Spatial Characteristics of Communication in Urban Vehicular System

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Abstract: We propose a model of information spreading based on urban traffic, where smart vehicles can carry data of sensor measurements and share them by short-range wireless communication. The spreading of information can be quite fast and widespread without central control within this ad hoc network. In this position paper, we want to characterize some spatial aspects of the spreading process. We planned to analyze the radius of gyration and the bounding box of the $2D$ positions of informed agents and communication events. First simulation results show a crossover in the time evolution of the system.

1 INTRODUCTION

Over the last decade, we have witnessed many research efforts that have investigated various aspects of Vehicular Ad hoc NETworks (VANET). Due to the equipped On Board Units (OBU) of modern smart vehicles they can continuously perform Vehicle-to-Vehicle (V2V) communication. Besides, vehicles can also exchange information with Road Side Units (RSU) via Vehicle-to-Infrastructure (V2I) communication. Messages related to traffic information, road conditions, local utility information are carried and forwarded by vehicles, thus the key component of the infotainment services in VANETs is the data dissemination. It is the base of several applications, such as adaptive navigation, vehicle safety, traffic management or different location-based services.

These systems attract industrial and scientific interest as the number of research papers shows. The traffic flow was analyzed and simulated in different scenarios (Fiore et al., 2007; Zeadally et al., 2012; Meignan et al., 2006). Wireless communication protocols (e.g. IEEE 802.11p) were developed and their performance were measured (Malla and Sahu, 2013; Ramakrishna, 2012; Sanguesa et al., 2016). After the communication is available within an urban system the topology of this network was also investigated (Zhang and Le, 2015; Kocsis and Varga, 2019). In intelligent transportation systems, vehicles can play the role of routers, not just simple senders or receivers. Thus special routing protocols were developed and introduced (Mtech and Malhotra, 2016; Malla and Sahu, 2013; Rehman et al., 2013; Ramakrishna, 2012) as well. The statistical physics of the information spreading processes was also published (Varga et al., 2018).

In this work, we would like to find the answers to further open questions. Where are the vehicles carrying information packets? How large is the area concerned by the dissemination? How does its size change in time? What is the shape of the affected area? Does it have almost circular symmetry or elongated prolate shape due to primary roads? Is the density of informed vehicles constant or are they spatially centralized? Is communication only on the perimeter of the area?

The rest of the paper is organized as follows. Section 2 provides our own model of urban traffic and the spreading of information. Section 3 presents the spatial characteristics we interested in and our hypotheses. Some preliminary results are in section 4. Finally, we conclude the paper.

2 MODEL

In order to study the spreading of information in VANET, an agent-based model (ABM) is proposed describing both the urban traffic and the self-organized communication of vehicles.

2.1 Traffic

An urban road map can be modeled by straight road segments, where a connection between two neighbor-

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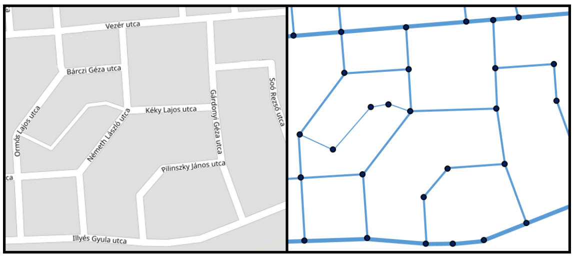

Figure 1: The urban road map of Debrecen (left) was converted to a weighted graph connecting real geographical locations with different kinds of straight road segments (right).

ing crossroads can be represented as a concatenated segment list. Thus the road map of Debrecen (OpenStreetMap, 2019) was converted to a graph, where the nodes are planar geographical locations, the endpoints of straight road segments as it is illustrated in Figure 1. The length of a link is defined by the distance of the nodes connected by the given link. The links also differ in other sense because the average speed of vehicles varies on different types of roads (primary route, living street, highway, etc.). In our model we assume that point-like vehicles move with a constant velocity determined by only the road type. In this way, it is a mesoscale approach of the traffic, where microscale objects (e.g. traffic lights, junctions, pedestrian crossing, etc.) are taken into account only by the average speed.

