IMPORTANCE OF THE STATIC INFRASTRUCTURE FOR DISSEMINATION OF INFORMATION WITHIN INTELLIGENT TRANSPORTATION SYSTEMS

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Resume

Intelligent transportation systems (ITS) are a today´s hot topic, especially in the context of the development of information technologies, which can be employed in transportation. Although the scope and the technical solution of these systems may vary, they are frequently based on VANET (Vehicular ad hoc network), i.e. a communication network, which is primarily generated among the moving subjects, which form ITS. Given the highly dynamic VANET, the questions are raised as to the data transmission. This paper is aimed to make a detail analysis of the communications within VANET using the simulation model, which includes the static infrastructure of ITS and to experimentally verify the impact of this infrastructure on the dynamics of information spreading in ITS. The authors present the results obtained from a few different scenarios, which have been tested.

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1 Introduction

As soon as the conditions for their emergence appeared, intelligent transportation systems (ITS) became a target of investigations. The main thing was an availability of appropriate technologies for a wireless data transmission and the performance of the IT equipment. This technology is currently changing rapidly and ITS is no longer an established concept. Some aspects of ITS thus need to be addressed. As an example, one can mention the ITS structure itself, which may be, from the data processing viewpoint, centralized or distributed and based on the peer-to-peer like systems and networks. There are also open questions as far as the personal data protection and security are concerned. The necessary technical infrastructure continues to be discussed, as well, i.e. whether the existing technical solutions are to be used or whether they are to be supplemented or extended with other elements.

The article focuses on examining the data exchange and transmission within VANET (Vehicular Ad-Hoc Networks) among mobile subjects (vehicles) and other (especially static) subjects of ITS. A key feature of the data communication within VANET (arising from the nature of the transportation system) is its considerable dynamics, in particular. VANETs can be described as typical systems with more agents without a central coordination. Each agent (subject, entity) may thus process the obtained data separately based on its settings and preferences, which may be distinctively different. For some more common tasks this may seem to be a needless duplicity of activities. This approach, on the other hand, leaves ample scope for individual innovations and commercial advantages.

There are, however, also the centralized solutions of ITS (e.g. traffic monitoring in Google Maps), where the input information is collected by means of both the communications with vehicles and the cooperation among the authorities (information on closures, barriers, traffic accidents, etc.). In these systems, however, the vehicles are providers or recipients of information only and the processing itself is carried out centrally. This solution, however, may suffer from the problems related to the overall policy of the system owner, which may result in the service being unavailable for certain groups of users. This is also why the article focuses on the data exchange within VANET with the support of static infrastructure. The reflections below assume that the technical basis of the wireless communication has already been created. The further processing of the content of messages and its use for vehicle management and making tactical and strategic decisions are not investigated, either.

2 Current state

Centralized solutions based on data collecting using mobile phones and networks are used by Google in Google Maps to monitor the traffic [1]. There are also the systems based on measuring the mobile network signals [2]. This article, however, does not investigate the technical execution of communication and focuses on the higher level of the solution, i.e. the communication in VANET through which the vehicles and other relevant (stationery) subjects may communicate at a reduced distance.

Communications in VANET may be carried out in various modes. The usual basis is the exchange of event messages in the monitored section of the roadway; the model being submitted expects that one message will contain the information about one event (see below). Messages may then be exchanged in the peer-to-peer mode between the two identified subjects (targeted communication) [3]. The content of the sender´s message may be adapted to the recipient, making it possible to transmit the messages addressed to a specific recipient only. The subject identification, however, may lead to the privacy protection problems. Another option is use of the transmission (non-targeted communication) as described by e.g. Wischhof et al. [4]. The subjects in this arrangement send a consistent information package at regular intervals. The basic simulation step size is set to 0.5 second in this article.

Using the messages obtained and the messages generated by the subjects themselves, the subjects create their own individual knowledge base and their own model (picture) of the situation on the route.

The communication in VANET may generally be very data-intensive and there are a number of options how to solve this problem, e.g. by aggregating less up-to-date data [5]. The article [6] also presents the self-organised protocol for data exchange. In [7], the author proposed a transmission technique using a time barrier method to eliminate communication that can disrupt the network. The complex traffic monitoring system based on the multi-lane road is described by Nadeem et al. [8].

Various tools, such as VISSIM, are used to simulate the traffic flow and its superstructured ITS. The study by Jelinek and Vysoka [9] uses the AnyLogic application. The study by Malik and Sahu [10] uses the SUMO application.

Given the similarity between the ITS communication and the peer-to-peer networks, the integrated solutions combining these areas can be found [11]. Proprietary solutions (such as in this article) are, however, used to fully control the simulation process.

As regards the technical implementation, the communication is usually provided by means of the radio units in every vehicle, which directly communicate with each other. The Wi-Fi standard is not ideal to this end; other alternatives such as LoRa, and the like, are more appropriate. It should be noted that there are also other solutions that employ the devices, which do not communicate directly but by means of another (static) infrastructure [12]. The tests focused on dissemination of information by means of optical means are worth noting, too. The analysis of this approach can be found in the study by Luo et al. [13].

In the not managed distributed system as the one described above, the main problem is the standard definition and compatibility. This is why vehicle makers implement specific solutions. The same problem arises in the case of the communication with a road infrastructure and it is even more intensified by the necessity of the investment in the infrastructure. As already mentioned, a certain progress has already been made on the strategic level of the traffic management (Google, Waze), as the generally available and widespread technologies (mobile phones) are used.

