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Investigation of Link Layer in Inter-Vehicle Wireless Communication

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Introduction

Wireless communication vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I), as a means of improving crash prevention performance, have recently attracted significant attention from the research community [1–7]. V2V and V2I as a tool to disseminate information among vehicles can be used. Many new applications in the fields of vehicle safety, comfort and infotainment will be possible.

Rapidly changing network topology and high mobility of the nodes have impact on throughput [1, 2], packet loss and other communication parameters. Therefore it is necessary to investigate communication conditions very accurately before engineering V2V and V2I communication systems.

The V2V propagation channel has strong impact on the coverage, reliability, and real-time capabilities of V2V networks. Wrong assumptions about the fading lead to erroneous conclusions on the effectiveness of inter-vehicle warning systems at intersections. The paper [3] provides an overview of existing V2V channel measurement campaigns, describing the most important environments.

Realistic models of propagation channel for V2V scenarios are different for Line of Sight (LOS) conditions and in obstructed case, when neighbouring cars are obstacles for radio propagation path and so compose Non-Line of Sight (NLOS) conditions. A set of experiments, investigating impact of vehicular obstructions in Vehicular Ad-Hoc Networks (VANET's), is done in [4]. Here authors identify the problem of wireless signal obstructions in VANET's.

A set of experiments, investigating impact of vehicular obstructions in VANET's, is done in [5]. Two types of experiments are performed: parking lot experiments and on the road experiments. In parking lot experiments Received Signal Strength Indicator (RSSI) value, which depends on distance and obstructing vehicle, is showed. RSSI attenuation can come up to 20 dB, which means, that it will influence radio coverage. In LOS condition packet delivery ratio does not depend on the area (highway, suburban and urban), but vehicles blocking the LOS significantly attenuate the signal when compared to LOS conditions across all scenarios. For the same distance between sender and receiver in NLOS condition packet delivery ratio in suburban and urban areas is smaller than in highway, as in highway cars are moving faster and distances between cars are bigger – less obstacles.

The results presented in the paper [4] inform on impact of obstructing vehicles on V2V communication, particular on mean packet delivery ratio. But there is no information about packet loss, about loss correlation and grouping as this is important for developing ensured emergency message transmission systems. Lost packet groups influence is important for delay of crash prevention tasks.

This paper presents experimental study on the impact of vehicles as obstacles for the radio signal on the road and gives detailed analysis of lost packet trend. Approximation polynomials for NLOS and LOS cases are calculated.

Lost packets are building groups, and this can be expressed using geometrical distribution. Corresponding curve is presented.

Communication channel model is described in this paper. Model is split into LOS and NLOS parts and can be used for realistic simulation tasks.

Experimental setup

We designed a set of experiments using two vehicles equipped with WLAN devices to characterize the impact of vehicles as obstacles. As WLAN equipment Acer Aspire One D250 notebooks, with integrated IEEE 802.11b/g network cards Atheros AR8132, working on 2.4 GHz frequency band. IEEE 802.11 g mode channel 11 was used. Notebooks with network cards were installed on the roofs (approx. 1.4 m height) of the cars to eliminate influence of car structure and to make it more close to IEEE 802.11p equipment, which will use external antennas on the roofs of the cars.

Web camera was installed at receiver PC, to be able to relate lost packet trend to passing cars.

For signal generation LanTraffic v2 software was used. 500 bytes long, UDP packets were generated. Packets were marked to make it possible to find lost ones. Wireshark v1.6.1 was used for packet transmission at transmitter side and for packet receiving at receiver side. Received packet time, data and other parameters were registered.

Scenario – the objective of this experiment is to measure the influence on packet loss of passing cars between transmitter and receiver. For this reason experiment is split into two parts: LOS measurement and obstructed measurement. LOS measurement gives the distance limit, up to which is possible to estimate just communication path crossing cars influence.

Primary measurements are performed each 25 m up to 350 m in LOS. In this LOS case 200 m was the limit, at which packet loss starts happen. For obstructed measurement it is done up to 225 m.