Each vehicle have a randomly selected departure and arrival location within the city and between them they proceed along the shortest travel time routes. They derive from the lengths of links and the average speed on them using the Dijkstra's algorithm (Dijkstra, 1959). The amount of vehicles in the model is constant since the simulated time intervals are short (circa 10 minutes) compared to the duration of the different phases of the daily life periods of the urban traffic. Thus rush-hours or off-peak periods can be modeled only separately. If a vehicle arrives at its destination, a new one will be launched, just for simplicity. The left side of Figure 2 demonstrates the motion of three vehicles using discrete timescale for computer simulation.

This model is quite similar to the model introduced by Varga et al. (2018), but there is a huge difference. The recent model is based on the real geographical locations contrary to the former model which was a simplified model ignoring the shape of roads and focusing on only the connections of crossroads. There the Cartesian coordinates of vehicles were not managed just the distances from the two neighboring junctions. In the recent work, there are nodes with degree $k = 2$ along bent roads between junctions. Thus the number of nodes is much higher resulting in more computational effort but makes us able to study the geographical properties of spreading.

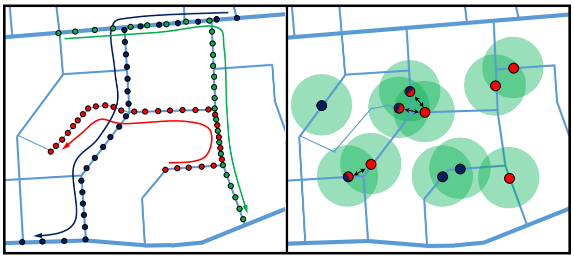

Figure 2: (Left) Colored circles illustrate the positions of 3 vehicles in different discrete-time moments along their routes during the time evolution. Distinct distances between consecutive circles show the various average speed on different ranked road segments. (right) A time moment of the system, where the communication ranges R of agents are presented by green areas. Blue and red circles refer uninformed and informed agent, respectively, while the newly informed agents have gradient color.

2.2 Information Spreading

Vehicles can be equipped with smart on-board units. Their sensors can perform different measurements and then they are able to share this information via short-range wireless communication. After the measurement, the given car can carry the information and in the vicinity of other vehicles, it is shared. In this way, the source of information packets are the vehicles themselves, there are no road-side units just vehicle-to-vehicle communication. Thus useful information (e.g. traffic or weather alerts) can spread in this complex system. For the sake of simplicity in this work we consider only one measurement and follow the spreading of this information packet.

Vehicles are the agents of this ABM, having only two states. Initially, all the agents are in an uninformed state denoted by $S_i = 0$ because they have not received information yet. Due to the sensor measurement, one of the agents becomes informed ($S_i = 1$). It is the $T = 0$ time moment of the simulation. Since agents are moving they can meet. If the uniformed agent j is within the R communication range of the informed agent i, then j becomes informed $S_j = 1$. Thus both of them can carry and share the information later. See the right side of the Figure 2. There is only one state change in this model similar to the Susceptible-Infected epidemic model (Newman, 2010).

3 SPATIAL FEATURES

In order to capture the geographical features of the spreading process, we planned to study the spatial distribution of three different location sets.

- Recent locations of informed agents,
- Spots of all the information exchanges in the past,
- Spots of information exchanges in the recent time moment.

All of them mean a set of $2D$ points, which are in the focus of our analysis to describe the spreading process. We are going to calculate four quantities of the above-mentioned position sets:

- Radius of gyration (R_g),
- Area of the bounding box (A),
- Ratio of the side lengths of the bounding box (L/W),
- Largest distance between an informed agent and the information source ($d_{\max}$).

The radius of gyration R_g is mathematically the root mean square distance of the points from the center of mass at $\vec{r}_c$ (assuming unit mass for all points). Formally it defined as

$$R_g^2 = \frac{1}{N}\sum_{i=1}^{N}(\vec{r}_i - \vec{r}_c), \qquad (1)$$

where N is the number of points and $\vec{r}_i$ is the position of location i. It can be interpreted as an average coverage of the set of points. Additionally, in polymer physics is it used to describe the shape. When the radius of gyration is proportional to the number of points it refers to linear shape, while if $R_g \propto N^2$ we have a planar structure.

