Prediction Based Context Data Dissemination and Storage Model for Cooperative Vehicular Networks

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Abstract. The vehicle as the context information source generates a huge amount of different information including from physical vehicle and environment sensors. The implementation of an efficient and scalable model for information dissemination in VANETs confronts with major problems. In this dynamic environment, an increasing number of context dissemination messages are increasing channels utilization which affects the network performance. This article discusses analyses and assesses the key proposals how to deal with the context data dissemination and how to decrease the amounts of transferred and stored data in vehicular cooperation environment. This is one of the most important topics of the pervasive computing.

Keywords: context data dissemination, storage, vehicular communication net-works, VANET.

1 Introduction

As the human mobility increasing day to day, the vehicle becomes a very important component of human life. The ITSs (Intelligent Transport Systems) en-compass a broad range of advanced information and communication technologies, which are applied in transport infrastructures and vehicular networks. They are expected to offer fundamental breakthroughs in enhancing road safety, reducing congestion, improving driving comfort and protecting environment, to name a few [1]. Future hybrid Vehicular Ad-Hoc Networks (VANET) will utilize both long range communications such as cellular networks, as well as short range communication technologies such as Wireless Fidelity (Wi-Fi) and Dedicated Short Range Communications (DSRC) [2]. These types of communications allow vehicles to share different kinds of information, for example, safety information for the purpose of accident prevention, post-accident

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investigation or traffic jams. Other type of information can be disseminated such as traveller related information which is considered as non-safety information. The intention behind distributing and sharing this information is to provide a safety message to warn drivers about expected hazards in order to decrease the number of accidents and save people's lives, or to provide passengers with pleasant journeys [3]. 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 [4]. 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 [5]. One of the ways to increase the user-vehicle interface autonomy and efficiency is to understand the context in which user and the vehicle are at the moment, also to know what context was in the past and to predict the context of the future.

To know the context it can be utilized various sensors and information sources of the vehicle, user and the environment. The vehicle as the context information source generates a huge amount of different information including from physical vehicle and environment sensors: GPS, speed, acceleration, temperature, radar, video, etc. and virtual sensors as road information, warnings, interaction with other vehicles, calls, etc.

The communication between vehicles and the Road side unit (RSU) and the infrastructure form three types of domains [3]. **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).

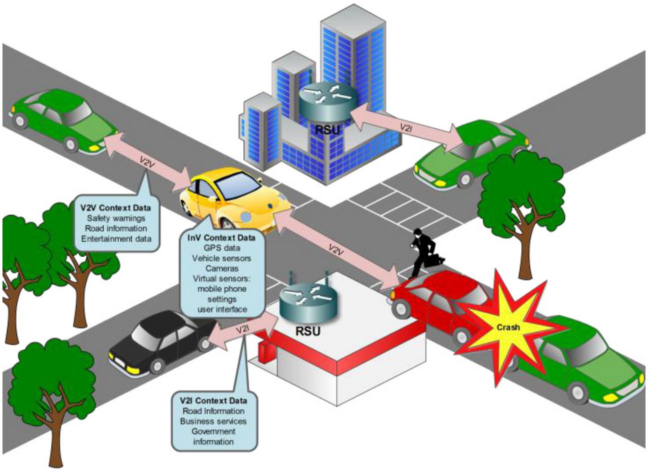

Fig. 1. Wireless communication types and context data producers in VANETs

One of the main problems in VANETs is how 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 dissemination and storage systems should be extended to support modelling and prediction of its dynamics in distributed algorithms for storage of real-time acquisition data with system scalability in mind. One of the solutions is presented in our research – the prediction based context data dissemination and storage model for cooperative vehicular networks.

2 Vehicular Communication Networks (VANETs) Applications

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 [6].

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 [3]. The investments by the vehicle manufacturers show that these applications are becoming extremely popular.

