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TGRP: Topological-Geographical adaptive Routing Protocol for vehicular environments

Miguel Báguena, Carlos T. Calafate, Juan-Carlos Cano, Pietro Manzoni
Department of Computer Engineering
Universitat Politècnica de València
Camino de Vera S/N, 46022, Spain.
mibaal@upvnet.upv.es, {calafate, jucano, pmanzoni}@disca.upv.es

***Abstract*—Vehicular networks represent an extremely variable and unpredictable environment. Scenarios can vary from very dense and congested configurations to sparsely populated arrangements. Therefore, protocols designed for such a general scope may fail to efficiently behave in certain configurations. In this paper we propose the Topological-Geographical Routing Protocol (TGRP), a novel solution that presents an adaptive behavior by using a set of standard routing strategies. According to the scenario, TGRP chooses among four different routing approaches — two-hop direct delivery, Dynamic MANET On-demand (DYMO), greedy georouting, and store-carry-and-forward technique— to dynamically adapt its behavior to every situation. Performance evaluation shows that TGRP presents a more stable performance under different circumstances, being more adaptable to the changing characteristics of vehicular networks. In fact, TGRP outperforms DYMO by 10% in low density scenarios. In dense networks, TGRP also outperforms the Delay Tolerant Network (DTN) protocol by 10%.**

***Index Terms*—vehicular networks; hybrid routing; adaptive routing;**

I. Introduction

Vehicular networks are a challenging environment which is being deeply studied by the research community. This kind of networks creates very variable topologies along time, topologies that may include isolated nodes, variable quality links, and variable node densities. Such highly mutable and heterogeneous context represents a problem for network protocols, which are typically focused on generic scenarios, and which show an unpredictable performance. In this context, routing is of utmost importance and the protocol used should provide a stable performance behavior independently from the target scenario.

Classic topological routing protocols, like Dynamic MANET On-demand (DYMO) [1] or Optimized Link State Routing (OLSR) [2], have been deeply evaluated for vehicular networks. However, as the node speed increases, global performance decreases [3]. Geographical routing emerged [4] as a more efficient solution, which takes advantage of location information for routing. However, geographical algorithms cannot achieve the best performance in every situation since packets may reach a local minimum. In these cases they make use of a recovery procedure based, for example, on the well-known right-hand rule, or they present a hybrid behavior by using a store-carry-and-forward solution. However, since these proposals only use geographical information to select the next hop, their structure is hardly generalizable, and they are not able to provide different services to upper layers.

An optimal protocol must be able to adjust its behavior to the current network state. Following this guideline, we present Topological-Geographical Routing Protocol (TGRP), an adaptive routing protocol which combines geographical and topological information to dynamically adapt its behavior to network conditions. It uses a NeighborHood Discovery Protocol (NHDP) [5] compatible implementation for sensing the network. According to its observations, it dynamically selects the most appropriate protocol approach to route each packet. TGRP combines four routing alternatives: two topological routing alternatives, i.e., two-hops direct delivery, and DYMO; one geographical routing delivery, i.e., greedy georouting; and one long-term store-carry-and-forward delivery strategy, i.e., a location prediction strategy.

Our TGRP architecture has been implemented and tested in simulated urban scenarios under realistic settings. Realistic propagation models have been used and urban layouts from the OpenStreetMap[6] database have been included in order to achieve a realistic road layout combined with an accurate building distribution. Results have been analyzed not only to demonstrate its adaptation capabilities under different conditions, but also to detect the areas of possible improvement, highlighting the different trade-offs and how they are addressed by the protocol. Simulations results show that the hybrid and adaptive approach of TGRP is able to improve network performance.

The rest of this paper is organized as follows: Section II reviews the state of the art and compares our protocol against other existing techniques. Section III presents the overall protocol behavior and its implementation, and reviews some of the basic common routing problems, explaining the solution adopted in TGRP. Section IV evaluates the protocol and discusses the results obtained. Finally, Section V concludes the paper.

II. Related work

Routing is a well known topic in all kinds of networks. Particularly, in vehicular networks, there are several routing performance tests and new routing algorithms that highlight the importance of this topic in communications.