A minimal bounding box of planar structure can be defined as the smallest rectangular area, where the longer line of symmetry is parallel to the line segment connecting the two furthermost points. In Figure 3, the length and width of this rectangular is denoted by L and W, respectively. The area of the bounding box is $A = L \times W$. The A denotes the planar size of the system (similar to R_g^2) and the L/W ratio of the side lengths refers to the shape.

The location of the sensor measures, where the initial source agent starts to share the information packet can be far from later informed agents, which get the packet via multiple information exchanges. The recent distance of agent i from the source is denoted by $d_i(t)$. The distance of the furthermost agent $d_{\max} \geq d_i$ can be also an interesting characteristic of the system.

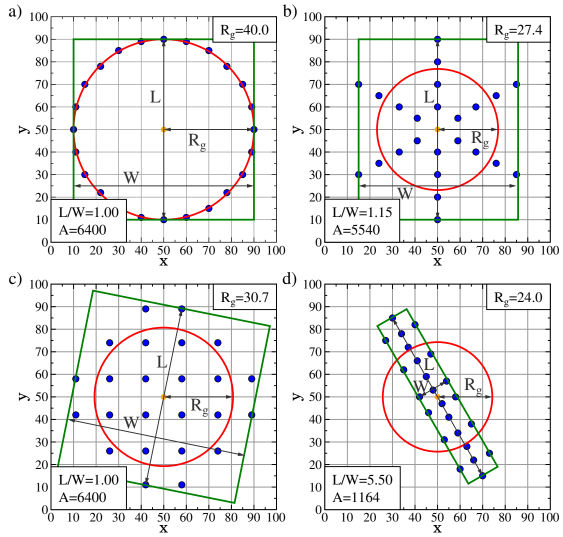

Figure 3: Regular arrangements of 24 planar points to illustrate various spacial properties. a) A circular structure with large radius of gyration. b) Radial structure with square-like bounding box ($L/W \approx 1$) and lower R_g. c) A square grid structure where the uniform distribution results in lower R_g then in case of circular structure nevertheless the value of A is the same. d) A prolate structure, which is dense (low value of R_g and A) and longish (high value of L/W).

By these quantities, we can capture differences between the structures in Figure 3, although all of them contain the same amount of points. The small value of R_g refers to a dense structure. (Compare Figure 3a and Figure 3b.) Similarly, a smaller value of A can be found in a more concentrated structure. (Compare Figure 3c and Figure 3d.) The large L/R ratio can be observed in Figure 3d because the shape is linear rather than planar.

3.1 Hypotheses

The number of informed agents increasing very intensively and quickly reach a saturation. Sooner or later the majority of agents will be in informed states. The information spans the whole city within a short time interval.

At a given time moment the communication takes place not only at the peripheral region of the area covered by the informed agent because there are uniformed agents within this area, so the area is not compact.

We suppose that at the beginning of the spreading process, the informed agents are within a linear area due to the relatively straight road segments. However later it still remains linear for intervals longer than distances between junctions due to the neighboring priority roads, which have precedence in case of long rides. After a long time of dissemination, the bounding box of the affected area starts to be square-like. Thus there will be a crossover between the linear and planar phase.

4 FIRST RESULTS

Our self-developed agent-based software is over the tests. We plan to carry out a lot of simulations in order to discover the parameter space. We are at the beginning of this long process, but some interesting features of the system have been already reported. The following results are obtained by the simulation of a few ten-thousand vehicles and using a communication range covering a few meters wide area.

