XXXVII SIMPÓSIO BRASILEIRO DE TELECOMUNICAÇÕES E PROCESSAMENTO DE SINAIS - SBrT2019, 29/09/2019–02/10/2019, PETRÓPOLIS, RJ

A Reduced Beacon Routing Protocol for Inter-Vehicle Communications

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Abstract— **Vehicles on cooperative inter-vehicular applications establish a mutual awareness of their presence by periodically broadcasting beacon messages. However, high vehicle density and poorly controlled beaconing lead to congested channel and degradation of system performance. Periodic beaconing may also lower the delivery rate of beacons and other types of messages. In this paper, we describe a beaconing rate control approach considering the density of nodes during beacon forwarding and adjusting the successive beacon delay to mitigate the congestion and maximize the delivery efficiency of beaconing. Our strategy can be adopted for any beacon-based algorithms. Therefore, we selected the widely adopted position-based routing protocol for VANETs known as Geographic Perimeter Stateless Routing (GPSR) to apply the proposed algorithm and evaluate the impact in the performance metrics. Our proposed algorithm shows performance improvement over standard GPSR related to the number of drops caused by collision and beacon load reduction, which keeps the information accuracy.**

GPSR, Adaptive, Beaconing, VANETs, SUMO, NS3

I. INTRODUCTION

Vehicular ad hoc networks (VANETs) were initially designed for safety applications as detection of accidents and road conditions. However, with the development of wireless technologies, new services were considered in the context of vehicular networks as traffic jam detection, publicity and entertainment, which increase the demand for fast and adaptive content dissemination. As a result, a variety of applications such as driver assistance are expected to be enabled and incorporated into vehicles in a near future due to the capacity of information sharing among the vehicles and infrastructure [1].

VANETs are constructed under the principles of mobile ad-hoc networks (MANETs). However, existing protocols for MANETs cannot be directly used in VANETs due to intrinsic differences of these networks. Therefore, routing algorithms in MANETs need to be redesigned to be feasible to VANETs [2]. Usually safety messages generated by a vehicle are useful to all the surrounding vehicles. Hence broadcast communication is preferred rather than unicast [3]. However, there are intrinsic challenges with broadcast communication in VANETs, such as broadcast storm problem [4].

For active neighboring discovery algorithms, the nodes send hello packets to interact with neighbors [5]. In this method, the routing decision is performed using the information obtained from the exchange of hello messages among the neighbors. The hello messages are periodically transmitted by each vehicle and can include a variety of information such as position, velocity, density and direction of the vehicles [6]. Those information's are useful to the vehicle to maintain an updated neighboring information list. However, since VANETs consist of high speed moving vehicles, the information collected by the vehicle regarding its neighbors changes continuously in a short period of time [7]. Therefore, the nodes need to periodically broadcast their updated information to their neighbors through beacon messages, increasing the total load on the wireless channel which may prevent or limit the transmission of other messages leading to the channel congestion [8].

Beacon congestion control can handle the beacon rate or the beacon transmit power to deal with channel congestion. For transmit power control scheme, the authors in [9] presented an algorithm that adjusts the transmit power as a function of the estimated neighbors. The node keeps monitoring the wireless channel and counts the number of neighbors, based on the received data from the neighbors. Then, the node increases or decreases the transmission power according to a threshold. Similarly, the study in [10] proposed the Distributed Fair Power Adjustment for Vehicular networks (D-FPAV) protocol that adapts the transmission power making use of max-min fairness in a distributed way controlling the beacon load below a given threshold by adjusting the nodes transmit power.

Related to beacon rate adaptation, the authors in [11] proposed a rate adaptation algorithm to distributively control the self-information broadcast behavior of each vehicle. The authors in [12] proposed an algorithm that maintains the beacon load under a given threshold by dynamically adapting the nodes beacon rate using two strategies: estimating the number of neighbors from the received beacons and monitoring the wireless channel. The authors in [13] proposed to use a model of the estimation of the position of the vehicle to adapt the beacon rate. The message is sent if the difference between the predicted value of the position and the actual position is greater than a specif threshold. The main difference of our proposed method from the methods above is that our method dynamically adjusts the beacon rate based on the density of the nodes avoiding using a predefined value of threshold which can work just for specific situations.

