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Cooperative Context Data Acquisition and Dissemination for Situation Identification in Vehicular Communication Networks

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Abstract One of the most interesting recent topics in pervasive computing is the smart adaptive service support systems. These systems are impossible without knowing the context with the entity at the moment, what context was in the past and what is possible in the near future. The context alone is not so important in human oriented services provided in connected vehicles. In this environment we need to know not only the exact context but also the higher level information—situation. The situation awareness can be increased by exchanging it to other participating nodes—vehicles. Because the vehicular communication network is a very dynamic environment, it is essential to adequately respond to the user's needs and to provide all the needed services in the right place at the right moment and in the right way. In this work we present our developed cooperative context data acquisition and dissemination model for situation identification in vehicular communication networks. Our solution is different from others as it uses additional virtual context information source—information from other vehicles is weighted and exchanged using the utility function. The proposed decision support system decides if the message should be transmitted to other vehicles, sent to the cloud, saved locally or dismissed. The simulation results show the promising context exchange rate between vehicles and huge saving on channel utilization.

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1 Introduction

Today, a road vehicle is a very important component of human life, so its combination with the intelligence based software and hardware equipment can improve the level of travel safety and comfort [1]. At the moment one of the most interesting and developed mobile technologies is the vehicular cooperation networks, for which the PHY, MAC and network layers obtained a lot of attention from the community [2]. In these networks vehicles communicating with each other and it open new opportunities for the vehicle industry and mobile service providers. Differently from other pervasive computing devices vehicles have specific requirements and does not have strict energy constraints so it can be equipped with powerful computational resources, wireless transmitters and various sensors [1, 3]. The vehicle must not distract drivers attention during driving it must provide user with services autonomous and without user intervention. To provide the necessary services at the right time in the right place and in the right way it is necessary to adapt services and their support to user needs.

To solve these problems the vehicle must understand its environment and to identify current, past and possible future situations. For the situation awareness it can be used data from various sensors but this data is complex (different modality, huge amount with complex dependencies between sources), dynamic (real-time update, critical ageing) and different confidence [4].

The communication between vehicles and the Road side unit (RSU) and the infrastructure form three types of domains [5]. 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 (Fig. 1).

There are also many works in literature, dealing with routing optimization [6, 7], since the network layer is crucial for all vehicular operations, due to its ability to find the best path among vehicles, ensuring an efficient relaying operation.

Situation identification system must be able to recognize many different situations, to understand their relationships and context, and to control these situations. The system must be aware of simultaneous different situations and of that it cannot occur at the same moment. Considering the complex environment of system operation, high level of dynamics, imprecise data of sensors and other circumstances it is very difficult challenge to achieve high level of situation identification.

One of the main problems in VANETs is how to disseminate to other cooperating vehicles and access huge amounts of different types of context information from such a complex system in real-time or even before the occurred event. The existing context data acquisition and dissemination systems should be extended to support modelling and prediction of network dynamics and including distributed algorithms for dissemination of real-time acquired context data. The aim of this work is to develop the cooperative context data

