Agent-Based Simulation of Information Spreading in VANET

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Abstract. A model of agent-based simulation of communicating vehicles is presented to study the information spreading in a vehicular ad hoc network (VANET). The agents are moving along the fastest paths between their starting points and their destinations on real urban topology. During the motion, they can exchange information by short-range wireless communication. The goal is to analyze the statistical properties of the information spreading in the system, e.g. the time evolution of the average awareness or the age distribution of information owned by separate vehicles.

Keywords: Agent-based simulation · Information spreading
VANET · Traffic simulation · City map

1 Introduction

Several smart city services are based on information dissemination in vehicular networks that is why the topic is in the focus of scientific research in the last couple of years. These applications try to make the urban traffic safer and our life even more comfortable. In order to increase the efficiency of these intelligent transportation systems the topological properties of urban road maps were analyzed [1,2], the traffic flow was measured and studied [3]. Different algorithms and methods were developed to simulate the motion of vehicles and generate traffic in urban or in highway environment [4–6]. Several communication protocols were introduced to ensure the communication of moving wireless devices using eighter Dedicated Short Range Communication (DSRC) or for example IEEE 802.11p standard [7–9]. In VANETs both the routing [10–12] and the broadcasting [4,13] is actively investigated fields.

Nevertheless, there are open questions still related to the statistical properties of the general spreading processes in VANETs. The goal of this research is to create a new framework in order to be able to answer some of the questions. What are the limits of the information spreading? Can we reach all actors of the traffic system based only on self-organization? Do all vehicles own up-to-date information? Similar questions have been appeared and already answered

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in social networks [14,15], but due to the continuously changing topology, the characteristics of spreading can be very different.

In Sect. 2 authors give some introduction how the realistic urban topology is built up. It is followed by the details of the simulation of vehicular motion in Sect. 3. The spreading of information based on carry-and-forward and multi-hop broadcast dissemination schemes is presented in Sect. 4 and then the first results of our investigation are shown in Sect. 5. This paper is closed by some conclusions.

2 Underlying Map Topology of Simulations

In order to reach realistic simulation environment, a real city map is applied as an underlying topology. The map of the authors' city was planned to apply. A very detailed dataset is available from the OpenStreetMap project [16]. For the later agent based simulation a much more simplified topology is needed, that is why the source was reduced keeping the topology of crossroad network and the distances between junctions, but losing the real geographical locations of road sections.

According to the original `.osm` format any crooked road can be build up from shorter straight segments and the geographical coordinates of their endpoints are given. In this way, a road section between crossroads can be described by a list of internal nodes with degree 2. In our traffic approach, the shape of a road section is negligible and only the length of the section is important. This was the base of our topology simplifying method. In case of any two road segments between nodes $A-B$ and nodes $B-C$, node B was eliminated if it has no other neighbors than A and C, merging the segments to only one longer segment between nodes $A-C$ with a distance equal to the sum of lengths of the previous segments (Fig. 1).

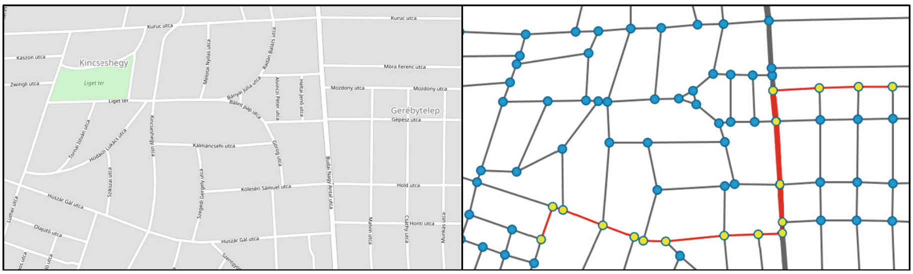

Fig. 1. Conversion of a street map to a simplified network. A small part of the map of Debrecen [16] is presented on the left. A visual representation of the corresponding graph is on the right, where crossroads are illustrated by circles. The thicker links represent road sections with higher average traffic speed. A possible route is highlighted.

Thus the map of Debrecen was reduced to a network of only 3422 nodes (junctions) connected by 4812 links (road sections). It was found that 84% of crossroads connects 3 or 4 roads. In the unit of linknumber (ignoring road length) the diameter of the network is 96. Taking into account the geographical distances the average distance between two crossroads is 121.5 m, however, the distribution is quite wide, there is almost 3 orders of magnitude difference between the shortest and the longest road section. (See the inset of Fig. 2.)

