Infotainment traffic flow dissemination in an urban VANET

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Abstract—Inter-vehicle communications will play an important role in future cars and traffic management in general. Many different services have been proposed in the literature using vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications. These services include safety applications like collision warning, up-to-date traffic information, active navigation, and also infotainment. Efficient data dissemination in vehicular networks (VANET) is of particular interest for both safety and infotainment services. In case of infotainment services, which are the object of our study, data dissemination is used to extend the radio coverage area of a Road Side Unit (RSU) to reach all users that can be interested in a given service. In this work, we propose a family of algorithms to extend the RSU coverage area in VANETs. These algorithms apply simple geometrical rules based on the position of the sending nodes. The algorithms are used to allow the data to cross road junctions and to propagate towards multiple directions, without using beacon or hello messages. By applying a simple geometrical analysis we show that the proposed solutions are able to increase the number of nodes reached by a broadcast message. Moreover, we study the performance of our solution through message flows injected in a dynamic scenario, where a Manhattan street grid is reproduced and populated through SUMO, which is able to provide realistic vehicle flows. The effect of traffic lights on vehicle flows in relation to network performance is also discussed.

Index Terms—Vehicular Ad Hoc Networks; data dissemination; IEEE 802.11p

I. INTRODUCTION

Vehicular Ad-Hoc Networks (VANET) are attracting the interest of network operators and service providers for the provision of infotainment services [1]. The inter-vehicular communication standard is the IEEE 802.11p [2] also known as Wireless Access in Vehicular Environments (WAVE). The WAVE protocols (IEEE 802.11p /1609) provide interoperability between wireless devices on board of vehicles (On-Board Unit, OBU) and devices located near the roads (Road Side Unit, RSU). We can distinguish between safety related messages, which need to be transferred in real time (fractions of seconds), but affecting an area of the order of the coverage area of a RSU/OBU, and non-safety message flows, involving especially V2V communications over an area of several km², but having less stringent delay requirements (seconds or tens of seconds). In this kind of services, also called Non-Public Safety services, we can list traffic information, electronic toll collection, advertisement, parking directions and handling, vehicle maintenance, tourist info and many others. A key component of infotainment services is the data dissemination that allows all users on board of vehicles to receive information relevant to services available in the considered area (we name it service area [3]). In a VANET, data dissemination may start from a RSU and propagates to a multiplicity of OBUs. A RSU typically reaches with a single hop only a fraction of the interested vehicles, depending on its radio transmission range. Multi-hop, inter-vehicle communications is necessary to reach vehicles in the whole service area. The goal is to obtain extended coverage with limited infrastructure deployment. The rest of the paper is structured as follows. Section II describes the related work and the contributions of this paper. The considered network scenario is presented in Section III while the proposed dissemination solutions are in Section IV. The performance analysis includes both a geometrical evaluation in a static scenario (Section V-A) and a dynamic evaluation (Section V-B). Conclusions of the work are in Section VI.

II. RELATED WORK

Vehicular networking has significant potential to enable several applications associated with traffic safety, traffic and energy efficiency and infotainment [4]. A key component of services that can be provided by VANETs is the data dissemination that allows users on vehicles to receive information relevant to an event that happens on the road (captured by a vehicle) as well as to receive data from the road infrastructure [5]. For infotainment applications we present a push model, with broadcast announcement of locally available services originated by an RSU, connected to the Internet and disseminated to vehicles. The data dissemination can be made more efficient by a cooperative sending of the information by vehicles. In a VANET, several solutions have been proposed for data dissemination. The work in [6] is based on a simple but quite effective way for reducing the redundant rebroadcasts and the consequent medium contention and collisions. The Distance Defer Transmission (DDT) protocol in [6] consists in relaying messages only by the receiver that is the farthest from the sender. The Road Oriented Dissemination (ROD) protocol [7] disseminates data separately in each direction, and optimizes data dissemination in the intersection. To fulfill the first two goals ROD, as DDT, uses the GPS position of the vehicle that is encoded in the header of the broadcast message. Additionally ROD encodes also the coordinates...
of intersections. The work in [8], on the basis of some geometrical rules, classifies vehicles according to the way they move and by this classification the propagation effect to vehicles in same roads is limited. A different kind of solution is proposed in [9]. The authors propose the Urban Multi-Hop Broadcast (UMB) protocol that selects the farthest node from the transmitter to relay a message and uses repeaters at intersections to retransmit a message and to overcome the problem of large buildings obstructing a message path. The objective of UMB is to avoid MAC collisions caused by hidden nodes, to efficiently use the channel, to make reliable transmission, and disseminate messages in all directions in an intersection. Mobility prediction is used in the paper of Lai et al. [10] where neighbors of the broadcasting vehicle are divided into several sets according to the movement direction. In [11] authors advocate the involvement of parked vehicles to overcome disconnections in sparse vehicular networks. They show that even a modest fraction of parked vehicles can strongly enhance coverage and connectivity in urban areas.