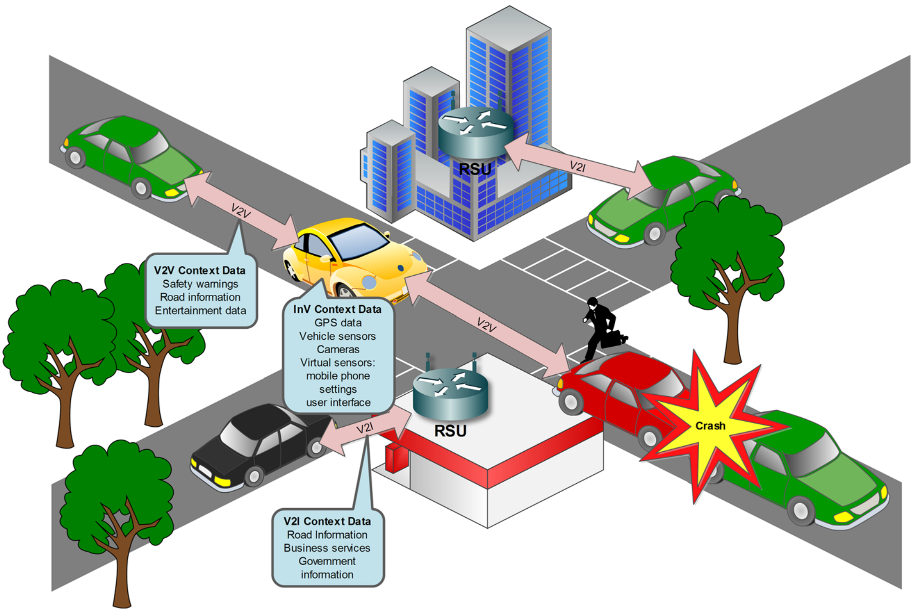

Fig. 1 Wireless communication types and context data producers in VANETs

acquisition and dissemination model for situation identification in vehicular communication networks.

2 Related Works

Despite the fact that it is increasing number of researches in context data acquisition and dissemination for the situation identification in pervasive computing domain but there is very small number of researches where it is addressed the specifics of vehicular communication and cooperation.

One of the latest attempts to analyse critical information aggregation and dissemination in VANETs based on a cognitive agent approach can be found in the [5]. Authors proposed cognitive agent based critical information aggregation and dissemination in VANETs by using regression mechanism. Regression based cognitive agent approach efficiently aggregates the collected critical information and minimizes redundant data dissemination. The scheme works over clustered vehicles by using a set of static and mobile agents. The scheme operates by validating and filtering of collected critical information, generation of beliefs based on valid and filtered critical information, aggregating the beliefs to develop desire using a regression technique, revision of desire for better quality of aggregation, finalizing the intention based on revised desire, disseminating aggregated information to neighbouring clusters. The proposed method was validated by simulation. The results show that the proposed scheme performs better than Event Suppression for Safety Message Dissemination (ESSMD) scheme in terms of critical information acquisition, aggregation, dissemination, end-to-end delay and bandwidth utilization. The authors in this research has not included the simulation results for other scenarios like highway, partitioned networks, traffic jams thus the quality of the scheme for different situations and services cannot be measured.

Another example of context dissemination for autonomic collaborative networks can be found in [8] where context data dissemination is performed through semantic subscription filter generation. The proposed approach enables the automated generation of semantic subscription filters which allow an element to define where, how, and when context needs to be requested from other entities. The proposed approach allows making the subscription filter generation dependent on the context. Authors also present algorithms that intelligently filter the knowledge that is stored in the ontology. The results show that the generation of subscription filters can be done in the order of tens of milliseconds however the solution is verified using the multimedia services (digital TV broadcasting, Video on Demand) over the wired networks and specifics of the highly dynamic networks such as VANETs was not addressed.

Other example analyzing the context and intra-vehicular context can be found in [9]. In this work authors presents an on-board system which is able to perceive certain characteristics of the intra-vehicular context of its EgoV. It was defined a formal representation of the intra-vehicular context. The proposed system fusions the data from different vehicle sensors by means of a CEP approach to perceive two characteristics of the vehicular context, the occupancy and the places or landmarks of the itineraries usually covered by the EgoV. The real-time constrains also was not addressed in this work.

In [10], the authors proposed an innovative security system based on VANET architecture, capable of increasing road safety through the inter-communication among vehicles and road infrastructures. The proposed GeoWave protocol takes advantages of IEEE802.11p standard and tries to enhance it adding useful messages in order to increase active and passive safety system. The network infrastructure is able to continuously gather information from environment, road conditions and traffic flows, and all gathered information are spread in the network.

The survey of context modelling and reasoning techniques can be found at [11]. Authors described the state-of-the-art in context modelling and reasoning that supports gathering, evaluation and dissemination of context information in pervasive computing. It was showed that the existing approaches to context information modelling differ in the expressive power of the context information models, in the support they can provide for reasoning about context information, and in the computational performance of reasoning. Unfortunately authors did not take into account the specifics of vehicular communication networks domain. Most of the analysed methods are applicable to healthcare and other pervasive systems.