Importance of the standardization and the ITS containing a static infrastructure is also underlined by the existence of the European Initiative C-Roads [14], which strives to investigate this issue and define standards in this field. The initiative defines the following types of communication (data exchange) in C-ITS:

1. Vehicle-to-vehicle (V2V),
2. Vehicle-to-infrastructure (V2I),
3. Infrastructure-to-vehicle (I2V),
4. Infrastructure-to-infrastructure (I2I).

As regards the approach described herein, the bullets 2 and 3 above can be considered identical as the communication between these two entities is taking place in both directions.

3 Model description

The details of the communication within ITS have been investigated in the simulation model presented in the article by Jelinek [15]. This model is built-up on the above described principle of message exchange using the peer-to-peer communication.

The entire model is divided into a few tiers. The basic one is formed by the traffic model on a defined road section (route). A two-lane roadway (one lane in each direction) is presumed and the vehicles are not expected to be overtaking. The model was designed using the multi-agent approach when every vehicle is modelled by an individual agent with its own behaviour. This behaviour is formed by a few basic rules:

1. Respecting the design features of a vehicle - these features are modelled using the maximum design speed, as well as the maximum acceleration values (acceleration and deceleration), which also reflect other vehicle characteristics, such as a weight and overall driveability. The model is simplified in this respect and presumes one value for acceleration and deceleration at all speeds.

2. The vehicle´s effort to move at a maximum speed. This is affected by a maximum speed in the given route section (the model makes it possible to divide the entire modelled section into smaller parts with different settings). The maximum design speed of the vehicle is respected as well.
3. Respecting the safe driving codes - these are reflected by keeping the safe distance from the vehicle or barrier in front of the vehicle being monitored. There are a few different methods how to determine this safe distance. The model uses the safe distance defined for the current speed of a vehicle by the time of two seconds.

The parameters of this basic model tier include the maximum speed in individual route sections and the traffic flow density given by the number of passing by vehicles per hour; the times of occurrence of individual vehicles at the route beginning (or at the route end for the opposite traffic direction) contain a stochastic component. The stochastic element also manifests itself in determining the maximum design speed and acceleration or deceleration of a vehicle. These values are selected from a defined interval.

The level of communication among individual subjects on the route follows up on the traffic model level. These subjects primarily include the moving vehicles, but may also include other technological equipment of the route, especially the static components of ITS capable of communication. These static elements may be completely separated and independent and may communicate with vehicles only or may be a part of a wider interconnected infrastructure. They are, basically, only the sensors in the data collection and exchange system.

Communication is taking place in VANET. It designates a rather logical structure than the physical or technical execution of the communication, which usually takes place upon the wireless radio connection with the given scope using various types of wireless technology (Wi-Fi, zigbee, etc.). The model presumes an optimistic option, i.e. every vehicle is equipped with a corresponding communication technology enabling it to connect to other vehicles or other available elements of ITS.

The communication among individual subjects itself is taking place upon the principle of various content messages, which have their sender and recipient (peer-to-peer communication). The message captures the details of a specific event, which occurred on the route. Messages are created by generating new events by each vehicle in each simulation step. In the case of the model being described, the content of messages is neither defined nor processed and only the message metadata (simulation time, location and driving direction of a vehicle generating the message) are applied. The received and generated messages form the individual knowledge bases of the communication participants. In the same way as the moving vehicles communicate with each other using the peer-to-peer technology, these vehicles can also communicate with the static infrastructure, or the infrastructure elements can directly communicate with each other on the same principle. The rationale of the given model is specially to investigate the speed of the information dissemination within the communication tier of ITS with respect to the presence of a static infrastructure.

The main parameter of the communication tier is the reach of the communication technology by which the set of potential communication partners of a given subject is defined. This communication radius is, moreover, essential for determining the transmissible data volume. It is important to realize that the VANET type networks quickly arise and disappear and that two communication partners occur within the range of each other for a limited time only, i.e. where their distance to each other is less than or equal to the defined communication range. If this range is e.g. 100 metres and the maximum speed of vehicles driving on the road is 90 km/h, it can be easily derived that two oncoming vehicles will have only 2 seconds to exchange their information with each other. In the situation where there are more communication partners and the communication can take place with all of them, this may considerably limit the volume of data being transmitted.

Within the communication tier (VANET), the selection of the information spreading strategy, i.e. which messages are to be communicated to other subjects, is absolutely essential. From this point of view, it is thus necessary to examine what the given message is to be used by the recipient for. If the message is supposed to optimize the behaviour of a given participant moving on the roadway, it is clear that the subject will no longer need the information on the situation in the road section driven through but only the information applicable to the section ahead of it. This fact may considerably limit the number of the messages being relayed. Another option is that the communication network is capable of transmitting messages throughout the monitored roadway section, i.e. even in the direction from the vehicles driving behind the vehicle being monitored. If used, this mechanism allows dissemination of targeted messages throughout the road section. The presented model is able to resolve both situations and both possible settings were applied during the experiments.