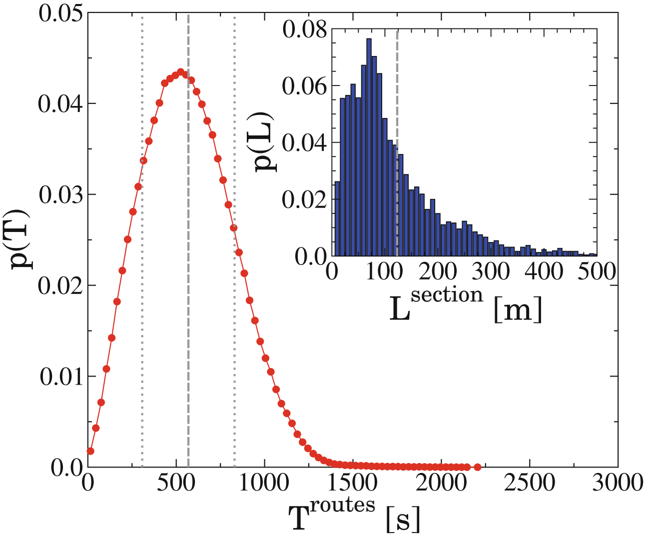

Fig. 2. Travel time distribution of routes. The vertical gray dashed line shows the average and the dotted lines indicate the standard deviation of the distribution. Inset: Length distribution of road sections (between crossroads).

3 Motion of Vehicles

It was assumed that vehicles proceed from their randomly chosen starting node toward their randomly chosen destination node along the fastest path because drivers usually use a route with the shortest travel time instead of the shortest distance route. The original dataset contains information about the rank of all road segments (for example: primary, secondary, residential, living street, etc.). The average speeds of cars depend on the rank of the road. Based on the speed prediction/offer of the Google Maps [17] different average velocity is applied in case of different road rank. Thus the shortest and the fastest route can be different.

Between two neighboring nodes, all vehicles proceed with constant velocity, at a crossroad they turn according to their route (and perhaps change speed). Traffic jams, traffic lights or the finite size of vehicles are not taken into account during the simulation because from the point of view of the later spreading process the short-term fluctuations of the speed of cars are negligible.

When a new vehicle is departed in the system it needs to get a route that is a node sequence to move along from the given location to the destination. Since the generation of shortest/fastest routes in a network of several thousand nodes is very time consuming, more than one million different random routes are generated and stored only once before the traffic simulation. In this way, the simulation itself can be fast because each vehicle just chooses a random route from the stored possibilities. However, the source and destination nodes are random the density of the traffic is really diversified due to the topology (connectivity, ranks).

It was assumed that the number of moving cars in the system at a given time can be constant because the simulated time interval is small compared to the daily life cycle of a city or the duration of rush-hours traffic. At the beginning of the simulation, the cardinality of vehicles is N. Later, when a vehicle arrives to its destination, it was removed and immediately a new one is initialized and started. At the beginning of the time evolution of the system, all the cars are just departed. In order to avoid artificial transient effects the measurement is started only later ($t = 0$) when the system become randomized, however, the simulation is started at $t = -T_0$. The length of the randomization time interval ($-T_0 \leq t < 0$) is longer then the most of trips ($T_0 = 750\,\mathrm{s}$, average travel time is $459 \pm 261\,\mathrm{s}$, see the main panel of Fig. 2), so when the scientific observation is started all the initial cars have been arrived and others are launched in different time moments.

The simulation is stopped at $t = T_{max}$. The time interval of the analysis ($0 \leq t \leq T_{max}$) is enough long to cover several generations of vehicles, so the total number of simulated cars (N_t) is at least five times greater the number of cars at a given moment ($N_t > 5N$). The time evolution of the system is discrete. The time step Δt is enough to move only a few meters, so it is tiny compared to the whole simulation time $\Delta t \ll T_0 + T_{max}$.