3 Specifics of Vehicular Communication Networks

Vehicular communication networks have special characteristics and features that distinguish it from the other kinds of mobile communication networks. The main unique characteristics:

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

Table 1 Influence of different vehicles movement scenarios

Parameter/scenario	Rural	Town	City	Highway
Average movement speed	Average	Low	Very low	Very high
Node density	Low	Average	Very high	Average/low
Interference	Low	Average	Very high	Low
Number of radio obstacles	Low	Average	Very high	Low

The vehicles have much bigger reserve of the energy comparing 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 occur. 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 is high level of interference and obstacles however the driving speed is lower and number of information sources is higher (see Table 1).

3.1 Sensors for the Situation Identification

To identify situation in the vehicular environment it can be used various sensors and other sources of information. 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 and 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 [12]. 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 covers much broader spectrum than used in the traditional ubiquitous environment.

Efficient information gathering mechanism should exhibit the following characteristics: (1) information gathering process must not interfere with the network, e.g., drivers and passengers should not be asked to initiate/gather the data. (2) Heterogeneous mobility patterns of vehicles must be considered. (3) Routing of safety information in a highly dynamic network where the nodes move very quickly. (4) Usually safety information are not addressed to a particular destination. (5) Information must rely on accurate and latest information of the surrounding environment. (6) After certain distance and/or time, information becomes irrelevant. (7) Information gathering algorithms must be fault tolerant. (8) Efficient information gathering algorithms without disruptions, even if some vehicles are disconnected [13].

Table 2 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
Radar (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

Table 2 shows the proposed sensors for the situation recognition in the vehicular communication networks environment.

Due to not strict requirements of energy consumption it can be used more different sensors (physical and virtual) and it can be acquired and analyzed more data. In this way using the methods of artificial intelligence the situations can be recognized more accurate and faster. In the Table 2 can be seen the update rate of the data, information source and data exchange ways: inV (in vehicle), V2I (vehicle to infrastructure), V2M (vehicle to mobile device), V2V (vehicle to vehicle). Different sensors provides different data types: binary, numerical and features so the software and hardware must be able to deal with all types of data.

4 Proposed Model

Our proposed system model (Fig. 2) 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 of it. The system acquires the data from different sources (physical and virtual) of sensors, then it is performed the information pre-processing and de-noising procedures. The processed data is checked if it is safety related and if the answer is yes it is immediately transmitted to other vehicles.

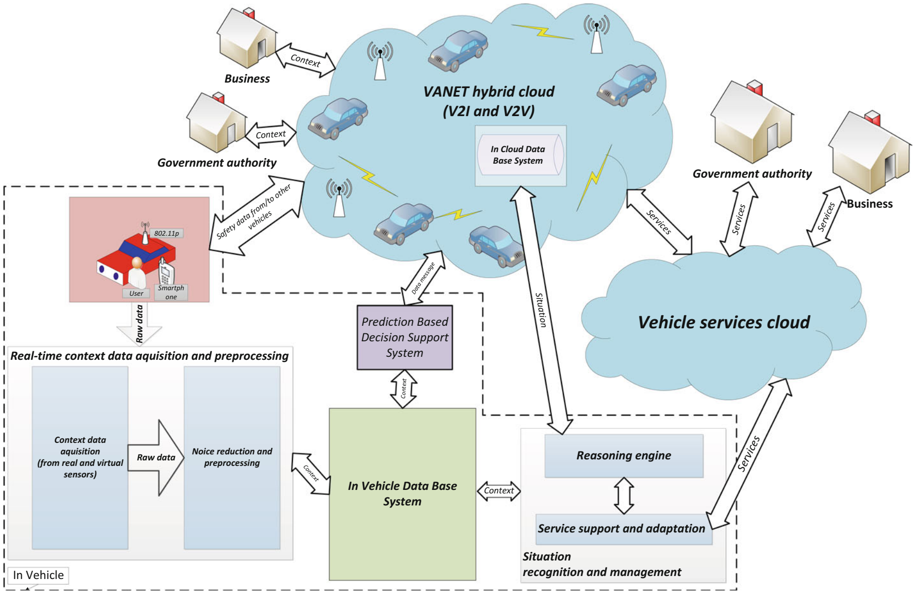

Fig. 2 Architecture of the proposed cooperative context data acquisition and dissemination model for situation identification in vehicular communication networks

If no 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 medium importance it is stored in the vehicle database then it is checked the availability of the wireless link channel. 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 critical important it is formed data message and sent to the Cloud database where it is stored, further processed and disseminated to other VANET Cloud members (Fig. 3).

