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QoS Support in Delay Tolerant Vehicular Ad Hoc Networks

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***Abstract*—In this paper, we propose a new intersection-based geographical routing protocol, called delay tolerant routing protocol (DTRP) that adapts to the changes in the local topology within city environments. DTRP is based on an effective selection of road intersections through which a packet must pass to reach the gateway to the Internet. The selection, in such delay tolerant VANETs, is made in a way that maximizes the connectivity probability of the route between mobile nodes and the gateway while maintaining a threshold for the end-to-end delay and the hop count within the network. To achieve this, we formulate the QoS routing problem mathematically as a constrained optimization problem. Specifically, analytical expressions for the connectivity probability as well as the delay and hop count of a route in a two-way road scenario are derived. Then, we propose a genetic algorithm to solve the optimization problem. Numerical and simulation results show that the proposed approach gives optimal or near-optimal solutions and improves significantly the VANETs performance when compared with several prominent routing protocols, such as GPSR, GPCR and OLSR.**

***Index Terms*— VANETs, delay tolerant routing, Quality of Service, performance analysis.**

I. Introduction

Many existing research consider vehicular ad hoc networks as a vehicle-to-vehicle or a vehicle-to-road side unit network architecture that can be easily deployed without relying on expensive network infrastructure. Nevertheless, enabling the communication between vehicles and pre-existing fixed infrastructure such as gateways to the Internet opens up a plethora of interesting applications to both drivers and passengers. The promising applications and the cost effectiveness of VANETs constitute major motivations behind the increasing interest in VANETs [1], [2]. The success of VANETs revolves around a number of key elements such as message routing between the mobile nodes (MNs) and the gateway to the Internet. Without an effective routing strategy, VANETs' success will continue to be limited.

The criteria for building these routes depend on the intended applications. For example, if a node is sending text messages, delay can be tolerated. On the other hand, if a node is downloading audio or video (multimedia application), time is critical and delay is not tolerable. Hence, a message routing scheme will depend on the performance metric to be optimized and the QoS constraints that should be taken into consideration.

VANET applications are categorized into delay tolerant and delay sensitive applications. In this paper, we focus on delay tolerant data routing between MNs and a gateway in VANETs, where the MNs are allowed to carry and forward data packets. Even though VANETs are considered to be a class of MANETs, they exhibit specific challenges due to their distinctive network characteristics. These features can be summarized in a frequently changing topology and high node mobility, leading to network disconnections. Consequently, it is imperative to devise new routing protocols for VANETs to ensure a reliable message routing. However, it remains a challenging task to find and preserve a route in VANETs. Given the highly changing nature of VANETs, the implementation of routing protocols can not be a static one.

A number of routing protocols have been developed for wireless ad hoc networks. Depending on the type of information used for routing, they can be classified into two categories: topology-based and position-based routing. Classical routing approaches for ad hoc networks are topology-based, such as OLSR [3], DSR [4], and AODV [5]. Topology-based means that routing decisions are taken based on existing links among network nodes. When nodes move, links change and paths must be recalculated. In a very dynamic scenario, such as VANETs, where network topologies change frequently and quickly, the control overhead generated to calculate routes can be extremely high, resulting in very low-performance networks [6].

In contrast to topology-based routing methods, in position-based forwarding protocols, such as DLS [7], GPSR [8], and GPCR [9], routing decisions are based on nodes' geographical coordinates. Such an approach seems to be more efficient for highly dynamic scenarios, like VANETs. In position-based methods, each node creates and maintains updated location table, containing the geographical position of all the neighbors. Nevertheless, the underlying position-based protocols do not consider characteristics of vehicles movement in their routing process and thus do not maintain stable routes (i.e., do not take into account the connectivity probability of the selected path). As such, in this paper, we capitalize on the position-based routing protocols that provide Internet access to the MNs, while satisfying QoS constraints on tolerable delay and bandwidth usage.

To this end, we first propose in this paper a Delay Tolerant Routing protocol (DTRP) that uses up-to-date information about the local topology in order to find optimal or near-optimal routes between MNs and the Internet gateway. The selection is made in a way that maximizes the connectivity probability of

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the selected path while satisfying QoS constraints such as the maximum tolerable delay within the network and the bandwidth usage. To achieve this, we formulate the QoS routing as a constrained optimization problem. Specifically, analytical expressions of connectivity probability, tolerable end-to-end delay and hop count for a two-way road scenario are derived. Then we propose a genetic algorithm in order to solve our NP-complete optimization problem. Numerical and simulation results show that the proposed protocol achieves an optimal or near optimal solutions, especially in sparse networks. Therefore, it stands out as a promising candidate compared to the well-known protocols: GPSR [8], GPCR [9] and OLSR [3].