Considering the assumptions in the paragraph above, one can define the scope of messages to be relayed between the communication subjects in a more detail way. Of a potential set of communication partners, each vehicle selects only the partners that comply with the given scenario (all the partners or the partners ahead of the vehicle); the communication always takes place even with the oncoming drivers. The communication between the subjects is targeted, so both partners know who they communicate with and whether they have already communicated with the given subjects in the past. Only the messages that have not been relayed yet are being transmitted. It means that especially the initial communication contact between partners is very intensive as to the data volume. During the next simulation step (provided that the sender and the recipient are still in contact), the complete exchange is not happening any more, but only newly recorded messages since the last simulation step are being relayed.

The communication between the subjects, basically, takes places in one direction (on the each-to-each basis). The peer-to-peer communication is thus initiated by both parties (the message is sent from the partner A to the recipient B and then sending the messages from the sender B to the recipient is initiated). This mechanism ensures that all the communicating subjects have all the information that is held by individual agents.

To prevent individual subjects from being overwhelmed with incoming messages, the messages are sorted out once they are received and those, which can no longer be used by the agent for the specified purpose or are not helpful to other agents will be deleted.

The static communication infrastructure elements are modelled in the same way as the vehicles. They thus communicate with all the vehicles within the communication range and create their own knowledge base from the received messages. They do not generate their own events as their metadata would be constant. In the case of modelling the elements for a bigger system of message processing, all the static elements may be set to share the common knowledge base.

This leads to the third tier of the simulation model. This tier consists of the overall management of the simulation process and the analytical part of the model. The simulation takes place in individual simulation steps sized from 0.25 to 1.0 second, which is in conformity with the knowledge obtained from the sources of information. In each step, the position of all the communication subjects (except for the static ones) is updated first and the potential set of potential communication partners for each communication subject is determined (this is given by the reach of the communication equipment). Then, the mutual communication upon the above mentioned rules is simulated in each step. As the final step, knowledge base is being adjusted and its content optimized (this last step does not have to be performed at all times, especially in the situation where one wants the vehicles to gain a perfect overview of not only the road section ahead, as well as of the section already driven through). The global parameters at this level are the total length of the monitored road section and the total simulation time.

Although there are already created frameworks for simulating the vehicle movement on the road, this model intended for the road monitoring in VANET was designed as stand-alone, which allowed to explore in detail and, where appropriate, to modify its individual parameters and the pre-set behavioural patterns. The result of the model activity is a vast set of very detailed data in the third tier documenting the entire simulation for individual vehicles or communication subjects. Precisely because of the scope of the data obtained and their various characters, it was decided to visualize these data in various types of graphs as a basic method for analysing them. The model currently generates 17 various graphs capturing the curve of the entire simulation. Some of these graphs are geared towards the global monitoring of the whole simulation and monitor the global parameters, such as the average size of the knowledge base in each step of the simulation process (across individual subjects) and the overall situation in the given road section (where and when individual subjects were located). The extent of the communication exchange (average number of messages relayed in a single simulation step) and other parameters are monitored, as well. To analyze also the detail behaviour of specific communication subjects, a specific vehicle, whose simulation characteristics are shown in other graphs, was selected. It is a vehicle, which is set off on the route in the straight direction as the first after the mid-point of the total simulation period.

4 Experiments

The experiments conducted on the described model were especially aimed at the speed of spreading the information on vehicle movement and location during the simulation. The impact of the static elements of ITS on the information spreading was especially monitored. Static elements were deployed in a few different positions within the road section being monitored. The main settings of the model were at follows: Route length 2,000 m, overall period of simulation 600 s, simulation step 0.25 s, traffic density 30 vehicles per hour in one direction, maximum speed on the route 90 km/h, maximum acceleration 1 m/s^2, maximum deceleration 4 m/s^2, maximum design speed for vehicles 70 to 180 km/h, communication radius 100 m, subject´s interest was limited to the situation ahead of a vehicle, etc. The static infrastructure was not defined in the main settings. For the given setup, the overall situation on the route was reconstructed upon the generated messages as per Figure 1. The vehicle whose parameters were monitored in the following scenarios is indicated with an arrow in Figure 1. The illustrated situation held true for all the experiments described herein as it was independent of the model parameters being modified.

Individual scenarios are discussed in the text below.

4.1 Model without any static infrastructure

In this scenario, there were no static elements represented in the model; the communications took place between the vehicles only. Here, the traffic density proved to be an essential factor. The vehicle obtained

