone	V2M
Reminders	Low	Smartphone	V2M
User preferences	Low	Smartphone	V2M
Road information	High	Other vehicles, government, environment	V2I, V2V, V2M
Warnings	High	Other vehicles, government, environment	V2I, V2V, V2M
Interaction with other vehicles	Average	Environment	V2I, V2V, V2M

The general architecture of the management system of the proposed vehicular communication network infrastructure is presented in Fig. 6. This system infers situations and links them with other types of information in the system. The system collects real-time information from available sources (physical and virtual), performs pre-processing of data and reduces noise. Processed data is transmitted through the interface to the context utility evaluation system, which uses the channel quality management and cluster identification systems for adaptively managing the communication network resources. It is performed within the context messages compilation system based on context data utility evaluation. The evaluation of the utility of messages enables it to decide how to use the compiled context data message: it can be transmitted to the vehicle DB management system through the interface which in turn puts a message in local comfort/information or security DB, and this information can be transferred to other communicating nodes.

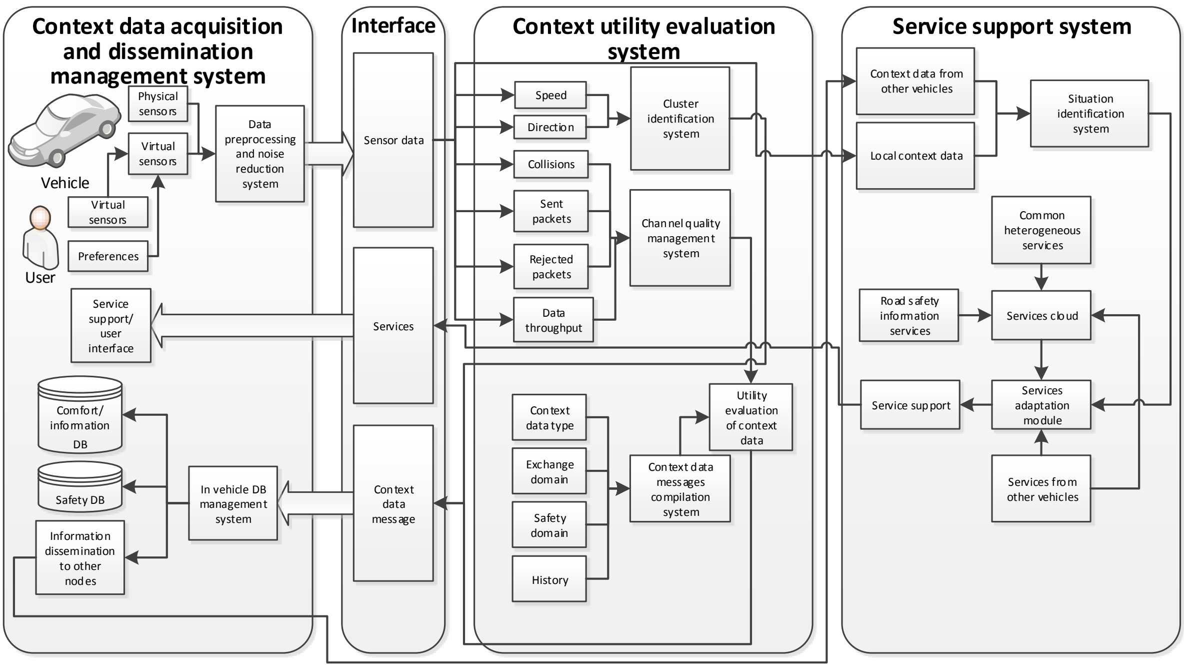


Fig. 6. *Common architecture of proposed system for control of vehicular communication network*

Context data acquired locally or from other vehicles is passed to the services support system, which is using the existing knowledge and identifies situation of user/vehicle. According to the identified situation, the necessary services are selected and provided through the cloud service platform or directly to other cars and adapted according to the user's needs in the adaptation module. The services are provided to user through service support system interface.

Evaluation of context data utility

The proposed system model for cooperative context data acquisition and dissemination for situation identification in vehicular communication networks measures the utility of each disseminated data message and makes decision for it. The system acquires the data from different sources (physical and virtual) of sensors, then the information pre-processing and de-noising procedures are performed. The processed data is checked if it is safety related and if the answer is yes, it is immediately transmitted to other vehicles. If not, the data is passed to the Decision Support System (DSS) where the utility of the data is calculated. If the DSS decides that the data is not important, it is deleted; if the DSS decides that data is of medium importance, it is stored in the vehicle database, then the availability of the wireless link channel is checked. If the channel is congested, the message is rejected and not transmitted to other vehicles. If the channel is available, the message is transmitted to the Cloud database. When the DSS decides that the context data is critically important, data message is formed and sent to the Cloud database where it is stored, further processed and disseminated to other VANET Cloud members (Fig. 7). In parallel Vehicle database system exchanges information with the Situation recognition and management subsystem where reasoning engine which employ different methods of artificial intelligence (logic rules, expert system, ontologies) associate the context with the data from different sensors. In this way the reasoning engine infers the current vehicle situation. By using the knowledge of the current, past and possible future situations the system selects best services from the Vehicle services cloud, adopts it to the user needs, according to its preferences and reasoning engine recommendations and provides it to the user.

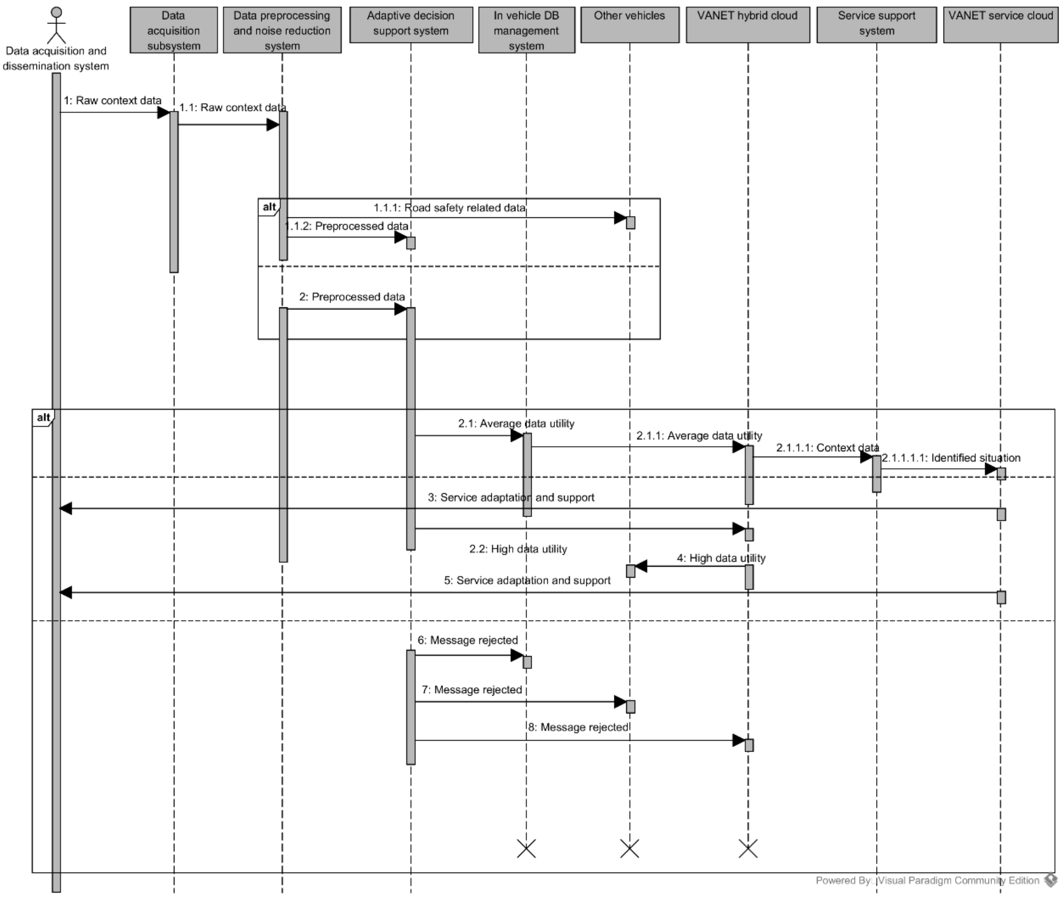


Fig. 7. *Dataflow of data dissemination process algorithm*

To deal with one of the biggest problems in data dissemination in the VANETs using any of the known techniques: flooding, broadcasting, neighbor knowledge based exchange and cluster based approach, is ensuring that safety and traffic management applications function successfully, this means that the channel congestion has to be minimized. We propose to introduce the utility function for the different kind of the contexts evaluation and to store it in the context matrix (M_L) for *l* data messages (*m*) from *n* sensors (*s*).

$$M_L = \begin{pmatrix} d_{L_{11}} & d_{L_{12}} & \dots & d_{L_{1n}} \\ d_{L_{21}} & d_{L_{22}} & \dots & d_{L_{2n}} \\ \dots & \dots & \dots & \dots \\ d_{L_{l1}} & d_{L_{l2}} & \dots & d_{L_{ln}} \end{pmatrix} \tag{1}$$

