Evaluation of Packet Forwarding Approaches for Emergency Vehicle Warning Application in VANETs

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***Abstract*—Cooperative Intelligent Transportation Systems (C-ITS) based on a communication between vehicles and intelligent roadside infrastructure can be of a great benefit regarding road safety, traffic congestion and environmental impact of the transport. One of their key technologies are the Vehicular Ad hoc Networks. Due to the high mobility of the nodes that form the network, some protocol data unit forwarding approaches cannot achieve acceptable results under certain conditions. In this paper we evaluated the performance of L2 broadcasting and L3 routing using AODV and GPSR routing protocols to forward messages of an emergency vehicle approach warning application for connected and autonomous vehicles under specific road traffic conditions in the city of Zilina. To run the simulations, we used the highly realistic simulation stack comprising of OMNeT++ network simulator coupled with SUMO traffic simulator by Veins simulation framework.**

Keywords—VANET; routing protocol; vehicular network; simulation;

I. INTRODUCTION

Vehicular Ad hoc Networks (VANETs) became a thoroughly discussed topic during the last years. Cooperative Intelligent Transportation Systems are expected to bring a new level of safety and situational awareness on the roads. However, it is crucial to figure out, how the actual communication should be carried out in a most effective manner. The European Commission in its Communication [1] released a set of so called Day 1 C-ITS applications that should be supported by all new vehicles on the roads starting in 2019 [2]. Since the bandwidth is limited and a number of cars is growing rapidly [3], it is extremely important to deal with the effectiveness of various technologies for the inter-vehicular communications in order to prevent troubles and failures in the future. In this paper we aim to study the VANET network load using different forwarding technologies. The network runs an emergency vehicle warning application and uses L2 broadcasting as well as L3 routing to forward the application messages. Routing approach may reduce the radio channel load by targeting the messages to specific network hosts instead of flooding the network by broadcasts. Since routing requires more signalization overhead and routing algorithms introduce latency, we would like to examine under which conditions this increased demand on network resources can be compensated by decreased number of retransmissions.

This paper is organized as follows. Section 2 contains an overview of tools used for the simulations. In the Section 3, the developed simulation model is described in detail. Results from the simulations are shown in the section 4, and conclusions are presented in the last section.

II. SIMULATION TOOLS

Vehicular Ad hoc Networks are a special case of Mobile Ad hoc Networks [4]. They are characterized by a high mobility of the communicating nodes, frequent disconnections and changes in the network topology [5],[6],[7],[17]. If the simulation is to correspond with the real-life conditions in a most realistic manner, the selection of the simulation tools is a crucial step to achieve this. In [8] we surveyed several possibilities available for the realistic VANET simulation.

Due to the VANETs' specific requirements, simply the simulation of the pure communication is not enough. If we want to examine these networks in a more serious manner, it is equally important to simulate also the mobility of the nodes. This can be achieved by a traffic simulator, which generates the vehicle trajectories for the network simulator. The network

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simulator is then able to take into account various physical layer characteristics, e.g. fading, obstacle shadowing, realistic path loss model and other parameters, which change in time. The resulting simulation is then more realistic compared to the static simulation.

In our case, we decided to use the well known and respected OMNeT++ discrete event network simulator for the simulation of network protocols [9].

For node movement simulation we used the Simulation of Urban Mobility (SUMO) open source traffic simulator [10].

Both simulators were coupled by the Traffic Control Interface (TraCI) provided by the Veins simulation framework [11]. This coupling enables a TCP based real-time bi-directional communication between the simulators, which is important for simulating VANET applications [12]. This way, the vehicle movements can be affected directly from the network simulator based on the contents of the transmitted messages.

III. Simulation model

For the purpose of simulations a computer model was built using software described in the Section 2.

A. Node model

Node model used in the the simulations extends the OMNeT++ INET Framework's AODVRouter and GPSRRouter models, depending on used routing protocol. In comparison with the standard routers, the IP address autoconfiguration feature was added for network addressing. Vehicles use different subnets as described in [13].

