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# Computer Modelling of Cooperative Intelligent Transportation Systems

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**Abstract**

The Cooperative Intelligent Transportation Systems (C-ITS) are one of the most important parts of intelligent transportation support. The possibilities of vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication modelling and computer simulation will be presented in this paper. The results of V2V and V2I communications simulation, with regard to expected C-ITS services will be shown. Gathered results will be evaluated in consideration of current and future communication technologies (VANET, 4G, 5G) capabilities.



*Keywords:* Intelligent Transportation Systems; VANET; Computer modelling; Simulation;

## 1. Introduction

Cooperative Intelligent Transportation Systems (C-ITS) are new, promising technology that is expected to bring safer, faster and more environmentally friendly transport. They are based on communication between vehicles and roadside infrastructure equipped with radio frequency communication technologies. However, transport-related applications should provide maximum safety and reliability in order to prevent dangerous situations and possible

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injuries of passengers. Due to this fact, a method for safe verification of network functionality is required during the network design process. In this stage a computer modelling and simulation can be used to study network behavior under various conditions.

In this paper, the most commonly used tools for vehicular networks simulation are presented. Then a simulation of a real-life traffic scenario is conducted in order to study network feasibility and its benefits for road traffic fluency and safety.

In the last section, other assumed communication technologies for C-ITS are described briefly.

## 2. V2X simulation tools

Massive research of Vehicular Ad hoc Networks (VANETs) in recent years created a request for simulation tools that would allow the complex examination of the network performance and security. There is a number of powerful network simulators available, to investigate the communication network in complex and very detailed manner. However, VANET networks differ greatly from the conventional ad hoc networks, due to the high mobility of the nodes and their specific behavioral patterns. To acquire realistic simulation results that would be very close to the real-life situations, a tandem of network simulator and a traffic simulator coupled to work together is required.

### *2.1. Traffic simulators*

Traffic simulators are widely used mainly by transport specialists to simulate various parameters of the traffic flow and their impact on traffic fluency or other aspects. Some of them can be used for VANET simulation as a mobility data generators for the network simulators. Traffic simulators which are commonly used in the process of VANET simulation are VanetMobiSim, SUMO, MOVE, STRAW, FreeSim and CityMob. Parameters of these simulators are summarized in the table below. [1]

Table 1. A comparison of parameters of various traffic simulators [1].

| Parameter | VanetMobiSim | SUMO | MOVE | STRAW | FreeSim | CityMob |
|---|---|---|---|---|---|---|
| Freeware | Yes | Yes | Yes | Yes | Yes | Yes |
| GUI | Yes | Yes | Yes | Yes | Yes | Yes |
| Real-world maps | Yes | Yes | Yes | Yes | Yes | No |
| User-defined maps | Yes | Yes | Yes | - | No | No |
| Macroscopic modelling | No | No | No | No | Yes | No |
| Microscopic modelling | Yes | Yes | Yes | Yes | Yes | Yes |
| Output | Ns-2, GloMoSim, QualNet, XML | XML, TraCI interface | Ns-2, GloMoSim, QualNet, XML | SWANS | - | Ns-2 |

### *2.2. Network simulators*

This group of simulators is mainly used for simulation of various parameters of network traffic to study the network behavior under various conditions. They can be also very successfully utilized for optimization of network topologies or communication protocols. Widely used network simulators for VANET simulation includes ns-2, GloMoSim, JiST/SWANS, SNS, OMNET++, OPNET.

### *2.3. Veins*

Veins is an open source framework that includes a suite of models for running vehicular network simulations. It is based on OMNET++ network simulator and SUMO traffic simulator. Both simulators are connected via standardized Traffic Control Interface (TraCI). For modelling of physical layer effects in wireless networks, Veins uses MiXiM, which offers detailed models of radio wave propagation, interference estimation, and enables to work with the distribution of transmit power over time and space [2][3].