The utility of the context data messages can be weighted in a function which assigns a value to each data message to be disseminated. The value is calculated by the Eq. (2):

$$d_{L_{ij}} = \left(Ty_j + H_j + Ex_j\right) m_i cr_i Pr_i,\ i = 1,...,l,\ j = 1,...,n \tag{2}$$

where *Ty* is the type of context data in the interval [1–3] (1—entertainment related, 2—entertainment and safety related, 3—safety related). *H* is the parameter in the interval [0, 1] showing if the data should be used for historical saving (1) or not (0). *Ex* is the parameter in the interval [1–4] showing the data exchange domain (1—V2M, 2—InV, 3—V2I, 4—V2V) and *cr* is the coordinates of the data generation location. The priority of the message (*Pr*) is calculated by the $\mathrm{Pr}_j = 1 + \frac{\mathrm{I_j}}{\mathrm{A_j}}$ and it is normalized with values falling in a predetermined interval [1–3], where 3 means that the message priority is critical and it must be disseminated immediately, 2 means that the message have medium priority, and 1 means that the message is not important and can be suspended or rejected. I_j is importance of the message in the interval [0, 1] where 0 is safety related message and 1 is comfort/information related message. $\mathrm{A_j}$ is message age function with normalized values in predetermined interval [1, 2, 3] which is calculated by (3) where $\mathrm{T_M}$ is difference between current and message compilation time.

$$A = \begin{cases} 1, \text{if } \mathrm{T_M} > 5s \\ 2, \text{if } 1 < \mathrm{T_M} < 5s \\ 3 \text{if } \mathrm{T_M} < 1s \end{cases} \tag{3}$$

During the development of the network management prototype for changing topology vehicular communication network it was found that it is appropriate to design three separate context data management algorithms: for locally stored, transmitted to other nodes and data directed to cloud computing. 3 context data storage and exchange models were offered. The developed algorithms allowed to adaptively reduce the amount of useless transferred data and to use channel resources cooperatively.

5. EXPERIMENTAL RESULTS FOR EVALUATION OF THE DEVELOPED PROTOTYPE FOR MANAGEMENT OF SERVICE SUPPORT IN VEHICULAR COMMUNICATION NETWORK

The experimental research is divided into 4 stages. In the first stage, a vehicle clustering experiments are performed, during which the clustering methods and tools necessary for information aggregation are experimentally determined. Also, it is determined what data attributes are appropriate to use for the clustering process. In the second stage, the simulation experiments are performed to determine the performance of exchange of the context data between the vehicles in real-time, which is a prerequisite in order to provide heterogeneous services in the changing topology communication network. In the third stage, the experiments of the distributed context data storage and access in mobile communication networks are carried out and performance of different data transfer protocols using different models of vehicle mobility are evaluated. Using different scenarios, the experiments were carried out under different traffic and mobility conditions. In the fourth stage, a developed adaptive context information acquisition and dissemination method are evaluated and the data transmission channel quality evaluation using Multilayer Perceptron, decision tree, rules induction, Naïve Bayes and quadratic discriminant analysis are studied.

Results of experiments of vehicles clusters formation

In the clusters based aggregation nodes aggregate data in groups, making it possible to significantly reduce the amount of overhead information and to increase the overall system efficiency, since dynamics of VANET topology are reduced. The main indicator of the efficient clustering is a relatively stable cluster structure. Frequent changes in the cluster consist of an additional communication channel load, which reduces the transmission bandwidth. The effective size of the cluster is associated with the radio range and vehicles density, which varies in time. The cluster structure is determined by the spatial dependence, which describes the similarity of mobility between different nodes.

For the clustering experiments the Roman taxi data set was used (Bracciale et al., 2014), which captured geographic coordinates and time taxis moving in the center of Rome. Data was acquired every 7 seconds. Using the Android OS Android LocationManager object getAccuracy function, data was filtered out having less than 20 m accuracy.

It was found that the direction of movement and speed characteristics should be used for clustering vehicles. To cluster vehicles according to the geographic position is not appropriate, since both RSU and every P2P network node can filter out their respective cluster nodes, which is appropriate to transfer the information. After a series of experiments for the vehicles clustering, the X-Means clustering algorithm was selected. This algorithm is an improved version of the well-known clustering algorithm k-MEANS, enabling to not have the number of clusters specified. The clustering experiments were performed using the RapidMiner 6.5 tool (Fig. 8).

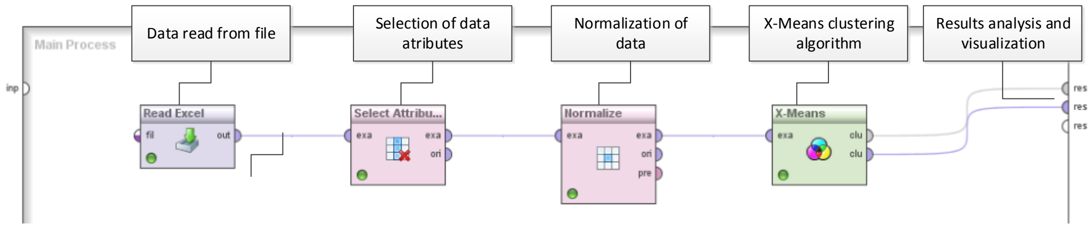


Fig. 8. *Developed model of clustering experiment using RapidMiner 6.5*

The results of vehicles clustering experiments are presented in Fig. 9. Nodes assigned to different clusters are shown in different colors. Nodes spatial distribution is displayed by the GPS coordinates. Graphs display clusters' change over time. The algorithm identified 4 clusters. From the graphs, it can be seen that the cluster structure is relatively stable, there are no often changes of cluster, which makes it possible to avoid additional communication channel load.

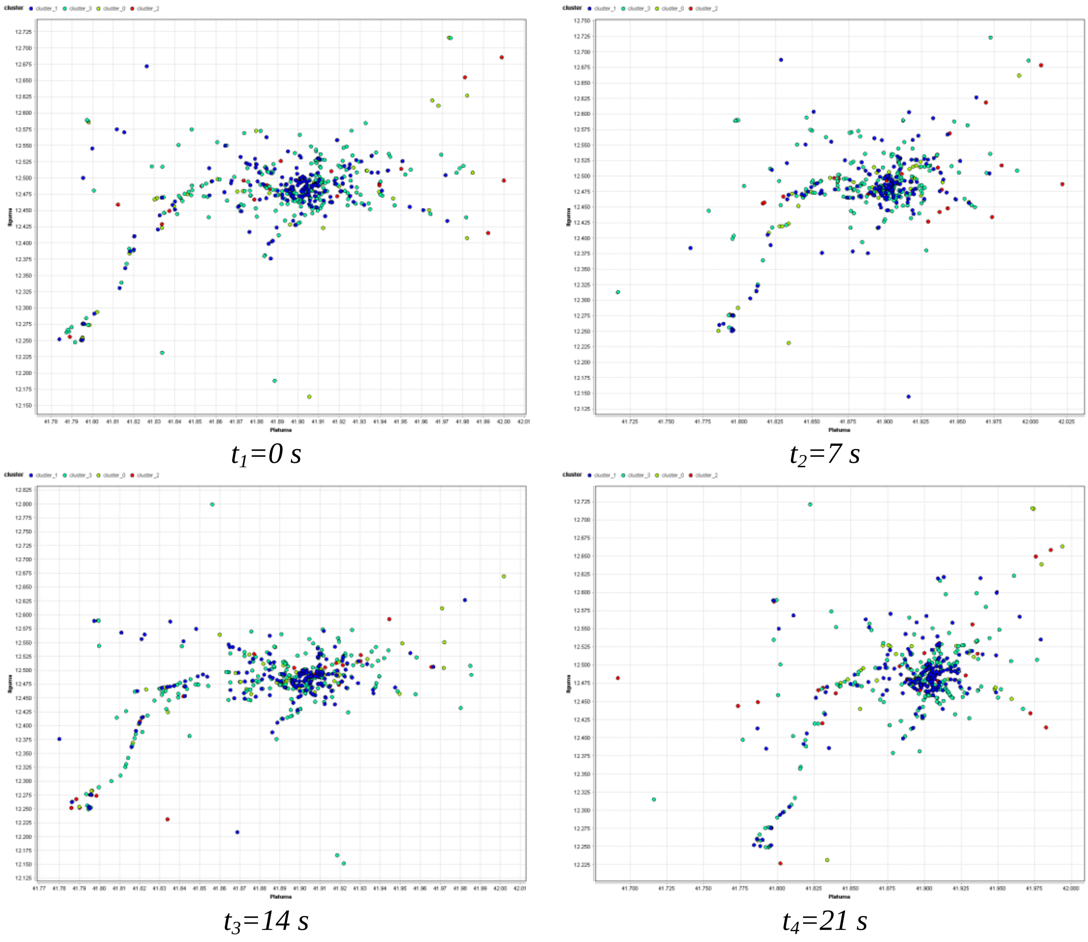


Fig. 9. *Results of vehicle clusters formation at time moments $t_1 - t_4$*

Results of simulation of context data exchange between vehicles in real-time

Requirements for the NCTUns simulation model were analyzed and structured (Table 3). The experiment was carried out when the number of nodes in the network were from 10 to 100 - simulating different traffic congestion to determine the impact of the vehicle's number for the data-transfer efficiency. Senders and receiver's nodes are moving at a high speed (130 km/h) in the opposite directions. The remaining vehicles are moving at different speeds from 90 km/h to 150 km/h, and their speed and directions of movement are spread evenly (Fig. 10). These parameters are chosen to simulate the realistic movement of cars on highway conditions.