In this paper, we propose a novel adaptive beacon rate scheme that can be applied to any beacon-based algorithm. We applied it to GPSR protocol which is a widely adopted position-based unicast routing strategy [14]. The algorithm considers the density of nodes during beacon forwarding and adjusts the beacon delay for the next beacon packet to minimize packet collision and packet traffic congestion's,

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which eventually leads to improved fairness of channel access and reception rate.

II. BACKGROUND

In this section, we provide a short description of the GPSR algorithm.

A. *Traditional GPSR Routing Strategy*

GPSR is one of the highly efficient location-based stateless routing schemes for dynamic networks [15]. It makes use of two forwarding schemes for delivering the packets from the source to the destination: greedy forwarding and perimeter forwarding (recovery mode). It is assumed that every node has its own position coordinates information available via GPS and/or Short-Range Localization and they periodically exchange this information with its one-hop neighbor through beacon messages. Therefore at any given time, every node has the position information of all of its neighbors within the communication range as well as the position of the destination through beacon messages.

Based on the response of beacon messages, the source node chooses the best neighbor which is closer to the destination according to greedy forwarding. But if the source node does not receive any response from a neighbor within a time-out interval, it considers the communication link as broken. There may be some situations where there is no best neighbor than the source node itself, which is known as local maximum condition. In this condition, GPSR can no longer maintain the greedy forwarding strategy, rather it turns into recovery mode to forward the packet to next node. In recovery mode strategy, all nodes follow the right-hand rule to transmit the packet to next node. Upon receiving the packets, every node checks the packet header field whether it is in greedy mode or recovery mode. Recovery mode usually considers planar graphs to forward the packets.

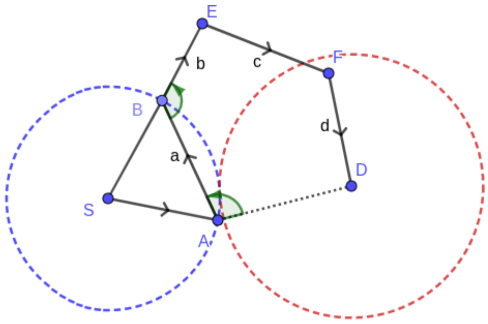


Fig. 1: GPSR Forwarding Example.

Consider Fig. 1 where node S wants to deliver packets to its desired destination node D. It is assumed that node S is equipped with GPS device which provides it with its own position coordinates. It adds its own IP with this position information in beacon messages and periodically broadcasts it. Likewise, all the neighbor nodes broadcast their *beacon messages* containing the same information. The dotted blue circle around node S indicates the communication range of it. Out of the two neighbors that lie within the communication range of node S, node A is the closest to the destination and hence best fitted for receiving the packets. Therefore, node S sends the packets to node A according to the greedy algorithm. After receiving the packets, node A wants to forward the packets to its best neighbor. But at this stage there is no node closer to the destination than node A itself, causing the problem of local maximum. The dotted red circle represents the perimeter of destination node D, i.e. the region in which A should forward the packets in the ideal case. Recovery mode helps node A to recover from local maximum and the nodes follow the right-hand rule to forward the packets. Node A forwards the packets to node B through edge a . Again, node B has no closer destination to node D than itself. So it further continues packet forwarding via recovery mode and forwards it to node E through edge b. At this stage, node E finds another node (node F) closer to the destination. Therefore, it turns back to greedy mode and forwards the packets to node F. Similarly node F forwards the packets and finally reaches to destination D.