4 Spreading of Information

In this system, smart vehicles are represented by agents which can interact by short-range communication. If the distance of two vehicles at a given time moment is less than the range R of the wireless communication, they can exchange information. Based on this, in our model the agents can have two different states. On the one hand agent i can be uninformed, so it has not received any data (denoted by $S_i = 0$). On the other hand, it can be informed, so it has already got some data (denoted by $S_i = 1$). Beside this Inter-Vehicular Communication (IVC) there is Vehicle-to-Roadside Communication (VRC) as well. In the latter case the On Board Units (OBU) of smart vehicles can receive information from Road Side Units (RSU). In our first model initially all agents are in uninformed state and only one RSU is present, playing the role of an information source. When an agent passes by the RSU it receives a new up-to-date information (e.g. traffic or weather alert). The agent stores it together with the actual time stamp and later it shares with others within the communication range. If one of these neighboring agents is uninformed it becomes informed. If both agents in the contact have been already informed, the agent with older time stamp will update its knowledge storing the newer information with the given timestamp. Thus information can spread in this dynamically changing network from the RSU to any vehicle even if they have never passed by the RSU. In order to characterize agent i in detail we introduce the quantity τ_i which is the latest/newest time stamp of information owned by the informed agent i or $\tau_i = -1$, if agent i is uninformed. (So $\tau_i > 0$ is the simulation time when the given information entered into the system by the RSU.) The behavior of the system is shown in Fig. 3.

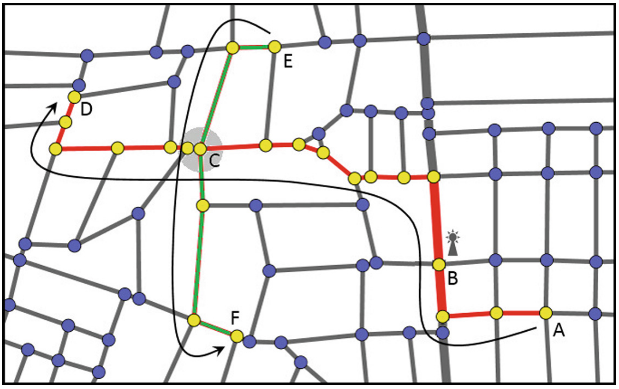

Fig. 3. The behavior of the system. A vehicle (agent i) proceeds from node A to node D. It goes by the RSU in node B receiving new information at $t = \tau$. An other vehicle (agent j) move from node E toward node F. Both of them are in the vicinity of the node C at the same time. Since they are within the range R, agent i can transmit the information to agent j. Between nodes A and B agent i is uninformed, but between C and D it is in an informed state, having timestamp τ. Agent j possesses also timestamp τ between nodes C and F.

At simulation time t an informed agent i have information with age $A_i = t - \tau_i$. The average age of information $\langle A \rangle$ owned by agents can be written as

$$\langle A \rangle = \frac{\sum_i \tau_i S_i}{N^i}, \tag{1}$$

where N^i is the number of informed agents, defined as $N^i = \sum_i S_i$. Large value of N^i indicate extensive information spreading. When the average age of information $\langle A \rangle$ is low, it means that our smart traffic system is in an up-to-date phase. Thus the number of informed agents N^i and the average age of information $\langle A \rangle$ are good measures of the effectiveness of information spreading in VANET.

5 Results

While an SI (Susceptible-Infected) model is applied more and more agents become informed. Nevertheless, the system never reaches a fully informed state, because of the continuously changing set of agents. Organically new, uninformed agents appear in the system, while informed ones disappear. Investigating the time evolution of the agents it was found that the system reaches a steady state described by saturating functions. In Fig. 4 one can observe that at $t = 0$ (when the RSU is just activated) there is no informed agents in the system, but soon some agents pass by the information source of the infrastructure. Then the vehicles carry the information during their motion to different places of the city meanwhile they also behave as information sources speeding up the spreading of information so leading to increasing $N^i(t)/N$ function with a significant slope.

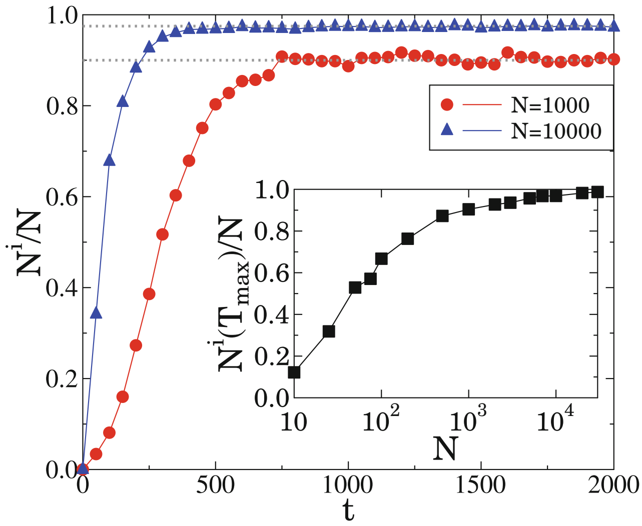

Fig. 4. Number of informed agents (vehicles) as a function of time for different numbers of agents. After a short time period a saturation is achieved at a quite high value. Inset: The saturation level depends on the number of vehicles in the system (of course more smart vehicle leads to higher level of awareness).