In parallel Vehicle database system exchanges information with the Situation recognition and management subsystem where reasoning engine which employing 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. By using the knowledge of the current, past and possible future situation the system selects best services from the Vehicle services cloud, adopts it to the user needs according its preferences and reasoning engine recommendations and provides it to the user.

4.1 Calculation of the Utility of the Context Data Messages

To deal with one of the biggest problems in data dissemination in the VANETs using any of the known technique: flooding, broadcasting, neighbour knowledge based exchange and cluster based approach is ensure that safety and traffic management applications function successfully thus means that the channel congestion has to be minimized. We propose to

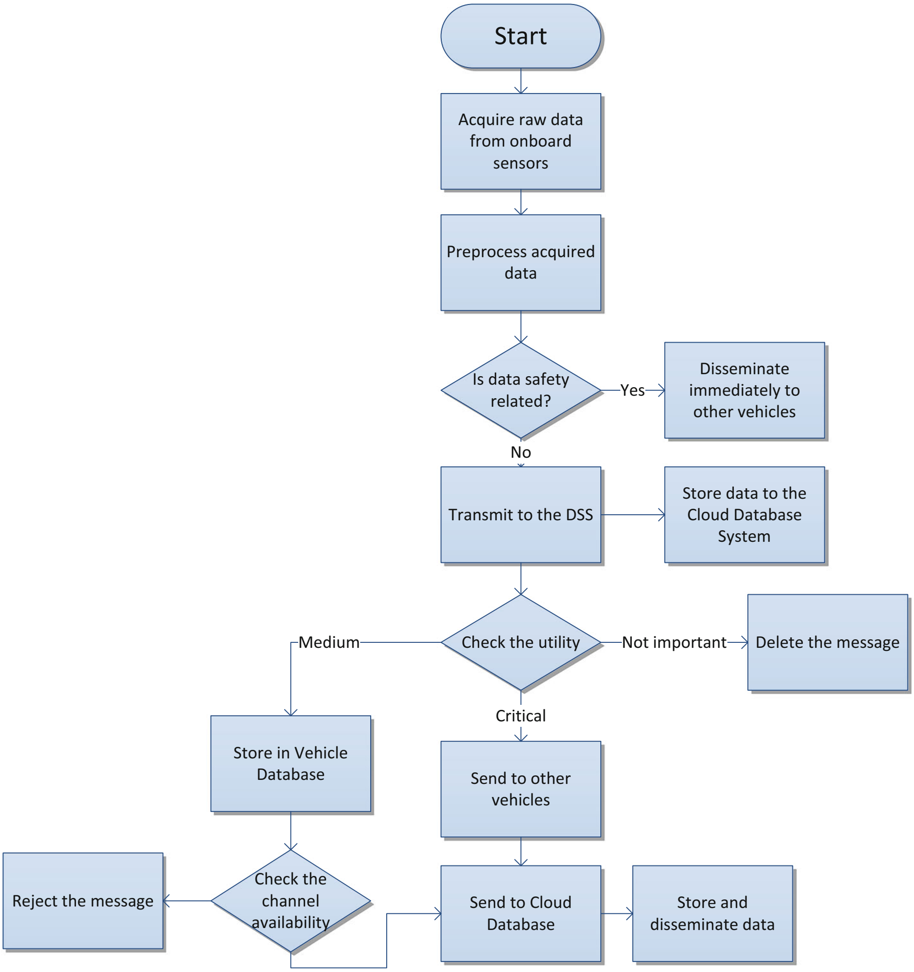

Fig. 3 Flow diagram of the data message dissemination process

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) (1).