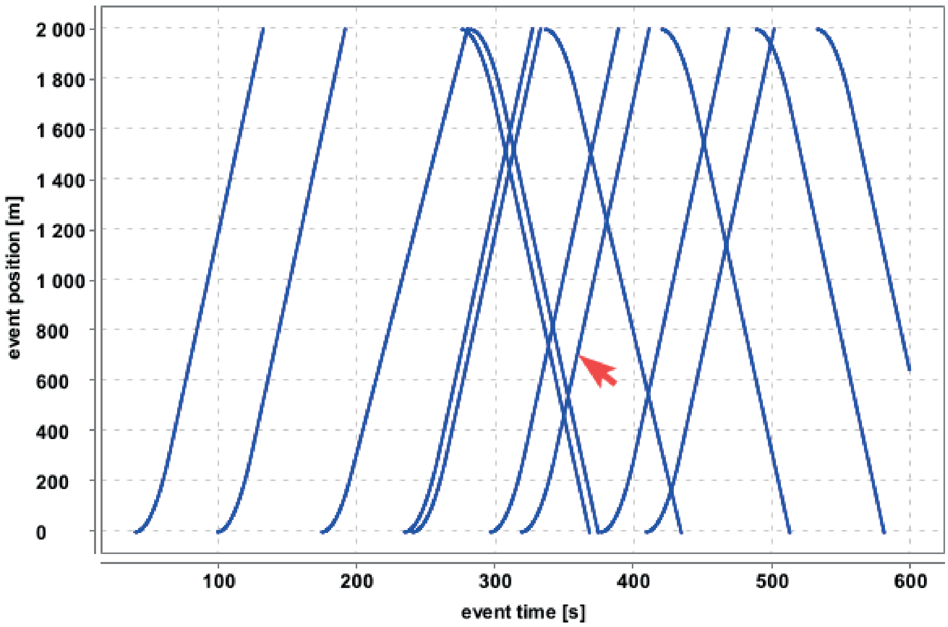

Figure 1 *Positions of vehicles on the route. All the messages generated in the simulation are shown*

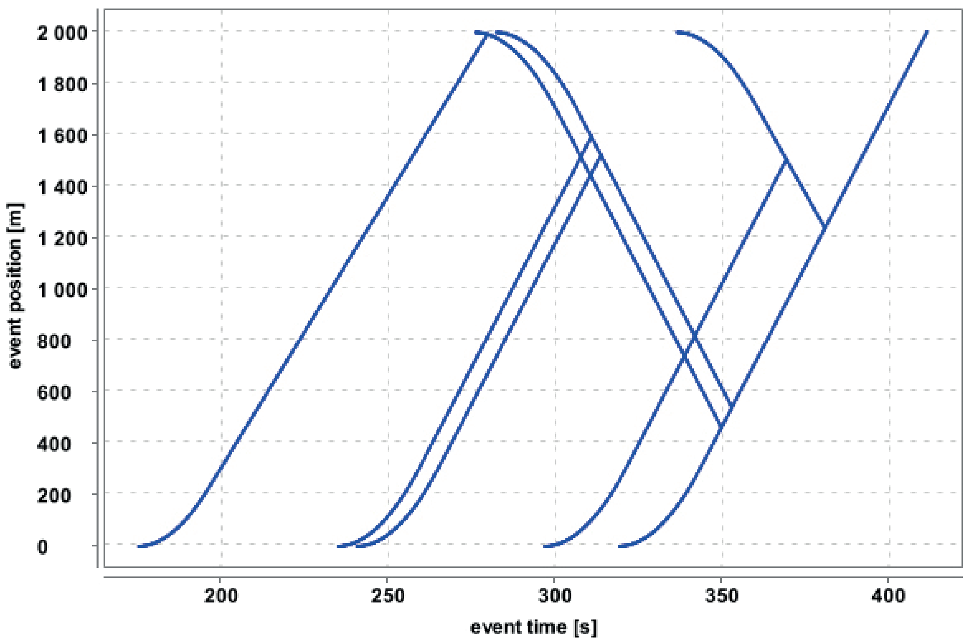

Figure 2 *Picture of the situation on the route as foreseen by the monitored vehicle*

information on the situation ahead especially from the oncoming cars; in the case of the communication range of 100 m, the communication with the vehicles moving in the same direction was not practically feasible (except for the cases where vehicles were moving close to each other).

The internal knowledge base of the monitored vehicle concerning the situation on the route is shown in Figure 2.

Figure 2, however, does not consider the times when the vehicle obtained the given information and whether the latter is up-to-date or not. This is illustrated in Figure 3, where the size of the point, representing the given message (event), corresponds to the time difference between the moment the event occurred and the moment the event was transmitted to the monitored vehicle.

A similar picture may be displayed even for the position difference, i.e. between the position of the monitored vehicle at the moment of receiving the message and the place where the event happened. This is illustrated in Figure 4.

Figures 3 and 4 clearly show that, despite the timeline, which clearly indicates how old the information is, in the perspective of the position difference it is obvious that the vehicle being monitored received the message on what was going on at practically the same point of the route (position of 400 m), which it was

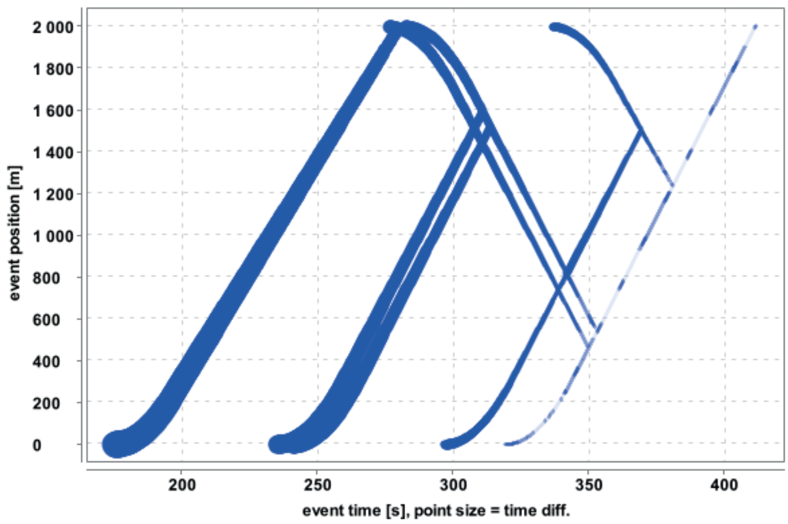

Figure 3 *Picture of the situation on the route as foreseen by the monitored vehicle, the point size corresponds to the time delay*