III. REDUCED BEACON GPSR ROUTING STRATEGY

The Reduced Beacon GPSR strategy (RB-GPSR) that we are proposing is a position-based routing scheme that aims to reduce the overhead caused by the traditional GPSR beacon signals (hello messages). Our goal is strictly to improve the beacon signals management in order to reduce the number of hello messages without degrading the system performance and still having similar results to the traditional GPSR. Our algorithm incorporates the following aspect: First, it observes the density of node at beacon forwarding process. Then, it adjusts the beacon delay to be added to the next beacon packet. The greedy forwarding and recovery mode used in our algorithm are the same used by GPSR.

Each node executes the beacon control algorithm independently and uses the number of entries in the Neighbors Table (NT) as a metric for the estimated node density. The beacon delay for an arbitrary node i is determined as follows:

$$D_i(t) = \begin{cases} r_i - \frac{r_i}{d_i(t)}, & \text{if } d_i(t) > 0 \\ 0, & \text{otherwise} \end{cases} \quad (1)$$

where r_i is the beacon interval and $d_i(t)$ is the the estimated density of node.

The details of RB-GPSR routing protocol are shown in Algorithm 1, where: R is the node receiving a packet, N is the set of one-hop neighbors of R, n is a node of the set N, p is a packet for destination node S, h is a *hello packet*, d is the node density, r is the beacon interval and D is the delay to be added to the hello packet forwarding.

Fig. 2 shows the delay (D) added to the beacon packet scheduler in relation to the node density (d) for beacon interval (r) varying from 0.5 to 2.5 seconds. The maximum delay allowed is upper bounded by r. Therefore, when $\lim_{x\to\infty}$, $D(x)$ is equal to r.

IV. RESULTS

In this section, we conduct simulation-based experiments to evaluate the performance of the proposed protocol against

Algorithm 1 Proposed Reduced Beacon GPSR algorithm.

```
At_Receiving_Hello_Packet
if is_New_Neighbor then
    $d$ = size($N$);
end if

At_Forwarding_Hello_Packet
if $d$ == 0 then
    $D$ = 0;
else
    $D$ = $r$-$r/d$
end if
Broadcast($h$, $r$+$D$);

At_Forwarding_Data_Packet
if $n \in N$ && Distance ($n$, $S$) $\leq$ Distance ($R$, $S$) then
    $n$ = Min_Distance($N$,$S$);
    Forward($p$, $n$);
else
    $n$ = Perimeter_mode($N$,$S$);
    Forward($p$, $n$);
end if
```

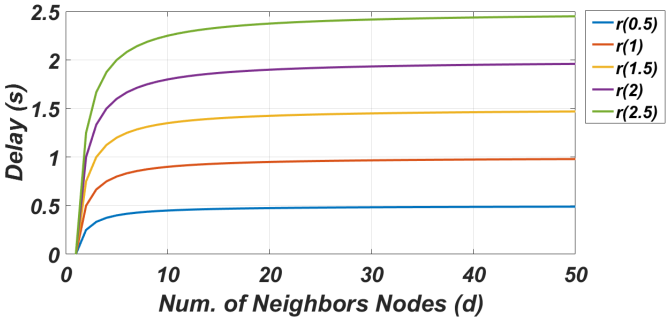


Fig. 2: Hello Interval Delay in Relation to Node Density.

GPSR with the use of Simulation of Urban MObility (SUMO) [16] and Network Simulator-version 3 (NS-3) [17]. We obtained the trace files corresponding to vehicle mobility from SUMO, converted these files to NS3-compatible files, and used them for network simulation.

The simulation topology is a Manhattan-like grid of 1000x1000m, as shown in Fig. 3. The hello packet interval is set to 1 second. The communication range of vehicles is set to 250 meters. The IEEE 802.11p standard is used to model MAC layer and Two-ray ground radio propagation model is used to compute the wireless channel fading characteristics. We considered the data traffic to be Constant Bit Rate (CBR) that is attached to each source node to generate packets of fixed size (200 bytes). The movements of the vehicles on the roads were based on the Car-following model (Krauss model) and the vehicles' speed were set not more than 20 m/s. A single pair source-destination was randomly chosen, which generated packets every 0.02 seconds. We further assumed UDP as the transport layer protocol for the simulation studies.