Nodes use the IEEE 802.11 – OCB compliant network interface for communications as well as frequency bands allocated for the C-ITS services is Europe.

Transmissions are carried out using a single 10 MHz radio channel, without channel switching. Every node uses the default 6 Mbps data rate [14] and the transmit power was set to 20 dBm.

B. Environment model

In order to make the simulations as close to reality as possible, a real section of a road infrastructure in a city of Žilina was modeled. Real traffic data were used to model the traffic density in SUMO. The traffic simulation was based on data gathered from a traffic survey for [15].

Openstreetmap project was used to extract the road infrastructure map layer for the simulations. After that, map was converted to XML format using SUMO netconvert tool. Acquired map of road infrastructure was then used for traffic flows modeling in SUMO.

Fig. 1 contains a screenshot of the Ľavobrežná road segment in the vicinity of the intersection, where the simulated data transmissions occur.

Fig. 1. Road segment with vehicles – simulation screenshot.

C. Application

To evaluate the performance of different forwarding methods, an emergency vehicle approach warning application was used. This application is used to inform vehicles on the specific road segment, that an emergency vehicle is approaching. Vehicles are informed in advance so they have enough time to clear the way for the emergency vehicle. Basically, there is no need to inform all the vehicles on the road about the approaching emergency vehicle. Only the vehicles whose trajectory interferes with the emergency vehicle's one are relevant for the warning application. Therefore, there are two possible communication scenarios:

- Application messages will be broadcast to every node in the network and only the nodes interfering with the emergency vehicle's trajectory will react by changing their direction. These nodes will rebroadcast the information to other nodes that are not in a communication range of the emergency vehicle.
- Application messages will be targeted directly to those specific vehicles using network layer routing

D. Simulation scenario

The scenario used for simulation consists of a traffic flow at a two-lane road segment in the city of Žilina. Most of the vehicles use the right lane, but some of them are using the left one. At a specific moment in time, when the traffic flow is evenly distributed across the road network, an ambulance occurs at the left lane. It starts the transmission of emergency vehicle approach warning application messages. Vehicles which are informed about the incoming ambulance move to the right lane to clear the way for the emergency vehicle.

During the transmissions, end-to-end delay and average bandwidth used by the application are recorded. Simulation runs for 350 seconds, vehicles move with an average speed of 48 km/s and the ambulance travels with speed of 90 km/h. List of set parameters can be seen in Table I.

TABLE I. SIMULATION PARAMETERS

Parameter	Value
Message length	300 B
Send Interval	1 s
Data rate	6 Mbps
Transmitter power	20 dBm
Channel bandwidth	10 MHz
Carrier frequency	5 900 MHz

IV. RESULTS

The results of our simulations are summarized in the tables II-VI. In the case of L3 routing scenarios, the simulation was carried out repeatedly, every time with one more vehicle to receive messages from the emergency vehicle. These vehicles were the ones, which occupied the left road lane and interfered with the emergency vehicle's trajectory.

As can be seen in the Table II., the delays differ minimally when using either 1 or 10 Hz frame generation frequency. Also the values of the delays are rather small. These results indicate, that in a case of a simple warning application with unidirectional communication, the broadcasting approach can achieve acceptable results in a network of this size. The main issue, in this scenario, lays in the interpretation of the message's information by the vehicles. As all the vehicles in the communication range of the emergency vehicle receive the same message, it is rather difficult to judge, who is the message relevant for.

If the packets containing application layer messages are unicast only to the specific nodes, the message format can be simplified, however, the emergency vehicle then has to decide the relevant recipient of the message.

