PHY and MAC Characteristics of VANETs in Dense Traffic Scenarios

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Abstract. *Intelligent Transportation Systems (ITS) will play an important role in increasing transportation safety, efficiency and decreasing costs. Today the Cooperative ITS (C-ITS) systems are hot topic both in academic and automotive industry circles. One of the key enabling technologies of the C-ITS systems are the Vehicular Ad hoc Networks (VANETs). In these networks it is absolutely vital to ensure reliable communication between the nodes as the communicated messages have direct impact on road safety. For this reason, there is need to know where are the network performance boundaries. A network simulation model of VANET is described in this paper and number of simulations are conducted in order to study the impact of various network parameters on the communication bit error rate (BER).*

Keywords

Vehicular Ad hoc Networks, Bit Error Rate, Intelligent Transportation Systems, simulation.

1. Introduction

These days, people are unable imagine their lives without transport. We use various means of transport to commute to work, to transport goods or to visit our relatives. The volume of traffic increases every year and so the roads become more congested and dangerous. On the other hand, the increasing fuel costs make the transportation even more expensive. In recent years the concept of Intelligent Transportation Systems gained high level of interest in our society. The concept promises high benefits in terms of reduced costs due to the increased fuel efficiency, less damages caused by traffic accidents and more predictable travel time. One of the biggest motivations to evolve this concept is also transportation safety. Road transport especially is one of the deadliest means of transport today. The Cooperative Intelligent Transportation Systems (C-ITS) are expected to bring savings also to this area. According to the Fig. 1., Toyota Motor Company expects major reduction of injuries and deaths caused by traffic accidents after deploying driving support systems based on Vehicle to Vehicle (V2V) and Vehicle to Infrastructure (V2I) communications.

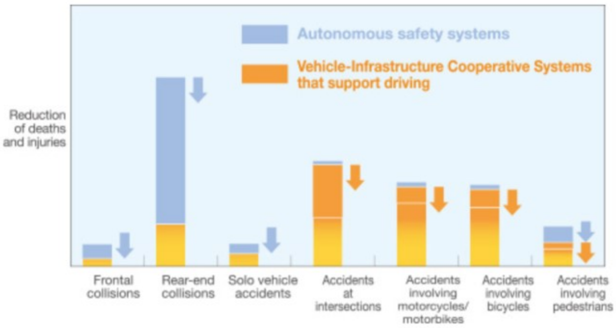

Fig. 1. Expected reduction of deaths and injuries after the deployment of cooperative driving assistance systems according to the Toyota Motor Company.

2. Communication technologies for VANETs

To support V2V and V2I communication, the IEEE 802.11p protocol was proposed. Derived from the well-known IEEE 802.11a, it uses 5,9 GHz frequency band to transmit Cooperative Awareness Messages called beacons. Beacons are sent periodically, typically with beacon generation frequency of 10 Hz. Beacons are broadcast to all vehicles without acknowledgements.

IEEE 802.11p uses similar PHY based on OFDM as the IEEE 802.11a. The key difference between the two protocols is the channel bandwidth, which is 10 MHz in case of the IEEE 802.11p. Another difference is at the MAC layer where IEEE 802.11p uses IEEE 802.11e MAC to support QoS. [1]

In Europe, the ETSI developed standard for ITS called ITS-G5. Its physical and MAC layers are based on IEEE 802.11-2012 [2]. The Logical Link Control is based on the ANSI/IEEE Std 802.2 [3].

The ITS-G5 standard adds the feature of Decentralized Congestion Control (DCC) [4] to prevent network overload. The DCC mechanism utilizes a state machine which changes some parameters of the MAC and PHY layers along with a change of its state. The change of MAC and PHY parameters is dynamic and depends on the actual channel busy time. The recommended thresholds for

	State					
	Relaxed	Active				Restrictive
		Access Category				
		AC_VO	AC_VI	AC_BE	AC_BK	
Power [dBm]	33	Ref	25	20	15	-10
Interval [s]	0,04	Ref	Ref	Ref	Ref	1
Data rate [Mbps]	3	Ref	Ref	Ref	Ref	12
Radio sensitivity [dBm]	-95	Ref	Ref	Ref	Ref	-65

Tab. 1. PHY and MAC layer parameters for the DCC state machine.