3 Related Works

During the last years there was a huge interest in context data dissemination and storage in cooperating vehicular networks research. Liu and Lee investigate timely and adaptive data dissemination in the dynamically changing traffic environment and present the analytical theoretical model of the effects of the dynamic traffic factors. [1]. Ali et al. examine query starvation and bandwidth utilization problem in multi-item queries in wireless broadcasting systems. [7]. Delot et al. present a system for data sharing in vehicular networks Vehicular Event Sharing with a mobile Peer-to-peer Architecture (VESPA). In this system, a technique based on the concept of Encounter Probability is proposed for vehicles to share information using vehicle-to-vehicle communications. [8]. Barberis and Malnati present the design and evaluation of a collaborative system for content diffusion and retrieval among traveling vehicles. This system relies on multicast epidemic dissemination of messages and exploits vehicles mobility and their local storage capabilities [9]. Despite the fact that there is increasing number of research in this are there is still lack of solutions for the efficient way how to predict which data is needed to store in local, which data should be forwarded to other vehicles and which should be stored in the hybrid vehicle cloud environment databases.

4 Methodologies and the Model

Fig. 2 illustrates a high-level view of our context dissemination and aggregation architecture and its logical flows of the contexts. In our approach the environment consists of the vehicle communicating with other vehicles directly using safety messages. The cooperating and communicating vehicles forms a hybrid VANET cloud system. Through the system it is exchanged entertainment related context data. The actual vehicle stores the acquired data in its local databases – safety DB and entertainment DB. Using the data from the local DB and from hybrid VANET cloud the vehicle reasoning engine reasons about the current, past and future situations and selects needed services from services cloud system. The services is adopted to user need and supported to the user.

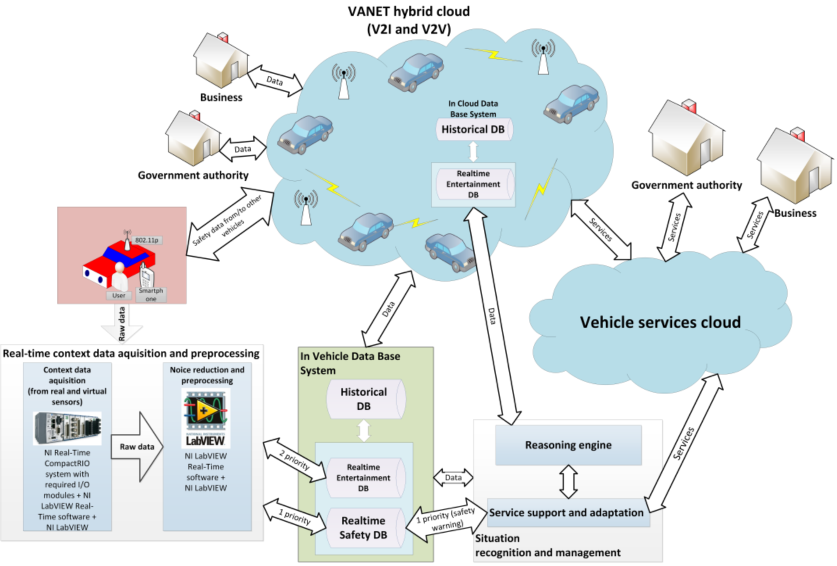

Fig. 2. High-level view of our context dissemination and aggregation architecture

Due to not strict requirements of energy consumption in the proposed system it can be used more different sensors (physical and virtual) which generates huge amounts of context data. The data have to be acquired in the real time and stored in the databases in efficient way thus using the methods of artificial intelligence it should be able to predict self-system and other systems performing in the transportation system dynamics and to model safety situations in real time and non-safety in near real-time. An example of the various sensors (physical and virtual) for the potential usage for the context acquisition is shown in the Table 1.