The total time of each simulation run was configured to 100 seconds. All the results shown in the paper represent the average of several simulation runs and a 95 % confidence interval. The configuration of simulation parameters are summarized in Table I. These parameters were selected based on the previous studies as their simulated vehicular scenario [18], [19] [2] [20]. The parameters evaluated in our simulations are defined as follows:

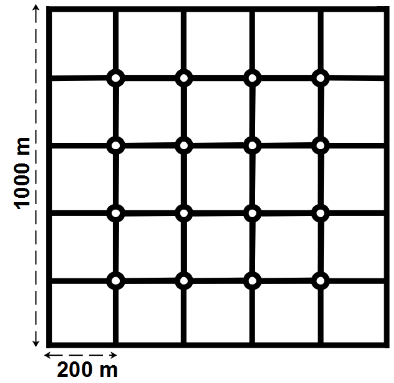


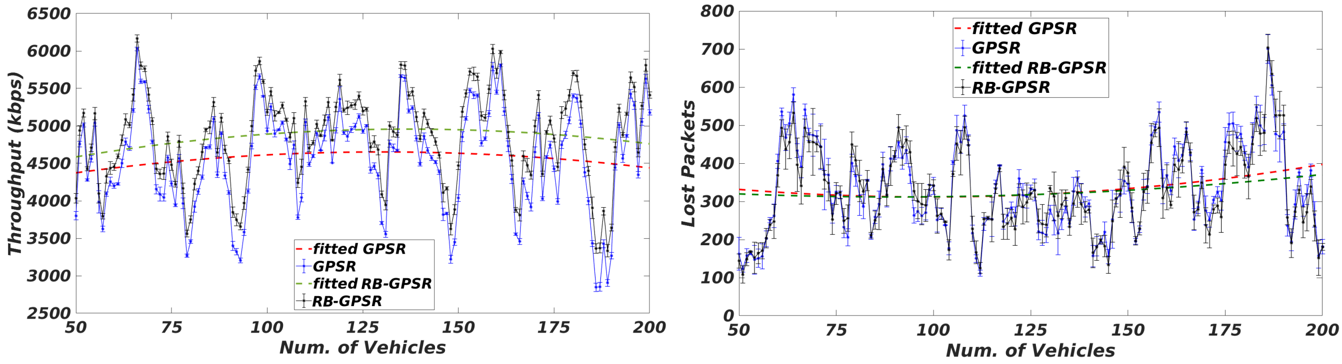
Fig. 3: Simulation Scenario.

- **Packet Delivery Ratio (PDR):** The percentage of packets received by the destination for total number of transmitted packets by the source.
- **Hop Count:** Average number of hops for all the packets received by the destination.
- **Delay:** Average end-to-end delay for the packets received by the destination.
- **Lost Packets:** Difference between number of packets transmitted and received.
- **Throughput:** Number of packets received by the destination multiplied by packet size.
- **PhyRx Drop:** Number of packets dropped by the device at PHY layer during reception. Packets drop caused by collisions or propagation loss.
- **Routing Load:** Number of hello packets that have been sent by all the nodes during the experiment.

TABLE I: Simulation Parameters.

