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Traffic-Aware Opportunistic Data Delivery Strategy for Urban Vehicular Ad Hoc Networks

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Abstract

Adapting the frequently changed topology is the main task of data delivery in vehicular ad hoc networks. Making advantage of the characteristics that the mobility patterns and positions of vehicles are predicable, this paper presents an improved dynamic hop choosing mechanism for data delivery. It exploits predicting the positions and mobility patterns of vehicles, and also takes into account the vehicular traffic density. Accordingly, the next hop chosen by the proposed strategy is seldom out of reach even if the topology is quickly changed. Simulation results show that our approach improves the packet delivery ratio and reduces the network latency when compared with state of the art protocols.

Keywords: vehicular density aware; opportunistic delivery; position-based routing

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1. Introduction

Vehicular ad hoc network (VANET) is a kind of mobile ad hoc network providing inter-vehicular communication. There are different ways for vehicles to deliver data to each other, mainly classified as infrastructure-based or infrastructure-free. VANET are self-organized networks that can run without any prior infrastructure. This characteristic of VANET is valuable, especially in some extreme situations, when it is costly to deploy any infrastructure.

IEEE802.11p is published in 2010 by IEEE 802 committee. It is a wireless communication standard for wireless access in the vehicular environment. It is used with dedicated short range communication system, which works well both for vehicle-to-vehicle communication and vehicle-to-infrastructure communication. The media access problem for nodes in VANET is solved by and large. However, routing in VANET is still a challenging task due to the high vehicular mobility and frequently changing topology.

Numbers of routing protocols for data delivery have been proposed in literature. We categorized them into two categories: topology-based and position-based. Topology-based routing protocols forward packets on the basis of topology information of the network. It works well in traditional networks even in MANET (Mobile Ad Hoc Network), but fails to keep the stability when exploited by VANET. The inherent nature of highly dynamic vehicular networks, caused by fast moving vehicles, results in frequently topology changes. That means the link states are unstable, hence the topology

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information used to make routing decision is unstable. That directly degrades the performance of the topology-based routing protocols. Unlike the former, position-based routing protocols forward packets according to the position information of the nodes participating. These kind of protocols are usually stateless, with no need for keeping the knowledge of link state information which is frequently changed and is accordingly less useful. They use the position information to make the forwarding decision. Thus, the forwarding strategy is not susceptible to the dynamic topology. Topology-based routing is more and more acceptable as on-board GPS devices are extensively used nowadays. Vehicles can read their own position information from GPS devices, and share it with their neighbors. Then vehicles can get others' position if they want to, then make routing decision according to the position information. So, position-based routing protocols have gained extensive attention. Some researchers have formally proved that the position-based routing algorithms are more scalable and outperform topology-based routings for highly dynamic vehicular networks [2].

The rest of this paper is organized as follows. Section 2 describes the related work on position-based routing. In section 3, we detail our design scheme of junction selection, node selection and failure management. Section 4 demonstrates and analyzes the simulation results which verified the efficiency of our proposed scheme. In section 5, we conclude this paper and present the future work.

2. Related Work

Kinds of position-based routing strategy for VANET have been proposed, such as Greedy Perimeter Stateless Routing (GPSR) [8] based on pure greedy forwarding, Geographic Source Routing (GSR) [11] based on a street level digital city map, improved Greedy Traffic Aware Routing protocol (GyTAR) [6] based on a dynamic junction selection mechanism, and Enhanced GyTAR (E-GyTAR) [1] which enhances the junction selection mechanism of GyTAR.

E-GyTAR is designed for routing in city environment. It assumes that vehicles in the discussed network have GPS devices, digital maps, and IFTIS on board, and always adopt some location services. GPS devices provide the vehicles their own geographic positions. Location services such as Grid Location Services (GLS) [10] provide the vehicle with their ultimate destination's position. Digital maps can provide the position information of the junctions in the city. IFTIS [5] is the infrastructure-free traffic information system which can calculate the real time vehicular density between adjacent junctions. These assumptions are reasonable, because of the sufficient power supplying and processing capacity vehicles always have.

