DEVELOPMENT OF METHOD FOR SERVICE SUPPORT MANAGEMENT IN VEHICULAR COMMUNICATION NETWORKS

Mindaugas KURMIS[1,3], *Miroslav VOZNAK*[2], *Gintaras KUCINSKAS*[1],
Darius DRUNGILAS[3], *Zydrunas LUKOSIUS*[3], *Sergej JAKOVLEV*[3], *Arunas ANDZIULIS*[3]

[1]Department of Information Technologies, Faculty of Technologies, Klaipeda State University of Applied Sciences, Jaunystes 1, 91274 Klaipeda, Lithuania
[2]Department of Telecommunications, Faculty of Electrical Engineering and Computer Science, VSB–Technical University of Ostrava, 17. listopadu 15, 708 00 Ostrava, Czech Republic
[3]Informatics and Statistics Department, Faculty of Marine Technologies and Natural Sciences, Klaipeda University, H. Manto 84, 92294 Klaipeda, Lithuania

m.kurmis@kvk.lt, miroslav.voznak@vsb.cz, g.kucinskas@kvk.lt, dorition@gmail.com, z.lukosius@yahoo.com, s.jakovlev.86@gmail.com, arunas.iik.ku@gmail.com

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Abstract. *In this work, the method and prototype for managing the quality of wireless communication channel is presented. The proposed methodology, based on multi-criteria information utility assessment process, is designed. The heterogeneous context awareness data collection subsystems integration is enabled by transforming the acquired data to the highly dynamic intelligent transport systems. 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 realizing 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 developing more complex heterogeneous services. It is believed that the obtained scientific results will have positive effect for the future research and development of context awareness and service adaptation systems.*

Keywords

Context-aware, VANET, vehicular communication networks.

1. Introduction

Currently, one of the most common attentions attracting mobile communication technology is Vehicular Ad-hoc NETworks (VANETS) [1]. 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.

The information collection from environmental and dissemination efficiency problem arises when developing adaptive systems for dynamic environments [2]. Context awareness and proper understanding as well as interpretation of this information require new methods which allow collecting the right information to understand it (or aggregate) and disseminate it to other nodes [3]. This information has to be directly attributed to the higher abstraction level of knowledge exclusion that is the concept of environmental situations [4] and [5]. The respective service selection and adaptation should be performed according to the perceived situation. Also, it enables quality improvement of the process integration automation.

Several studies have focused on building context-aware service support management systems for ubiquitous environment in recent years. The problem of vehicular traffic optimization in VANETs was addressed in [6]. Authors tried to reduce the roads density and proposed a map model based on a weighted oriented graph. The main idea is to evaluate a re-routing strategy based on the analysis of the roads structure. The integration of congestion and awareness control in vehicular networks problems were analysed by [7]. Authors introduce the integrated congestion and awareness control protocol that dynamically adapts the transmission parameters taking into account the vehicle's application requirements and the experienced channel load. The results demonstrate that INTERN is able to maintain the channel load under control in certain situations while ensuring that the application requirements of each vehicle are satisfied. New work presenting an integrated VANET-based data dissemination and collection protocol for complex urban scenarios was proposed by [8]. Authors introduce a protocol, named DISCOVER, that disseminates and collects the data of interest in a quite large city area efficiently and timely by using a single network structure made up only of vehicles nodes. DISCOVER is distributed and adaptive to different traffic conditions. The performed several numerical results show that it attains very good performance in different type of city maps. The experiments were performed using the OMNET++ simulation tool. However, more complex and different urban and highway scenarios should be taken into the consideration. Another approach dealing with optimization of VANETs and high loads of multimedia data is addressed in [8]. In this work, authors propose an Enhanced version of AODV (Ad hoc On-Demand Distance Vector) protocol to deal with routes instability issue in VANETs. En-AODV leverages cross-layer information on the link quality combined with the knowledge of the final destination of the receiver vehicle to establish more stable routes. The obtained simulation results confirm the efficiency of En-AODV and highlight its supremacy over AODV under various metrics and scenarios. En-AODV has showed its ability to establish stable routes while reducing the overhead which is generated by sending the control packets, freeing up the channel to carry more data packets. Although the results are promising, the main multimedia data will come from other types of networks including 4G and coming 5G. The novel multi-hop broadcast protocol that reduces the number of unnecessary messages on the network and also the delays in message delivery protocol was proposed by [9]. Based on a receiver oriented approach, proposed method selects a relay node based on the local density and distance from neighboring nodes. The method uses an adaptive beacon congestion control to reduce the beacon load and to address the broadcast storm problem.