TABLE II. L2 BROADCASTING END-TO-END DELAY AND SENT FRAMES

Frame generation frequency	Average E2E delay [ms]	Sent frames
1 Hz	0.74	235
10 Hz	0.744	2350

TABLE III. L3 ROUTING AVERAGE END-TO-END DELAY AND RECEIVED PACKETS (3 DESTINATION NODES)

Vehicle ID	Packet generation frequency - 1 Hz				Packet generation frequency - 10 Hz			
	AODV		*GPSR*		*AODV*		*GPSR*	
	E2E delay [ms]	*Rcvd Pk*	*E2E delay [ms]*	*Rcvd Pk*	*E2E delay [ms]*	*RcvdPk*	*E2E delay [ms]*	*RcvdPk*
v[22]	55.91	48	6.21	3	17	510	2.43	39
v[15]	107.8	47	4.16	3	13.04	402	2.77	45
v[9]	309.99	24	3.88	5	8.91	310	4.85	39

TABLE IV. L3 ROUTING AVERAGE END-TO-END DELAY AND RECEIVED PACKETS (4 DESTINATION NODES)

Vehicle ID	Packet generation frequency - 1 Hz				Packet generation frequency - 10 Hz			
	AODV		*GPSR*		*AODV*		*GPSR*	
	E2E delay [ms]	*Rcvd Pk*	*E2E delay [ms]*	*Rcvd Pk*	*E2E delay [ms]*	*Rcvd Pk*	*E2E delay [ms]*	*Rcvd Pk*
v[28]	3.53	47	1.18	7	10.12	467	1.26	81
v[22]	89.95	31	12.79	3	13.35	376	3.01	37
v[15]	90.16	33	4.12	5	13.48	316	2.66	39
v[9]	431.17	21	6.14	4	14.63	215	5.07	22

TABLE V. L3 ROUTING AVERAGE END-TO-END DELAY AND RECEIVED PACKETS (5 DESTINATION NODES)

Vehicle ID	Packet generation frequency - 1 Hz				Packet generation frequency - 10 Hz			
	AODV		*GPSR*		*AODV*		*GPSR*	
	E2E delay [ms]	*Rcvd Pk*	*E2E delay [ms]*	*Rcvd Pk*	*E2E delay [ms]*	*Rcvd Pk*	*E2E delay [ms]*	*Rcvd Pk*
v[35]	9.6	41	0.99	3	5.14	422	0.65	46
v[28]	4.92	40	1.19	8	3.12	374	1.07	60
v[22]	100	31	4.28	3	6.08	299	3.96	31
v[15]	214.22	31	4.78	3	18.68	247	2.68	29
v[9]	289.63	12	9.68	1	8.83	180	5.44	18

TABLE VI. L3 ROUTING AVERAGE END-TO-END DELAY AND RECEIVED PACKETS (6 DESTINATION NODES)

Vehicle ID	Packet generation frequency - 1 Hz				Packet generation frequency - 10 Hz			
	AODV		*GPSR*		*AODV*		*GPSR*	
	E2E delay [ms]	*Rcvd Pk*	*E2E delay [ms]*	*Rcvd Pk*	*E2E delay [ms]*	*Rcvd Pk*	*E2E delay [ms]*	*Rcvd Pk*
v[41]	0.92	44	0.77	4	0.52	387	0.69	89
v[35]	27.48	38	0.79	3	0.91	354	0.67	43
v[28]	16.05	27	0.91	6	4.2	333	1.03	52
v[22]	150.46	25	3.79	4	22.54	235	2.48	17
v[15]	206.74	15	3.81	2	26.93	187	2.58	16
v[9]	443.76	18	9.68	1	18.21	169	5.32	19

According to the simulation results presented in the tables above, the average End-to-End delay is considerably lower when the message generation frequency is increased. In this case, the standard deviation of the latency is much lower (100 x) than in the case of lower packet generation frequency. This phenomenon can be caused by a fact, that as the generation frequency increases, more packets traverse the network via same set of nodes to reach the destination, until a considerable change of the network topology occurs. When this happens, the routing protocol has to calculate a new route to the destination and spread the routing table updates across the network, which increases the delay significantly.

Fig. 2 and Fig. 3 show an average number of hops a packet have to traverse to reach its destination node. As the transmitter power increases, the communication range is also increasing. Due to this fact, the number of hops to reach destination decreases.