With respect to the previous literature our goals are:
- to define new beaconless dissemination techniques, based only on the position of the vehicles (without the use of extra relay devices) and able to extend the RSU service area up to several tens of times the radio coverage area of RSUs;
- to assess the proposed solutions under a general geometrical analysis;
- to verify the proposed solutions in dynamic scenarios with realistic vehicle and traffic conditions simulated via SUMO [12] under a continuous message flow.

III. Network Scenario

The reference scenario is an urban area with a limited number of RSUs having a partial coverage of the area interested in infotainment services. Each vehicle can collect its position data by a GPS device and can be represented by a couple of coordinates $OBU(x, y)$.

Let $N$ be the number of OBUs mounted on vehicles circulating in the considered area. Let $K$ be the ratio of the area of the considered map (RSU service area) and the area directly covered by the RSU. This parameter is the expansion ratio of the coverage of the RSU, obtained by OBU forwarding. If it were $K = 1$, then no multi hopping would be required and messages from RSU would be delivered directly to all OBUs. The bigger $K$, the larger is the virtual coverage of the RSU, gained by means of inter-vehicle message forwarding. Since we are interested in infotainment services having a local significance, practical areas of interest may range between few square km up to several tens of square km, that means $K$ ranging between few units up to several tens.

IV. Data Dissemination Algorithm

A key issue is reaching OBUs in the service area while avoiding the broadcast storm problem that can arise, especially in dense urban scenarios [13]. Indeed this problem may become very significant if the VANET is used for sending a flow of packets at a given bit rate. Following the logics of the Distance Defer Transmission protocol [6], we generalized it in the Distance Based Forwarding algorithm (DBF), that consists in relaying packets only by receiver that is the farthest from the sender. To do that, each vehicle that receives a packet waits for a defer timer which is inversely proportional to the sender-receiver distance before retransmitting it. In this way, the farthest vehicle retransmits the packet first. A second rule is that an OBU receiving multiple copies of a packet is inhibited from transmission of such packet. We propose three different algorithms that are based on the same mechanism of DBF, but they apply simple geometrical rules based on the positions of the sending nodes that are used to allow the data to cross intersection of roads and to propagate toward multiple directions. The three algorithms, called Single Angle Forwarding (SAF), Two Angles Forwarding (TAF) and Multi-Two Angles Forwarding (MTAF), use different geometrical conditions based on a given parameter, denoted as $\delta_{th}$, to take the forwarding decision.

A. Triangle forwarding rule

When a node receives the same packet from two different nodes, it is able to define a triangle with as vertices the three involved vehicles (see Figure 1). It uses the following geometrical information: its position, according to the on board GPS device, $RX(x, y)$; the position of the node that has transmitted the first received copy of the packet, $TX_1(x, y)$; the position of the node that has transmitted the second received copy of the packet, $TX_2(x, y)$. Similar to DBF, in our algorithms when node $RX$ receives a packet from another node (e.g. $TX_1$ in Figure 1), it schedules its transmission after a time interval $\eta = T_{forward}(1 - d/r)$, where $T_{forward}$ is a constant that scales $\eta$, $d$ is the distance $TX_{1,2}-RX$ and $r$ is the OBU transmission range. If, during $\eta$, $RX$ receives the same packet from another node (e.g. $TX_2$ in Figure 1), DBF directly discards the packet, while in our three algorithms the forwarding decision of RX is updated on the basis of a condition related to the triangle of vertices $RX$, $TX_1$ and $TX_2$. If this condition is verified, the packet will be forwarded at the end of the time interval $\eta$, otherwise node RX discards the packet.