The goal of this work is to develop the method and its prototype for service support management in vehicular communication networks. The proposed methods and their application methodology extend 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.

2. Common Architecture of Proposed System

The general architecture of the management system of the proposed vehicular communication network infrastructure is presented in Fig. 1. This system consists of 4 subsystems. The context data acquisition and dissemination management system is responsible for data acquisition from sensors, its pre-processing and storage. The context utility evaluation system is the main interest of this work. It acquires the context of the vehicles, evaluates quality of the wireless medium channel and context data utility. The service support system is responsible for identification of situations and services selection and providing. The processed data are transmitted through the interfaces between subsystems. The evaluation of the utility of messages enables deciding 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. The context data, acquired locally and from cooperating vehicles, are transferred to the services support subsystem. The service support subsystem using the context data and machine learning reasoning algorithms infers 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.

2.1. 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 decisions for it. The system acquires the data from different sources, then the information preprocessing and de-noising procedures are performed. The processed data are checked if they are safety related and if the answer is yes, they are immediately transmitted to other vehicles. If not, the data are

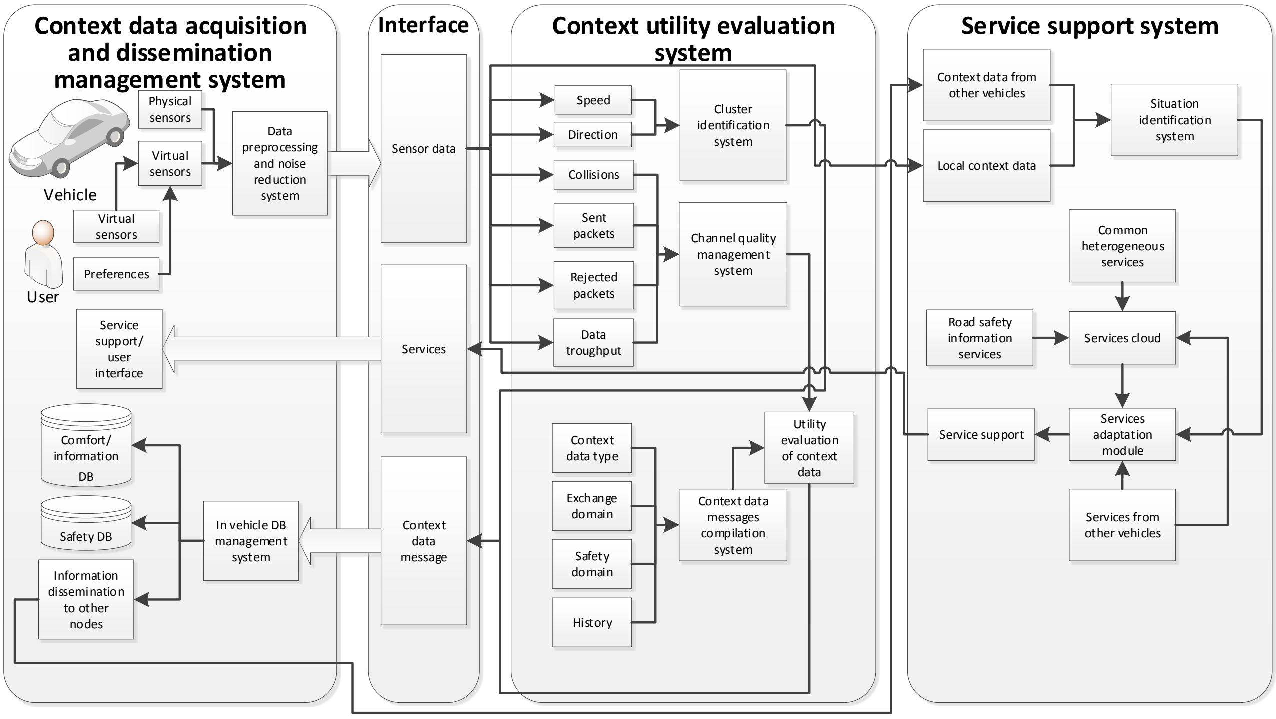

Fig. 1: General architecture of the proposed management system for vehicular communication networks.

passed to the Decision Support System (DSS) where the utility of the data is calculated.

If the DSS decides that the data are not important, they are deleted; if the DSS decides that data are of medium importance, they are stored in the vehicle database, and 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 are 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. In parallel Vehicle database system exchanges information with the Situation recognition and management subsystem where reasoning engine, which employs different methods of artificial intelligence (logic rules, expert system, ontologies), associates the context with the data from different sensors. In this way, the reasoning engine infers the current vehicle situation. The system selects best services from the Vehicle services cloud using the knowledge of the current, past and possible future situations. It adapts services to the user needs and preferences. The adaptation is performed by the reasoning engine. One of the biggest challenges in VANETs is to ensure that the safety and traffic management applications will get the required data in time with minimal delay. This means that the channel congestion has to be minimized. The literature shows that these problems arise using any of known mass data dissemination techniques including flooding, broadcasting, neighbor knowledge based exchange and cluster based approach.