Table 4. *Parameters of experimental model for context data exchange between vehicles*

Parameter	Value
Simulation time	60 s
Physical layer protocol	802.11b
Number of nodes	from 10 to 100
Nodes mobility model	Random, highway
Channel frequency	2,4 GHz
Routing protocol	*AODV*

During the experiments, data transmission efficiency was evaluated – outgoing throughput, download throughput, packet drops and collisions with a different number of vehicles on the network. The data was transmitted using the UDP protocol, and a packet size of 1000 bytes. Simulation was carried out for 60 seconds. The assumption was made that the communication time between the sender and the recipient is directly proportional to the number of cars on the network. Furthermore, with increasing number of nodes it is expected to increase the collision rate and rejected packets.

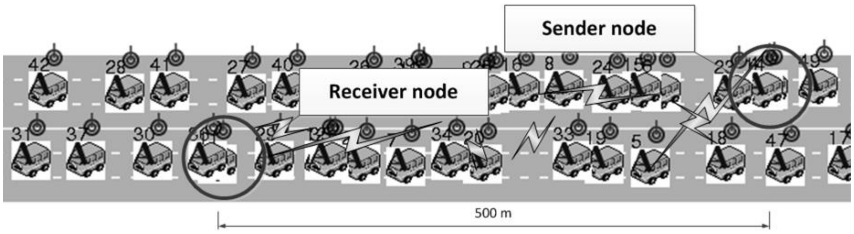


Fig. 10. *The experimental scenario*

Analysis of the data collected during the experiments shows the download speed versus time, with a different node's number on the network (Fig. 11). The graph shows that the longest communication time is achieved by operating the largest network of vehicles — 100. With the maximum number of vehicles, the network coverage increases, so the data can be transferred for a longer period of time. With 100 vehicles and about 330 KB/s data transfer rate, we have managed to maintain communication for 30 seconds. The speed from 31 s decreased to 50 Kb/s, but from 37 s to 41 s the rate rises to 230 Kb/s, and from 46 s to 48 s — to 130 KB/s. When the vehicles passed each other, the connection was lost. The minimum data rate was achieved by the network operating 50 vehicles. Moreover, in this case, the shortest communication time is achieved. With a small number of vehicles (10-30) a relatively high data transfer rate is maintained due to the low collision rate.

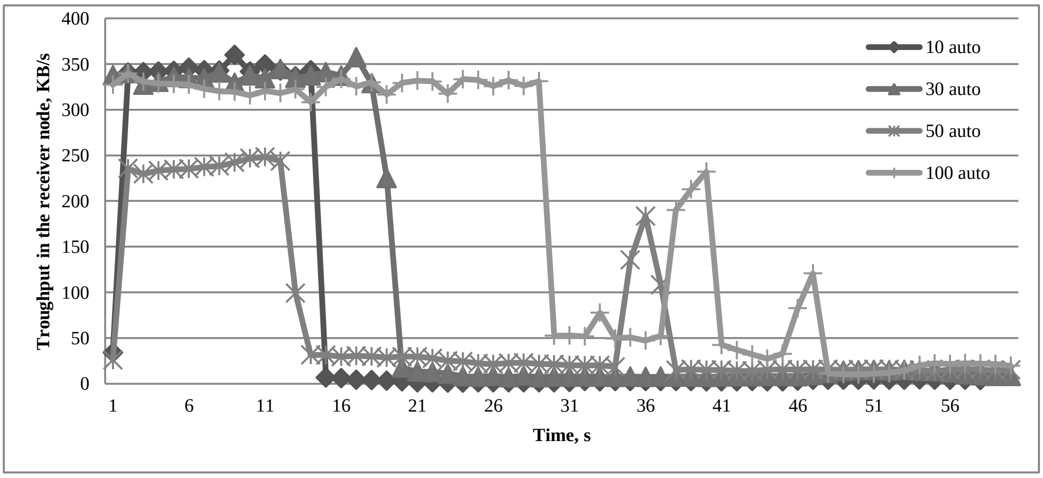


Fig. 11. *Variation of throughput in time with different number of network nodes*

After the experiment, another important parameter — the average data uplink and downlink throughput — was measured (Fig. 12). In this case, the highest mean transfer rate achieved by the network operating 20 vehicles, while the meanest - 30. The maximum average data rate of downlink – 100 vehicles, while the meanest – 50.

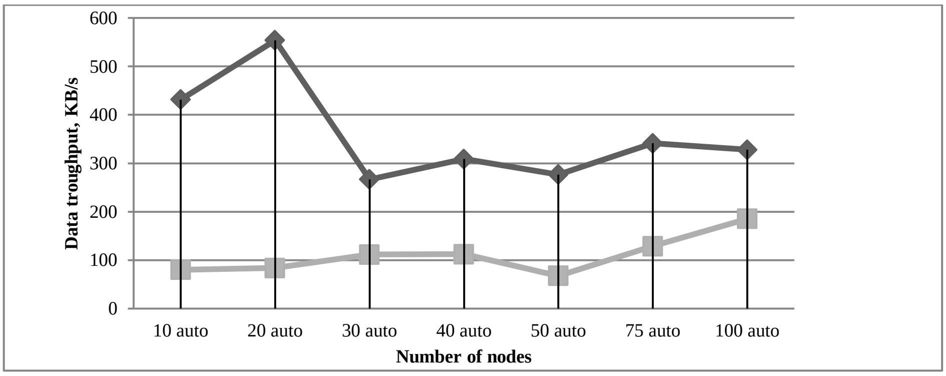


Fig. 12. *Average context data incoming and outgoing throughput using different number of network nodes*

Collision's dependence on sender and receiver nodes with a different number of vehicles was found out. Collision rate is directly proportional to the number of vehicles. Up to 40 vehicles, collisions rate at the receiver and sender nodes is similar, but from 50 vehicles, collision is greater in sender node because of mechanisms of unsuitable channel access.

Other experiments were performed for the distributed context data storage and access in mobile communication networks. The network model is created where the context data from the server running Citadel database is retrieved using the LabVIEW DSC module and is provided to the 4G LTE mobile nodes. The modeled 4G LTE network consists of four type nodes: Packet Data Network gateway (PDN GW); serving gateway/Mobility Management Entity (SGW/MME); eNodeB; and User Equipment. Also the same data was transferred to mobile nodes, the connection is provided by the 802.11g protocol. The algorithm for program integration and system tools for vehicle movement and probable network mobility was created as well as predicates for context data acquisition and system verification of dissemination management.

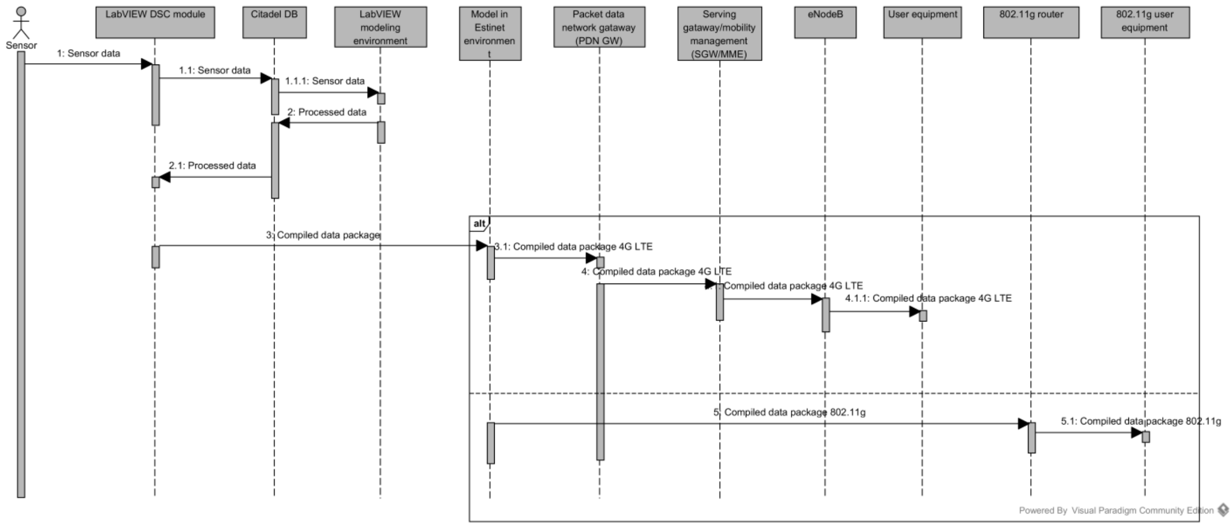


Fig. 13. *Algorithm for integration of program and system tools for vehicle movement and probable network mobility predicates for context data acquisition and dissemination control system verification*

The analyzed results showed the throughput in the LTE eNodeB with a different number of nodes (clients). Using 10 nodes the throughput was stable with the average of 0.089 MB/s. With 20 and 30 nodes the throughput was fluctuating with the average of 0.094 MB/s and 0.092, respectively. Similar analysis was made for the input throughput in the LTE eNodeB with a different number of clients. The results are close to those for the output throughput. With 10 nodes the average throughput was 2,544 MB/s, with 20 nodes – 2.56 MB/s, and with 30 nodes –

2.56 MB/s (Fig. 14). It can be seen that at a small number of user equipment nodes in the network, the changes do not have significant influence on the throughput.