## 3. CommunicationtTechnologies for VANETs

Communication between vehicles and other parts of the Intelligent Transportation System is often reffered to as V2X communication. It is possible to distinguish:

- Vehicle-to-Vehicle (V2V) communication
- Vehicle-to-Infrastructure (V2I) communication
- Vehicle-to-Pedestrian (V2P) communication

Naturally, abovementioned categories are the most used, but not only ones. Most of the research carried out in the field of Cooperative Intelligent Transportation Systems (C-ITS) is related to the V2V and V2I communications, because they are very difficult to optimize and have highest potential to decrease the number of road traffic accidents.

Currently, there are three major standards for vehicular communication:

- IEEE 1609 WAVE
- ETSI ITS
- ISO CALM

In addition to these, Japanese organization ARIB (Association of Radio Industries and Businesses) developed ARIB STD-T109 for V2V and V2I communications in the 700 MHz frequency band [4]. For the means of simulation, the IEEE WAVE standard was chosen, due to its maturity and its widespread use. Table 2 summarizes the performance requirements for the V2X communication.

Table 2. Performance requirements for VANET applications [5].

| Performance class | Latency [ms] | Packet generation frequency [p/s] | Communication range [m] | Application |
|---|---|---|---|---|
| Low latency, high frequency | $\leqslant$ 100 | 10-20 | $\leqslant$ 150 | Accident, control loss, cooperative collision warning |
| Medium latency, medium frequency | $\leqslant$ 200 | 5-10 | $\leqslant$ 100-130 | Intersection collision warning, lane overtake assistance, extended brake signaling |
| High latency, low frequency | $\leqslant$ 1000 | 1-2 | $\leqslant$ 1000 | Work zone warning, low bridge warning, road condition warning |

## 4. V2X simulation

To simulate the V2V and V2I communication and its impact on road safety and congestion in conditions close to real-life traffic, a scenario based on real data and realistic situation was modelled using various tools described further in this section. Traffic data were obtained from the Traffic General Plan of Žilina [6].

### *4.1. The simulation scenario*

The simulation scenario can be seen in the Fig.1. It takes place at the Košická intersection and its surroundings. The intersection is the most loaded road traffic node in the city of Žilina. This intersection is used by all road transport heading to Košice direction from Bratislava, Czech Republic and Poland. Košická is known for frequent congestions and vehicle collisions. In the simulation scenario, a traffic accident occurs near the intersection. By the means of V2V and V2I communication, other vehicles approaching the intersection are informed about the accident and are directed to take a detour, avoiding further congestion.

First simulation scenario uses only V2V communication. Information about the accident is spread across the network only by vehicles, which have to inform all their neighbors in the communication range about an incident on the road.

Second simulation adds a roadside infrastructure which is comprised of three roadside units (RSUs). Vehicle which detects an accident informs its neighbors about the incident and also sends the message to the nearest RSU. The relevant RSU then starts to inform all the incoming vehicles to use a detour. Beaconing frequency of the relevant RSU was set to 1 Hz.