We propose to introduce the utility function for the different kind of the contexts evaluation and to store it in the context utility matrix ($\mathbf{M}_{\mathrm{L}}$). The matrix is formed for each vehicle participating in network and is used for l data messages (m) from n sensors (s):

$$\mathbf{M}_{\mathrm{L}} = \begin{pmatrix} d_{L_{11}} & d_{L_{12}} & \dots & d_{L_{1n}} \\ d_{L_{21}} & d_{L_{22}} & \dots & d_{L_{2n}} \\ \dots & \dots & \dots & \dots \\ d_{L_{l1}} & d_{L_{l2}} & \dots & d_{L_{ln}} \end{pmatrix}. \tag{1}$$

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):

$$\begin{aligned} d_{L_{ij}} &= (Ty_j + H_j + Ex_j) m_i cr_i Pr_i, \\ & i = 1, \dots, l, \quad j = 1, \dots, n. \end{aligned} \tag{2}$$

The priority of the message (Pr) is calculated by the $Pr_j = 1 + \frac{I_j}{A_j}$ and it is normalized with values falling in a predetermined interval [1, 2, 3], where 3 means that the message priority is critical and it must be disseminated immediately, 2 means that the message has 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

Tab. 1: Terms for the Eq. (2).

Term	Explanation
Ty	type of context data in the interval [1, 2, 3] (1—entertainment related, 2—entertainment and safety related, 3—safety related)
H	parameter in the interval [0, 1] showing if the data should be used for historical saving (1) or not (0)
Ex	parameter in the interval [1, 2, 3, 4] showing the data exchange domain (1—V2M, 2—InV, 3—V2I, 4—V2V)
cr	coordinates of the data generation location

is safety related message and 1 is comfort/information related message. A_j is message age function with normalized values in predetermined interval [1, 2, 3] which is calculated by Eq. (3) where T_M is difference between current and message compilation time.

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

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.

2.2. 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 [10], which captured geographic coordinates and time of taxis moving in the centre of Rome. Data were acquired every 7 seconds.

The data having less than 20 m accuracy were filtered out. It was found that the direction of movement and speed characteristics should be used for clustering vehicles. The clustering of 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 and enables not to have the number of clusters specified. The clustering experiments were performed using the RapidMiner 6.5 tool. The example of results of vehicles clustering experiments are presented in Fig. 2. Nodes assigned to different clusters are shown in different colours. Nodes spatial distribution is displayed by the GPS coordinates. Graphs display clusters' change over time. The algorithm identified 4 clusters. The cluster structure was relatively stable, there are no often changes of cluster, which makes it possible to avoid additional communication channel load.