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

The utility of the contextual 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):

$$\begin{aligned} d_{L_{ij}} = {} & (Ty_1 + H_1 + Ex_1)m_1 cr_1 Pr_1, (Ty_2 + H_2 + Ex_2)m_2 cr_2 Pr_1, \dots, \\ & (Ty_n + H_n + Ex_n)m_j cr_j Pr_j \end{aligned} \tag{2}$$

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 $\Pr_j = 1 + \frac{I_j}{A_j}$ 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.

5 Experimental Results

It was created a program to test the developed system (see Fig. 4) in LabVIEW graphical programming environment. It acquires data from various sensors with the cRIO Real-Time controller. It was used 4 AI modules to acquire 16 channels of context data at 40 kS/s per channel. A DMA FIFO was used to pass the data to the real-time controller, which then, via an RT FIFO, passes the data to a TCP/IP consumer loop and streams the data over the network to a host PC.

The PC Host program was used to get the context data to the host PC over the network (see Fig. 5). The data was pre-processed and transferred to the reasoning engine. Then the context data was transferred to the emulated mobile nodes (vehicles) in the ESTINET simulation environment. It was investigated the context data transfer capabilities in the mobile network.

The emulation were carried out in the simulation environment ESTINET 8.0 [14]. The environment was chosen as it uses the existent Linux TCP/UDP/IP protocols stack, it provides high-accuracy results; it can be used with any actual Unix application on a