On the one hand we have topology-based routing. This type of routing protocols are used in current wired, wireless and mobile ad-hoc networks. They are based on network topology discovery and packet routing using the most efficient path. They are split into two different groups: reactive and proactive routing protocols. Proactive routing protocols are those which maintain a routing table that summarizes the network topology. When a packet has to be routed, the table allows choosing the best next hop. The most widespread protocol in this group is OLSR [2]. However, OLSR has shown several drawbacks when it is evaluated in vehicular networks [7], [8], forcing it to increase the beacon frequency to improve performance, but causing channel saturation and collisions.

The second group of topology-based routing protocols are reactive protocols. These are able to retrieve a route to the destination on-demand. The Ad-hoc On-Demand Distance Vector (AODV) [9] and the Dynamic MANET On-demand (DYMO) [1] protocols have been evaluated in vehicular networks. Particularly, C. Sommer and F. Dresler [10] found that DYMO shows an acceptable performance in VANETs when vehicular density is not too low, but it could saturate the network in high-density scenarios.

On the other hand we have geographic-routing approaches. They take advantage of positioning technologies as a new information source to route packets. Among geographic approaches we highlight the Greedy-Face-Greedy (GFG) algorithm [11], which is able to guarantee delivery in ideal scenarios by alternatively using greedy and face routing algorithms. It was followed by new approaches, such as Greedy Perimeter Stateless Routing (GPSR) [12] or Greedy Routing with Abstract Network Table (GRANT) [13], which improve upon the original proposal to adapt it to different scenarios. Moreover, new proposals include urban maps knowledge to route packets. For example, the Geographic Source Routing (GSR) [14] uses a position-based routing strategy supported by the city map. However, other studies [15] have shown that there are several problems inherent to this kind of routing, like inability to deal with partitioned networks, high dependence on beaconing services, and location-service related problems.

In order to deal with partitioning, store-carry-and-forward algorithms for DTN have been proposed. These algorithms not only exploit geographical information, but also information like social patterns, thus allowing to make long term predictions about car mobility. Some examples of this new paradigm is GeOpps [16], which uses the car route as a selection criteria to find the best node to deliver the packets, or [17], which uses multi-criteria functions to evaluate the different available custodians. Although they cut down the impact of partitioned networks, new problems has been introduced with this new paradigm, being the most important one related to inaccuracies in the predictions or partial information constraints.

To make the most of these two geographic approaches, hybrid protocols have been also proposed. This kind of solutions combines different forwarding techniques, typically a DTN approach and a geographical approach, to improve global behavior of the protocols using different algorithms for a single packet delivery. Examples include routing protocols like GeoDTN+Nav [18] and L. Zhao et. al. [19]. However, none of them has a structure easy to generalize, they have a narrow scope about available routing alternatives, and they cannot provide different kinds of services to upper layers.

TGRP aims at solving these problems in a hybrid and adaptive way, combining the strengths of topological, geographical and DTN approaches to finally deliver a packet. This solution offers an structured approach while it tries to cover as many scenarios as possible.

III. The Topological-Geographical Routing Protocol

The Topological-Geographical Routing Protocol offers a component-oriented routing architecture. In order to take advantage of topological and geographical information, our protocol combines four routing solutions: two-hop direct delivery, DYMO, greedy georouting, and store-carry-and-forward, being the latter typically used in Delay Tolerant Networks (DTN).

Figure 1 shows the TGRP architecture. It is composed by three main elements: a) the sensing component, b) the decision layer, and c) the routing layer.

The sensing component provides information to allow the decision layer to update its neighbor table and make routing decisions. The decision layer is in charge of deciding which routing protocol is more appropriate to route the packet according to the network state. The routing layer combines the routing algorithms shown in Figure 1. Each individual routing protocol is intended to offer its routing services to the decision layer.