The moving pattern of vehicles in city scenario is predicable, as they must move along the streets. With the help of the on-board digital map, all the packets traveling routes can be presented by series of junctions. Hence junction selection is the core job while working out the route. In E-GyTAR, each candidate junction is scored based on its position and the directional density [1]. Forwarding vehicles dynamically score the neighbor junctions using Eq. (1).

$$score(N_j) = \alpha \times (1 - \frac{D_n}{D_c}) + \beta \times Den_{Dir} \tag{1}$$

where D_n is the curvemetric distance (the distance measured following the geometric shape of the roads passing by) between the candidate junction N_j and the destination, D_c is the curvemetric distance from the current junction to the destination, Den_{Dir} is the total number of vehicles between current junction and next candidate junction moving towards N_j, which represents the directional density, α and β are the weighing factor for the distance and traffic density respectively, and add up to 1.Junction with the highest score among the neighbor junctions is selected as the target junction when the source generate a packet, or each time a packet comes to a junction. As for the segment between the two involved junctions, E-GyTAR exploits improved greedy approach.

When E-GyTAR suffers from local maximum problem (the forwarder is the closest among its neighbor to the target junction), the forwarder will carry the packet until it arrived at the target junction or until another node closer to the target junction appears. This recovery strategy is called *carry and forward*, and is exploited by a large number of position-based routing protocols.

3. TAO-Traffic Aware Opportunistic Data Delivery

The proposed data delivery mechanism improves aforementioned selecting strategy for junctions and next forwarders, and also improves the recovery strategy used by E-GyTAR. We make a reasonable assumption that vehicles have GPS, digital maps, GLS and IFTIS on board. TAO dynamically selects the junctions consisting a routing path. When a source vehicle generates a packet or each time a packet arrives at a junction, the neighbor junctions are scored. Packets are relayed as a combination of opportunistic way and the way proposed by [4]. When a packet encounters a local optimum, the local optimal node will score its neighbor vehicles and itself, and decide whether to forward the packet or carry it. The following subsections details these three main procedures.

3.1. Next Junction Selection

We make the junction selection dynamically to adapt the frequently changing topology of VANET. Some exit routing protocols [3] settle down a junction sequence in advance, using some Dijkstra alike shortest path algorithm. However, we find a risk that there may be no vehicle on some segments in the predetermined junction sequence, where there is no node for data delivery.

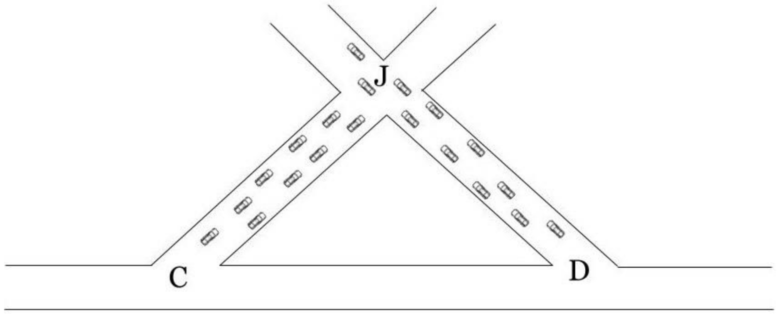

Figure 1. Find a path according to the density

Consider the situation in Figure 1, node at junction *C* wants to transmit a message to junction *D*. Road *CD* will be selected as the path if shortest path algorithm is exploited, even if there is no vehicle on that road segment. If *CD* is selected, vehicle has to carry the packet from junction *C* to junction *D* as there are no nodes in the segment to pass the packet on. However, the speed of a moving vehicle is much slower than the speed of wireless radio. Carrying packet on costs much more time than passing the packet towards junction *J*, then junction *D*.