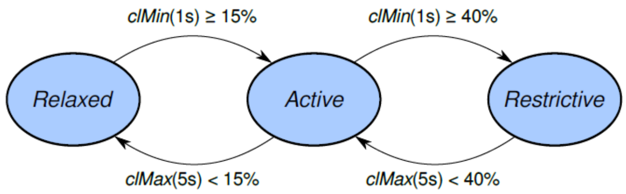

Fig. 2. DCC state machine for the CCH.

the Control Channel (CCH) are 15% and 40%. Fig. 2. shows the DCC state machine and its states.

The parameters of the MAC and PHY layer which are changed by the DCC state machine are listed in the Tab.2. The value *ref* means there is no change in the parameter after the transition to the respective state [6]

The ITS-G5 standard defines three frequency bands to be used for Intelligent Transportation Systems:

- ITS-G5A: Frequency range from 5,875 GHz to 5,905 GHz for transmission of safety related information
- ITS-G5B: Frequency range from 5,855 GHz to 5,875 GHz for non-safety applications
- ITS-G5D: Frequency range from 5,905 GHz to 5,925 GHz for general ITS applications [5]

3. Simulation model

To perform simulations a simulation model was built using OPNET Modeler 14.5. Parameters of the nodes used in the simulation are summarized in this section.

3.1 Topology

Simulated topology consists of a number of nodes representing vehicles equipped with a DSRC communication module and an intelligent intersection node. The vehicles are approaching the intersection which represents a crossing of three roads each with 4 lanes. The number of vehicles *n* was set from 3 to 768, simulating low traffic density and also totally congested intersection. The maximum distance between two vehicles was set to 1 km which is the maximum communication range intended for the VANET networks. All of the vehicles were equipped with an isotropic antenna. The intelligent intersection node is located in the middle of the vehicle cloud and therefore receives beacons from all of the vehicles. This node does not transmit any data and acts as a receiver. It is included for testing purposes as a reference for delay and signal level related parameters measurement.

3.2 Channel Settings

Frequency of the radio channel used to transmit beacons is specified in the Min Frequency field of the node's attributes in OPNET Modeler. For ITS safety related applications in Europe the ITS-G5A frequency band (5875-5905 MHz) was allocated according to the ETSI EN 302 571 standard. To exchange beacons with safety related payload the Control Channel (CCH) at center frequency 5900 MHz is used. Since the channel bandwidth is 10 MHz, the minimum frequency parameter should be set to 5895 MHz.

3.3 Wireless LAN Parameters

ITS-G5 standard supports data rates from 3 to 27 Mbps. Simulations were performed using 6 Mbps data rate as this is the default data rate for the ITS G5 Control Channel. Another parameter which has a great impact on the bit error rate is the Transmit Power attribute. It can be changed in the range from 0 to 1.995 W (0 - 33 dBm) to obey Harmonized European Standard [7]. In the simulation, transmit power of 0,5 W (27 dBm) was used. Physical Characteristics parameter was set to OFDM(802.11a) which is the closest characteristics available in OPNET Modeler. In order to keep the simulation model simple, the DCC state machine mechanism was not modeled.

3.4 EDCA Parameters

The ITS-G5 uses EDCA as MAC protocol to support QoS by message prioritization. There are four access categories (ACs) defined with different probabilities of collision: AC_BK for background traffic, AC_BE for best effort, AC_VI for video and AC_VO for voice traffic. Default values for ITS-G5 ACs are shown in Tab. 1. These values are used as EDCA parameters of the simulation model.

AC	CW_{min}	CW_{max}	AIFSN
AC_VO	3	7	2
AC_VI	7	15	3
AC_BE	15	1023	6
AC_BK	15	1023	9

Tab. 2. EDCA parameters for CCH.

3.5 Packet generation arguments

Beacon generation frequency in OPNET can be controlled by the Interarrival Time attribute. In vehicular safety applications beacons should be delivered in defined time period - typically 100 ms deadline is assumed. Considering this restriction a beacon generation frequency of 10 Hz was used for all simulations. This value is widely used in many research papers and seems to be adequate. The Interarrival Time attribute was set to 0.1 which corresponds to a beacon being generated ten times per second.

In order to simulate the worst possible scenario, packet size of generated beacons was set to 1400 bytes as this value approaches the maximum allowed size of beacon payload.

4. Simulation Results

Output parameters of the simulation were Control Channel´s average Bit Error Rate (BER), Medium Access Delay (MAD) and Signal to Noise Ratio (SNR). These parameters were simulated for discrete number of vehicles *n* (3,6,12,24,36,48,60,72,84,96,192,384,768) and then approximated by curves according to the Fig. 3 to Fig. 5.