A. The sensing component

For the protocol to gain awareness of nearby nodes, our TGRP approach uses a neighbor discovery protocol based on periodic beaconing. It follows the NeighborHood Discovery Protocol (NHDP) [5] packet definition described in [20]. This is a beaconing element which periodically broadcasts control packets to their one hop neighbors including several fields which detail the neighbor topological and geographical state, which can be retrieved from the GPS module. The beacon interval can be set arbitrarily, although recommended values are discussed in Section III-C. However, for evaluation purposes we have set it to two seconds, which is the recommended value in the

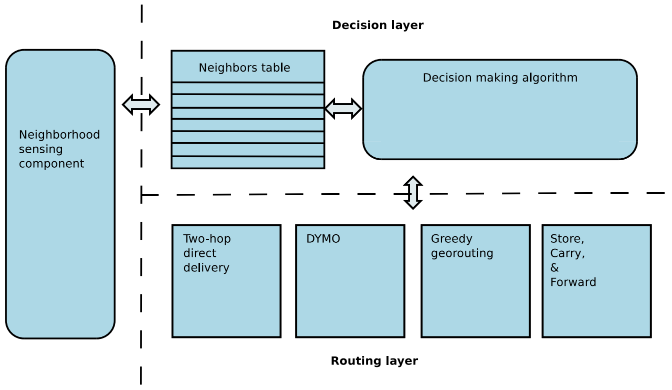


Figure 1: Protocol architecture.

NHDP's RFC document. The proposed TGRP control packet includes the following relevant information: IP address, 1-hop neighbors IP addresses, link state, geographical information, current location (coordinates), current speed/direction, and final destination (coordinates).

Since the control packets follow the NHDP packet definition, their information can be easily extended according to the rules in [20] to accommodate more relevant information.

B. The decision layer

Algorithm 1 details our routing decision algorithm, which is the main component of our decision layer. It selects, among the available routing protocols, which one must be used based on the information retrieved by the neighborhood sensing component. Basically, when a packet has to be routed, the decision layer sequentially checks which protocol is suitable for handling it according to the observed network state. The two-hop direct-delivery routing is used when the target is one or two hops away. If this condition does not hold, then DYMO determines if a route is available. To avoid generating too much overhead, the DYMO route discovery process is only initiated when the destination is close-by, that is, when an NHDP packet from that node has been received in the last few seconds. If DYMO is unable to find a route, then the decision layer switches to georouting, which is usable only when neighbors that are nearer to the destination were discovered. Finally, if no neighbors are discovered, the store, carry and forward strategy is selected.

The parameter MAX in Algorithm 1 corresponds to a timestamp that prevents DYMO from starting. A vehicle can still reach an RSU in five hops after almost three minutes with a transmission range of 500m (at a maximum speed of 14 m/s). Since vehicles do not move always at maximum speed, we decided to double this value and set MAX to six minutes in our tests, and making the most of the DYMO algorithm.

Additionally, notice that packet reordering is observed since those packets that are routed by protocols introducing delay, such as DYMO or the store-carry-and-forward approach, can be overtaken by subsequent packets.

Algorithm 1 The TGRP algorithm

```
procedure route(packet)
  # Checking whether it is a V2V or V2I communication
  # If destination is unknown it is assumed V2I anycast
  if packet.destination $\notin$ neighborTable then
    actualDestination = closestRSU;
  else
    actualDestination = packet.destination;

  # Direct Routing
  if $\exists$ route to actualDestination and
      linkStatus == SYMMETRIC then
    twoHopDirectRouting(packet);

  # DYMO Routing
  if last actualDestination contact timestamp
      < MAX then
    initiateDYMORouteDiscovery();
    if route found then
      DYMORouting(packet);

  # Geographical Routing
  if $\exists$ closer neighbor then
    geoRouting(packet);

  # DTN Routing
  if $\exists$ better custodian then
    forward(packet);
  else
    store(packet);
```

C. The routing layer

This layer includes the selected routing protocols, that is, two-hop direct delivery, DYMO, greedy georouting, and the store-carry-and-forward. They have been selected since they complement each other in a wide set of vehicular situations.