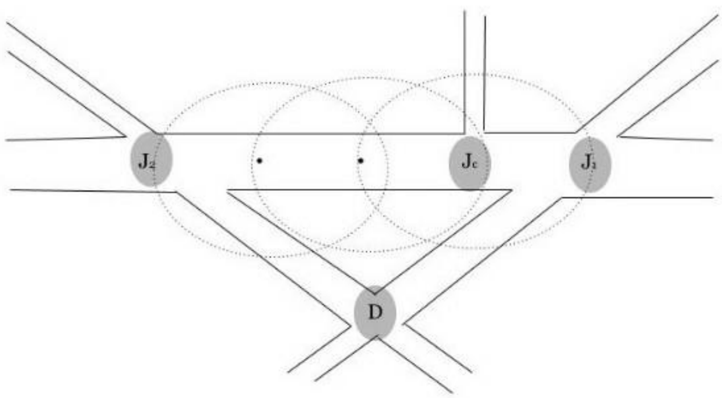

Figure 2. Dynamic junction selection mechanism

For this reason, we score the next neighbor junction, when a node finds itself around a junction, to avoid this kind of empty road segment being selected. A node can recognize itself around an intersection by computing the correlation coefficient of its neighbors. When a node determines itself at a junction, it scores the neighbor junctions of the current junction. We use curvemetric and path density, but not the ratio [illegible] and directional density as mentioned in E-GyTAR, to score a junction. On one hand, considering the scenario in Figure 2, the score of junction J_2 is larger than the score of junction J_1 if we use Eq. (1). That means J_2 will be chosen as the next junction, which is obviously wrong since J_c can directly relay the packet to J_1, but needs 2 more hops when relaying packets to J_2. Apparently, choosing junction J_1 is more reasonable. On the other hand, using path density is more sensible than using directional density to evaluate if there are enough nodes in the radios range. The reason is the node moving speed is very much smaller than the wireless radio transmitting speed. When choosing the next hop, there is no need to consider its moving direction. So, we redesign the junction selection algorithm as followed (pseudo code):

```
For (all candidate junctions Jn) {
        D := the destination;
        Jc := the current junction;
        Jt := the target junction;
        Dcd := the Euclidean distance between Jc and D;
        Dnd := the curvemetric distance from Jn to D;
        Dcn := the curvemetric distance from Jc to Jn;
        Navg:= average number of vehicles per cell;
        Ncon := constant which represents the ideal connectivity degree we can have within a cell;
        calculate score (Jn) using Eq. (2) with α + β=1;
}
```

$$score(J_n) = \alpha \times \frac{D_{cd}}{D_{cn} + D_{nd}} + \beta \times \min\left(\frac{N_{avg}}{N_{con}}, 1\right) \tag{2}$$

The junction of the highest score is selected to be the next target junction. After finding the target junction, the node writes this useful information in the header of the packet. Along all the way the packet travels before it arrives at the target junction, every node who receives the packet will know its target junction by reading the packet header. This selecting mechanism takes into account both the traffic density and the candidate junctions' position.

3.2. Opportunistic Data Delivery

TAO is a position-based routing protocol which does not employ greedy forwarding but opportunistic forwarding. As reference [7] indicates greedy forwarding based on the position of the destination may not be the best choice. The furthest node chosen in this way is very likely on the edge of the radio range of the relay node. Hence it is more likely that the node will move out of the radio range during the interval between two beacon messages. This can cause route breaking. Abandoning all these furthest nodes to avoid route breaking would certainly cause less packet advance every hop, accordingly more hop counts during packet travelling. So, opportunistic data delivery is employed to eliminate this unnecessary sacrifice.