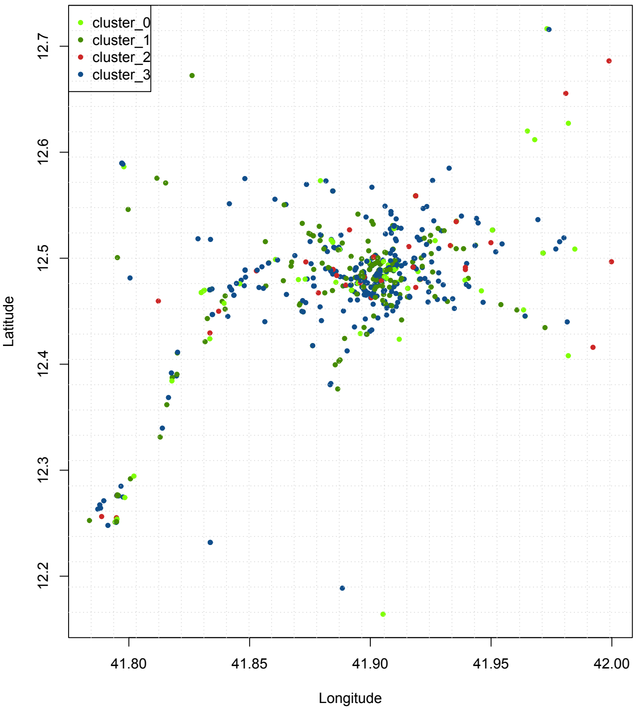

Fig. 2: Example of identified vehicle clusters.

2.3. Evaluation of Channel Quality

The classification problem was solved in order to increase speed of information utility computational process. 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 uses 4 features. These features were determined during the experiments in Estinet simulation environment when