The topology information managing issue was exploited by our routing policy using either two-hop direct delivery system or a limited DYMO. The two-hop information that the neighbor discovery protocol disseminates is stored in the neighbor table, being kept for a beacon interval. Then, when a packet has to be routed, this table is searched to determine if the destination is a one or two hop neighbor, in which case it would be able to send the packet directly or through its most recent neighbor.

However, our protocol goes a step further. To take advantage of topological information while avoiding the aforementioned problems, we use a bounded DYMO. Our bounded DYMO works by reducing the maximum scope of its route search. This allows us i) to avoid long routes that can be possibly broken while the sending process is being carried out, and ii) to avoid wasting network resources with frequent broadcasts storms.

Focusing on geographic routing, the adopted mechanism simply looks for the closest neighbor, computing the euclidean distance to destination, and forwards the packet to it. However, this strategy has two basic drawbacks: i) a greedy strategy does not guarantee finding the right path to the destination, so a recovery protocol must be included, and ii) a location service is needed. In Section IV we evaluate a greedy georouting approach and, although georouting should be, in theory, equally effective in dense and sparse networks, we show that the combination of these two factors make DYMO outperform geographic approaches in terms of packet delivery in more than 10% in some cases.

The store-carry-and-forward algorithm is based on making a prediction about the neighbors location at a later time, using a linear projection based on their current position, their speed, and their direction. According to this prediction, we select the best one as a custodian, which is the node carrying the packet at a specific time. When a contact between two nodes occurs, that is, a node which holds a packet receives an NHDP packet from other node, their future location is calculated based on their current location and their current speed and direction. Then, if the contacted node is a better custodian for some packets, i.e., it will be closer to the destination that the current one, they are sent to that node. The decision algorithm has to be able to choose among these protocols depending on the network state, following different strategies to finally achieve its goals.

1) Local minimums: In geographical greedy protocols, a recovery process is triggered to find a route to destination when local minimums exists. In TGRP, different routing protocols can act as recovery or backup solutions for geographic algorithms because they use different sources of information and strategies. Either DYMO, which uses topological information, or the store-carry-and-forward approach act as a recovery system.

2) The location service: In geographical routing, a component able to translate IP addresses into geographical coordinates is required. Therefore, a new point of failure is added to the structure, and packet losses associated to the lack of precision from this service can degrade the overall performance.

Location services are used in geographical approaches to translate IP addresses into geopositions. TGRP uses NHDP periodic beaconing as the main source of geographical information, along with the RSU location, which is *a priori* known. We have selected beaconing as a location service to get information about neighbors because it does not need cellular communication technologies.

Several studies [7], [8], [3] show that choosing an adequate beacon frequency is a critical issue. A high beacon frequency will saturate the network. However, a low beacon frequency gives the protocol a wrong perception about the network state, thus reducing performance. Since we want to allow the rest of protocols to operate freely, we chose a low beacon frequency (two seconds).

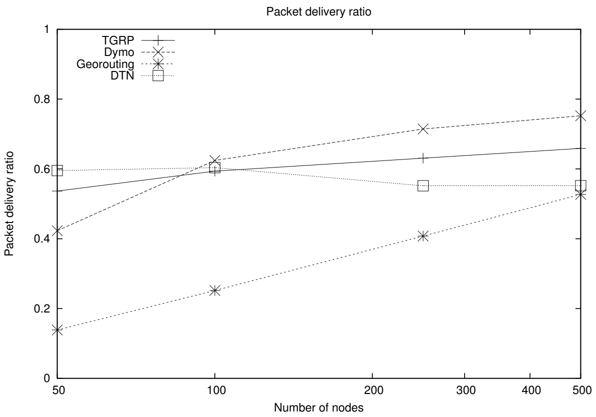


Figure 2: Packet delivery ratio.

IV. Performance evaluation

In this section we evaluate TGRP through simulation. It was implemented using the OMNeT++ [21] simulator, as well as the INETMANET package.