Traditional opportunistic forwarding makes the sender determine the forwarding set, and attached the list of the set to the packet to inform every receiver. TAO makes every neighbor of the sender calculate itself whether it is in the forwarding set, using Eq. (3).

$$\sqrt{(long_{\_N} - long_{\_B})^2 + (lat_{\_N} - lat_{\_B})^2} \le r \tag{3}$$

where $long_{\_N}$ is the longitude of the receiver, and $lat_{\_N}$ is the latitude of the receiver, $long_{\_B}$ and $lat_{\_B}$ are the longitude and latitude of the sender's neighbor which is nearest to the target junction. These nodes form the forwarding set, which is the hatched area in Figure 3. *C* is the current forwarding node, *B* is *C*'s neighbor which is nearest to target junction *J*. The reason for choosing nodes in this area is because they are all in each other's transmission range, which makes the best guarantee that every node receives a packet from others and suppress its own forwarding.

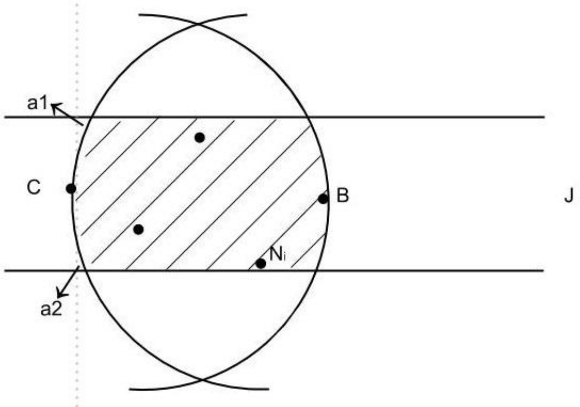

Figure 3. Forwarding set selection

The forwarding set selection is not done by the current forwarder, but by all its neighbors who have received the packet from C. This mechanism largely reduces the protocol cost, as there is no need to transfer the forwarding set by adding it before the payload of a packet. Each neighbor computes its identity using Eq. (3) the moment it receives the packet. If it is not in the forwarding set, it just drops the packet. Otherwise, it has to set a timer before which it should listen to the other neighbors in the forwarding set. If there is someone forwarding the packet with a same sequence number, the listener drop the exact packet it has just received. The listener should forward the packet when the timer elapses, and hasn't yet heard any forwarded packets from others.

<table>
<tr><td colspan="4">802.11p Header</td></tr>
<tr><td>Dest</td><td>TarJun</td><td>BestFor</td><td>Tag</td></tr>
<tr><td>Source</td><td>ThisHop</td><td>SerNum</td><td>……</td></tr>
<tr><td colspan="4">Payload</td></tr>
</table>

Figure 4. Packet header format

To achieve this purpose, we redesign the packet header as Figure 4. Where *Dest* is the position of the ultimate destination, *TarJun* is the target junction selected using algorithm described in section 3.1, *BestFor* is the best next hop which is computed out by the current forwarder, whose position is the nearest to the *Dest*. *Tag* in the header stands for the position of the node that generates this packet. If it is a junction node, this field should be set to 1, otherwise be set to 0. When a node received a packet, it should detect the change of this field. If it changes from 0 to 1, it indicates that the packet comes to a junction from a straight road segment. Then, the next junction selection algorithm should be triggered, and the *TarJun* filed must be update. Otherwise, the node just set a timer using Eq. (4).

$$T = RT \times \frac{(CB - CN) + BN}{CB + \max\{BN_i + CN_i\}} \tag{4}$$

where *CB* is the distance between node *C* and *B*, *CN* is the distance between node *C* and *N*, *BN* is the distance between node *B* and *N*, N_i stands for an arbitrary node in forwarding set and *RT* is the retransmission timer which is set to be $2 \times Prop + C$ [9], *Prop* is the propagation delays account for the time it takes for the broadcast to reach the desired node and to come back, *C* is the maximum forwarding delay which varies with the transmission rate and the processing time. A node in the forwarding set has to forward the packet only when the timer elapses.

As for the packet sender, if it experiences repeated retransmit timeouts, it then retransmits the packet to a specific forwarder selected by a conventional algorithm [4]. This kind of packet loss is mainly due to the collision caused by opportunistic delivery. This scheme makes the data delivery more intelligent and more scalable.