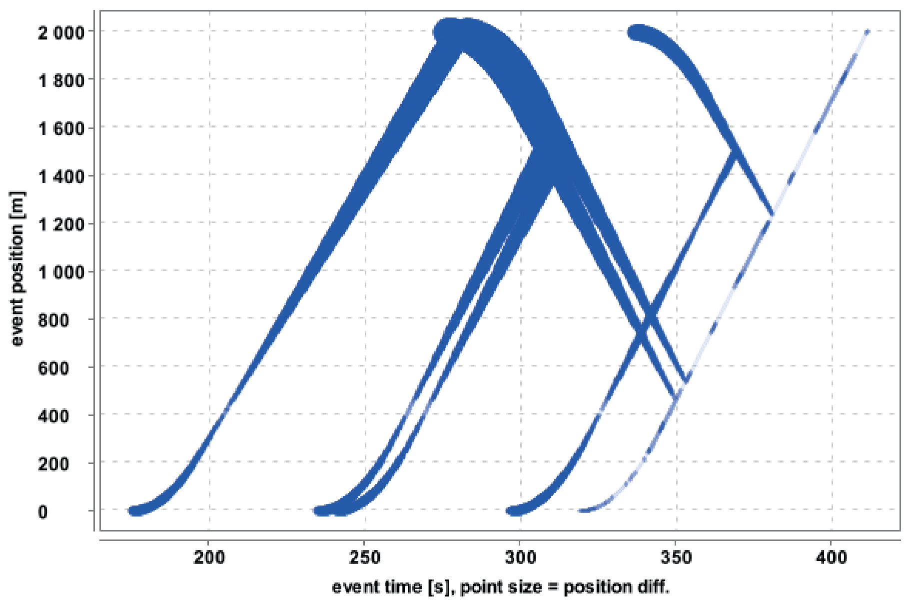

Figure 4 *Picture of the situation on the route as foreseen by the monitored vehicle, the point size corresponds to the position difference*

driving through at that moment, i.e. from the current location viewpoint. Figure 3, however, shows that this information was relatively obsolete in terms of timing. The average size of the knowledge base covering all the vehicles amounted up to 1,600 messages during the simulation.

4.2 Model with an individual static component

In this scenario, the static element, enabling the communication in the same way as the moving vehicles, was located in the mid-point of the route being monitored (this element generated its own knowledge base and then transferred it to other communication partners within the communication range). As to the technical implementation, this could be an autonomous unit not linked to any other system, which supports the data exchange within the VANET only. Other parameters of the model have not changed. The graphs corresponding to Figure 3 and Figure 4 are marked as Figure 5 and Figure 6, respectively.

Figure 5 already makes it clear that the presence of the static element leads to the enhancement of the knowledge of the monitored subject, which now has the information on all vehicles, which are halfway through the route. The communication range is not relevant in this direction. The information has been obtained with considerable delay, though.

Figure 6 makes it clear that the information on vehicles on the route is obtained from various sources. For 150 seconds of simulation, the static infrastructure served as a source; after this value, the oncoming vehicles were the source. The average size of the

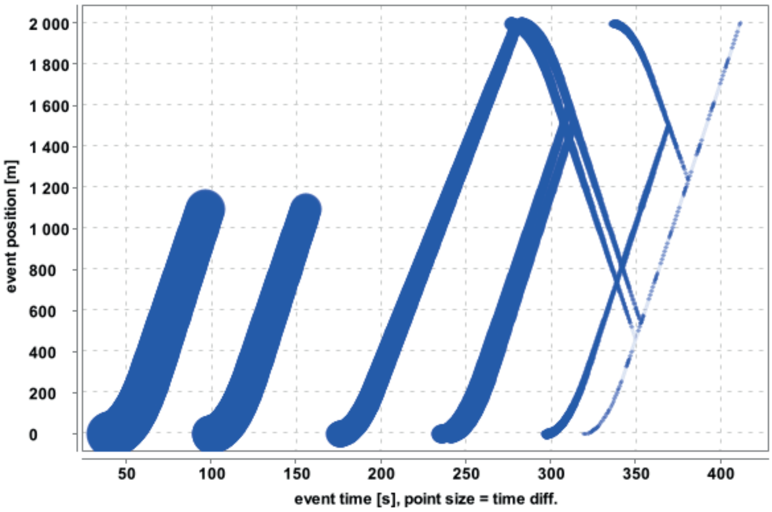

Figure 5 *Picture of the situation on the route with the presence of one static element located halfway on the route as foreseen by the monitored vehicle, the point size corresponds to the time delay*