The remainder of this paper is organized as follows. Section II describes our proposed DTRP protocol. In Section III, we present the analytical framework used to evaluate the QoS routing problem. In Section IV, we formulate the QoS routing problem as an optimization problem. Numerical and simulation results are presented in Section V. Finally, Section VI contains our concluding remarks.

II. Delay Tolerant Routing protocol

In this section, we introduce the DTRP protocol. First, we present the system model used to build our framework. Then, we present the functionality of DTRP.

In DTRP, a sending node needs to know the route which it should use to forward data packets to the Internet gateway. This information is provided by the Internet gateway. This gateway functions also as a location server where it is responsible for saving current location information about all MNs in its vicinity. This can be addressed using our previously proposed location service management protocol RLSMP [10]. Specifically, each vehicle reports its location information to the gateway each time it moves one transmission range farther from its previous location. This enables the gateway to have a view of the local network topology where it stores a detailed information about the MNs that it manages. This information contains the node ID, the transmission range T_r, X and Y coordinates of the node location, time of the last update, and velocity and direction of the node's movement. Moreover, we consider that each node can determine the position of its neighboring road intersections through pre-loaded digital maps, which provides a road-level map. This can be done when vehicles are equipped with an on-board navigation system.

The functionality of DTRP is as follows. In DTRP, the gateway constructs a set of routes between itself and the mobile nodes based on its view about the local network topology. Nevertheless, one should note that if these routes consist of intermediate mobile nodes, these routes can not be considered to be stable due to intermediate nodes' mobility. To increase their stability, DTRP builds routes based on intermediate and adjacent road intersections towards the gateway as described in Figure 1 These routes are called backbone routes. Figure 1 shows three alternative backbone routes (2-3-4, 2-5, and 1-6-5) between a mobile node and the gateway.

The service provided by VANETs, which is delivering text messages to the Internet, can tolerate delay. In order to meet the end-to-end delay requirement, the selected backbone routes should have high connectivity probability. In low density roads, one way to increase the connectivity probability is to increase the transmission range Tr of the MNs. On the other hand, when the road density increases, the Tr should be reduced to avoid high interference; but the Tr should still guarantee high connectivity. Hence in DTRP, the gateway will decide on the transmission range that each vehicle should use in order to achieve high route connectivity.

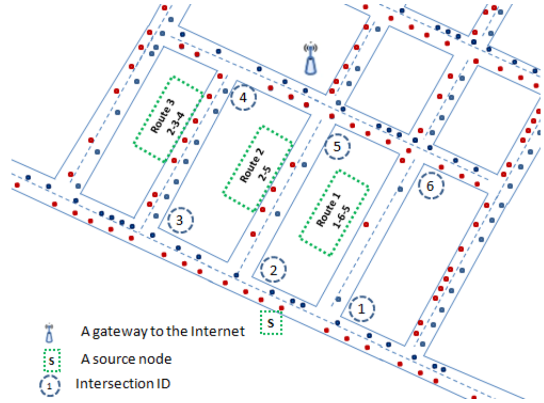

Fig. 1. Message routing in DTRP

Algorithm 1 Delay tolerant routing protocol

In the network
if (gateway) **then**
  if there is significant change in the node density **then**
    Recalculate the transmission range;
    Recalculate the routes between the different intersections and the gateway;
    Send this data to the nodes in the network;
  end if
end if
if (a mobile node) **then**
  Receive the updated information;
  Adjust the transmission range;
  Save the updated route information;
  Use this route to forward the data packets to the Internet gateway;
  Send the current detailed information to the gateway;
end if

It is worth noting that VANETs exhibit a bipolar behavior, where it may have a connected topology with high traffic volume (high density) or sparse topology where the traffic volume is low (low density) [11]. This implies a variation in the traffic patterns, which DTRP aims to mitigate. Variation in traffic patterns results in variation in data sent by the mobile nodes. In this case, each gateway will adjust Tr values and will construct backbone routes that adapt to the changes in the data received from the mobile nodes in its vicinity. Algorithm 1 illustrates the functionality of DTRP. Significant change in the node density triggers recalculating of both T_r values and backbone routes. Table I illustrates the ranges of node density and the corresponding T_r values; more details will be presented in Section V.