3.3. Recovery Mode

There is still a risk that the packet gets stuck in local optimum. E-GyTAR and many other position-based routing algorithms adopt unconditional carry and forward approach as the recovery strategy. However, this decision may result in unnecessary packets dropping sometimes. As in Figure 5, node C encounters a local optimum, and it will carry the packet rather than relay it to node N. In fact, node N will be closer to the destination than node C a few minutes later. Through our recovery strategy, node C can know this potential candidate forwarder. In TAO, when packets gets stuck in local maximum, the node immediately scores itself and its neighbors, and chooses the one of the highest score to forward the packet to. Eq. (5) describes how to compute the score of every node, including the calculating node itself and all its one hop neighbors.

$$score\ (N)=m[\ \gamma (1-d/L)+\ \lambda (v/v_{max})] \tag{5}$$

where *d* is the distance between the scored node and the target junction, *v* is the velocity of the node being scored, *L* and v_{max} are the length and maximal velocity respectively of the road segment, which can be got from the on board digital map, γ and λ are the weighting factors for the distance and speed (with $\gamma + \lambda = 1$), m is the directional factor with 1 for node moving towards the target junction and -1 for those moving towards the opposite direction.

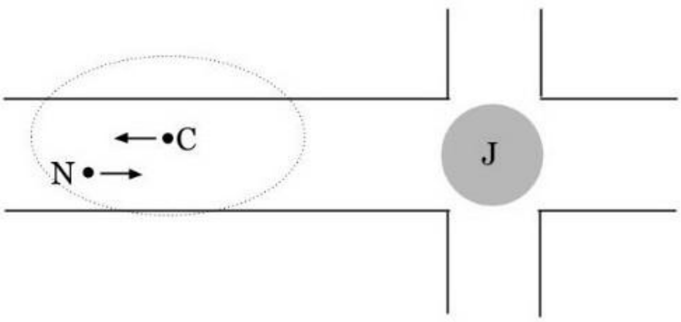

Figure 5. Enhanced carry and forward

4. Simulation

We compared the performances of TAO with state of the art protocols. The experiments were conducted on NS-2 simulator. Medium access control (MAC) is IEEE 802.11p, with a radio range of 260m. The mobility traces were generated by VANetMobiSim with the micro-mobility controlled by IDM_IM. Table 1 illustrates the simulation parameters.

Table 1. Simulation Parameters.

Parameter	Value
Simulation time	400s
Dimension	2500m ×2000m
Number of intersection	20
Number of roads	42
Number of vehicles	100-300
Average vehicle speed	45Km/h
Transmission Range	260m
Packet sending rate	0.1s-1s
Packet size	128 B
Weighting fators (α ; β)	(0.5 ; 0.5)
Weighting fators (γ ; λ)	(0.5 ; 0.5)

4.1. Effect on Packet Delivery Ratio

Figure 6 illustrates the packet delivery ratio increases as the traffic density increases. This is because the probability of connectivity will be higher in higher traffic density. It is also the key reason of our proposed strategy taking into account the vehicular traffic density. TAO shows better in PDR because of the opportunistic data delivery algorithm and the enhanced recovery mode it adopts. Opportunistic forwarding can reduce packet loss due to the reduction of route breaking. Primitive carrying decision of other protocols when encountering local optimum will contribute to the packet loss rate.