Table 1. An excerpt of example of the sensors used for the context acquisition and storage

	Sensor	Sample rate (S/s)	No of Channels	No of Devices	Bandwidth (KB/s)	Information source	Data exchange	Historical data?	Safety (Sf)or entertainment data (E)?
1	GPS coordinates	100	1	1	0.1	Vehicle	inV	+	Sf, E
2	Speed	10	1	1	0.01	Vehicle	inV	+	Sf, E
3	Reminders	1	1	1	0.001	Smartphone	V2M	-	E
4	User preferences	1	1	1	0.001	Smartphone	V2M	+	E
5	Road information	10	3	1	0.03	Other vehicles, government, environment	V2I, V2V, V2M	+	Sf
6	Warnings	1000 event	3	1	3	Other vehicles, government, environment	V2I, V2V, V2M	-	Sf
7	Interaction with other vehicles	1000 event	12	1	12	Environment	V2I, V2V, V2M	+	Sf, E

To achieve the higher efficiency of the data being saved in the local DB we propose to save the utility of the local context in a matrix (M_L) for l data messages (m) from n sensors (s) (1).

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

The predicted utility of the contextual data messages can be weighted in a function which assigns a value to each data message of the data sensor. The value is calculated by the equation (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, 2, 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 $\mathrm{Pr}_j = 1 + \frac{\mathrm{I_j}}{\mathrm{A_j}}$ normalized with values falling in a predetermined interval [1, 2, 3], where 3 means that the message priority is critical and it must be sent immediately and stored in the corresponding DB, 2 means that the message have medium priority, and 1 means that the message is not important and can be rejected.

I_j is the importance of the message in a predetermined interval [0, 1] where 0 is the safety related message and 1 is the infotainment related message. $\mathrm{A_j}$ is the message age function normalized with values falling in a predetermined interval [1, 2, 3] which is calculated by the (3), where $\mathrm{T_M}$ is the subtraction from the current time and the message creation time.

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

To reduce the bandwidth and achieve a better efficiency of the data being provided for the exchange with other vehicles we propose to store the utility of the context in a matrix (M_O) for *l* data messages (*m*) for the *n* of vehicles (*v*) (4).

$$M_O = \begin{pmatrix} d_{11} & d_{12} & \dots & d_{1n} \\ d_{21} & d_{22} & \dots & d_{2n} \\ \dots & \dots & \dots & \dots \\ d_{l1} & d_{l2} & \dots & d_{\mathrm{ln}} \end{pmatrix} \tag{4}$$

The predicted utility of the contextual data messages can be weighted in a function which assign a value to each data message (m_l) intended to send to the vehicle (v_n). The value is calculated by the equation (5):

$$\begin{gathered} d_{O_{ij}} = (Ty_1 + Exc_1 + Z_1)m_1cr_1Pr_1n_1, (Ty_2 + Exc_2 + Z_2)m_2cr_2Pr_2n_2, \dots, \\ (Ty_n + Exc_n + Z_2)m_jcr_jPr_jn_j \end{gathered} \tag{5}$$

Where *Exc* is the parameter in the interval [1-4] of the special set of non-confidential data and showing the data exchange domain (1 – V2M, 2 – InV, 3 – V2I, 4 – V2V), n is showing number of cooperating vehicles in the cluster, *Z* is the parameter of prediction of the communication channel availability and calculated by the following:

$$Z_t = \frac{1 + \left(\frac{C_t + D_t}{2} \right)}{Tr} \tag{6}$$

Where C is the collision parameter calculated by the: $C = 1 - \left(\frac{1}{1 + c_{t-1}} \right)$, where D is the drop parameter calculated by the $D = 1 - \left(\frac{1}{1 + d_{t-1}} \right)$ and *Tr* is the throughput parameter and calculated by the $Tr = 1 + \left(\frac{tr_{t-1}}{100} \right)$.