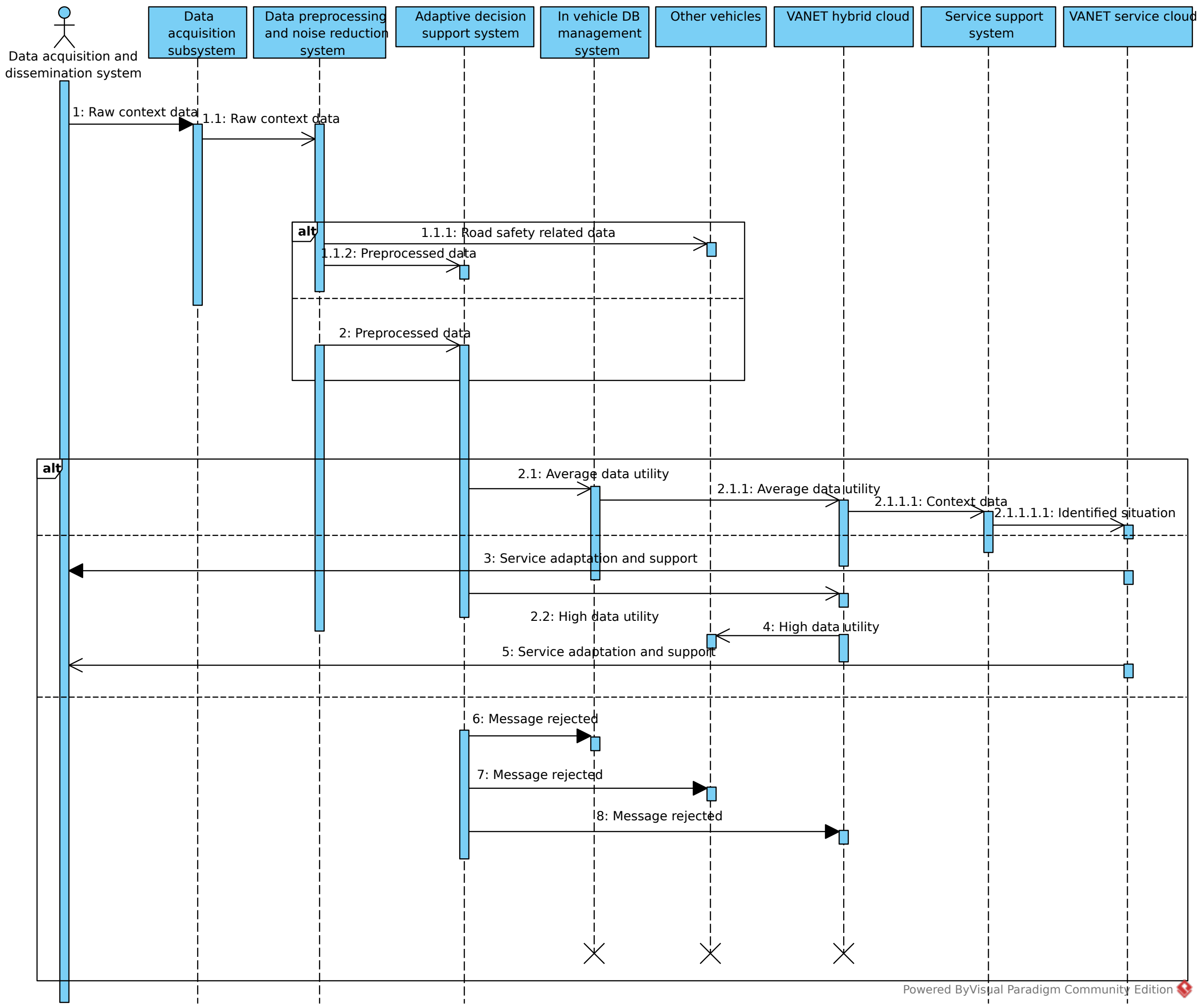

Fig. 3: Dataflow of data dissemination process algorithm.

communicating different number of vehicles moving under different mobility patterns. The main simulation parameters are summarized in Tab. 2.

Tab. 2: Main simulation parameters.

Parameter	Value
Simulation time	60 s
Physical layer protocol	802.11b
Number of vehicles	10–100
Mobility model	Random waypoint, highway
Channel frequency	2.4 GHz
Routing protocol	AODV

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, Naive Bayes, decision trees, induction rules, and quadratic discriminant analysis classification methods were chosen. The classification accuracy and Kappa statistics were evaluated. Cohen's kappa coefficient is a statistic which measures inter-rater agreement for qualitative (categorical) items. It is generally thought to be a more robust measure than simple percent agreement calculation, since it takes into account the possibility of the agreement occurring by chance [8]. For the model, 10 times cross-validation is used to determine how effectively it works with unknown data. The dataflow of developed data dissemination process algorithm is presented in Fig. 3.

3. Experimental Results

The results of classification experiments using the developed decision tree model are shown in Fig. 4. The model builds a tree enabling classification of the channel quality in near real-time.