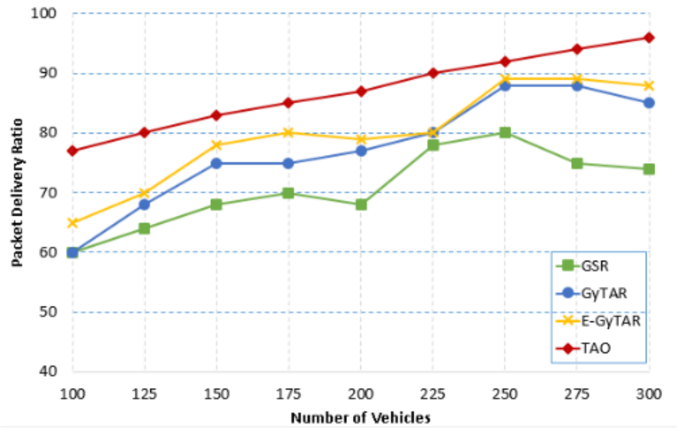

Figure 6. Packet delivery ratio

4.2. Effect on Average Latencies

Figure 7 shows that TAO overcomes the other three protocols in network average latencies. This is because the junction selection mechanism of TAO is the most reasonable. As is discussed in section 3.1, the next junction selection algorithm always chooses the candidate junction closest to both the destination and the current junction. In the meantime, the traffic density on the path is also given consideration to. This always makes packets travel faster and with fewer forwarding hops, consequently smaller latency.

4.3. Effect on Routing Overhead

GSR shows higher routing overhead than the other three in Figure 8. This is because it sends more control messages. The routing overhead increases as the number of vehicles increases, but TAO is always lower than the other two and many other opportunistic routing protocols. This is because TAO attached less control message on data packets and had a transmission schedule to suppress packed duplication. This makes TAO has smaller communication traffic and routing overload than the other two.

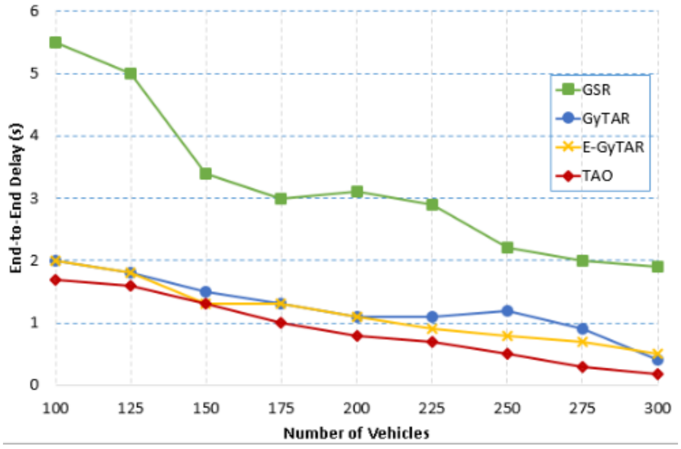

Figure 7. Average latency

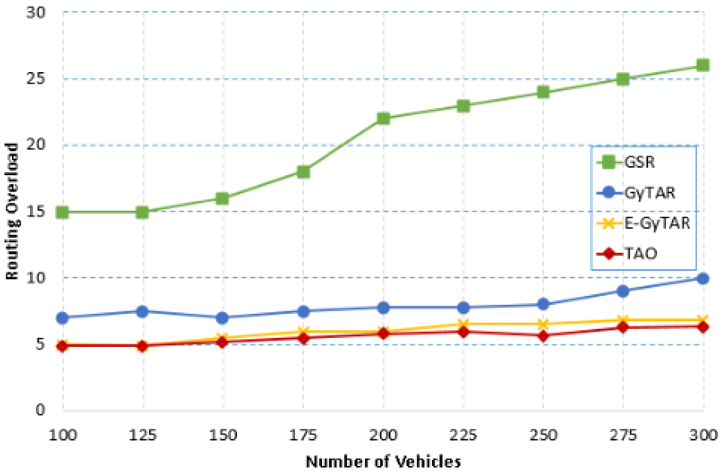

Figure 8. Routing overload

5. Conclusion

This work aims to improve the routing efficiency of data delivery in vehicular ad-hot networks. The simulation results have proved the proposed scheme works well in VANET with various vehicular traffic in city environment. The proposed algorithms have improved the delivery ratio and reduced the network latencies in different node densities compared to some other routing protocols. In the future, we will try to analyse the impact of the weighting factors used for calculating junction score in the future.

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