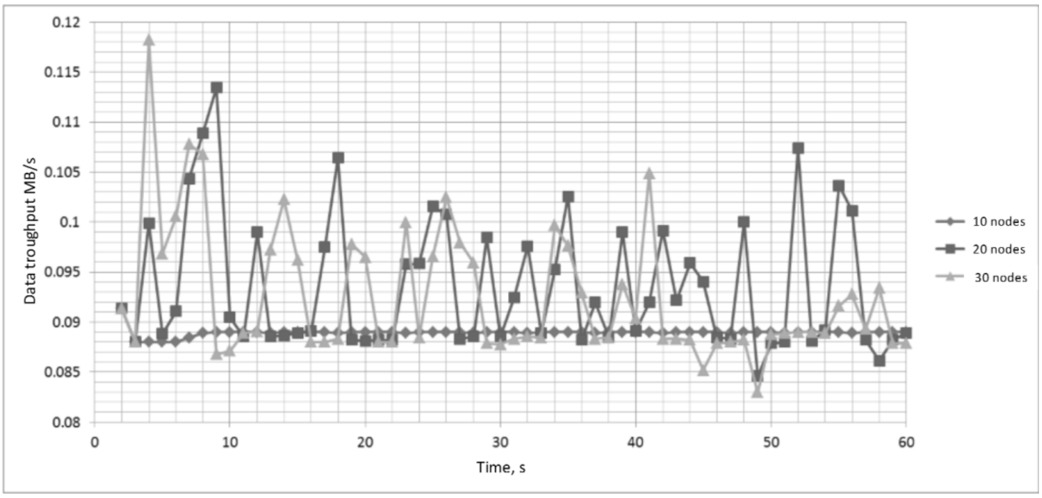


Fig. 14. *Throughput of data transfer in LTE eNodeB output using different number of clients*

Evaluation of method for context data acquisition and adaptive dissemination in ITS networks

In order to increase information, the speed for evaluating context information utility, avoiding redundant computations, it was decided to solve the classification problem. According to the concluded channel, metrics evaluating the upload speed, the number of collisions, the number of packets sent per time unit and the number of rejected packets in sender node, training and test data samples were formed. The classification used 4 features. These features were determined during the experiments in Estinet simulation environment when communicating different number of vehicles moving under different mobility patterns. In order to determine the most effective classification method for managing the channels, ensuring a high quality channel, a number of experiments were performed. For investigation, artificial neural networks with different number of neurons in the hidden layers, Naïve Bayes, decision trees, induction rules, and quadratic discriminant analysis classification methods were chosen. The classification accuracy and Kappa statistics were evaluated. The developed model of classification experiment using the cross validation is shown in Fig. 15. For the model, 10 times cross-validation is used to determine how effectively it works with unknown data. The model in the Fig. 15 shows neural networks as the classification algorithm but it is similar to models with other investigated classification methods.

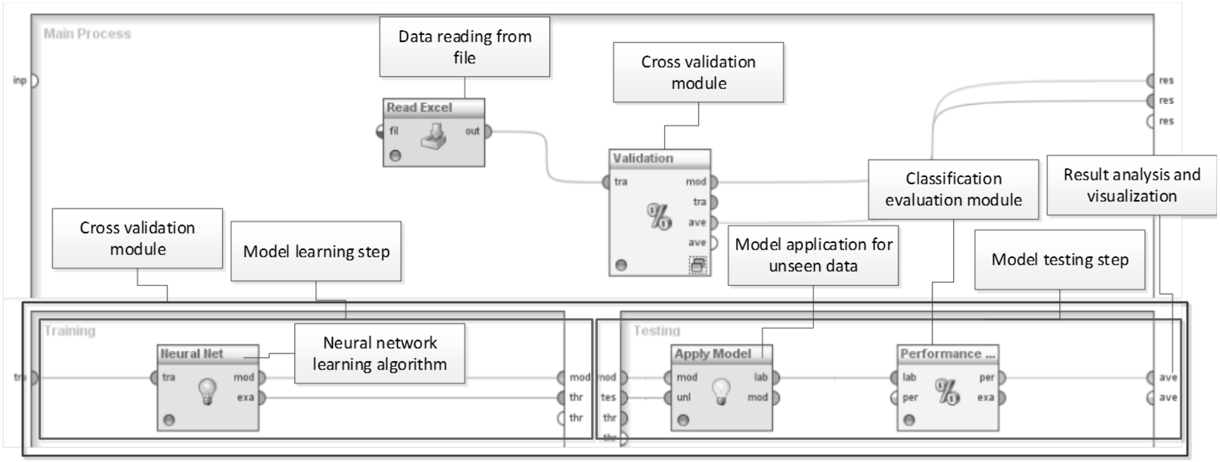
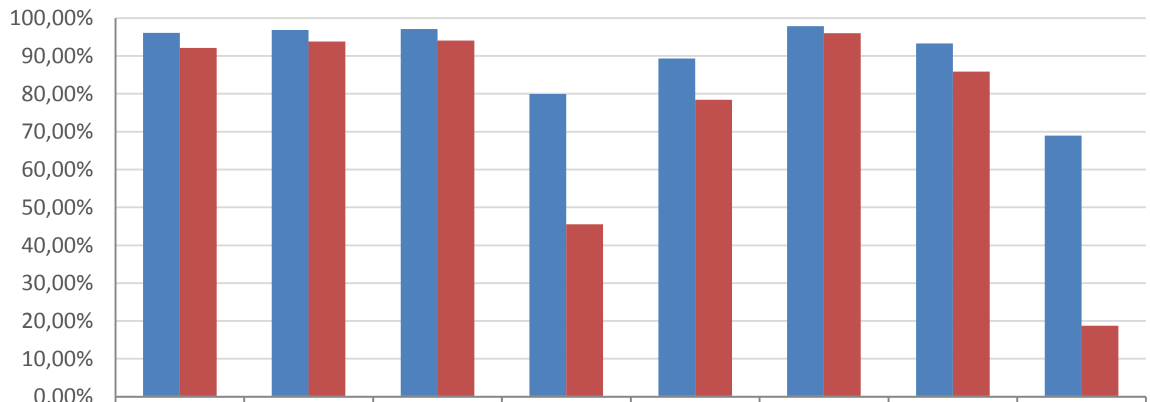


Fig. 15. *Developed model of classification experiment using the cross validation in RapidMiner 6.5*

After a series of experiments in terms of the channel management techniques, using different data classification methods and their different operating parameters, results were systematized which are presented in Fig 16. The results showed that the most effective in this case was the decision tree algorithm, showed (97,88 +-1,19)%, and 0,960 + -0,024 Kappa value. Not too far behind performed the Multilayer Perceptron method which using different numbers of hidden layers showed from (79,97 + -15,60)% and 0,455 + -0,456 Kappa with 4 hidden layers to (97,07 + -1,39)% and 0,941 + -0,028 Kappa, with 3 neurons in the hidden layers. The square discriminant analysis method showed the worst results with the (68,95 + -1,18)% classification accuracy and only 0.187 + -0.038 Kappa.



	NN 1 hidden layer	NN 2 hidden layers	NN 3 hidden layers	NN 4 hidden layers	Naive Bayes	Decision tree	Rules induction	Square discriminant analysis
Accuracy	96,07%	96,89%	97,07%	79,97%	89,34%	97,88%	93,27%	68,95%
Kappa	0,921	0,938	0,941	0,455	0,784	0,96	0,859	0,187

Fig. 16. *Comparison of investigated classification methods by accuracy and Kappa*

Another series of experiments were carried out to determine efficiency of the created data aggregation methods. The accumulated predicted utility, *Exc*, normalized *Z* and *Ty* parameters over time is shown in Fig. 17. The results show that the performance of the accumulated value changes over time, according to the channel quality parameters, including channel bandwidth, collisions and number of rejected packets, which prove the effectiveness of the proposed method.

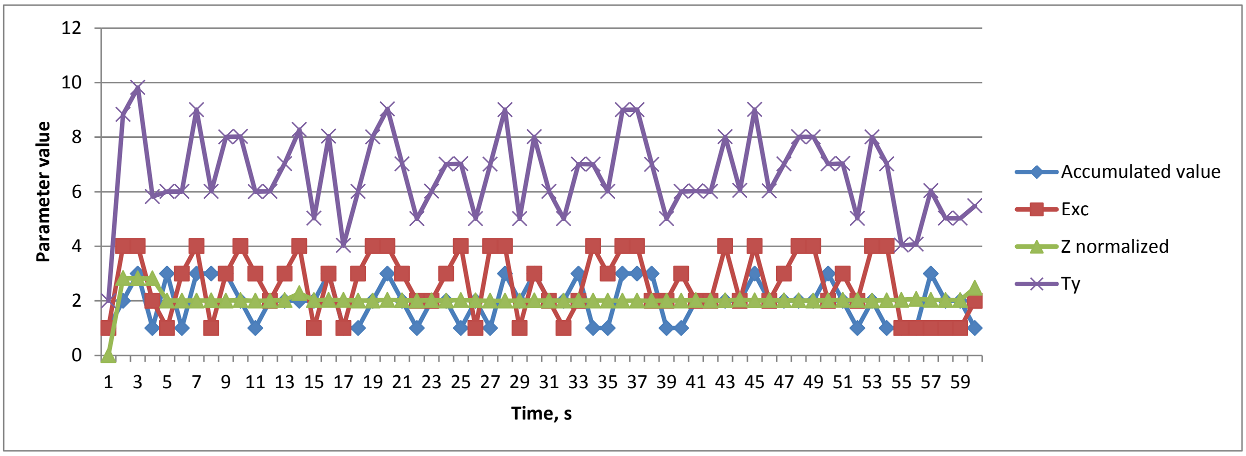


Fig. 17. *Accumulated predicted utility, Exc, normalized Z and Ty parameters variation in time*

The Fig. 18 shows the average data throughput from vehicles with installed method and without for the communication using 802.11p. Also, the number of nodes influence the networking of visible. The results show that using two-way context data transmission with 1-10 vehicles using the proposed method produced about 23% of the required bandwidth savings. Using a one-way transmission with 1 vehicle we get a 22% savings, with 5 cars — 47% and 10 vehicles — 69% savings.