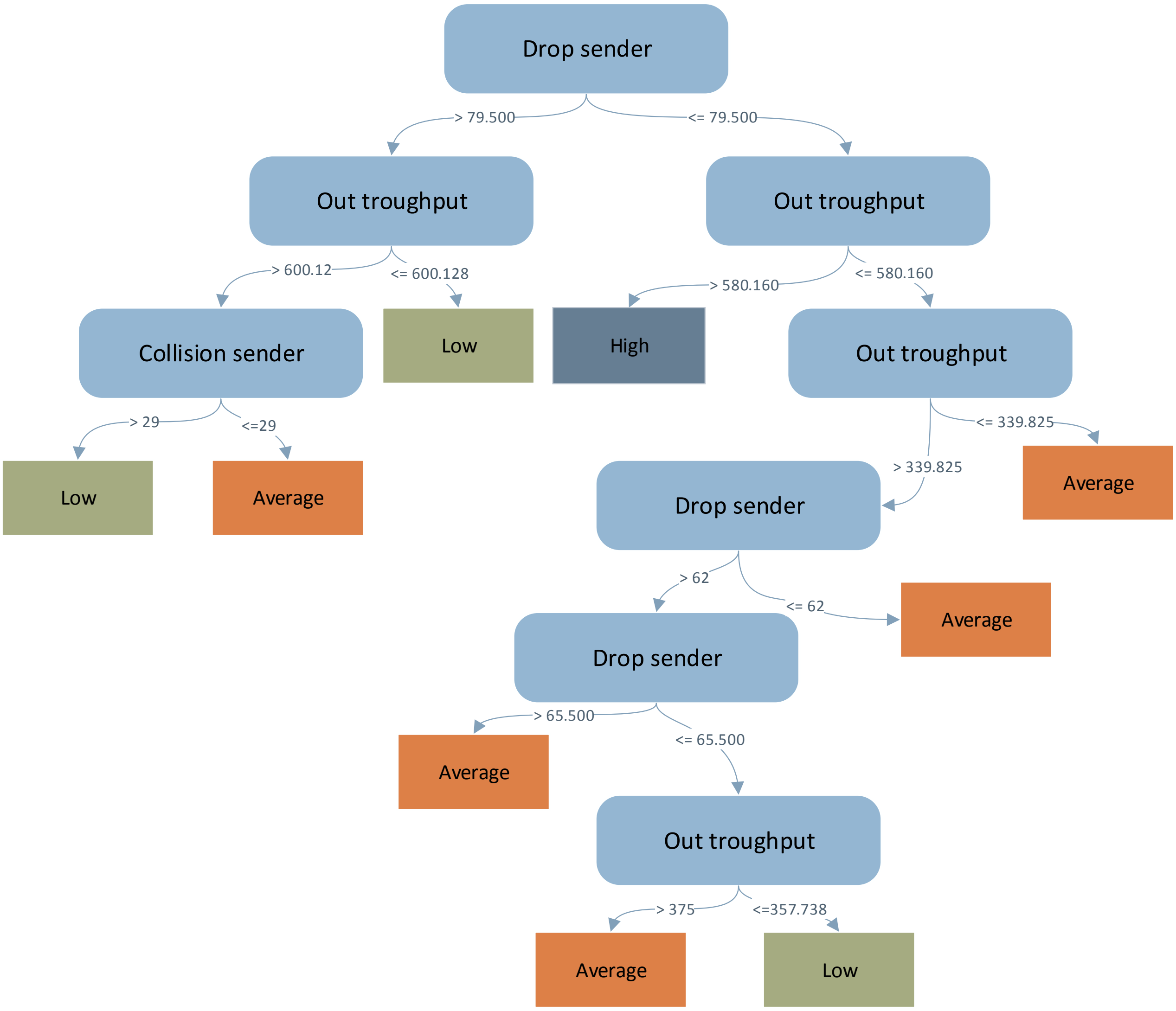

Fig. 4: The results of decision tree model experiments.

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 and they are presented in Fig. 5. The results showed that the most effective algorithm in this case was the decision tree algorithm, it showed (97.88 ± 1.19) %, and 0.96 ± 0.02 Kappa value.

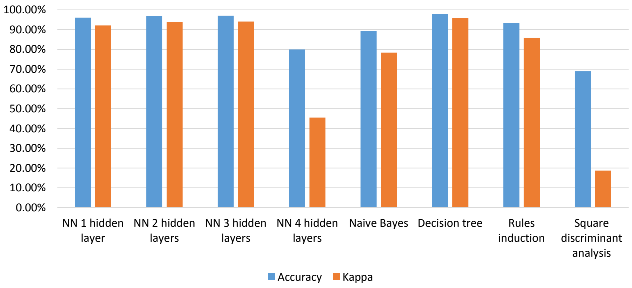

Fig. 5: Comparison of investigated classification methods by accuracy and Kappa.

The Multilayer Perceptron method using different numbers of hidden layers showed (79.97 ± 15.60) % and 0.46 ± 0.46 Kappa with 4 hidden layers to (97.07 ± 1.39) % and 0.94 ± 0.03 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 0.19 ± 0.04 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 are shown in Fig. 6. 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.