In the following, we present the analytical framework which DTRP uses to derive the connectivity probability, end-to-end delay, and hop count.

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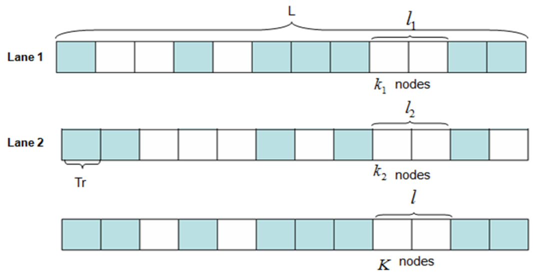


Fig. 2. Two lane road segment

III. Analytical Framework

The road network is modeled as a road graph $G = (V, E)$ consisting of junctions (i.e., intersections of roads) $v \in V$ and road segments $e \in E$ connecting these junctions. DTRP considers a two-way road scenario, where the vehicles are moving in two opposite directions on each road segment; the messages are relayed in the same direction of the vehicles' movement direction. Each road segment is modeled as shown in Figure 2. The road segment is divided into equal slots. Each slot corresponds to one transmission range T_r. That is, the two lane road is divided into slots according to the transmission range of the nodes.

DTRP adapts to changes in the information received from the mobile nodes. In DTRP, the local gateway needs to have an up-to-date view about the local network topology, so that it can update the estimated statistics about each segment in the road graph G. These statistics include: (i) the average speed of nodes on the segment j (denoted by $\widehat{S}$); and (ii) the average spatial node density (denoted by γ_1 and γ_2 for lanes 1 and 2, respectively).

In the following sections, analytical expressions for the connectivity probability P_c, the delay D, as well as the hop count H_c of a backbone route y in a two-way road scenario are derived. The backbone route y consists of a number of intersections $v_1, v_2, ..., v_m$ which are connected by a set of road segments $e_1, e_2, ..., e_n$; $n = m - 1$.

A. Connectivity Probability P_c

To compute P_c, let us first derive the connectivity probability P_{cj} of the road segment j ($j \in \{e_1, e_2, ..., e_n\}$). In this work, data packets are relayed in the same direction as the vehicles' movement direction, as opposed to the strategy proposed in [12]. To increase the connectivity probability, one may be able to take advantage of the vehicles moving in the opposite direction on a two-way road scenario (see Figure 2).

In this context, let us define a broken link between two consecutive vehicles N_i and N_{i+1} within a road segment j as a link with length $l = X_i > T_r$. This broken link is fixable if there are vehicles in the opposite direction within the transmission range of each other and connecting N_i to N_{i+1}. This implies that the distance between any two consecutive vehicles of the new path on lane 2 must be smaller than the transmission range T_r.

Let $k1$ and $k2$ be random variables denoting the number of vehicles that are present in an interval of length T_r on lanes 1 and 2, respectively (see Figure 2). Assuming that the vehicles on both lanes are uniformly distributed with the node spatial density γ_1 for lane 1 and γ_2 for lane 2, then $k1$ and $k2$ are Poisson distributed with the probability mass function given as follows:

$$f(k_1) = \frac{(\gamma_1 T_r)^{k_1}}{k_1!} e^{-\gamma_1 T_r} \tag{1}$$

$$f(k_2) = \frac{(\gamma_2 T_r)^{k_2}}{k_2!} e^{-\gamma_2 T_r} \tag{2}$$

Using (2), the probability P_f that a broken link between two consecutive vehicles N_i and N_{i+1} is fixable can thus be given by:

$$\begin{aligned} P_f &= \prod_{k=1}^{\lfloor X_i/T_r \rfloor} (1 - f(k_2 = 0)) \\ &= (1 - e^{-\gamma_2 T_r})^{\lfloor X_i/T_r \rfloor} \end{aligned} \tag{3}$$