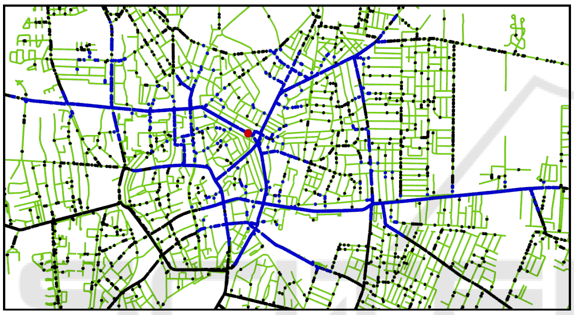

Figure 4: A snapshot of the system covering just the central part of Debrecen. The black and blue spots represent the uninformed and informed vehicles, respectively. The red circle in the middle marks the location of the information source when it triggered off the spreading process. As one can see the main roads are very crowded while residential ones have low loads. The information dissemination is more dominant along the primary roads.

At first sight, the general behavior of the system is very realistic even though the model is quite simple. However real-life measurements and statistics are not available, the distribution of vehicles is very similar to the traffic, we experience every day as local drivers.

After an agent starts to share information as an initial source neighboring agents receive and forward it. Thus more and more agents become informed until we reach saturation, where almost all the smart vehicles are informed within a few minutes. A snapshot of the spreading process is shown in Figure 4.

All the studied quantities have two distinct phases. At first, the linear spreading dominates the system. The radius of gyration and the maximal distance of informed agents from the source are increasing rapidly. The length L and the width W of the minimal bounding box are definitely different. Later, as more agents carry the information all over the city the slopes of the $R_g(t)$, $A(t)$ and the $d^{\max}(t)$ are decreasing significantly and the bounding box becomes more square-like (see Figure 5). The reason for this can be the local topology. In the former phase, the affected area covers only one almost straight main road. Contrary later the informed agents mainly proceed on several primary roads in different directions of the 2D plane.

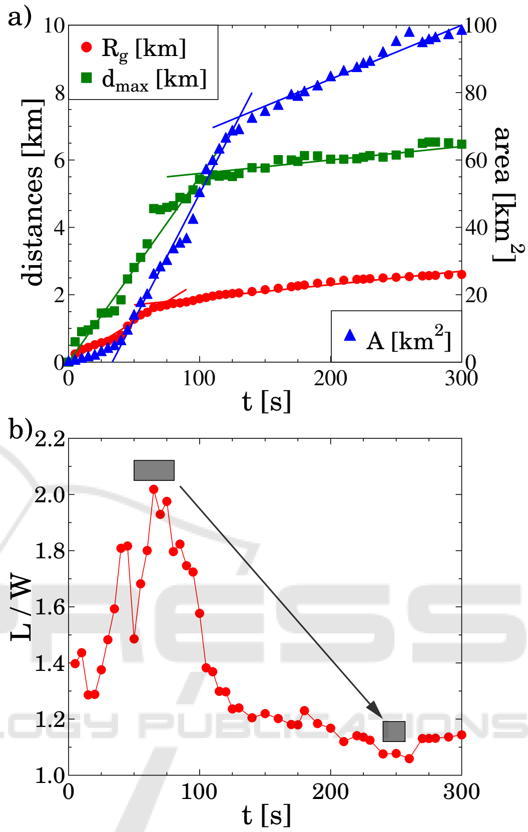

Figure 5: A) A crossover can be observed in several quantities. Both the radius of gyration, the maximal distance from the source and the area of the bounding box changes qualitatively in time. The presented curves are obtained from the recent locations of informed vehicles. b) The shape of the bounding box is gradually changing from rectangular form to square-like form as the L/W ratio is converging to a value close to 1.

5 CONCLUSIONS

Our self-developed software implements a simple but efficient mesoscopic model of urban traffic. Based on this, one can observe an ad hoc communication network of moving devices, which can accomplish information dissemination. We would like to analyze the spatial features of the spreading process observing the sets of different locations.

We found empirical correspondence of the simulations and the real observations. A lot of simulations and the evaluation of their results are ahead of us. However we are just at the beginning of a long, detailed analysis, some interesting features of the system have already been found. The spreading process is not uniform, one can observe two distinct phases of the time evolution of the spreading caused by the local urban topology.

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