Results show that with increasing number of vehicles in such a network the SNR value decreases according to the exponential curve. It reaches values where the useful signal level is lower than the power level of noise. This fact is caused by the transmissions from other vehicles which interfere with the ongoing transmission and act as a noise.

Second simulated characteristics was Medium Access Delay. It is defined as a time the beacon stays at the MAC layer until it is transmitted by the PHY layer through the wireless channel. With the increasing number of transmitting vehicles the MAD grows significantly. This is caused by the channel load and collisions which start to happen on the wireless channel as many nodes are trying to transmit their beacons over the common communication channel. Node then has to wait until it senses the wireless channel idle which is less and less probable with the increasing number of nodes in the network.

The average BER parameter increases almost linearly up to a certain point (in this simulation at the *n = 64 vehicles*) where it starts to asymptotically approach maximum value of 1. It is obvious from the simulation results that the BER value increases significantly with the growing number of vehicles and quickly reaches limits where the communication is practically not feasible. Another simulations [8] show that the BER characteristics of VANETs can be improved significantly by the use of directional antennas and intelligent antenna arrays.

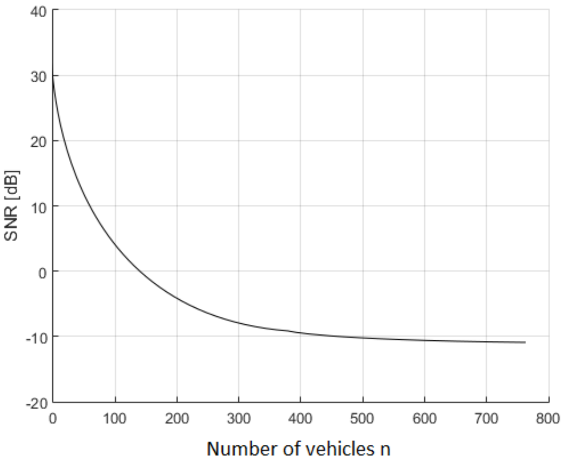

Fig. 3. Intelligent intersection SNR at the receiver point.

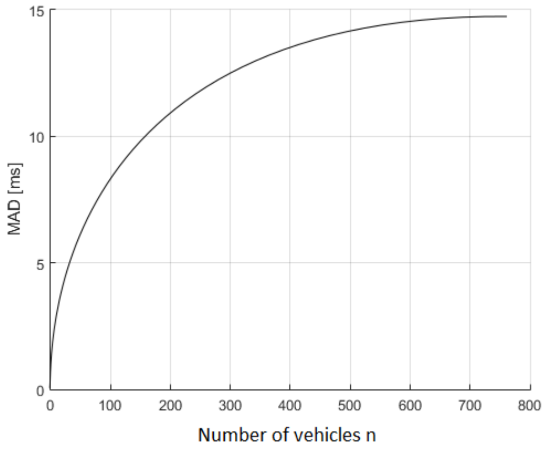

Fig. 4. Control Channel average MAD.

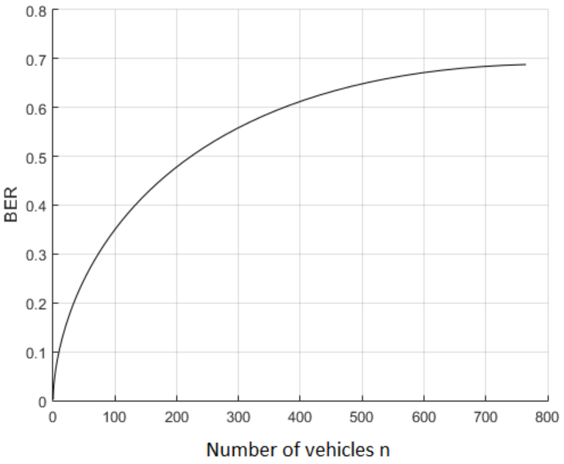

Fig. 5. Intelligent intersection measured BER at the receiver point.

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Tibor PETROV was born in Plovdiv, Bulgaria in 1990. In 2015 he finished MSc at the University of Žilina, Faculty of Electrical Engineering, Department of Telecommunications and Multimedia. Currently he studies doctoral degree at the same department. His research activities include wireless networks and cooperative technologies in the Intelligent Transportation Systems (ITS) environment.

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