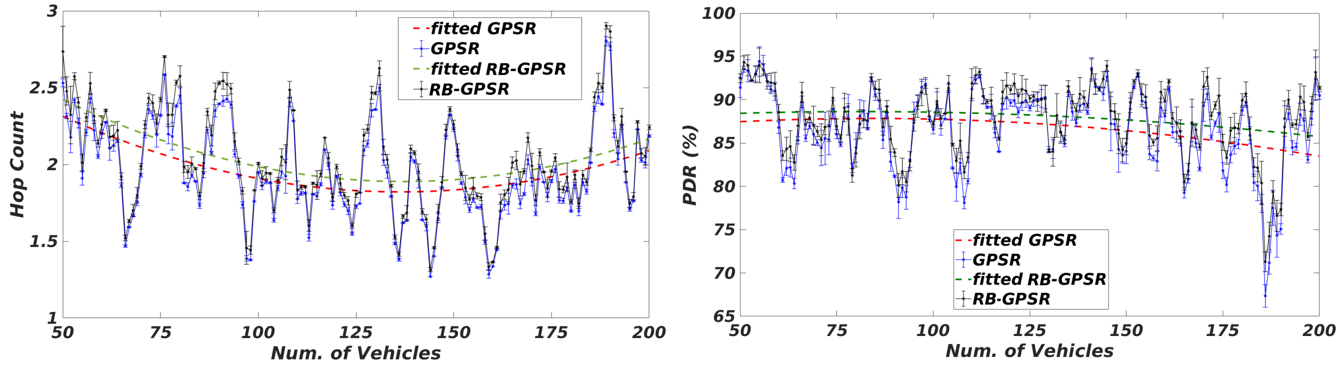
Parameter	Value
Simulator	NS-3/SUMO
Packet Size	200 bytes
Simulation Time	100s
Simulation Area	1000x1000m
Simulation Scenario	Manhattan grid
Pair Source-Destination	1 (Random)
Number of Nodes	[50-200]
Max. Speed	20 m/s
Data Type	CBR
Hello Interval	1s
Transport Protocol	UDP
Packet Interval	0.02s
Mac Protocol	802.11p
Transmission Range	250m
Propagation Model	Two-ray ground
Routing Protocol	GPSR, RB-GPSR

In Fig. 4, seven key performance metrics are compared between our proposed RB-GPSR and the default GPSR. Figures 4a, 4b, 4c, 4d, 4e, 4f and 4g describe, respectively, the throughput in kbps, Lost Packets, Hop Count, Packet Delivery Ratio, Delay in milliseconds, PHY reception drop and Routing Load (RL) for different number of vehicles and their fitted curves. To calculate the fitted curves we used the MATLAB *polyfit* and *polyval* functions. Under normal circumstances, if



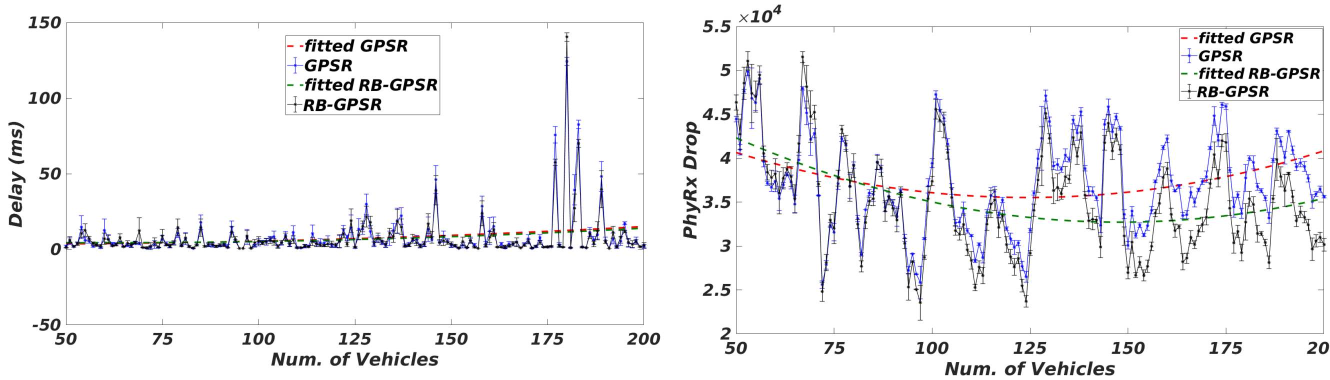
(a) Throughput Comparison.