Note that the number of vehicles on lane 1 follows a Poisson distribution and the distance X_i between N_i and N_{i+1} is exponentially distributed with parameter γ_1. To compute P_{cj}, one should note that more than one broken link on lane 1 can occur. Let Q be a random variable denoting the number of broken links on lane 1. The road segment j will be considered as connected if all the Q links are fixable. Let $P_{c|Q}$ be the conditional connectivity probability given that there are Q broken links. $P_{c|Q}$ can be written as:

$$\begin{aligned} P_{c|Q}(q) &= \prod_{i=1}^{q} P_f \qquad \forall q = 0, 1, \ldots, C_j - 1 \\ &= (1 - e^{-\gamma_2 T_r})^{\sum_{i=1}^{q} \lfloor X_i/T_r \rfloor} \\ &= (1 - e^{-\gamma_2 T_r})^{(\alpha - \frac{(C_j - 1 - q)}{\gamma_1 T_r})} \end{aligned} \tag{4}$$

Where C_j denotes the number of nodes on lane 1 of the road segment j.To obtain the total connectivity probability of the segment j, it is important to know the probability mass function of Q (i.e., $P_Q(q), \forall q = 0, 1, \ldots, C_j - 1$). Recall that a link is broken if the distance between any two consecutive vehicles is larger than T_r. Let P_b be the probability that a link q is broken. Since the distance between any two consecutive vehicles is exponentially distributed, it follows that

$$P_b = Pr\{X_i > T_r\} = e^{-\gamma_1 T_r} \tag{5}$$

Hence,

$$P_Q(q) = \binom{C_j - 1}{q} \times P_b^q \times (1 - P_b)^{(C_j - 1 - q)} \tag{6}$$

Therefore, the total connectivity probability of the road segment j can be expressed as:

$$P_{cj} = \sum_{q=0}^{C_j - 1} P_{c|Q}(q) \times P_Q(q) \tag{7}$$

Finally, the connectivity probability of the backbone route which is formed by n road segments is given by:

$$P_c = \prod_{j=1}^{n} P_{cj} \tag{8}$$

It is worth noting that using 7, the gateway will estimate the transmission range T_r that each vehicle should use along each road segment in order to achieve high connectivity. To do so, it uses the node density values of the road segment j on both

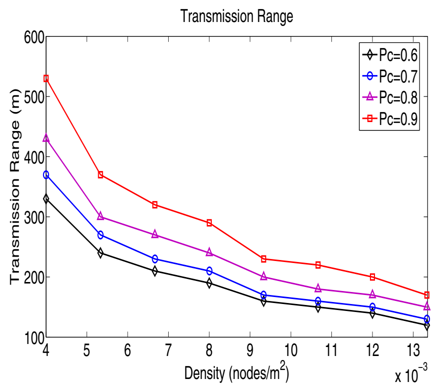


Fig. 3. Transmission range as a function of node density

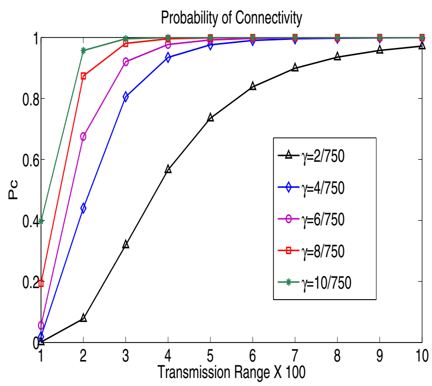


Fig. 4. Probability of Connectivity changes with both transmission range and node density

lanes 1 and 2 and decides on T_r that guarantees a probability of connectivity approaching 1.

To illustrate this, let us consider Figures 3 and 4. Figure 3 shows the relationship between the road density and the transmission range for different values of probability of connectivity. As we can see, when the node density is low, we need to increase the transmission range in order to achieve high connectivity. On the other hand, when the node density is high, a small transmission range value is enough to guarantee high connectivity.

From Figure 4, we can also notice that the connectivity probability increases with the increase of the transmission range. For example, when the density is $\frac{10}{750}$ a transmission range of $300m$ gives a connectivity probability approaching one. On the other hand, when the density decreases to $\frac{4}{750}$, the transmission range should be increased to $600m$.