In the first algorithm, called SAF (Single Angle Forwarding), node $RX$ calculates $\cos \alpha$ (see Figure 1) and compares it with a given threshold $\delta_{th}$. Node RX broadcasts the packet after a time interval $\eta$, if $\cos \alpha < \delta_{th}$. The SAF algorithm performs the following steps:

1) RX receives a packet $p$ from $TX_1$;
2) the packet $p$ is marked with the flag $z_p = 1$ and RX starts the timer $\eta$;
3) if during $\eta$, RX receives another copy of $p$, from $TX_2$ (see Figure 1), it computes the triangle rule for $TX_1$ - RX - $TX_2$;
4) if the triangle rule condition is verified the packet flag is not modified, otherwise the packet flag is set $z_p = 0$;
5) if during $\eta$, RX receives the $n$-th copy of $p$, from $TX_{n}$, it computes the triangle rule for $TX_{n-1}$-RX-$TX_{n}$, setting
the flag $z_p$ as in 4); 
6) when the timer $\eta$ expires, the packet $p$ will be forwarded only if its flag is $z_p = 1$.

In the second version of the algorithm, called TAF (Two Angles Forwarding), node RX calculates the cosines of the two angles $\alpha \in \beta$ in Figure 1 and forwards the packet if both of angles are lower than the threshold $\delta_k$. As SAF, TAF performs the previous 6 steps using the condition on two angles.

The last version is called multiple TAF (MTAF). This is similar to the previous one, but in this case the node RX performs more controls before the packet forwarding. As TAF, MTAF performs the previous 6 steps using the condition on two angles, but the fifth step is modified as follows:

5) if during $\eta$, RX receives the $n$-th copy of $p$, from $TX_n$, it computes the triangle rule for $TX_m$-RX-$TX_k$ with $m = 1, ..., n - 1$ and $k = m + 1, ..., n$, setting the flag $z_p$ as in 4).

V. PERFORMANCE ANALYSIS

We analyze the performance of our algorithms under two different perspectives: i) the geometrical behavior of the proposed solutions in graphs that can be assumed representative of urban VANETs; ii) the dynamic behavior of the proposed solutions in a simulated urban area with specific traffic patterns. As for the first analysis the aim is to assess the benefits of the proposed geometrical rules and to better highlight the differences among the three proposed algorithms. In the second case instead, the simulations account for vehicle mobility with all road and intersections details, for the protocol stack (network down to PHY layers) and for the radio channel.

In both cases, we consider a square area with orthogonal bidirectional roads. Square side length is $\ell$ km. The coverage expansion ratio is $K = \ell^2/(\pi r^2)$. In the following, $n_A$ vertical roads are referred to as “avenues”, and $n_S$ horizontal ones are named “streets”. A RSU is placed in the considered area in the middle of the most central road of the scenario. We analyze the performance of the data dissemination algorithms for different values of the average number $N$ of vehicles in the scenario. We define the average density $\rho = N/(2(n_A + n_S)\ell)$, that gives the mean number of vehicles per km of road lane.

A. Geometrical evaluation

When we focus on a single packet out of a flow from the RSU, we can safely assume that vehicles remain fixed. This is consistent with an urban environment where average speeds are relatively low. As a matter of example, if average speeds are upper limited to 30 km/h, vehicle movements are within the order of 1 m provided that the packet is spread in a time below 120 $\mu$s. We will discuss delay results later on. We study the dissemination algorithm performance from a geometrical perspective by using MatLab. In this phase we are interested in studying how the vehicular network performance are influenced by the network geometry and so, in this model, we do not consider the MAC layer and we use the free space propagation model, with the constrain that if two vehicles are located on different streets, they are able to communicate to each other only if they are near the same junction. The $N$ vehicles placed in the scenario are assumed to be uniformly scattered along all the available road lane (uniform density). As a first step, we studied the connection probability of the network formed by vehicles, that are nodes of a graph; two nodes are connected by an arc if they are within radio coverage. Figure 2, represents this probability as a function of the vehicles on a lane density $\rho$. It can be noticed that with $\rho = 20$ veh/km, the network is connected with a probability greater than 90%. We use this result to configure the network simulation parameters. Performance parameters that are of interest from a geometrical perspective are:

- $Q_{TX}$: fraction of the $N$ OBUs that transmit a packet (forwarding nodes);
- $Q_{NR}$: fraction of the $N$ OBUs not reached by the packet;
- $T_S$: packet spreading time, defined as the time elapsing since first emission of a packet from RSU up to the last packet forwarding in the observed area and expressed as a multiple of $T_{forward}$.