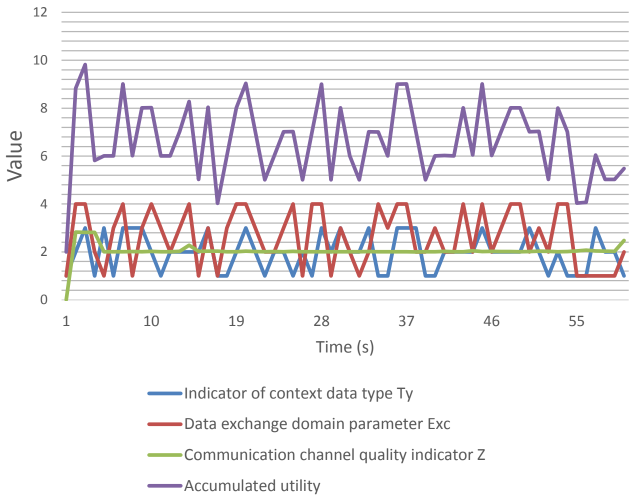

Fig. 6: Accumulated predicted utility, Exc, normalized Z and Ty parameters variation in time.

The results showed that using two-way context data transmission with 1–10 vehicles using the proposed method produce about 23 % of the required bandwidth savings. By using a one-way transmission, we get 22 % savings with 1 vehicle, with 5 cars — 47 % and with 10 vehicles — 69 % savings.

4. Conclusion

This paper has proposed and evaluated a new integrated context-aware method for managing of wireless channel load in vehicular communication networks. It dynamically adapts the transmission parameters taking into account the utility of transmitted information and the quality of wireless channel. The results demonstrate that proposed method is able to maintain the channel quality under different scenarios. It was found that it is appropriate to design three separate context data management algorithms: for locally stored data, data transmitted to other nodes and data directed to cloud computing. Three context data storage and exchange models were proposed. The developed algorithms allowed to adaptively reduce the amount of useless transferred data and to use channel resources cooperatively.

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About Authors

Mindaugas KURMIS is an assoc. prof. with Department of Information technologies of Klaipeda State University of Applied Sciences and Department of Informatics and Statistics of Klaipeda University. He received his Ph.D. from Vilnius University in 2016. His research interests include mobile communications, vehicular communication networks, and artificial intelligence.

Miroslav VOZNAK is a professor with Department of Telecommunications, the department chair in Faculty of Electrical Engineering and Computer Science, VSB–Technical University of Ostrava, Czech Republic. He received his Ph.D. degree in telecommunications in 2002 and topics of his research include next generation networks, IP telephony, speech quality and network security. He is a senior member of IEEE Communications Society and many boards of conferences supported by IEEE such as TSP, INBIS or CN.

Gintaras KUCINSKAS is a Head of Department of Information technologies of Klaipeda State University of Applied Sciences. He received his M.Sc. degree from Klaipeda University in 2007. His research interests include mobile communications, virtual and augmented reality.

Darius DRUNGILAS is a doctor of Technological Sciences, Informatics Engineering. He defended a Ph.D. thesis at Vilnius University (Lithuania), Institute of Mathematics and Informatics in 2014. His research interests include methods of artificial intelligence, digital adaptive control, machine learning and machine vision.

Zydrunas LUKOSIUS is Ph.D. student at Department of Informatics Engineering, Vilnius University (Lithuania). He graduated M.Sc. degree in Informatics Engineering, Klaipeda University in 2011. His research interests include intelligent and biomedical systems.

Sergej JAKOVLEV is a researcher at Marine science and technology center and lecturer at Department of Informatics and Statistics at Klaipeda University. He received his Ph.D. from Klaipeda University in 2016 in area of Transport engineering. His research interests include: transport control systems and operations research.

Arunas ANDZIULIS is professor, head of the Department of Informatics and Statistics of the Klaipeda University (Lithuania). He holds a Ph.D. in electronic engineering in 1968 of Kaunas Institute of Technology. His research interests include operation research, intelligent transportation systems.