B. Delay D

The end-to-end delay D of a backbone route y, defines how long it takes for a data packet to arrive at the gateway from the time it was sent out from the mobile node. Given the fact that route y from a mobile node to the gateway consists of a total number of road segments n and each road segment j has an estimated delay D_j, then D can be expressed as:

$$D = \sum_{j=1}^{n} D_j \tag{9}$$

The delay D_j depends on the number of mobile nodes C_j traveling on road segment j, and on the time required for a message to be transmitted between the two mobile nods N_i and N_{i+1} which are traveling on road segment j. The time required for a message to travel from a node N_i to node N_{i+1} depends on the strategy N_i uses to forward the message. If N_i uses hop by hop greedy forwarding the delay will be the time needed to process and transmit the message which is denoted as t_p. On the other hand, if N_i uses carry and forward strategy, the message carried by N_i will travel with the same speed S_i as that of the mobile node N_i. Thus the delay depends on S_i and the distance traveled by N_i while carrying the message until it is able to forward the message to the next mobile node N_{i+1}; i.e, when it comes within the transmission range of N_{i+1}. In order to estimate the delay D, two cases are considered.

case 1: one vehicle is allowed to forward the message along the road segment. This case occurs if the segment length L is less than one transmission range T_r. Let α be defined as $\alpha = \frac{L}{T_r}$. In this case, $\alpha \leq 1$. The delay of that segment will be t_p, where t_p is the time that the vehicle needs to process and transmit the message on that segment.

case 2: More than one vehicle are allowed to forward messages along the road segment. This case occurs when the road segment length is larger than the transmission range (i.e., $\alpha \geq 1$), which is likely to be the case in real networks. In this context, more than one hop is needed to forward the message along that segment.

Let K be a random variable denoting the number of vehicles present in the interval of length T_r on both lanes, as shown in Figure 2. Likewise, K follows a Poisson distribution with the following probability mass function:

$$f(K) = \frac{\left((\gamma_1 + \gamma_2)T_r\right)^K}{K!} e^{-(\gamma_1+\gamma_2)T_r} \tag{10}$$

In order to compute the delay on the road segment, the strategy that the mobile node uses to forward the message is considered. If the message is forwarded hop by hop, the delay on such a link will be t_p as in the first case. On the other hand, if the message is carried and forwarded by nodes, an estimate of the portion β of the road segment that does not have any node to forward the message is needed. In this case, the last node on that portion receiving the message is allowed to carry and forward the message along that portion. The vehicle will not transmit the message until it comes within the transmission range of another vehicle. This portion (β) can be estimated as:

$$\beta = f(K=0) = e^{-(\gamma_1+\gamma_2)T_r} \tag{11}$$

In this case, the average delay can be computed using the average speed of nodes on the road segment j (i.e., $\widehat{S} = \frac{\sum_{k=1}^{C_j} S_k}{C_j}$); recall that C_j is the number of nodes on lane 1 of the road segment j.

Thus, the average delay on the road segment j can be given as:

$$D_j = \begin{cases} t_p & \text{if } \alpha \leq 1 \\ \alpha(1-\beta)t_p + \beta\frac{L}{\widehat{S}} & \text{otherwise.} \end{cases} \tag{12}$$

C. Hop Count H_c

For a given backbone route y, the number of hops the message travels on one road segment j is controlled by the length (L) of the road segment and the transmission range T_r of the nodes traveling on that road segment. If L is less than T_r ($\alpha \leq 1$), then one hop will be enough to transmit the message on that road segment. On the other hand, if L is larger than T_r ($\alpha \geq 1$) the

TABLE I
PARAMETER SETTINGS

Parameter	Value	Parameter	Value
t_s	1000 sec	T_r	250m
t_p	3 msec [13]	μ	0.3
D_{th}	110 $\sim$ 170 (default 130)	θ	0.8
H_{th}	32 $\sim$ 44 (default 40)	N_g	20
S_k	50km/h	p_z	10

message can be transmitted hop by hop or it can be carried and forwarded. Thus, the average hop count on road segment j can be given as:

$$H_{cj} = \begin{cases} 1 & \text{if } \alpha \leq 1 \\ \alpha(1-\beta) + \beta C_j & \text{otherwise.} \end{cases} \tag{13}$$

Accordingly, the hop count of a backbone route y formed by n road segments is given by:

$$H_c = \sum_{j=1}^{n} H_{cj} \tag{14}$$

IV. Maximum Connectivity Probability

This section addresses the problem of finding the optimal or near optimal backbone route y which consists of a number of intersections $v_1, v_2, ..., v_m$ which are connected by a set of road segments $e_1, e_2, ..., e_n$; $n = m - 1$. Intersection v_1 is the first intersection in the backbone route that is connected to the source node and v_m is the last intersection in the route that is connected to the gateway. The optimal or near optimal backbone route is the route that maximizes the probability of connectivity while satisfying the constraints on both tolerable end to end delay and hop count. The gateway uses this objective function to decide on the backbone routes used by the MNs in its vicinity to forward their data packets.