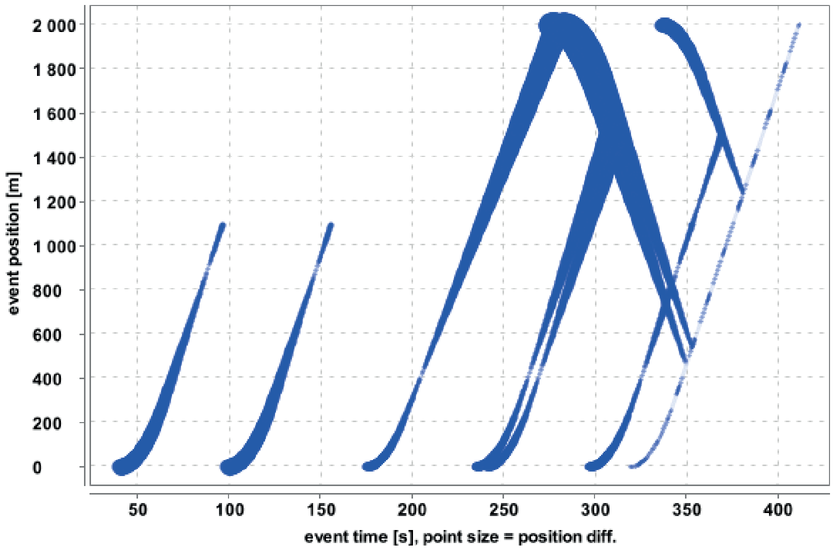

Figure 6 *Picture of the situation on the route with the presence of one static element located halfway on the route as foreseen by the monitored vehicle, the point size corresponds to the position difference*

knowledge base in individual steps amounted to 2,220 messages, which also implies the scope of messages obtained from a static element.

Apparently, the location of a static unit may significantly contribute to a better awareness of individual communication subjects (vehicles), especially in the situation when the traffic density on the given road is not too high and the distance between moving vehicles driving on the road is usually not less than the defined communication range. In this case, a static infrastructure plays a significant role.

4.3 Model with more static components

This scenario is an extension of a previous arrangement. The model contains three static elements that are independent of each other and that maintain their individual knowledge bases formed by the messages obtained from the passing-by vehicles. The elements were situated at the beginning and the end of the route and halfway the route. Relevant graphs are shown in Figures 7 and 8. Other parameters of the model remained unchanged again.

It is apparent that also in this case, the vehicles´ awareness of a situation on the road is further improved; it is especially the messages concerning the end of the route, which matter. Improvement, thus, has a regional dimension only as individual static elements do not cooperate.

A similar trend is also clearly shown in Figure 8. Here, the vehicle obtains quite up-to-date information with a lower position difference, i.e. from around the place where it was currently situated. An average size of the knowledge base in simulation steps amounted to 2,450 messages.

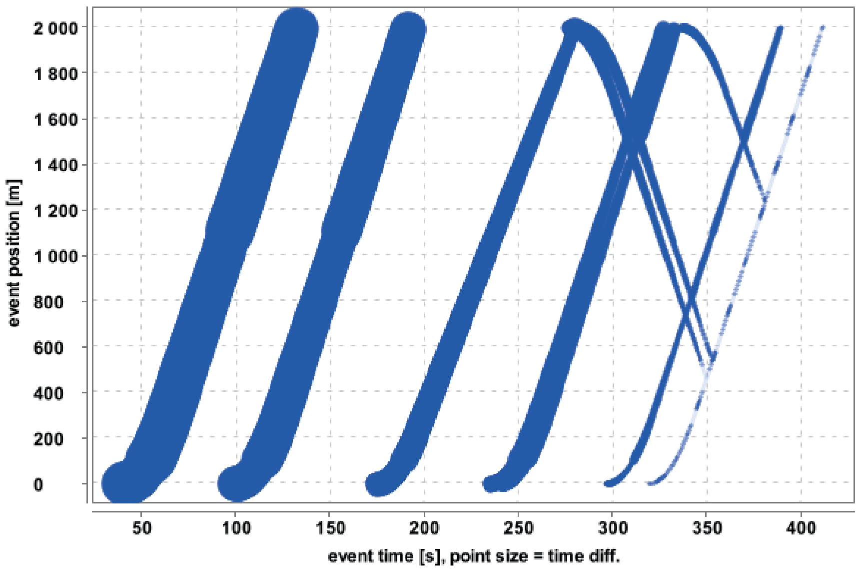

Figure 7 *Picture of the situation on the route with three static elements located along the route as foreseen by the monitored vehicle, the point size corresponds to the time delay*

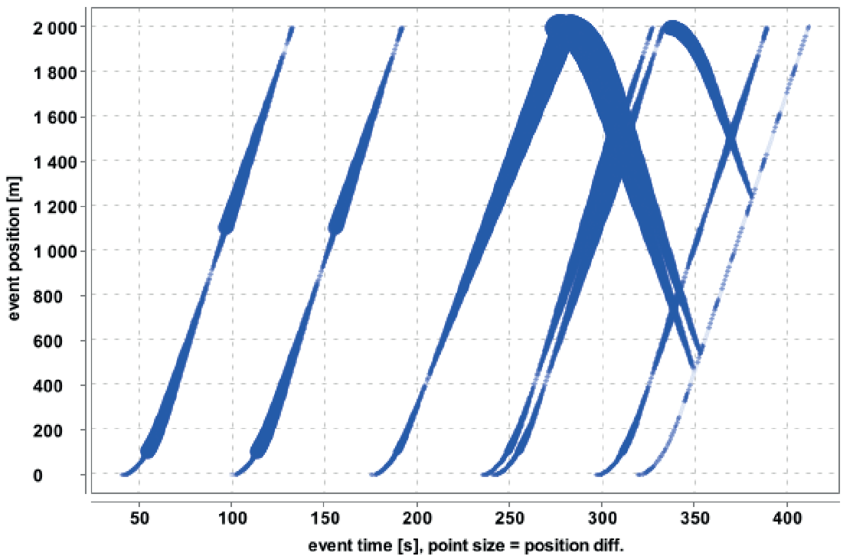

Figure 8 *Picture of the situation on the route with three static elements located along the route as foreseen by the monitored vehicle, the point size corresponds to the position difference*

4.4 Model with more interlinked static components

The last modelled scenario is the situation from a previous simulation (three static elements alongside the monitored section). However, in this case, the static elements form a single communication subject. They share the common knowledge base and they are interlinked through a communication channel independent of the VANET. Individual elements are thus represented only by communication sensors of a bigger message processing system. Other model parameters have not changed again and the relevant graphs are shown in Figures 9 and 10.