Fig. 2. Connection probability related to a network formed by vehicles in a Manhattan scenario as a function of the vehicles on a lane density $\rho$.

We compare our algorithms with DBF [6], and as for the $Q_{TX}$ parameter with a theoretical value, called $\text{minTeo}$, that indicates the minimum number of forwarding nodes needed to cover all streets and avenues that can be computed as $H \equiv \ell(n_A + n_S)/r - n_A n_S$, where the last term is subtracted out to account for avenue-street crossings. This number is obtained by considering that each road has a length $\ell$ and there are $n_A + n_S$ roads overall. Figures 3(a), 3(b), 3(c) present the numerical results obtained by averaging over 500 different
simulations, for $K = 12$, $n_A = n_S = 5$ and $r = 100$ m. Figures 3(a) and 3(b) show the fraction of the transmitting nodes and the fraction of the not reached nodes in the RSU extended coverage area as a function of the density $\rho$; Figure 3(c) shows the packet spreading time, expressed as the fraction of the time interval $T_{forward}$, as a function of the density $\rho$. From these results it is possible to notice that the three proposed algorithms outperform DBF, using the geographical information to cross the junctions in a more efficient way. In particular, the three forwarding rules enable a greater number of transmitting nodes than the DBF, decreasing the number of nodes not reached in the RSU extended coverage area.

Figures 3(a) and 3(b), point out that each algorithm presents a tradeoff in terms of the two performance indicators $Q_{TX}$ and $Q_{NR}$. SAF reduces the number of not reached nodes with respect to MTAF and TAF, but this result is obtained with more transmitting nodes than the other algorithms. As a consequence, MTAF presents the better performance tradeoff in terms of the first two performance parameters. However, if we consider the third performance parameter, $T_S$ (Figure 3(c)), it can be noticed that TAF has a better packet spreading time than MTAF. We can conclude that, at one hand, MTAF presents the best performance tradeoff in terms of packet delivery with the minimum effort, and so it can be suitable to spread a single packet (e.g., parking information, road blocked notification, etc.), on the other hand, TAF presents the best performance tradeoff in terms of packet delivery delay, and so it is particularly useful to spread a flow of packets (e.g., streaming video, downloading data from RSU, etc.).

### B. Dynamic evaluation

To perform a performance evaluation in a dynamic scenario, we have implemented our algorithms in a simulation stack, already used in literature for these networks [14], composed by three tools: SUMO (Simulation of Urban Mobility) [12], NS-2 (Network Simulator 2) [15] and MOVE (MOBility model generator for VEHicular networks) [16]. These three tools provide, respectively, the vehicle mobility, the network protocols simulator and the interface for the interworking between the two packages.

The scenario is a Manhattan street grid with traffic lights at every junction. Such a scenario is populated through SUMO. Precedence rules, traffic lights, and vehicle collisions are implemented. Vehicles movements are ruled by the car forwarding model of SUMO: $d(v_t) + g \geq d(v_f) + v_f \tau$ where, $d(*)$, is a function which is proportional to the distance to the next vehicle; $g$, is the distance between the two vehicles; $v_t$ is the speed of the leading vehicle; $v_f$, is the speed of the following vehicle; $\tau$ is the driver reaction time (usually 1 s). Through this model vehicles move in a very smooth way, which is very close to the real case, especially at road intersections. In our scenario, each vehicle enters the considered area in a given time instant $t_{in}$ in correspondence of the beginning of every street or avenue and moves towards the opposite side of such street/avenue in both directions. The vehicle exits the area at the opposite side of the entered street or avenue (at the time instant $t_{out}$). This procedure creates vehicle flows: by modifying the parameter of per-flow vehicles/min, we can get different densities within our scenario. For example, for $\rho = 16$ we generate 7 vehicles/min for every direction of every flow. It is assumed that the RSU broadcasts data with a constant rate $R = 1$ packet/RSU sec. Details on the parameters used in the considered scenario are reported in the Table I.