Experiment was performed in Vilnius city. There is long and straight road, far away from obstructing 2.4 GHz devices, and many trucks passing the measurement line. The sending vehicle was positioned in one side of the road and receiving vehicle on another side of the road as shown in Fig. 1. Each passing vehicle crosses LOS of transmitter and receiver. Such transmitter and receiver arrangement suits dangerous situations, e.g., one of communicating cars takes over non equipped vehicle; communicating cars are driving different road sides. Similar conditions appear, when one of communicating cars is driving near cross section.

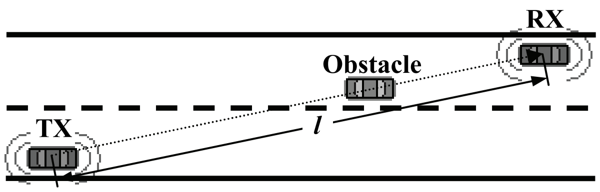

Fig. 1. Vehicle arrangement (here *l* – distance between cars)

Experiment results

To investigate vehicle obstruction problem we performed packet delivery measurements for different distances *l* between the cars without obstacles – LOS measurements, and on the same road for the same distances with obstacles between cars – passing cars and trucks. Experiment was performed from 25 to 350 m for LOS and from 25 to 250 m NLOS cases. Each distance was measured three times sending up to 20000 UDP packets

Video camera was used during experiments, as video records were necessary for data analysis. Example of approaching and passing trucks influence on packet loss is shown in Fig. 2. Here “0” represents arrived packets, and “1” shows lost packets. Observing video records we clearly distinguish, when LOS is blocked packets are being lost. And when LOS is clear, all packets reach receiver.

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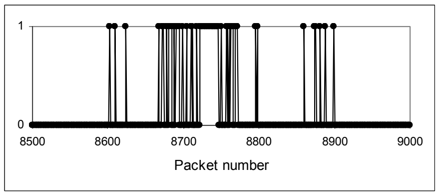

Fig. 2. Example of packet loss trace in obstructed measurement (“0” – corresponds to received packet, “1” – to lost)

LOS and NLOS packet loss ratio measurement results are shown in Fig. 3 and 4. Here should be noted, that in LOS case, packet loss happens quite often, when distance between cars is more than 200 m. And for LOS case no packet loss was detected up to 200 m. In NLOS case lost packets occurs when distance is 25 m, which means, that this loss is dependent on obstacles, when LOS blocked by other vehicles on the road.

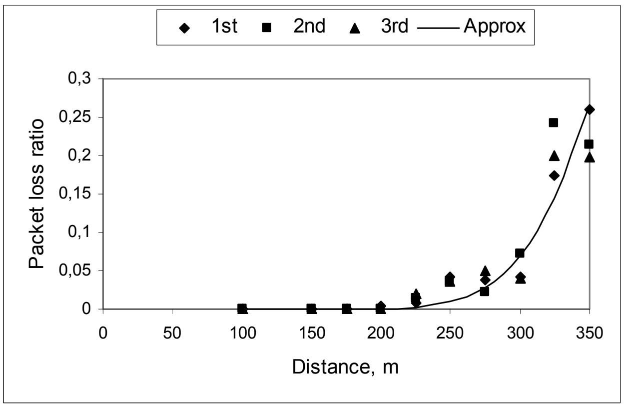

Fig. 3. Packet loss ratio respect to distance between cars – LOS conditions

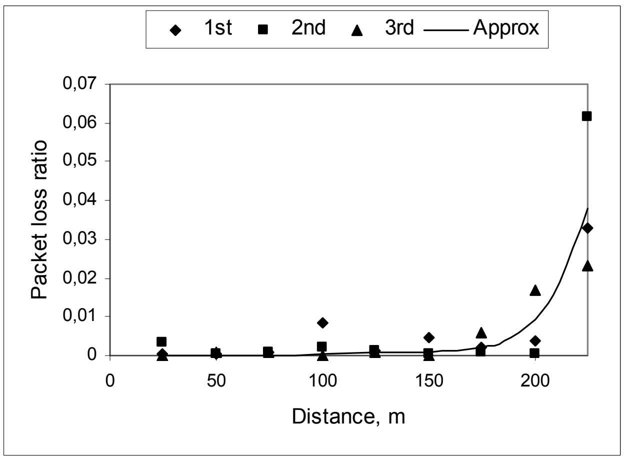

Fig. 4. Packet loss ratio respect to distance between cars – NLOS conditions

Packet loss results presented in Fig. 3 and 4 can not be directly used for simulation tasks. For this purpose, approximation curves should be found. Experiment results shows that packet loss ratio is dependent on distance and can be approximated using polynomials.