An essential difference compared to previous scenarios is not in obtaining more messages regarding the situation on the route, but the value of the time delay with which these messages are obtained. In comparison to the previous scenario, the time delay has significantly reduced (point sizes in the graph are lower).

The situation shown in Figure 10 seems to deteriorate as the position difference (point size) has increased. The reason, however, is not a deterioration of the situation, but its improvement. For instance, the information about the first two vehicles towards the end of the route is obtained by the monitored vehicle not halfway on the route (as in a previous scenario), but already at its beginning! An average size of the knowledge base in simulation steps amounted to 3,000 messages.

The significant influence of the interlinked static infrastructure on the awareness of individual vehicles within the monitored section is absolutely clear. The

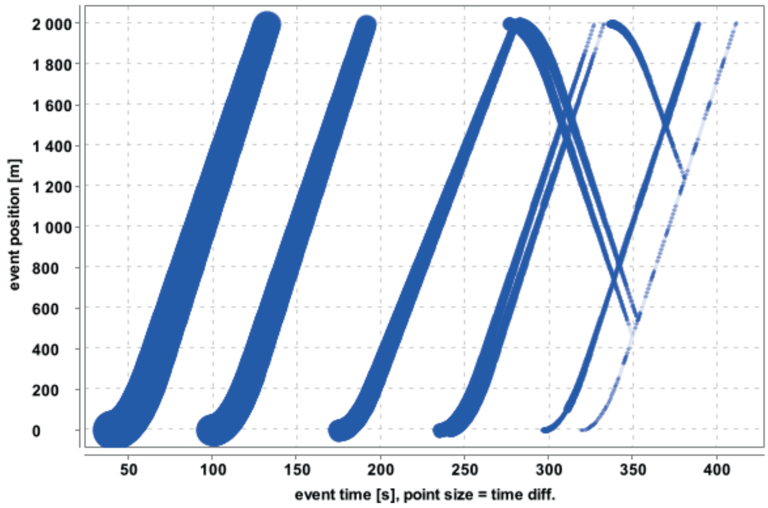

Figure 9 *Picture of the situation on the route with three cooperating static elements along the route as foreseen by the monitored vehicle, the point size corresponds to the time delay*

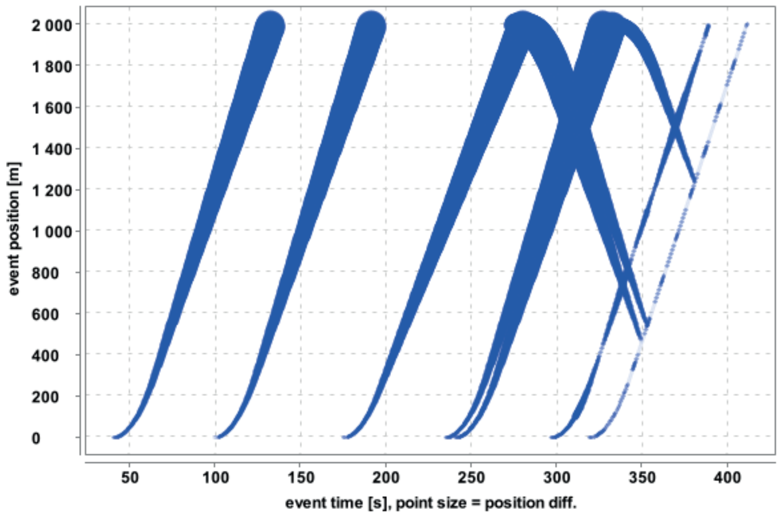

Figure 10 *Picture of the situation on the route with three cooperating static elements along the route as viewed by the monitored vehicle, the point size corresponds to the position difference*

interconnection significantly reduces the delay in obtaining the information, especially where the traffic density is lower. When the vehicle passes by the static subject, the data are being exchanged to a large extent and the vehicle may obtain a lot of information on the situation even at a considerable distance ahead. In this case, a high speed of communicating the information among the static infrastructure elements, usually being incomparable with obtaining the similar information, for instance, from an oncoming car, plays a crucial role.

4.5 Model with more interlinked static components without limitations

To supplement the information on influence of the static elements, one more experiment was conducted in line with the scenario listed in 4.4. In this case, however, the limitation of message collection to the area ahead of the vehicle was cancelled. Vehicles thus gained a complete overview of the traffic on the route both ahead of and behind them. Relevant graphs are shown in Figures 11 and 12. An average size of the knowledge base amounted to 5,500 messages.