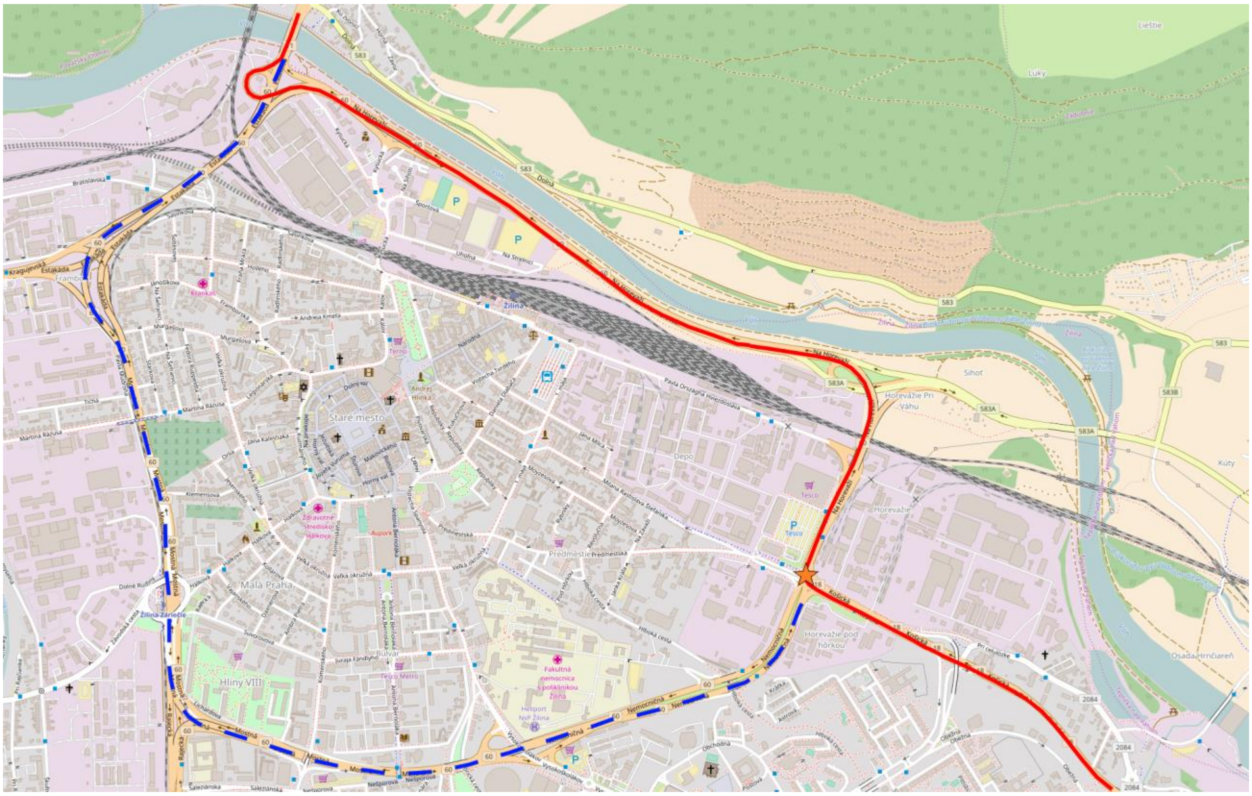

Fig. 1. The simulation scenario: original route (red), site of the accident (orange star) and detour taken by V2X enabled vehicles (blue).

### *4.2. Map and mobility*

The map data were exported from the OpenStreetMap (openstreetmap.org) project website. Collected OSM map file was converted using SUMO netconvert utility. Converted XML map file with some modification is suitable to be used by the SUMO traffic simulator, which was used to generate mobility of the vehicles present in the scenario.

Since the current version of SUMO (0.25.0) does not support generation of Poisson distributed traffic flow natively, a stochastic traffic flow generator for SUMO was written in C++ for this purpose [7].

## 5. Simulation results

Simulation was performed in two mutations. In the first simulation, data were transmitted only using V2V communication. In the second one, information was transmitted by V2V as well as by V2I communication means. In both scenarios, traffic accident happened after 132 seconds of simulation. Total simulated time was 1000 s.

### *5.1. V2V communication only*

The information about the accident reached the vehicle #46 – the first vehicle which was able to react on the situation by taking a detour, 17,42 ms after the accident happened. The most loaded vehicle´s onboard unit had to process 9425 frames during the simulation, with total busy time of 17,313 s. The average busy time of a vehicle´s onboard unit in this scenario was 9,629 s. The average end-to-end delay of transmitted message was 2,504 ms with maximum of 15,85 ms. Fig. 2 shows and average end-to-end delay of all messages transmitted during the simulation.