In this analysis we measured again the $Q_{TX}$ by averaging on all OBUs that implement a forward operation and for all packets emitted by the RSU during the simulation. We also measured two other performance parameters: Information Coverage: it is defined as the ratio between the number of packets received by an OBU and the overall number of packets emitted by the RSU in the period that the OBU crosses the map ($t_{out} - t_{in}$). This metric is averaged on all OBUs present during the simulation. MAC collisions: this metric provides information on the number of MAC collisions that occur in our scenario. It measures the number of collisions per OBU and per packet sent by the RSU.

Figures 4(a-c) are in case of traffic lights, while figures 4(d-f) are obtained without traffic lights.

From Figure 4(a) it emerges that TAF performs better than DBF for each traffic density, because of the better spreading which is granted by the triangle rule: we can get a visual idea of this behavior through Figure 5, which displays the nodes that actually do perform the forwarding operations. From this Figure it can be noticed that TAF is able to cover areas which result totally uncovered by the other algorithms. Such better spreading is also endorsed by Figure 4(b), where we notice a greater number of copies produced by DBF, which is a parameter that strongly decreases and then converges to the TAF one, according to the density (better network coverage needs less smart forwarding policies). Clearly, flooding, because of the already quoted broadcast storm problem, performs really bad for every metric examined and especially for MAC collisions (Figure 4(c)), which are definitely higher for flooding and about the same for DBF and TAF, mostly caused by close proximities when vehicles are queued because of traffic lights.

It is important to notice that after a certain density, network performance deteriorates, as we can see in Figure 4(a) for $\rho \geq 27$ veh/km. As we increase vehicle density, traffic becomes bursty, with long queues at every traffic lights. As a consequence, traffic congestion becomes higher, cars concentrate at crossroads, thus occasionally leading to disconnections in the network graph, which lead to a worst information coverage. This phenomenon is confirmed by Figure 4(d) representing the results measured in scenarios without traffic lights, but only with precedence rules at junctions. In that case, junction crossing times are in the order of few seconds, at least one order of magnitude less than the traffic lights case. In this case the information coverage increases as the traffic density increases, as it happens for the initial behavior of the scenario with traffic lights. A similar reasoning holds for the fraction of re-transmitting nodes in Figure 4(e), with the only difference that after the previously specified density value, the number...
Fig. 3. (a) Fraction of transmitting nodes, in case of DBF, MTA, SAF, TAF, minTeo, (b) Fraction of not reached nodes, in case of DBF, MTA, SAF, TAF, (c) Message spreading time, in case of DBF, MTA, SAF, TAF, as a function of ρ.

Fig. 4. (a)-(c) performance analysis in a scenario with traffic lights; (d)-(f) in a scenario without traffic lights.

### (a) Scenario and vehicular traffic parameters

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<th>Values</th>
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<td>Number of vertical streets (n_a)</td>
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### (b) Network parameters

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<td>RSU Packet sending period (T_{RSU})</td>
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<td>Cosine threshold δ_{th} (TAF)</td>
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<tr>
<td>Location of RSU</td>
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### TABLE I

<table>
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<th>Parameters</th>
<th>Values</th>
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<td>Information coverage (%)</td>
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<tr>
<td>Collision (%)</td>
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</table>

(a) Information Coverage  
(b) Q_{TX}  
(c) MAC Collisions  
(d) Information Coverage  
(e) Q_{TX}  
(f) MAC Collisions
of forwarding nodes starts growing, because of the already stated vehicles high proximities issue. Finally, the MAC layer collisions without traffic lights (Figure 4(f)) have a totally similar behavior with respect to the traffic lights scenario case. The simulation results, shown in Figures 4(c) and 4(f), confirm the validity of the results of the network model presented in the section V-A, showing that the MAC layer collision effects can be neglected in this kind of networks if we use an efficient forwarding algorithm.

VI. CONCLUSION

A key component of services that can be provided by VANETs is the infotainment dissemination, allowing users on vehicles to receive road information or data from the road infrastructure. In this paper, we investigate the merits of using geographical information to disseminate data in a VANET. We propose three enhanced dissemination algorithms and show that they are able to outperform a powerful and simple dissemination mechanism, as the distance based forwarding algorithm, just using an additional information set, known or easily obtainable, by the vehicles. In particular, we have shown that the proposed solutions are able to increase the number of nodes reached by one or more broadcast messages, in an area greater than the physical coverage area of a RSU, without using additional signaling or any neighborhood information. Future work will focus on realistic map scenarios and unicast V2X communications.

REFERENCES