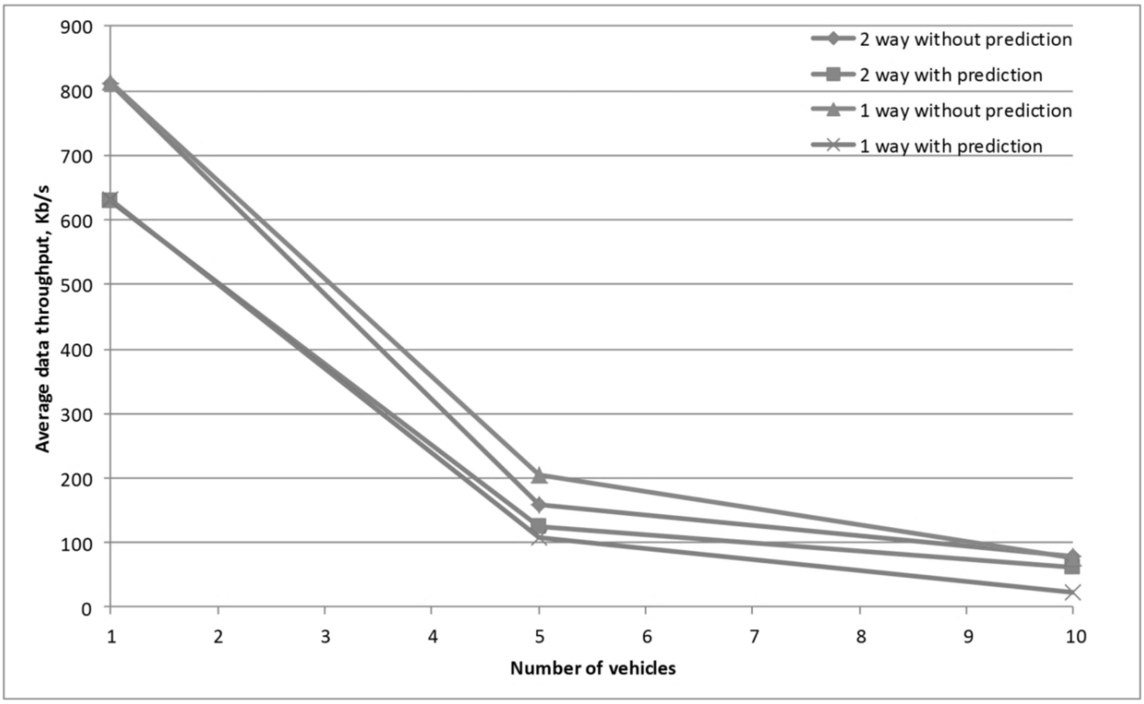


Fig. 18. *Average data throughput from vehicles with installed method and without*

GENERAL CONCLUSIONS

1. The analysis of the research material, standards and newly proposed network protocols for heterogeneous services support in VANETs, stimulating the development of new enriched services, showed that the support of the services must become adaptive. The growing information flows and rapid changing mobile network topology are open research questions because network utilization fragmentation leads to problems avoiding network congestion with different traffic and network mobility conditions.

2. Research of the systemic and software platforms declaring the ability to perform contextual data collection, aggregation and dissemination processes for adaptive heterogeneous services support systems for communication networks of cooperative vehicular showed that for the author research is only partly suitable for the context spaces and multi attribute utility theory general statements. For the new solutions of this problem it is appropriate to apply the new algorithms for exchange of context information between the nodes and to integrate this information with enriched environmental context information.

3. The analysis of systemic and software platforms, allowing to simulate the movement of vehicles and network mobility likely predicate values together showed that for the context data acquisition and dissemination management system (prototype) design and verification by examined coverage, the most appropriate tools are:

- NCTUns/ESTINET package, used to perform finite transport traffic micro modelling and network simulation with different operating modes.
- For the design of system prototype and software component developing the National Instruments LabVIEW software and CompactRIO systemic platforms were used.
- For the design, testing and verification of the system for adaptive management of the channel quality and data stream reduction by creating vehicular clusters, the RapidMiner 6.5 tool was chosen.
- It was shown that there is a need to create an algorithm for integration of these software and system tools.

4. The prototype for configuration of changing topology vehicular communication network was created. It is designed for the situation-aware, adaptive vehicular communication based systems design and is able to evaluate and enrich context information real-time. The established methodology enables efficient creation of new situations-aware systems, enabling a more efficient exchange of context information. 3 specialized models for management of context data storage and exchange were proposed in these domains: the locally stored, transmitted to other nodes and cloud computing systems data.
5. During the experiments using the research by construction method and simulating situations on the road and emulating heterogeneous services support, it was proved that the performance of the system prototype is efficient, under the simulated traffic conditions, and the offered software and system tools integration solutions allow reduction of transmitted useless data in changing topology vehicular communication network, without losing enriched context data quality. The experimental results showed that the introduction of the proposed network management techniques lead to efficiency increase of bandwidth usage from 22 to 69%.

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SHORT DESCRIPTION ABOUT THE AUTHOR

Mindaugas Kurmis was born on 16 June, 1986. He graduated from Klaipėda University Faculty of Marine Engineering in 2009 acquiring Bachelor’s Degree in Informatics Engineering. He gained his Master’s Degree in Technical Information Systems Engineering at Klaipėda University Faculty of Marine Engineering in 2011. Since 2011 to 2015 he has been a PhD student at Vilnius University Institute of Mathematics and Informatics. From 2009 he works as a lecturer at Klaipėda University, Department of Informatics and Statistics.

ĮVAIRIALYPIŲ PASLAUGŲ INTEGRAVIMO KINTANČIOS TOPOLOGIJOS AUTOMOBILIŲ KOMUNIKACIJOS TINKLUOSE GALIMYBIŲ IŠVYSTYMAS

Temos aktualumas

Intelektinės transporto sistemos (*ITS*) reikalauja pažangių informacinių ir ryšių technologijų (IRT) bei sąveikos priemonių vystymo ir taikymo transporto infrastruktūroje, grindžiamoje belaidžių komunikacinių tinklų technologiniais sprendimais. Belaidžių technologijų bei įterptinių sistemų tyrimai ir gauti rezultatai bei komercinių taikymų proveržis transporto sistemose, leido sukurti specializuotą, sparčiai besivystančią, *ITS* sritį – automobilių komunikacijos *Ad-Hoc* tinklus. Tikimasi, kad šios technologijos ypač pagerins eismo saugumą, leis sumažinti kelių apkrovas, padidins kelionių komfortą ir suteiks galimybių išsaugoti švaresnę aplinką.

Automobilių komunikacijos *Ad-Hoc* tinklai (angl. *Vehicular Ad-Hoc Networks – VANET*) gali būti realizuojami per didelio nuotolio komunikaciją (remiantis mobiliojo ryšio *3G* ar *4G* tinklais), tiek ir per trumpam nuotoliui skirtas technologijas (*Wi-Fi* ar *DSRC*). Šie komunikacijos tipai vartotojams, automobiliuose leidžia teikti eismo saugumo paslaugas, dalijantis saugumo informacija, siekiant išvengti nelaimingų atsitikimų, nelaimių tyrimo po įvykio ar išvengti transporto spūsčių. Kita paslaugų grupė – keleivius dominančios paslaugos, kurios, nesusijusios su saugumo paslaugomis.

Viena plačiausiai išnagrinėtų temų automobilių komunikacinių tinklų srityje – ryšio užtikrinimo automobilių komunikacijai tyrimai, naudojant skirtingas belaidės prieigos sistemas buvo vykdyti (Bazzi et al., 2015; Cespedes et al., 2013; N. Cheng et al., 2014; Kiokes et al., 2009; Li et al., 2014; Mumtaz et al., 2015; Shen et al., 2013; Sukuvaara et al., 2013). Daugumoje tyrimų koncentruojamasi į dinaminį heterogeninių ryšio užtikrinimo protokolų valdymą, šių protokolų adaptavimą automobilių komunikaciniams tinklams, mobilumo įtaką ryšio kokybei. Ne taip detaliai išnagrinėtas infrastruktūros kanalų konfigūravimas, skirtingo tipo paslaugų prioritetų nustatymas.

Kita mokslinių tyrimų sritis – *Ad-Hoc* tinklų maršrutų paieškos protokolai bei algoritmai duomenų perdavimo, automobilių komunikacijos tinkle, valdymui ir duomenų sklaidai, užliejant tinklą. Pastarųjų metų tyrimai vykdyti (Annese et al., 2011; Bazzi, Zanella, 2015; de Oliveira Barros et al., 2013; Omar et al., 2015; Soares et al., 2014; Tian et al., 2015). Šie tyrimai išsiskiria į dvi dalis: *V2V* komunikacijos bei *V2I* sąveikos nagrinėjimo aspektus. Plačiausiai tiriami komunikacijos tinklų tipai, tai topologija grindžiami proaktyvieji, reaktyvieji bei hibridiniai; pozicija grindžiami tolerantiški bei netolerantiški vėlinimui tinklai. Taip pat programinės bei sisteminės platformos, grindžiamos klasteriais bei statine ar mobilia infrastruktūra. Maršrutizavimo protokolų analizė plačiai pateikiama (Bitam et al., 2015; Dua et al., 2014; Plestys, Zakarevicius, 2010, 2011; Sharef et al., 2014; Tornell et al., 2015) darbuose. Daugumoje analizuotų darbų daugiausia dėmesio skiriama komunikacijos efektyvumo tarp automobilių didinimui, tačiau svarbūs specifiniai aspektai, tokie kaip atsijungimai nuo tinklo, paslaugų kokybės (*QoS*) metrikos, eismo saugumas, išplečiamumas bei atsižvelgimas į įvairialypių paslaugų teikiamo ypatumus, lieka nenagrinėti.