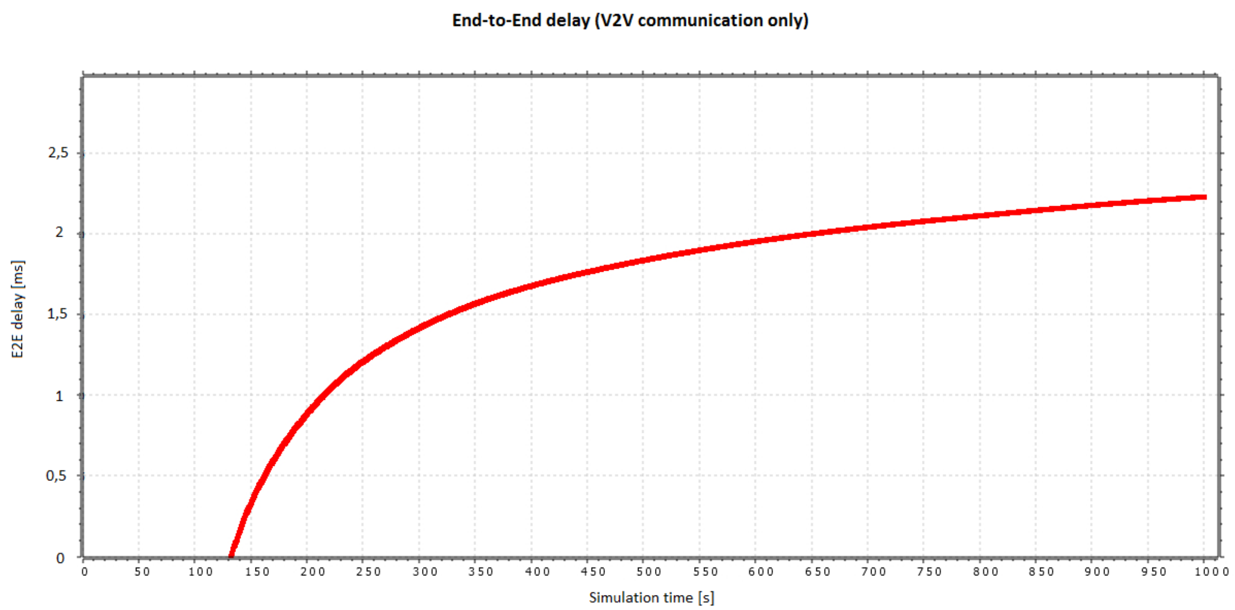


Fig. 2. Average end-to-end delay of messages transmitted using V2V communication.

### *5.2. V2V and V2I communication*

In this scenario, the first vehicle to take a detour was the same as in the previous one, except the time it took the message to reach the vehicle. The vehicle was informed about the accident 16,767 ms after the accident happened.

The most loaded vehicle had to process only 154 messages. An average busy time of a vehicle´s onboard unit in this scenario was 0,124 s and average end-to-end delay of a transmitted frame was 1,66 ms. These values are significantly lower than corresponding values from the V2V communication only scenario. The average end-to-end delay of the frames transmitted during this scenario can be seen in the Fig. 3.