For LOS approximation equation is

$$p_{\mathrm{LOS}}(l) = A(l-175)^2 + B(l-175)^4 , \qquad (1)$$

here $A = 1 \cdot 10^{-7}$, $B = 2.8 \cdot 10^{-10}$, l – distance.

For NLOS approximation equation is:

$$\begin{cases} p_{\mathrm{NLOS}}(l\ ) = A(l-50)^2, \text{when } l\ <110, \\ p_{\mathrm{NLOS}}(l) = A(l-50)^2 + C(l\ \ -150)^4, l \geq 110, \end{cases} \qquad (2)$$

here $A = 1 \cdot 10^{-7}$, $C = 1.1 \cdot 10^{-9}$, l – distance.

Parameters A and B are found using the smallest mean square criterion.

Given results show, that packets are lost more frequently, when distance between communicating cars is increasing. It means, that weaker signals are reaching receiver. In NLOS case packet loss happens in smaller distance than in LOS case. This distance difference is 100 m and corresponds to 10% packet loss. It shows that reception of emergency signals in NLOS case is worse.

Here should be noted, that in emergency situations, when cars are braking, distances between cars are getting smaller and communication conditions are getting better. Packet loss, caused by obstacles, is getting smaller.

Lost packet groups

Lost packets are forming groups (as presented in Fig. 2), which are depending on shading strength and obstacle speed. The distribution of lost packet group occurrence rate for NLOS are shown in Fig. 5. Here data arrays are presented when distance is from 125 to 225 m.

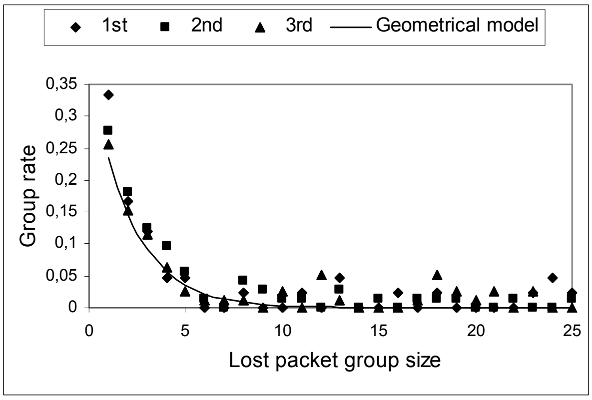

Fig. 5. Lost packet group rate

This distribution of lost packet group rate can be approximated using geometric distribution

$$q_i = (1-\alpha) \cdot \alpha^i , \qquad (3)$$

here i – packet group size, i = 0,1,2,... . Coefficient α is also found using the smallest mean square criterion. For current case (Fig. 5) α is 0.62.

Communication loss time

Selected experiment methodology, when high frequency signals are transmitted, gives opportunity to investigate not just packet loss frequency, but also the duration of packet loss. When packet group i is lost, then communication channel loss duration is

$$\tau_i = (i+1) \cdot T , \qquad (4)$$

here T – packet transmission period.

Cumulative probability distribution function, for packet loss smaller than kT, using lost packet group geometrical distribution, is expressed following

$$P(\tau \leq kT) = (1-\alpha) \cdot \sum_{i=0}^{k} \alpha^i = (1-\alpha^k) . \qquad (5)$$

For the current experiment one packet transmission period was $T = 1.2$ ms.

Lost packet group rate geometrical distribution parameters depend on distance between cars. Results are shown in table 1.

Table 1. Parameter α dependency on distance for LOS and NLOS cases

NLOS		LOS	
Distance, m	**α**	**Distance, m**	**α**
225	0.78	325	0,85
200	0.51	300	0.77
175	0.5	275	0.77
150	0.5	250	0.75

Experiment was performed using IEEE 802.11g equipment, which made influence on packet transmission time, because on changing communication condition, data rate changed.