Komunikacijos technologijų taikymas automobilių transporte turi specifinius reikalavimus ir neturi griežtų energijos sunaudojimo apribojimų, todėl gali būti aprūpinti pajėgiais skaičiavimo sisteminiais įrankiais, belaidžio ryšio siųstuvais ir įvairiais jutikliais. Vienas iš svarbiausių komunikacijos sistemų reikalavimų – sistema neturi atitraukti vairuotojo dėmesio nuo kelio ir vartotojui be įsikišimo turi būti suteikiamos reikiamos paslaugos, reikiamoje vietoje, reikiamu laiku ir reikiamu būdu adaptuotos prie vartotojo poreikių. Vienas iš būdų padidinti vartotojo-automobilio sąsajos autonomiškumą ir efektyvumą yra suvokti situaciją, kurioje tuo metu yra vartotojas, suvokti kokia situacija buvo praeityje bei nuspėti būsimą situaciją.

Kontekstui suvokti gali būti panaudoti įvairūs automobilio, žmogaus ir aplinkos jutikliai ir informacijos šaltiniai. Automobilio jutiklių sistema, kaip informacijos šaltinis, generuoja didelius kiekius skirtingos informacijos, apimant fizinius automobilio ir aplinkos jutiklius: GPS, greičio, pagreičio, temperatūros, radarų, video ir kt. bei virtualius jutiklius, tarp kurių: eismo būklės informacija, pavojaus įspėjimai, sąveika su kitais automobiliais, skambučiai ir kt.

Vykdant mokslinius tyrimus intelektualių sistemų kūrimo srityje buvo pasiūlyta keletas sprendimų, kuriant adaptyvias paslaugas teikiančias sistemas (Bielskis et al., 2012; Drungilas, Bielskis, 2012; Dzemydienė et al., 2010; Dzemydiene, Dzindzalieta, 2010; Gricius et al., 2015). Tolimesnis, intelektualias paslaugas teikiančių adaptyvių sistemų vystymas reikalauja tiesioginio supančios aplinkos atpažinimo ir duomenų perdavimo valdymo metodų integravimo.

Pastaruoju metu itin daug dėmesio sulaukė kintančios topologijos mobilių komunikacijos tinklų sritis, kur transporto priemonių vairuotojai susiduria su nuolat didėjančiais informacijos srautais, todėl svarbiu uždaviniu tampa naudingų žinių išgavimas iš įvairialypių duomenų šaltinių ir tinkamas jų pateikimas praplėstos realybės paslaugų sistemoms. Svarbiu klausimu tampa – kaip realiu laiku, pagal išgautas žinias iš konteksto, teikti adaptuoti (prisitaikyti pagal vartotojo poreikius) įvairialypes paslaugas. Teikiant vairuotojui paslaugas, kurios padėtų ir palengvintų valdymą bei būtų teikiamos visur esančioje praturtintoje realybėje, bei praplėstų tos realybė ribas, kyla keletas klausimų:

- kokia informacija susijusi su dalykine sritimi yra svarbi arba svarbesnė (prioritetų teikimo klausimas),
- kokios paslaugos domina vartotoją (paslaugų teikimo bei adaptavimo pagal poreikius klausimas),
- kokios svarbos, saugumo paslaugos turėtų būtų pateikiamos automatiškai.

Problemos formulavimas

Kuriant dinamiškoje aplinkoje veikiančias ir paslaugas adaptuojančias sistemas, iškyla efektyvaus aplinkos informacijos surinkimo ir skleidimo problema (Kakkasageri, Manvi, 2014). Konteksto informacijos suvokimas ir jos tinkamas interpretavimas kompiuterinėje sistemoje reikalaują metodų, kurie leistų surinkti tinkamą informaciją, ją suprasti (ar agreguoti) ir perduoti bei tiesiogiai susieti su aukštesnio abstrakcijos lygmens žinių išskyrimu, t. y. aplinkos situacijų samprata. Pagal šias situacijas būtų atliekamas atitinkamų paslaugų parinkimo, adaptavimo ir kokybės gerinimo proceso automatizavimas.

Vykdant duomenų surinkimo iš skirtingo tipo jutiklių, agregavimo ir skleidimo procesus, specifines problemas sukelia didelis automobilių mobilumas, lemiantis greitai kintančią topologiją ir sudėtingą, daug tinklo resursų reikalaujantį, informacijos interpretavimą. Siekiant geriau suvokti aplinką, būtina turimomais duomenimis keistis su kitais tinklo mazgais – automobiliais, taip sudarant kooperuojančią sistemą. Tinklo mazgams užliejant tinklą, perduodant visus surinktus konteksto duomenis visiems aplinkiniams mazgams, neturint jokios informacijos apie tinklo topologiją, iškyla tinklo apkrovos problema, lemianti infrastruktūros, tam tikroje zonoje, sulėtėjimą ar net visišką neveiksnumą. Tinklo apkrovos mažinimui galima pasitelkti duomenų filtravimo bei agregavimo metodus, tačiau šiuo atveju iškyla klausimas: kaip pasirinkti, kuriuos duomenis perduoti aplinkiniams mazgams, neprarandant konteksto duomenų kokybės ir nesumažinant bendro tinklo efektyvumo. Šių problemų sprendimui reikalingi intelektualūs adaptyvūs metodai, leidžiantys įvertinti vidinę (lokaciją, laiką, aplinką, vartotojo būseną, automobilio dinamiką), išorinę konteksto informaciją (informaciją gaunamą iš kitų automobilių) o taip pat, tinklo mobilumo sąlygas ir apkrovą, pagal tai vykdant duomenų paketų formavimo ir perdavimo procesus.

Tyrimo objektas

Intelektualūs konteksto duomenų surinkimo, agregavimo ir skleidimo automobilių komunikacijos tinkluose metodai bei programinės ir sisteminės priemonės, leidžiančios išvystyti įvairialypių paslaugų teikimą ir adaptavimą automobilių komunikacija grindžiamose sistemose.

Darbo tikslas

Disertacinio darbo tikslas – sukurti automobilių komunikacijos tinklų infrastruktūros konfigūravimo sistemos prototipą, integruojantį konteksto informacijos skleidimo metodus, grindžiamus daugiakriteriniu duomenų naudingumo vertinimu.

Tikslui pasiekti keliami šie darbo uždaviniai

1. Išanalizuoti ir apibendrinti, įvairialypių paslaugų teikimo automobilių komunikacijos tinklu, metodus, įvertinant šių tinklų konfigūravimo specifiką.
2. Atlikti esamų adaptyvių įvairialypių paslaugų teikimo sisteminių ir programinių platformų, įgalinančių vykdyti konteksto duomenų surinkimo, agregavimo ir skleidimo procesus, analizę ir nustatyti, kaip racionaliai atlikti konteksto duomenų valdymą, įvertinant praturtintų konteksto duomenų kokybę ir gausą automobilių komunikacijos tinkluose.
3. Pasiūlyti sistemines ir programines platformas, leidžiančias kartu modeliuoti automobilių judėjimą ir tinklo mobilumo tikėtinas predikatų reikšmes, nustatant jų tinkamumą konteksto duomenų surinkimo ir skleidimo valdymo sistemos (prototipo) projektavimui bei verifikavimui.
4. Sukurti kintančios topologijos automobilių komunikacijos tinklo valdymo prototipą įvairialypėms paslaugoms teikti, leidžiantį valdyti tinklo infrastruktūros apkrovą, pagal iš aplinkos bei kooperuojančių įrenginių išgautą praturtinto konteksto informaciją, daugiakriteriškai įvertinant jos naudingumą ir skleidimo spartą tarp kitų mazgų.
5. Eksperimentiškai įvertinti sukurto, automobilių komunikacijos tinklo infrastruktūros valdymo sistemos, prototipo skirto adaptyviai sumažinti nenaudingos perduodamos konteksto informacijos kiekį tinkle, skirtingomis eismo bei tinklo mobilumo sąlygomis.

Tyrimo metodika

Darbe taikomi informacijos paieškos, sisteminimo, analizės, lyginamosios analizės ir apibendrinimo metodai. Tyrimo objektas ir problema konkretizuojami, analizuojant naujausią mokslinę literatūrą iš mokslinių duomenų bazių, tokiu būdu įvertinant darbe keliamų uždavinių išsprendimo lygį. Siekiant sukurti naują metodą, realiu laiku integruojantį konteksto žinias, išgautas iš aplinkos bei kooperuojančių įrenginių, daugiakriterinį šių žinių naudingumo įvertinimą bei žinių sklaidą tarp kitų mazgų, darbe nagrinėjami konteksto duomenų surinkimo, agregavimo, skleidimo ir transformavimo į įvairialypių paslaugų taikymo lygmenį metodus, taikomi automobilių komunikacijos tinklams.

Kuriant prototipą, taikomas kiekybinio tyrimo konstravimu metodas, apimantis teorinius daugiakriterinio vertinimo, mašininio mokymo metodus bei jų taikymą. Taip pat, siūlomi nauji konteksto duomenų surinkimo bei skleidimo modeliai bei konstruojama prototipinė sistema. Siekiant eksperimentiškai įvertinti sukurtą kooperatyvaus konteksto duomenų surinkimo, ir skleidimo automobilių komunikacijos tinkluose sistemos elgseną bei efektyvumą, skirtingomis eismo bei tinklo mobilumo sąlygomis, sudaryti imitaciniai modeliai *NCTUns*, *ESTINET*, *LabVIEW* bei *RapidMiner* aplinkose. Eksperimento rezultatai įvertinti, taikant statistinius metodus.