This approach is formulated as an optimization problem. The objective function is given as follows:

$$\max_{y} P_c(y) \tag{15}$$

$$P_c(y) = \prod_{j=1}^{n} P_{cj}(y) \tag{16}$$

subject to

$$D(y) = \sum_{j=1}^{n} D_j(y) \leq D_{th} \text{ and } H_c(y) = \sum_{j=1}^{n} H_{cj}(y) \leq H_{th}.$$

$P_c(y)$ is the connectivity probability of route y, and D_{th} and H_{th} are thresholds on the tolerable end-to-end delay and hop count, respectively. The optimization problem is solved using a genetic algorithm. However, due to space limitations, the details about our genetic algorithm are omitted.

V. Numerical and Simulation Results

In this section, we compare our proposal with respect to three benchmark routing protocols GPSR, GPCR and OLSR. To this end, we developed our own discrete-event simulator using Matlab.

In our experiments, we consider different scenarios representing morning rush hours (i.e., dense network), the noon time having intermediate density, and the night time with low density (sparse network). To do so, we use different number of vehicles given that the area of the simulated network is fixed. Indeed, the number of nodes is varied between 150 and 620 nodes. In addition, the mobility of nodes is modeled based on a given street map where the mobility generator SUMO [14] is used to generate vehicle mobility traces. The parameter settings in our experiments are listed in Table I, where t_s denotes the simulation time and N_g is the number of generations for our genetic algorithm. Additional genetic algorithm parameters are mutation rate μ, crossover rate θ, and population size p_z.

To get an insight into our mathematical model, we compare between the routes chosen by the gateway using the mathematical model and the simulation environment. In both scenarios, there is a 99% confidence interval that the chosen routes are the same.

Let us now focus on the performance comparison of DTRP with that of GPSR, GPCR and OLSR. Figure 5 depicts the connectivity probability for all protocols as a function of the number of nodes in the network. We simulate DTRP under two scenarios. First, a fixed value of T_r ($T_r = 250m$) is used. This value guarantees high connectivity degree in case of high density, as shown in Figure 3. Second, the T_r value is adapted to the changes in node densities on the different road segments. Table II shows four T_r values that we used in the latter case. As stated before, the gateway will inform the MNs about the new T_r. Compared to DTRP that does not use adaptive T_r, DTRP with adaptive T_r can achieve higher connectivity probability as depicted in Figure 5. In addition, less delay and less number of nodes can be achieved (see Figures 6 and 7, respectively). The difference in performance between these two scenarios appears to be more severe in case of low density network compared to the case of high density network.

From Figure 5 we can also notice that DTRP, with or without adaptive T_r, achieves a higher connectivity probability compared to the remaining protocols since it selects routes with higher number of nodes. On the other hand, GPCR and GPSR select the nodes on routes that have minimum distance from the gateway. Therefore, they select the path with minimum number of intersections, without taking into consideration the connectivity degree. As such, in GPCR and GPSR, more nodes are allowed to use the store and forward mechanism, which decreases the probability of connectivity and increases the delay. For OLSR, since the intermediate nodes build routes based on the topology information in the local table, the message forwarded on these routes may face a route failure due to the stale information resulted from high mobility of nodes. At that time, the intermediate node waits for a route maintenance reply to begin to forward the message again.

Figures 6 and 7 depict, respectively, the delay and hop count for all protocols as a function of the number of nodes in the network. Since there is a specific threshold for the tolerable delay specified by the service provider to guarantee QoS, DTRP selects routes with delay less or equal to the delay threshold, as depicted in Figure 6. In addition, Figure 7 shows that routes constructed by DTRP have an enough number of nodes to avoid disconnectivity. On the other hand, GPCR chooses the next road intersection without considering if there are enough nodes to relay the message. As a result, less number of nodes are selected, as seen in Figure 7, but a relatively higher delay is experienced (see Figure 6) due to the frequent use of the carry and forward