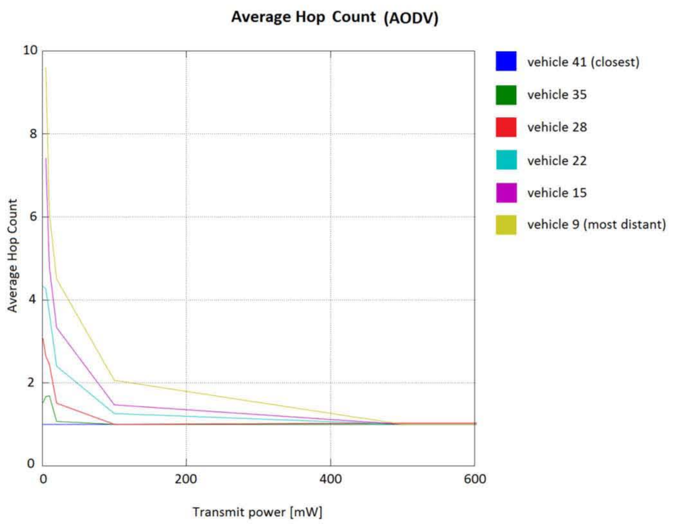

Fig. 2. Average hop count from source to a destination node as a function of transmitter power for AODV routing protocol.

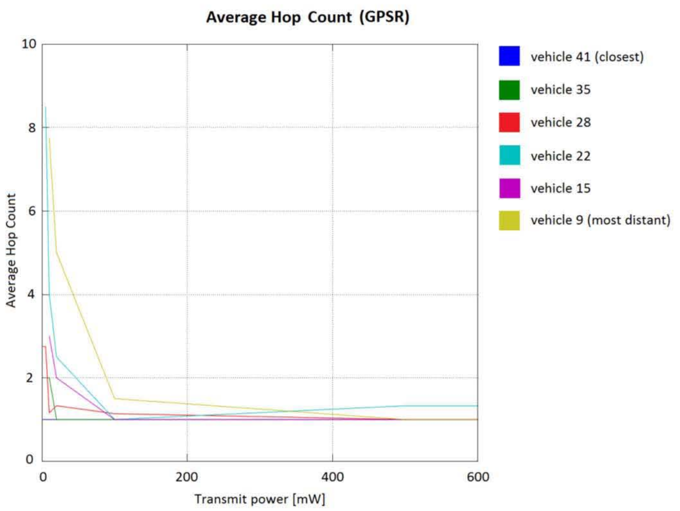

Fig. 3. Average hop count from source to a destination node as a function of transmitter power for GPSR routing protocol.

V. CONCLUSION AND FURTHER WORK

As can be seen from the tables, the end-to-end delay can be directly linked to the number of hops the protocol uses to forward the packets to the destination node. Due to the high mobility of the nodes in the network, the number of hops changed during the transmission time. The more often the number of hops changed, the larger end-to-end delay was introduced. Also, the standard deviation of the delay was extremely high when the frequent change in hop counts occurred.

The number of hops calculated by the routing protocol depends on the transmitter power. When the transmit power is very low, the number of hops to the destination grows, as the communication range of the nodes decrease. However, when the transmit power is set to a high values, the signal-to-noise ratio drops quickly with the increasing number of transmitting nodes. When the communication network is very dense, the bit error rate quickly achieves high values and communication is no longer feasible [16]. It is vital for the transmission power control mechanism in VANET nodes to find an optimal trade-off between number of hops required for the successful and timely communication and minimal interference between nodes.

The GPSR protocol in our simulations showed lower average End-to-End delay for the successful packet exchange when using lower transmitter power, but the average packet loss was higher than in the case of AODV protocol.

In the future, we would like to propose the packet format for the emergency vehicle approach warning application for VANETs based on our current and future simulation results. We would like to propose optimal forwarding scheme for this application as well, to achieve the lowest possible latency and highest possible packet delivery ratio.

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