Gauti rezultatai:

- Sukurtas naujas tinklo infrastruktūros valdymo sistemos prototipas daugialypėms paslaugos teikti, kuriame integruoti konteksto duomenų saugojimo ir apsikeitimo modeliai ir sukurti algoritmai, leidžiantys sumažinti perduodamų duomenų kiekį ir kooperatyviai pasinaudoti tinklo kanalų resursais automobilių komunikacijos procesuose.
- Įvairių modeliavimo, emuliavimo ir analizės aplinkų (platformų) panaudojimas leido realizuoti skirtingus konteksto duomenų valdymo scenarijus ir įvertinti duomenų saugojimui lokaliose DB pajėgumus, reikalingus apsikeitimui su kitais automobiliais bei apsikeitimui su hibridiniu VANET debesimi.
- Sukurta situacijas suvokiančios, automobilių komunikavimu grindžiamos sistemos projektavimo metodika, realiu laiku įvertinanti išgautą iš aplinkos bei kooperuojančių įrenginių konteksto informaciją, integruotas daugiakriterinis šios informacijos naudingumo įvertinimo metodas bei žinių sklaidos apribojimo tarp kitų transporto priemonių mazgų būdas.
- Vertinant konteksto skleidimo duomenų kokybę, remiamasi konteksto kokybės prioriteto nustatymo metodu, kurio pagrindiniai rodikliai: duomenų tikslumas, naujumas, geografinės koordinatės, duomenų perdavimo sritis, teikiamos paslaugos sritis.
- Sukurtas naujas, adaptyvus konteksto informacijos skleidimo metodas, grindžiamas daugiakriteriniu perduodamos informacijos naudingumo vertinimu, įgalinantis ženkliai sumažinti perduodamos nenaudingos konteksto informacijos kiekį automobilių komunikacijos tinkle ir išvengti tinklo infrastruktūros perkrovos.

Darbo mokslinis naujumas

Rengiant disertaciją buvo gauti šie informatikos inžinerijos mokslui nauji rezultatai. Darbe pasiūlyti metodai ir jų taikymo metodika praplečia įvairialypių paslaugų teikimo ir integravimo automobilių komunikacijos tinkluose sistemų kūrimo ir vystymo galimybes. Skirtingai nei šiuo metu siūlomos konteksto duomenų skleidimo sistemos, pasiūlytas metodas, priklausomai nuo skirtingų sričių konteksto, leidžia adaptuoti duomenų perdavimo srautus, tokiu būdu, sumažindamas belaidžio tinklo apkrovą ir leisdamas efektyviai teikti paslaugas vartotojui dinaminio pobūdžio dalykinėse srityse.

Darbe pasiūlyta metodika, grindžiama daugiakriteriniu perduodamos informacijos naudingumo vertinimu skleidimo procese yra skirta išskirstytų, heterogeninių duomenų surinkimo posistemių integravimui, jų generuojamus duomenis transformuojant į itin dinamiškų intelektinių transporto sistemų konteksto suvokimo informaciją. Kiekvienas šios intelektinės transporto sistemos elementas veikia, kaip atskiras komponentas, turintis specifinius aplinkos stebėjimo ir valdymo elementus. Konteksto informacijos naudingumo vertinimas leido realizuoti metodus ir algoritmus, kurie adaptyviai sumažino belaidžio ryšio kanalo apkrovą bei perduodamų ir saugojamų duomenų apimtis, neprarandant praturtintos konteksto informacijos kokybės, kas leidžia toliau vystyti sudėtingesnes įvairialypes paslaugas. Manoma, jog gauti moksliniai rezultatai turės įtakos tolimesnėje intelektinių transporto sistemų plėtroje, ypač, vystant konteksto suvokimo ir paslaugų adaptavimo sistemas.

Sukurtas kintančios topologijos automobilių komunikacijos tinklo valdymo prototipas, skirtas situaciją suvokiančių, automobilių komunikavimu grindžiamų sistemų projektavimui, realiu laiku įvertinantis bei praturtinantis konteksto informaciją, daugiakriterinį šios informacijos naudingumo įvertinimą bei žinių sklaidą tarp kitų mazgų, suteikia galimybes ne tik palengvinti ir pagreitinti įvairialypių paslaugų, grindžiamų konteksto suvokimu realizaciją, bet ir efektyviai naudoti belaidžio ryšio technologijas automobilių komunikacijos tinkluose bei užtikrinti šios aplinkos dalyvių tarpusavio suderinamumą ir tokių sistemų praplečiamumą.

Adaptyvioms, prie vartotojų poreikių prisitaikančioms sistemoms kurti itin dinamiškose dalykinėse srityse, pasiūlyti specialiai adaptuoti konteksto duomenų skleidimo realiu laiku metodai, kurie leido su kuo mažesnėmis laiko sąnaudomis ir kuo tiksliau įvertinti sistemos reakcijas į aplinkos pokyčius.

Praktinė darbo reikšmė

Sukurtas kintančios topologijos automobilių komunikacijos tinklo valdymo prototipas, skirtas situaciją suvokiančių, automobilių komunikavimu grindžiamų sistemų projektavimui, realiu laiku įvertinantis bei praturtinantis konteksto informaciją. Pasiūlyti 3 konteksto duomenų saugojimo ir apsikeitimo modeliai, skirti valdyti lokaliai saugomiems, perduodamiems kitiems mazgams bei debesų kompiuterijos sistemai, duomenims. Tai leido adaptyviai sumažinti perduodamų duomenų kiekį ir kooperatyviai naudoti kanalo resursus.

Sukurta situaciją suvokiančių, automobilių komunikavimu grindžiamų sistemų projektavimo metodologija, realiu laiku įvertinanti išgautą iš aplinkos bei kooperuojančių įrenginių konteksto informaciją, daugiakriterinį šios informacijos naudingumo įvertinimą bei žinių sklaidą tarp kitų mazgų leidžia efektyviau kurti naujas situacijas suvokiančias sistemas bei išplėsti dabartines eismo srautų valdymo, vartotojų informavimo, stebėjimo ir kitas intelektinio transporto sistemas, suteikiant galimybes sistemoms kooperatyviai keistis konteksto informacija.

Šiame darbe pasiūlyti duomenų surinkimo, agregavimo bei skleidimo metodai buvo panaudoti vykdant šiuos MTEP projektus: VGTU-KU-KTU-LEI projektą „Transporto statinių, transporto priemonių ir jų srautų inovatyvių tyrimo metodų ir sprendimų kūrimas bei taikymas“, 2013-2015; „Išmaniųjų technologijų pritaikymo krovos procese Klaipėdos uosto įmonėse tyrimai, siekiant padidinti krovos ir energetinį efektyvumą“, 2014; „LLII-215 JRTC Extension in Area of Development of Distributed Real-Time Signal Processing and Control Systems“, 2012-2014; LLII-061 „Development of Joint Research and Training Centre in High Technology Area“, 2010-2012; „Mobiliųjų ir bevielių paslaugų virtualios informacinės aplinkos sukūrimas“, 2011-2012.

Ginamieji disertacijos teiginiai

1. Adaptyvioms įvairialypių paslaugų teikimo automobilių komunikaciniuose tinkluose sistemoms kurti siūloma taikyti konteksto informacijos naudingumo vertinimo algoritmus, įvertinančius aplinkos praturtinto konteksto informaciją daugiakriteriniu požiūriu.
2. Sudėtingomis kintančios topologijos automobilių komunikacijos tinklo ryšio užtikrinimo sąlygomis, tikslinga projektuoti ir taikyti atskirus specializuotus konteksto duomenų įvertinimo ir valdymo algoritmus, susijusius su lokaliai saugomais duomenimis ir jų perdavimu kitiems tinklo mazgams bei duomenims nukreiptiems į debesų kompiuterijos serverius.
3. Sukurtas sistemos prototipas leidžia įvertinti kintančios topologijos tinklų pajėgumus, selektyviai perduodant įvairialypių paslaugų duomenis ir sumažinti perduodamos nenaudingos informacijos duomenų kiekius kintančios topologijos automobilių komunikacijos tinkle, neprarandant konteksto duomenų kokybės.

Darbo rezultatų aprobavimas

Doktorantūros laikotarpiu Informatikos inžinerijos mokslo kryptyje publikuota 16 mokslinių darbų, iš kurių: 5 straipsniai *ISI Web of Science* duomenų bazėje referuojamuose ir turinčiuose citavimo indeksą leidiniuose, 10 straipsnių recenzuojamuose moksliniuose periodiniuose leidiniuose, 3 straipsniai tarptautinių mokslinių konferencijų pranešimų medžiagoje.

Disertacijos tema publikuota 10 mokslinių darbų, iš kurių: 1 straipsnis *ISI Web of Science* duomenų bazėje referuojamuose ir turinčiuose citavimo indeksą leidiniuose, 6 straipsniai recenzuojamuose moksliniuose periodiniuose leidiniuose, 3 straipsniai tarptautinių mokslinių konferencijų pranešimų medžiagoje (publikacijų sąrašas pateiktas darbo gale).