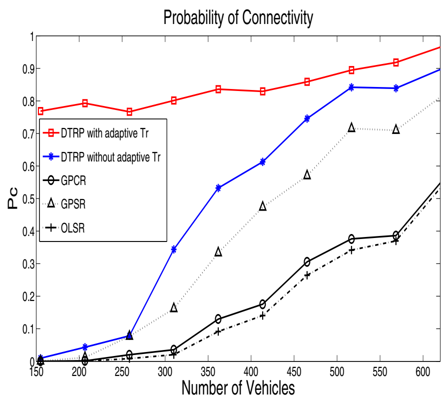


Fig. 5. Connectivity probability

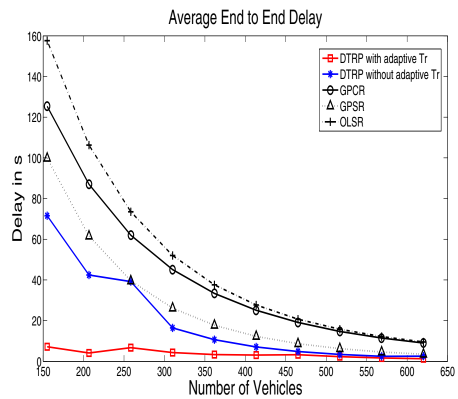


Fig. 6. End-to-end delay

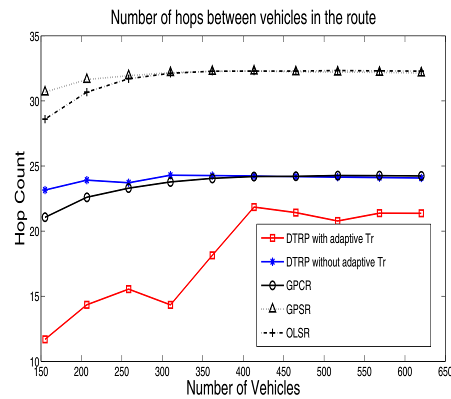


Fig. 7. Hop count

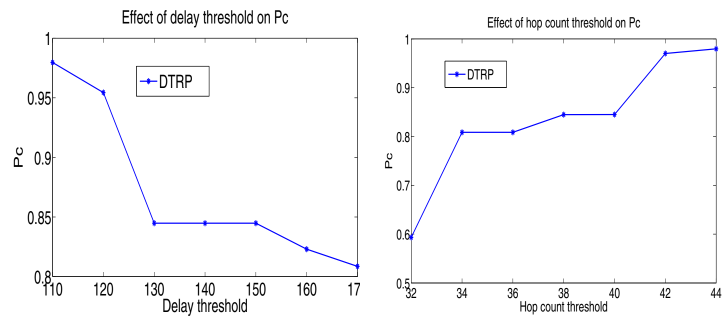
TABLE II
T_r SETTINGS

$T_r(m)$	750	550	350	250
γ	$0 - 0.004$	0.004-0.005	$0.005 - 0.008$	≥ 0.008

strategy. Considering OLSR, routes fail often which increases the number of nodes in the route towards the gateway, and consequently increases the delay. Regarding GPSR, since it is a position based routing protocol, it selects routes that have nodes close to each other which results in higher connectivity, less delay and very high number of nodes compared to both GPCR and OLSR.

Figures 8(a) and 8(b) show, respectively, the effect of delay threshold (i.e., D_{th}) and hop count threshold (i.e., H_{th}) on the connectivity probability. From Figure 8(a), we can notice that the connectivity probability decreases when increasing the tolerable delay threshold. This is related to the fact that more MNs are allowed to carry the message which will be transmitted with the same speed as that of the MNs. As such, the routes will have more MNs that are distant by more than the transmission range, thus, decreasing the connectivity probability.

On the other hand, the connectivity probability increases when increasing the hop count threshold , as shown in Figure 8(b). This is due to the fact that routes with more and more vehicles are allowed to be selected. This enforces hop by hop forwarding and may result in a higher connectivity probability. Note that variations of the threshold levels (i.e., D_{th} or H_{th}) do not affect the performance of GPSR, GPCR, or OLSR since they do not consider these parameters in the routing process.



(a) (b)

Fig. 8. Effect of D_{th} and H_{th} on the connectivity probability

VI. Conclusion

In this paper, we proposed a new approach for routing delay tolerant data packets in vehicular ad hoc networks. Our proposal tends to satisfy QoS constraints on the tolerable delay by using paths that maximizes the connectivity probability while limiting the bandwidth usage by controlling the path hop count. To achieve this, we formulated the QoS routing problem as a constrained optimization problem. We also derived analytical expressions for both the delay, connectivity probability and hop count in a two-way street scenario. Using both analytical and simulation approaches, we compared our proposal with GPSR, GPCR and OLSR. We found that our protocol achieves better performance. As such, our solution stands out as a promising candidate for large scale ad hoc networks such as VANETs.

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