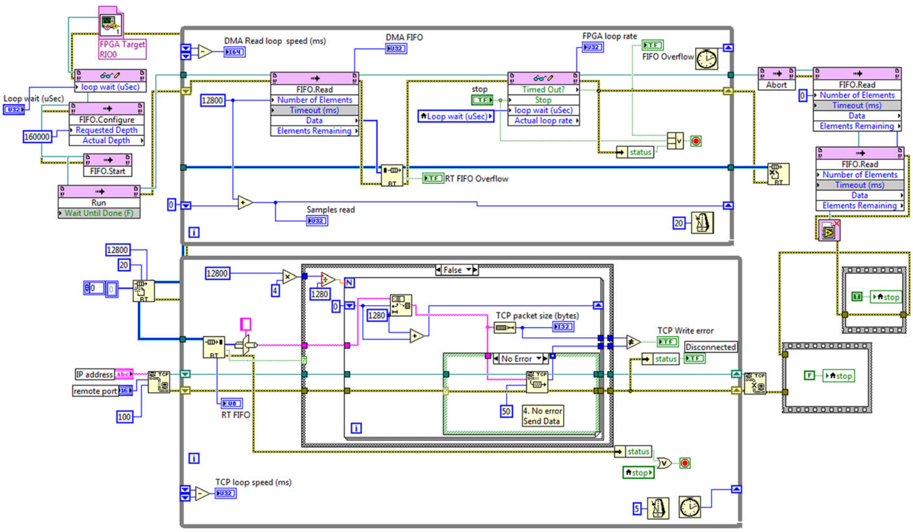

Fig. 4 LabVIEW environment program for the signal acquisition from sensors

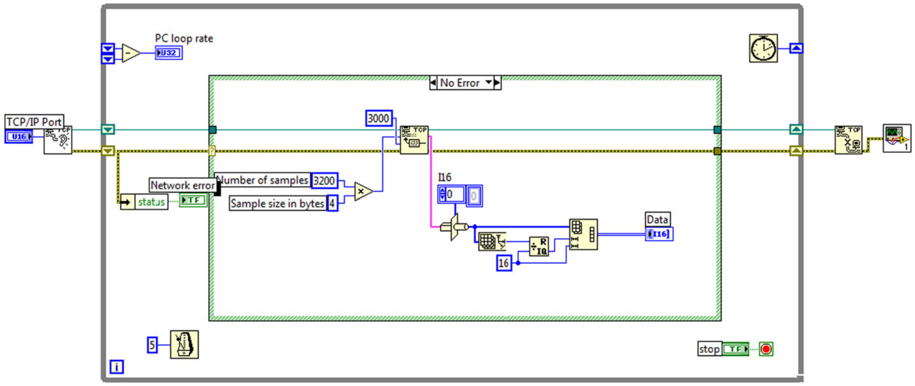

Fig. 5 PC Host program to get the context data to the host PC over the network

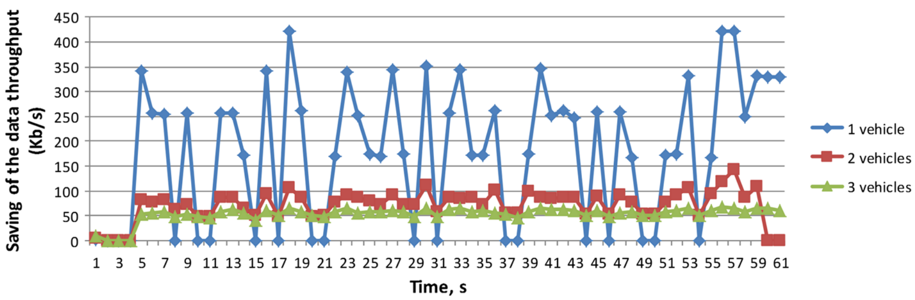

Fig. 6 Savings of the data throughput with different number of vehicles

simulated node without additional modifications; it supports 802.11a/b/p communication networks and vehicle mobility modelling, user-friendly user interface, and it is capable of repeated the simulation results. In the experimental scenario the context data was sent from one vehicle to the other. Communication is provided via 801.11b standard interface and is used multi-hop data transmission method.

The experiment was carried out when the number of nodes in the network is 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 high speed (130 km/h) in the opposite directions. The remaining vehicles are moving at different speeds from 90 to 150 km/h, and their speed and directions of movement are spread evenly. These parameters are chosen to simulate the realistic movement of cars on highway conditions.

Figure 6 shows the savings of the data throughput with a different number of vehicles in the network. The results show that the developed method saves a large number of bandwidth and there is a huge potential by calibrating and adjusting the prediction functions parameters.

During the experiments the average data uplink and downlink throughput was measured (Fig. 7). In this case, the highest mean transfer rate achieved by the network operating 20

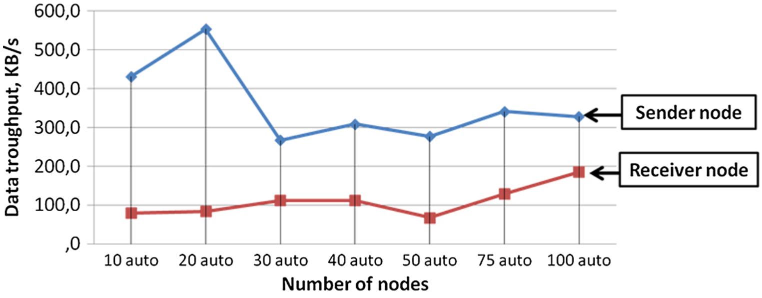

Fig. 7 The average context data downlink and uplink throughput with a different number of vehicles on the network

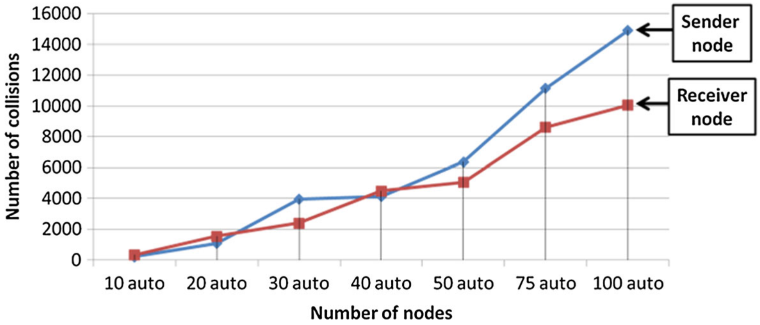

Fig. 8 Collisions rate dependence on receiver and sender nodes with a different number of vehicles on the network

vehicles, while the meanest—30. The maximum average data rate of downlink—100 vehicles, while the meanest—50. The data rate is sufficient for the real implementation of the solution.