In this experiment, the delay in receiving messages is not reduced (as in a previous scenario) but their number increases. The only limit here is the presence of the monitored vehicle on the given route (if the car leaves the route, the knowledge base will no longer be updated).

In terms of the space, it is apparent that the information even on vehicles driving behind the monitored one is obtained as soon as the vehicle passes by the static elements.

5 Discussion

The first experiment was performed with a model without the use of static elements. The transfer of

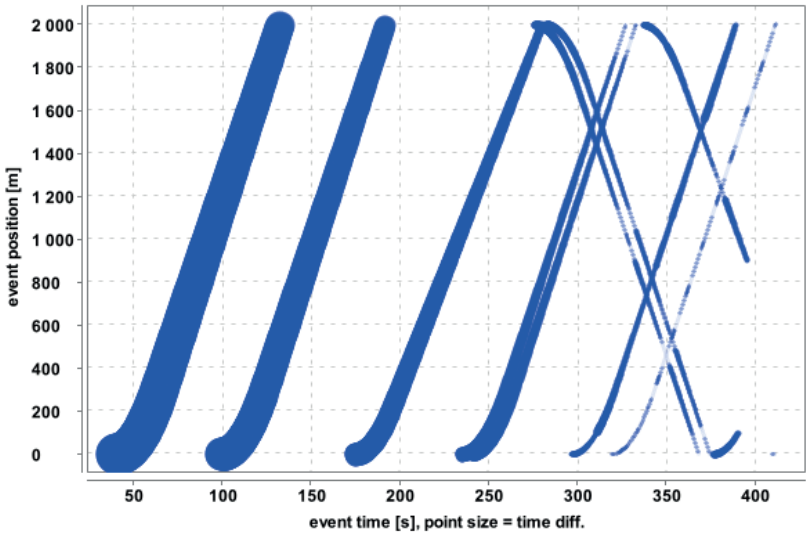

Figure 11 *Picture of the situation throughout the route with three cooperating static elements along the route as foreseen by the monitored vehicle, the point size corresponds to the time delay*

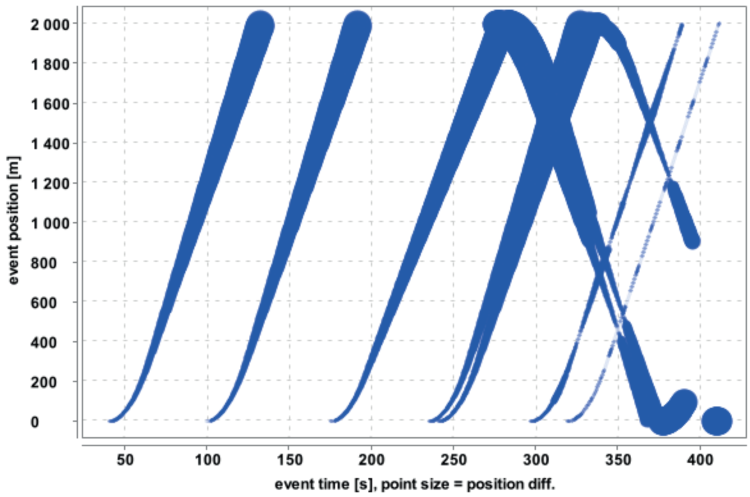

Figure 12 *Picture of the situation throughout the route with three cooperating static elements along the route as foreseen by the monitored vehicle, the point size corresponds to the time delay*

information in this experiment occurred mainly due to vehicles from the oncoming cars. For vehicles in the same direction, communication was practically impossible with a communication range of 100 m due to the low traffic density. From a spatial point of view, the monitored vehicle had up-to-date information. However, in terms of time, the information obtained can be considered relatively outdated. In the second experiment, one independent static element was located in the mid-point of the route being monitored. Thanks to this, the monitored vehicle had information about all the vehicles that passed halfway. The introduction of a static element has led to an increase in awareness by obtaining information from various sources. However, the information was obtained with a considerable delay. In the third experiment, three independent static elements were placed on the route. This has led to a further improvement in vehicle awareness, in particular for end-of-route reports. In the fourth experiment, more interlinked static elements were used. This experiment showed a significant reduction in the time delay of obtaining information compared to previous experiments. The transfer of information between the static elements of the infrastructure is essential here. The vehicle obtains information from all the static elements at once. The above experiments were focused only on collecting information in front of the vehicle. Experiment 4 extends Experiment 3 to gather information behind the vehicle, as well. In contrast to experiment 4, there is no reduction in the delay in receiving messages, but an increase in their number.

Experiments have shown that the inclusion of static elements in the VANET network leads to a significant increase in vehicle awareness of the route in the event of a low traffic density. If the individual static elements communicate with each other, a significant reduction in the time delay for obtaining information is also achieved. The suitability of the static elements use within the network thus depends, among other things, on the traffic density of the given area. However, the use of static elements requires acquisition costs and maintenance costs. It is also necessary to consider their distribution and number according to the area of use.

6 Conclusion

The conducted experiments have proved that the static communication infrastructure, which may be a part of the transportation systems being built-up, may significantly contribute to higher awareness of vehicles on the route and improving the message delivery times in order to ensure better conditions for decision making as regards the next movement of vehicles. Significant benefits may be attributed especially to the infrastructure elements, which will be interconnected and spaced along the route at distances that enable, primarily in the case of a low traffic density, bridging the gap in receiving messages from the oncoming vehicles.

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