The utility of the context data for the exchange with the hybrid VANET cloud is stored in the matrix M_C for *l* data messages (*m*) for the *r* of the receiving entities (7).

$$M_C = \begin{pmatrix} d_{11} & d_{12} & \dots & d_{1n} \\ d_{21} & d_{22} & \dots & d_{2n} \\ \dots & \dots & \dots & \dots \\ d_{l1} & d_{l2} & \dots & d_{\ln} \end{pmatrix} \tag{7}$$

The predicted utility of the contextual data messages for the exchange with the hybrid VANET cloud can be weighted in a function which assign a value to each data message m_l intended to send to the receiving entity r_n. The value is calculated by the equation (8).

$$\begin{aligned} d_{C_{ij}} &= (Tye_1 + Hx_1 + Exc_1 + Z_1) m_1 cr_1 Pr_1, (Ty_2 + Hx_2 + Exc_2 + Z_1) m_2 cr_2 Pr_2, \dots, \\ & (Ty_n + Hx_n + Exc_n + Z_1) m_j cr_j Pr_j \end{aligned} \tag{8}$$

Where *Tye* is the reduced *Ty* parameter in the interval [1, 2] (1 – entertainment related data, 2 – entertainment and safety related data), *Hx* is the special set of non-confidential data parameter in the interval [0, 1] showing if the data should be used for historical saving (1) or not (0).

5 Results and Discussion

In this section we briefly present our simulation and modelling results. First we introduce the simulation scenarios and then the evaluation of our solution.

The evaluation of the proposed model is carried out by means of simulations and numerical methods. For the experiments it was used the data from the simula-tion environment NCTUns [10], It was chosen as using the existent Linux TCP/UDP/IP protocol stack providing high-accuracy results; it can be used with any actual Unix application on a simulated node without additional modifications. In experimental scenario a (Fig. 3) the network model is created where the data from the vehicles is sending to the VANET hybrid cloud DB server. The modelled network consists of the DB server, 802.11p RSU and 1 to 10 vehicles equipped with the 802.11 OBUs. In the experimental scenario b, the data is transferred in both ways – from vehicles to DB and from DB to vehicles. The simulations have carried out for 60 s. For the link layer bit rate it was used 27 Mb/s, the packet size – 1000 B.

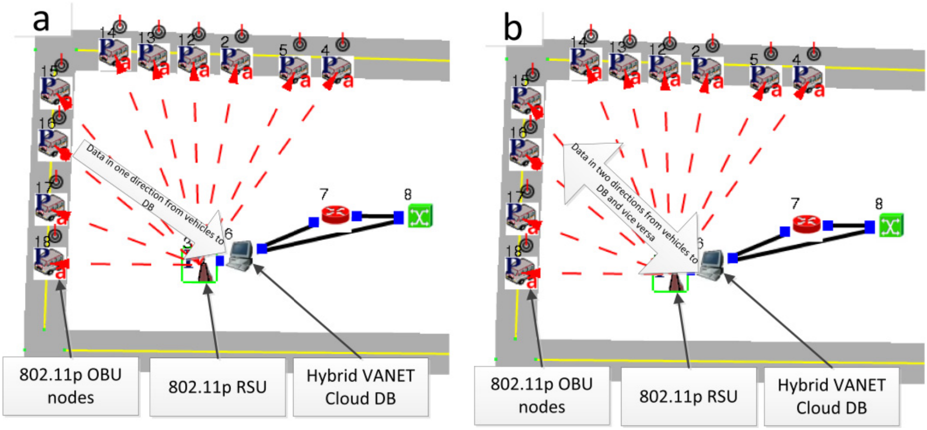

Fig. 3. Simulation scenarios of the context data exchange using the 802.11p

5.1 Evaluation of the Solution

The Fig. 4 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.