A. Simulation settings

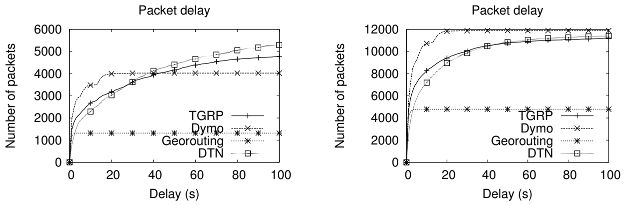
Simulated nodes are configured to communicate using 802.11p devices. Regarding the physical channel, it was modeled using [22].

Vehicular mobility has been defined using VACaMobil [23], a vehicular mobility manager which uses SUMO to achieve a realistic vehicular simulation while maintaining a constant average number of vehicles throughout the whole simulation. We have simulated our network in a real urban map: a $12km^2$ area from the Muscovite suburbs. In these tests we focus on V2I communication. We chose an urban map which shows many different behaviors in different areas, going from those similar to highways to those with dense road distributions. Vehicles send short bursts of packets to an RSU at random points of its route. Using this traffic pattern we can test the protocol performance for traffic sources in different points of the network, checking where the protocols are able to properly route the packets.

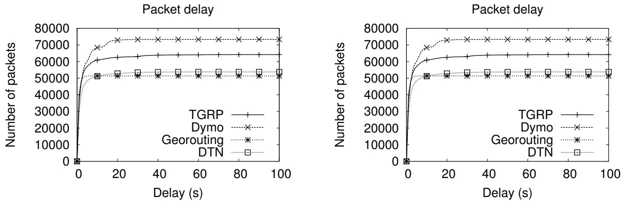
We assess the effectiveness of TGRP by comparing its performance against each individual protocol. The evaluations have been made in terms of packet delivery ratio, packet delay, packet loss causes, mean packet hop number, and Protocol Usage Ratio. We also test the influence of different propagation models.

B. Overall protocol performance

Firstly, TGRP's delivery rate has been evaluated for different vehicular densities. Figure 2 shows the packet delivery ratio of TGRP compared to the performance obtained by each protocol separately. This scenario can reach two different states depending on the network density. In low densities, only store-carry-and-forward approaches are able to correctly deliver the packet due to network



(a) 50 vehicles. (b) 100 vehicles.



(c) 250 vehicles. (d) 500 vehicles.

Figure 3: Delay distribution.

fragmentation. However, in high density networks, location service problems and channel issues makes topological approaches the best option, i.e. DYMO. TGRP obtains an average behavior in the range between the two best options. This makes TGRP the most flexible protocol, achieving a good performance in all the available scenarios. In fact, TGRP outperforms DYMO by 10% in low density scenarios. In dense networks, TGRP also outperforms DTN by 10% in dense scenarios at the expense of only losing 6% in sparse scenarios. Georouting performance improves when the vehicle density grows, as expected, but density increment is not enough to outperform the other approaches in this scenario.

We now focus on TGRP's packet delay metric. The delay curves can be seen in Figure 3. They follow the same trend than in the previous studies. Looking at this graph, we see that TGRP is again the most flexible protocol, achieving a good performance in all the available scenarios, as seen before. On the one hand, TGRP increments the packet delay for the sake of packet delivery and to avoid network congestion. On the other hand, TGRP outperforms DTN delay because it can route some packets more quickly using their topological alternatives.

C. TGRP detailed analysis

In this section we aim at analyzing TGRP and exposing its behavior step by step. Due to its modular architecture, TGRP can be easily examined and its performance in different network densities can be characterized.

We define the Protocol Usage Ratio (PUR) metric. This metric is defined as the total number of hops routed using a specific protocol over the total number of hops for the entire simulation. Its mathematical definition can be seen in Equation 1:

$$PUR(x) = R(x)/\sum_{i=0}^{n} R(i) \qquad (1)$$

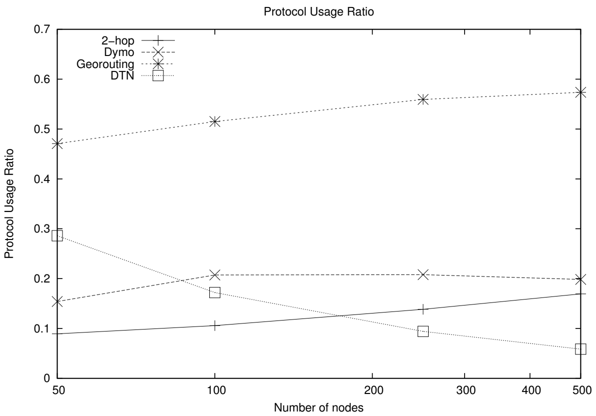
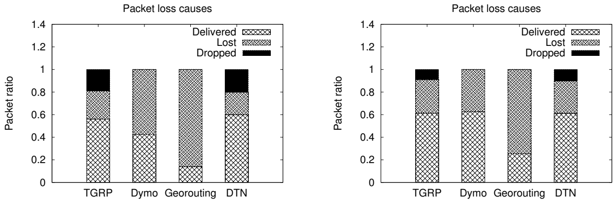
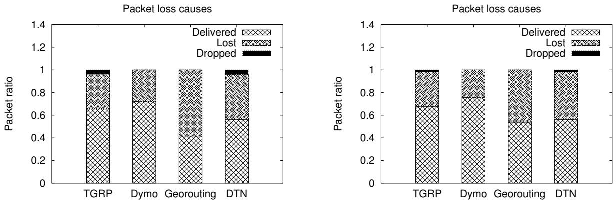


Figure 4: Protocol Usage Ratio.



(a) 50 vehicles. (b) 100 vehicles.



(c) 250 vehicles. (d) 500 vehicles.

Figure 5: Packet loss causes.

where $R(x)$ is the total number of hops routed using routing item x, and n is the total number of routing items. The sum of all PUR values must be 100% (the total amount of hops routed by TGRP).

Figure 4 shows the PUR value for each routing protocol under different network densities. We can see how TGRP cuts down the usage of store-carry-and-forward strategies by more that 20% when vehicle density increases. Therefore, the usage of the rest of approaches is incremented by about 10% for geographical approaches, and by an additional 10% for topological approaches. Moreover, this balance is automatically done depending on the network disconnection states at different instants of time.

The packet loss causes can be examined in Figure 5. There are two kinds of losses: (1) the node ends its trip but it was carrying a packet, and (2) the packet is transmitted to a new node, but it cannot reach its destination. The first group can only be reduced by improving the DTN algorithm. The second group is composed by channel losses and location inaccuracy losses. Since the latter is the biggest cause of loss, research must be focused there to improve the final behavior.

This set of figures shows an interesting piece of information related to geographical routing, too. Packet losses in high density networks are unrelated to network disconnection, as they are in greedy georouting in sparse networks, nor to a bad custodian selection, because the packet drop rate is low. In this scenario, environmental losses, such as location system inaccuracies and channel fading effects, are more relevant.

V. Conclusions

Vehicular networks are a highly mutable environment, whose issues have typically been addressed separately. In the literature we can find specific routing protocols for dense scenarios, sparse scenarios, very dynamic scenarios, and static scenarios, but few are able to deal with all these situations efficiently by adapting its behavior. However, since vehicular networks are highly mutable and can quickly change from one state to another, an adaptive protocol that can perform well in every situation would represent a step forward.

This paper presents TGRP, an adaptive routing framework based on a flexible architecture able to combine several routing approaches that exploit different sources of information. The proposed solution was able to counter the particular drawbacks of each routing solution, while taking advantage of the behavior that they offer. These algorithms are heterogeneous, being based on topological knowledge (two-hop delivery, DYMO), geographical knowledge (Georouting), or they focus on disconnected networks (store-carry-and-forward algorithm). TGRP also solves or reduces the impact of the most common routing issues, such as location service setup or loop avoidance.

Experimental results show how different routing algorithms can be efficiently combined to improve performance in different scenarios, achieving a high overall performance and outperforming single protocol behavior in most cases. In particular, it outperforms DYMO by 10% in low density scenario, and it outperforms DTN by 10% in dense networks. This makes TGRP an effective routing solution, which must be a major requirement for routing protocols in vehicular networks.

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