(b) Lost Packets Comparison.



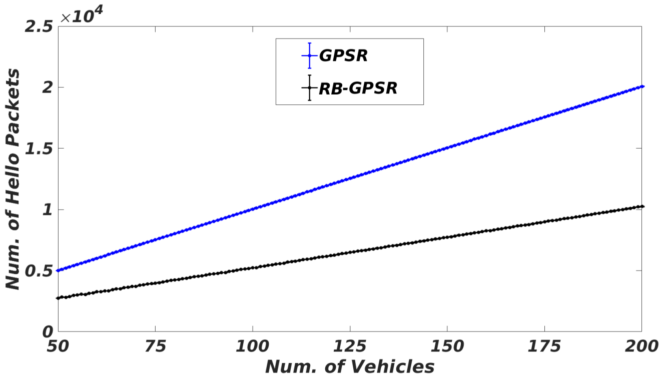
(c) Hop Count Comparison

(d) PDR Comparison



(e) Delay Comparison

(f) PHY Drops at Reception Comparisson



(g) Number of Hello Packets Comparison

Fig. 4: Performance comparison between RB-GPSR and GPSR for different metrics.

we reduce the interval of beacon exchanging, we would expect to see a degradation in PDR due to the outdated and inaccurate localization information. However, our protocol guarantees similar or better results in all scenario variations. Indeed, analyzing the fitted curves of Figures 4b and 4e, we can observe very similar results. This is expected since we are only working with beacon management. To improve these metrics, a new routing decisions (based on speed, density, direction, for example) should be incorporated into the algorithm.

Fig. 4c shows a slight increase of hop count (the values are the average number of hops considering the communication of all nodes in the scenario) because of the reduction of beacon messages, which can lead to a non optimal choice of the next hop sometimes. However, the results are almost the same. For Figs. 4a, 4d, 4f and 4g the RB-GPSR have better performance, mainly in relation of reduction of the number of hello packets and PHY drop at reception. Fig. 4a shows that our algorithm receives more packets at the destination. This is expected since we have a light increase of PDR as shown is Fig. 4d.

Our algorithm shows better results in relation to PHY drop for scenario above of 80 nodes as shown in Fig. 4f. The reason behind this is due to high densities in the highly connected network, the chance of interference occurrences caused by beacon flooding is high. In this case, RB-GPSR is more suitable for highly dense scenarios. Fig. 4g shows the number of hello packets transmitted achieved by both protocols as the density of vehicles increases. It can be noted that the number of hello packets increases linearly but with the proposed RB-GPSR reaching about 50% of reduction in comparison to the standard GPSR.

Lastly, the high spikes observed in some figures (e.g., Fig. 4e) are caused due to the independence of the scenarios. Each scenario starts with a random pair of source-destination. Therefore, each pair can be far away from each other (or not), causing this “noisy” effect in the results. For future work, we will reduce this “noisy” effect and improve the results by using more than one pair of source-destination.

V. CONCLUSION

In this paper, we described a modification for the well-known GPSR protocol to reduce the overhead due to the control mechanism. Our strategy uses the density of nodes (based on the size of NT) since the higher beacon transmission rate degrades the link performance and results in beacon losses. In general, low beacon transmission rate implies in imprecise neighborhood vehicle information. Our proposed method, however, can be applied to any beacon-based algorithm and succeeded in keeping fairness between beacon load and information accuracy for GPSR algorithm.

We simulated our proposed method in a mobility scenario in NS-3 with traces collected with SUMO. Through extensive simulation results, we have demonstrated that the proposed protocol shows performance improvement over standard GPSR protocol regarding the number of hello packets transmitted and PHY reception drops. As a continuation of this work, we intend to improve our proposed RB-GPSR to take into account the speed, direction and nodes density to improve the other metrics like PDR, delay, throughput, lost packets and hop count. Moreover, we intend to apply the same beacon reduction strategy to evaluate the performance metrics in different beacon-based algorithms.

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