Also it was found investigated collision's dependence on sender and receiver nodes with a different number of vehicles (Fig. 8). 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 unsuitable channel access mechanisms.

6 Conclusion

In this work we present our developed model for cooperative context data acquisition and dissemination for situation identification in vehicular communication networks. We have tested our solution during various experiments. The results showed that the solution is able to work in the real-time vehicular communication networks environment. There are still many problems in the field of routing protocols with a huge number of nodes. Future plans are to extend the study and to test the system in real life vehicular environment.

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References

1. Fazio, P., De Rango, F., & Lupia, A. (2013). Vehicular networks and road safety: An application for emergency/danger situations management using the WAVE/802.11p standard. *Advances in Electrical and Electronic Engineering, 11*(5), 357–364.
2. Fazio, P., et al. (2013). Routing optimization in vehicular networks: A new approach based on multi-objective metrics and minimum spanning tree. *International Journal of Distributed Sensor Networks*, *2013*, 1–13.
3. Cheng, H. T., Shan, H., & Zhuang, W. (2011). Infotainment and road safety service support in vehicular networking: From a communication perspective. *Mechanical Systems and Signal Processing, 25*(6), 2020–2038.
4. Ye, J., Dobson, S., & McKeever, S. (2012). Situation identification techniques in pervasive computing: A review. *Pervasive and Mobile Computing, 8*(1), 36–66.
5. Kakkasageri, M. S., & Manvi, S. S. (2014). Regression based critical information aggregation and dissemination in VANETs: A cognitive agent approach. *Vehicular Communications, 1*, 1–13.
6. Fazio, P., De Rango, F., & Sottile, C. (2012). An on demand interference aware routing protocol for VANETS. *Journal of Networks, 7*(11), 1728–1738.
7. Fazio, P., De Rango, F., & Sottile, C. (2011). A new interference aware on demand routing protocol for vehicular networks. In *Proceedings of the international symposium on performance evaluation of computer and telecommunication systems* (pp. 98–103).
8. Latré, S., Famaey, J., Strassner, J., & De Turck, F. (2013). Automated context dissemination for autonomic collaborative networks through semantic subscription filter generation. *Journal of Network and Computer Applications, 36*(6), 1405–1417.
9. Terroso-Sáenz, F., Valdés-Vela, M., Campuzano, F., Botia, J., & Skarmeta-Gómez, A. F. (2012). A complex event processing approach to perceive the vehicular context. *Information Fusion, 21*, 187–209.
10. Santamaria, A. F., Sottile, C., Lupia, A., & Raimondo, P. (2014). An efficient traffic management protocol based on IEEE802.11p standard. In *Proceedings of the international symposium on performance evaluation of computer and telecommunication systems, SPECTS* (pp. 634–641).
11. Bettini, C., Brdiczka, O., Henricksen, K., Indulska, J., Nicklas, D., Ranganathan, A., & Riboni, D. (2010). A survey of context modelling and reasoning techniques. *Pervasive Mobile Computing, 6*(2), 161–180.
12. Latré, S., Famaey, J., Strassner, J., & De Turck, F. (2013). Automated context dissemination for autonomic collaborative networks through semantic subscription filter generation. *Journal of Network and Computer Applications*, *36*(6), 1405–1417.
13. Kakkasageri, M. S., & Manvi, S. S. (2014). Information management in vehicular ad hoc networks: A review. *Journal of Network and Computer Applications, 39*, 334–350.
14. Wang, S., & Huang, Y. (2012). NCTUns distributed network emulator. *Internet Journal, 4*(2), 61–94.

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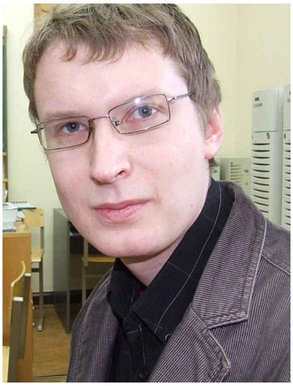

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