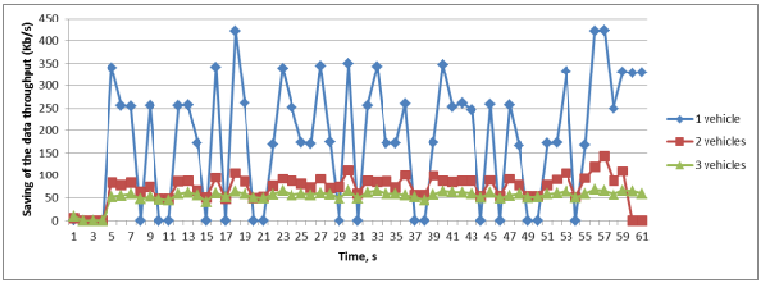

Fig. 4. Savings of the data throughput with different number of vehicles

Fig. 5 shows the average results in terms of accumulated prediction utility val-ue, Exc, normalized Z and Ty parameters change over time. Using the b simulation model it was performed the experiments and evaluated how the prediction of the communication channel availability parameter Z changes over time. As the pa-rameter is inversely proportional it can be seen that as the number of vehicles in-creases the parameter is also increasing. It means that the collision and dropped packets is increasing thus leading to poorer channel availability.

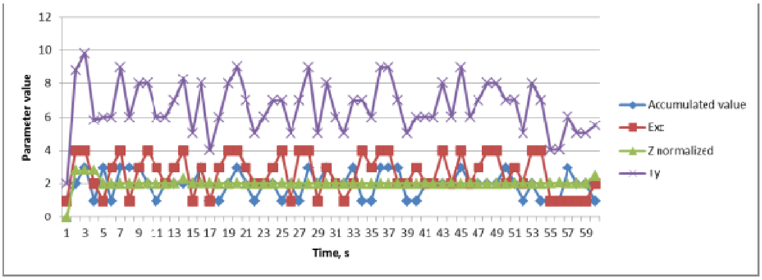

Fig. 5. Accumulated, Exc, normalized Z and Ty parameters change over time

Fig. 6 clearly presents the best result in terms of used throughput efficiency at the cost of having simulation results with our model implemented and without it. Also the influence of different number of vehicles can also be seen. The results show that using the two way context data sending with 1 to 10 vehicles using our model we get about 23% savings in required bandwidth. Using one way sending we get 22% savings with 1 vehicle, 47% savings using 5 vehicles and 69% savings with 10 vehicles.

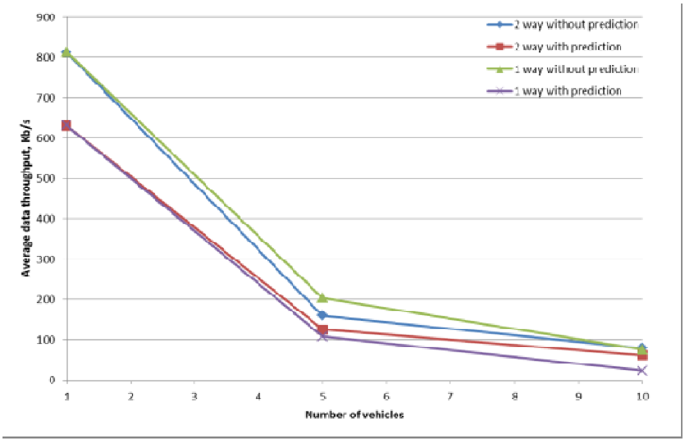

Fig. 6. Average data throughput from the vehicles (1, 5, 10) with and without the developed prediction model using the 802.11p

6 Conclusions

We have analyzed a complex problem of context data dissemination in vehicular communication networks. Three models were proposed for the context data dissemination bandwidth reduction and cooperating usage of the channel availability. The solutions were evaluated by the simulation models and numerical methods. Results suggest that an environment with our implemented solutions and a network with the larger number of vehicles can perform much better than without it and it is showing 22% (with 1 vehicle) to 69% (with 10 vehicles) savings in required bandwidth.

Thus it can be used in real life applications where large number of data is needed to be stored locally, exchanged with other vehicles and vehicular hybrid cloud.

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