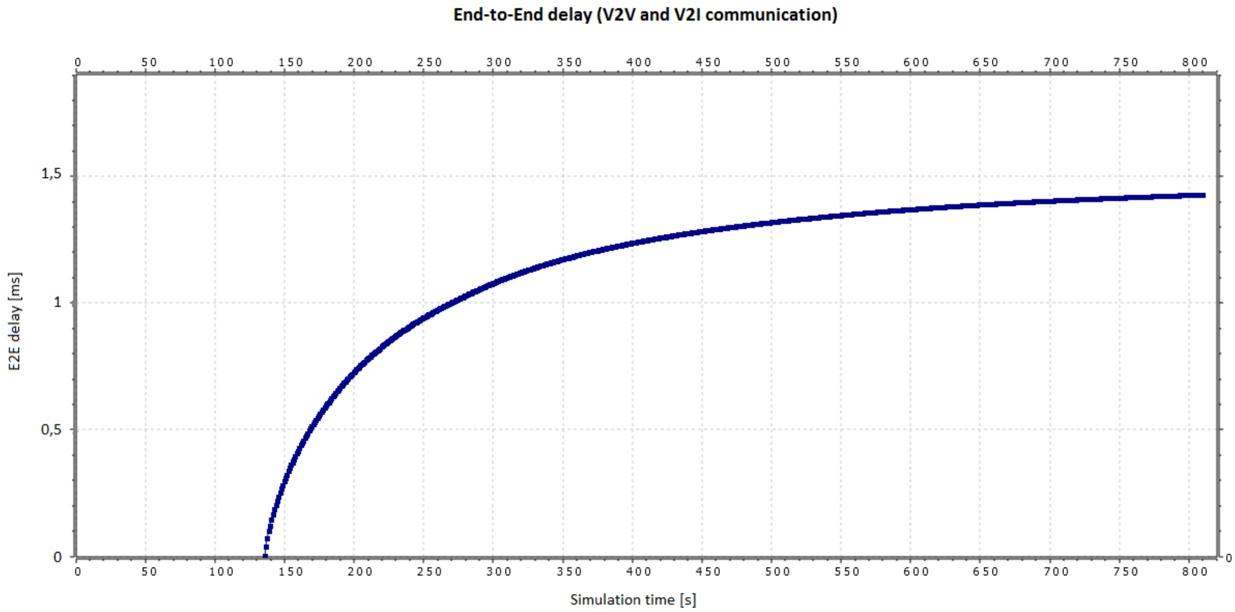


Fig. 3. Average end-to-end delay of messages transmitted using V2V and V2I communication.

Simulation results acquired from both simulation scenarios are summarized in the Table 3.

Table 3. Simulation results.

| Communication used | V2V | V2V & V2I |
|---|---|---|
| Maximum messages processed by a vehicle | 9425 | 154 |
| Time to spread message across the network [ms] | 17,492 | 16,767 |
| Maximum busy time of a device [s] | 17,313 | 2,347 |
| Average busy time of a device [s] | 9,629 | 0,124 |
| Maximum end-to-end delay [ms] | 15,85 | 14,91 |
| Average end-to-end-delay [ms] | 2,504 | 1,66 |

## 6. Discussion

Simulation results indicate, that VANET using IEEE WAVE protocol stack could be successfully deployed at the Košická intersection. By the means of V2V and V2I communication, traffic congestion can be reduced. Properly optimized combination of V2V and V2I communication seems to provide better results in terms of radio channel load, end-to-end delay and information spread time, than pure V2V communication. Roadside unit beaconing frequency of 1 Hz was sufficient in this case and the roadside infrastructure succeeded to inform all of the incoming vehicles about accident near the intersection.

## 7. Consideration of other communication technologies

There were significant efforts in the research community to study the feasibility of vehicular communication using existing 4G network infrastructure. In [8] authors conclude, that while probability of beacon delivery using LTE network is higher than in VANETs under certain conditions, the overall ability of LTE to support vehicular beaconing for safety-related applications is rather poor. According to the simulation, network easily gets overloaded, even under idealistic assumptions.

However, the situation is likely to change with the arrival of new cellular technologies such as 5G. A 5G network standard has not been issued yet, but involved stakeholders have raised several expectations about the key technologies and system architecture [9]. Compared to the current 4G networks, 5G should increase the network capacity 1000 times, spectral efficiency, energy efficiency and data rate 10 times and should provide a support for direct M2M communication for IoT devices [10]. Taking these expected characteristics in consideration, the upcoming fifth generation of mobile cellular networks looks like a promising technology for the Cooperative ITS systems deployment.

Obviously, a lot of work will have to be done when the official 5G standard is released. Detailed studies and field tests will have to be conducted to check the system performance and its suitability for safety-related applications.

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