Communication channel model

Situation on the road is constantly changing because of moving vehicles. Communication condition changes from LOS to NLOS and vice versa all the time. NLOS happens when between two communicating cars enters non equipped car – obstacle. Packet loss can happen for both LOS and NLOS, wherefore the same basic model can be used. For realistic simulations, communication channel model should be varying, consisting of different random packet losses, when packet loss ratio is expressed by (1) and (2). Conditional models are created using random time generators. To get realistic statistical data about switching from LOS to NLOS big traffic flow should be imitated or complicated measurements on the field performed. Such measurement will have sense just when most of the cars will be equipped. For current conditions most cars have no communication equipment and communication path will be blocked often. Blocking car quantity relates to traffic density and dimensions of the car.

Communication conditions between two cars are described in this paper. For inter-vehicle communication modeling using multi-hop transmission [8] very important is to determine neighboring vehicles shadowing consequences. Communication chain can be disturbed by obstacles (non equipped vehicles) or in worst case it can break. This leads to additional delay time for emergency message dissemination.

Conclusions

Implementing driver warning systems, very important is to investigate the reliability of emergency message transmission and also driver trust on such system. One of the trust reducing factors are loss of the emergency messages.

This paper presents measurements on lost packets, which are the main criteria for emergency message dissemination. Lost packets are related to two factors: obstacles and distance. Influence on obstacles is shown in Fig. 3 and 4. Here no packet loss is happening in LOS case for distances up to 200 m, where in NLOS case packet loss starts from 25 m. Influence on distance is seen in both LOS an NLOS cases, and here packet loss is growing with higher distance. Approximation polynomials, (1) and (2), for both cases are found using smallest mean square criterion.

Lost packets are building groups and are expressed using geometrical distribution (Fig.5). Lost packet groups leads to higher delay times for emergency messages.

When distances between cars are small (<100m) wireless communication is relatively reliable even with obstacles. This paper and other authors experiment proves this. In highways, where distances between the cars are bigger, obstacles can be a problem for reliable communication between cars and emergency message can arrive targets too late.

Inter-vehicle communication channel packet loss density can be modelled using (1) and (2) for LOS and NLOS cases, depending on distance between cars. Lost packet times can be estimated using (4). For more accurate data parameter α can be chosen from table 1.

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A. Kajackas, S. Stanaitis, K. Mikenas. Investigation of Link Layer in Inter-Vehicle Wireless Communication // Electronics and Electrical Engineering. – Kaunas: Technologija, 2012. – No. 6(122). – P. 71–74.

Safety message transmission is the key task of inter-vehicle communication. It is affected by obstacles on the road, and in many cases these obstacles are non-equipped vehicles. This paper presents link layer investigation between two cars. Lost packet distribution is given for LOS and NLOS cases and approximation polynomials are found using mean square criterion. Lost packets are building groups and trend of this grouping is also approximated using polynomials. As an outcome communication channel model is presented which can be used for realistic modelling tasks. Ill. 5, bibl. 7, tabl. 1 (in English; abstracts in English and Lithuanian).

A. Kajackas, S. Stanaitis, K. Mikėnas. Ryšio tarp automobilių kanalo lygmens tyrimai // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2012. – Nr. 6(122). – P. 71–74.

Saugos pranešimų perdavimas yra svarbi ir aktuali tarpusavio ryšio automobilių problema. Šią problemą apsunkina tai, kad patys automobiliai tampa kliūtimis radijo bangų kelyje. Straipsnyje pristatomi eksperimentiniai kanalo tarp dviejų automobilių lygmens tyrimai. Pateikiami prarastų paketų skirstiniai esant tiesioginiam matomumui ir kelyje su kliūtimis. Straipsnyje mažiausiųjų kvadratų metodu apskaičiuojami skirstinių aproksimacijos polinomai. Prarasti paketai formuoja grupes, kurias taip pat išreiškiamos aproksimacijos polinomu. Straipsnio rezultatas – komunikacijos kanalo modelis, kuris gali būti naudojamas realioms modeliavimo užduotims įgyvendinti. Il. 5, bibl. 7, lent. 1 (anglų kalba; santraukos anglų ir lietuvių k.).