Disertacijos tema tyrimų rezultatai buvo pristatyti 4 nacionalinėse ir 8 tarptautinėse mokslinėse konferencijose Lietuvoje bei užsienyje:

1. NOSTRADAMUS 2014. International Conference on Prediction, Modeling and Analysis of Complex Systems, Ostrava, Czech Republic, 2014 23rd - 25th June.
2. Jūros mokslai ir technologijos – 2014, Klaipėda, Lietuva, 2014, Balandžio 23-25d.
3. 13th International Conference on Knowledge in Telecommunication Technologies and Optics KTTO 2013, Ostrava, Czech Republic, 2013 September 4th - 6th. (Best Paper Award)
4. 2nd International Scientific Conference Baltic Applied Astroinformatics and Space Data Processing, Latvia, Ventspils, 2013 May 15 – 16.
5. International Conference Social Technologies ‘13 Development of Social Technologies in the Complex World: Special focus on e-Health, Lithuania, Vilnius, 2013 October 10-11.
6. XVI tarptautinė mokslinė kompiuterininkų konferencija Kompiuterininkų dienos – 2013, Šiauliai, Lietuva, 2013 rugsėjo 19–21 d.
7. 7-oji mokslinė – praktinė konferencija Jūros ir krantų tyrimai – 2013, Lietuva, Klaipėda, 2013 balandžio 3-5.
8. Tenth International Baltic Conference on Databases and Information Systems. Vilnius, 2012.
9. International Scientific Conference Baltic Applied Astroinformatics and Space Data Processing, Latvia, 2012.
10. Technologijos mokslo darbai Vakarų Lietuvoje VIII, Klaipėda, 2012.
11. Mokslinė konferencija Socialinės Technologijos '11, Vilnius, 2011.
12. New Electrical and Electronic Technologies and Their Industrial Implementation: NEET 2011: 7th International Conference, Zakopane, Poland, June 28 - July 1, 2011.

Darbo apimtis ir struktūra

Disertaciją sudaro įvadas, 5 skyriai ir bendrosios išvados. Disertacijos apimtis – 127 puslapiai, 53 paveikslai ir 7 lentelės.

Įvade aprašomas mokslinio tyrimo aktualumas, analizuojama jo reikšmė, pateikiamas šiuolaikinių mokslinių tyrimų kontekstas, pateikiama problemos formuluotė, nagrinėjamos problemos aktualumas, formuluojamas tikslas ir uždaviniai, apibrėžiami ginamieji teiginiai, aprašoma darbo metodika. Pateikiami pagrindiniai mokslinio darbo rezultatai bei disertacijos gautų rezultatų praktinė vertė ir naujumas, disertacijos rezultatų publikavimo rodikliai ir aprobavimas.

1 skyriuje nagrinėjami įvairialypių paslaugų teikimo metodai. Apžvelgiama automobilių komunikacijos tinklų architektūra ir pavyzdžiai, įskaitant automobilių komunikacijos tinklų infrastruktūros komponentus bei belaidės prieigos automobilių komunikacijos tinkluose būdus. Įvardijamos pagrindinės specifinės automobilių komunikacijos tinklų charakteristikos. Analizuojamos paslaugos teikiamos šiuose tinkluose ir šių paslaugų kūrimo bei vystymo metodai.

2 skyriuje analizuojamas situacijų identifikavimas įvairialypių paslaugų teikimui kooperatyviuose automobilių komunikacijos tinkluose. Aiškinama konteksto, konteksto kokybės bei situacijos suvokimo koncepcija, analizuojami konteksto kokybės rodikliai bei konteksto valdymas automobilių komunikacijos tinkluose. Pristatoma konteksto duomenų surinkimo, agregavimo bei skleidimo metodų apžvalga, pristatomi šių metodų privalumai bei trūkumai.

3 skyriuje nagrinėjama automobilių komunikacijos tinklų ir teikiamų paslaugų modeliavimo programinė įranga. Pateikiama imitacinio modeliavimo priemonių taksonomija bei analizė. Detaliai analizuojama *NCTUns/Estinet* integruota tinklų bei mobilumo modeliavimo ir emuliavimo aplinka, bei automobilių komunikacijos tinklų standartų ir protokolų architektūra šioje aplinkoje.

4 skyriuje nagrinėjama automobilių komunikavimu grindžiamos, situaciją suvokiančios sistemų projektavimo metodika. Analizuojami duomenų perdavimo kokybės reikalavimai eismo saugumo ir įvairialypių paslaugų teikimui. Pateikiama situacijų identifikavimo automobilių kooperacijos aplinkoje sistemos architektūra bei paskirstyto konteksto duomenų saugojimo ir prieigos mobiliuose komunikacijos tinkluose sistemos projektavimas. Analizuojamas siūlomas konteksto duomenų naudingumo įvertinimo metodas ir konteksto duomenų surinkimo ir skleidimo sistemos veikimo algoritmas.

5 skyriuje pateikiami eksperimentinių tyrimų rezultatai, siekiant verifikuoti sukurtą automobilių komunikacijos tinklų infrastruktūros valdymo sistemos prototipą ir informacijos perdavimo pajėgumus. Nustatyti sistemos veikimo režimai, įvertinti tinklo ir sistemos sąveikos stabilumas. Pateikiami sistemos verifikavimo ir testavimo rezultatai, siekiant įrodyti, kad sistema įgalina sumažinti perduodamos nenaudingos konteksto informacijos kiekį automobilių komunikacijos tinkle, neprarandant konteksto duomenų kokybės. Eksperimentai atlikti panaudojant imitacinio modeliavimo programinę įrangą *NCTUns/Estinet* bei grafinio programavimo aplinką *LabVIEW*. Naudojant skirtingus scenarijus eksperimentai atlikti esant skirtingomis eismo bei mobilumo sąlygomis.

Pateikiami darbo rezultatai ir išvados, kurios pagrindžia ginamus teiginius.

BENDROSIOS IŠVADOS

1. Išanalizavus įvairialypių paslaugų teikimo belaidžiuose automobilių komunikacijos tinkluose mokslinių tyrimų medžiagą, standartus ir naujai siūlomus tinklo protokolus, skatinančius vystyti įvairialypes praturtintas paslaugas, pastebėta, kad paslaugų teikimas turi tapti adaptyvus, nes dėl augančių informacijos srautų ir greitai kintančios mobilaus tinklo topologijos, yra neišspręstos tolygios apkrovos problemos, t.y. problematiška išvengti tinklo perkrovos, skirtingomis eismo bei tinklo mobilumo sąlygomis.
2. Tiriant siūlomas adaptyvių įvairialypių paslaugų teikimo sistemines ir programines platformas kooperatyviems automobilių komunikacijos tinklams, deklaruojančias gebėjimą vykdyti konteksto duomenų surinkimo, agregavimo ir skleidimo procesus, nustatyta, kad pasirinktam tyrimui konstravimo būdu tik iš dalies tinka konteksto erdvių modelis ir daugiakriterinės naudingumo teorijos bendrieji teiginiai, todėl šio uždavinio naujuose sprendimuose yra tikslinga taikyti konteksto informacijos apsikeitimo tarp mazgų naujus algoritmus, ir šią informaciją integruoti su iš aplinkos gauta praturtinta konteksto informacija.
3. Išanalizavus sistemines ir programines platformas, leidžiančias kartu modeliuoti automobilių judėjimą bei tinklo mobilumą, konteksto duomenų surinkimo ir skleidimo valdymo sistemos (prototipo) projektavimui bei verifikavimui, nagrinėjamoje aprėptyje, siūlomos naudoti priemonės:
   - Paketas– *NCTUns/ESTINET*, panaudotas atlikti baigtinių transporto srautų mikro modeliavimą bei tinklo veikimo, taikant skirtingus darbo režimus ir protokolus modeliavimą.

- National Instruments *LabVIEW* programinė ir *CompactRIO* sisteminė platformos, panaudotos sistemos valdymo prototipo projektavimui ir programinių komponentų realizavimui.
- *RapidMiner 6.5* duomenų tyrybos priemonė, panaudota adaptyvaus kanalo kokybės valdymo projektavimui, tyrimui ir verifikavimui bei duomenų srauto mažinimui, sudarant automobilių klasterius.
- Siūlomų naudoti priemonių integravimui sukurtas algoritmas, įgalinantis šias priemones pritaikyti vykdomo tyrimo uždaviniams spręsti.

4. Sukurtas kintančios topologijos automobilių komunikacijos tinklo konfigūravimo prototipas, skirtas situaciją suvokiančių, automobilių komunikavimu grindžiamų adaptyvių sistemų projektavimui, realiu laiku įvertinantis bei praturtinantis konteksto informaciją. Sukurta metodika leidžia efektyviau kurti naujas situacijas suvokiančias sistemas, įgalinant efektyviau keistis konteksto informacija. Pasiūlyti 3 specializuoti konteksto duomenų saugojimo ir apsikeitimo modeliai, skirti valdyti duomenų apsikeitimui sudėtingomis ryšio užtikrinimo sąlygomis, atsižvelgiantys į konteksto duomenų paskirtį: lokaliai saugomiems, perduodamiems kitiems mazgams bei debesų kompiuterijos sistemai, duomenims.

5. Eksperimentu, konstravimo būdu, imituojant situacijas kelyje ir įvairialypių paslaugų teikimą, įrodyta, kad sukurto sistemos prototipo veikimas yra efektyvus, prie modeliuojamų eismo intensyvumo sąlygų, o pasiūlyti programinių ir sisteminių įrankių integracijos sprendiniai leidžia sumažti perduodamus nenaudingų duomenų kiekius kintančios topologijos automobilių komunikacijos tinkle. Eksperimentų rezultatai parodė, kad įdiegus siūlomus tinklo valdymo metodus galima pasiekti efektyvų duomenų pralaidumo padidėjimą nuo 22–69%.

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