After a quite short time period, a dominant proportion of agents are in the informed state, spreading slows down resulting in saturation of the number of informed agents. The average movement of vehicles during a simulation step Δt is the half of the applied range of communication R. (Of course, increasing range R speeds up the spreading.) Due to this, the propagation of information can be faster then the motion of vehicles, so that is why we reach saturation so quickly. The $N^i(t)/N$ curves never reach 1.0, the saturation level depends on the number of agents (the density of smart vehicles in the city). It is illustrated in the inset of Fig. 4. As we can observe the information coverage of VANET can be effective only if the number of smart vehicles exceeds a given threshold (about few hundreds of vehicles in Debrecen).

The number of informed agents is proved to be relatively high in the system, but the really important questions are the follows. How old is the average information? Is the system in an up-to-date phase continuously? The average information age as a function of time $\langle A \rangle (t)$ can give the answers. It is illustrated in Fig. 5 the most of agents have relatively young information. Recent information from RSU overwrites the system very quickly without any outer control. Of course the level of $\langle A \rangle (t)$ (far from the opening time period) determined by the number of agents. More smart vehicles lead to a more up-to-date system. (See the inset of Fig. 5.) The average age of information is even less than the length of time period needed to reach the saturation of the number of informed agents.

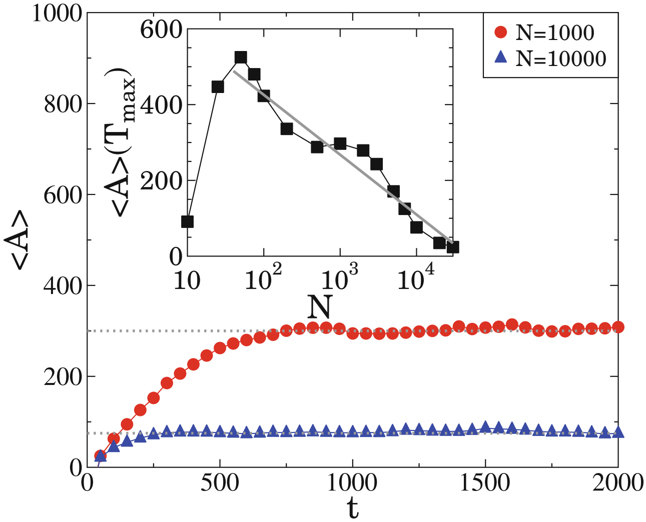

Fig. 5. The average age of information owned by the vehicles as a function of time. It shows saturation for different system size. Inset: The average age of information in the saturation phase decreases logarithmically with the number of vehicles, so denser vehicle park in the city results more up-to-date system.

6 Summary

An agent-based model of information spreading in VANET was presented. The time-dependent network topology of agents was based on the motion of smart vehicles. The changing set of vehicles (with constant cardinality) are following their routes based on shortest travel time between the randomly selected start and destination points of a real city. Due to the short-range communication moving vehicles can receive information from each other or from fix infrastructure unit(s). In this ad hoc network, the statistical properties of information spreading can be investigated. Above a threshold of smart vehicles information spreads in a very fast way, and a dominant part of the system can be in an up-to-date state.

However this work is mainly focused on the implementation of the model, the some results of the computer simulation show that there are hidden potentials in the introduced complex system. In our further research, we try to find answers to essential, practical questions. What happens if the RSU is removed (turned off)? How does an old information die out? How to avoid the presence old (fake, not up-to-date) information? What is the effect of the introduction of an Susceptible-Infected-Susceptible (SIS) model (forgetting old information)? How to optimize spreading reducing the number of information exchanges (energy efficiency), but keeping system in an up-to-date phase? What is the topology of this ad hoc communication network?

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