Spray and Locate Routing for Vehicular Delay-Tolerant Networks

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Abstract— **Vehicular Delay-Tolerant Networks (VDTNs) are networks where there are no permanent end-to-end connections. VDTNs have a variable topology, with frequent partitions in the connections. Given the dynamic characteristics of these networks, routing protocols can take advantage of dynamic information, such as the node's location, to route messages. Geolocation-based routing protocols choose the node that moves closer to the location of the message destination as the message carrier.**

In this article, the Spray and Locate geographical routing protocol was proposed. First, the protocol replicates a limited number of messages in the network, and then it uses the direction of movement of the nodes to route messages in the known destination's direction. In order to obtain the locations of nodes in the network, a VDTN localization system, known as VDTN-Locate, in which each node in the network maintains a dictionary with the last location information known, including position, movement direction, speed and age, was also proposed.

The performance of Spray and Locate was compared with geographic and non-geographic routing protocols. The results show that the Spray and Locate protocol has a higher delivery rate and lower latency than the other evaluated protocols.

Keywords- Vehicular Delay-Tolerant Networks; Routing Protocols; Localization System; Geographic Routing

I. Introduction

Vehicular Delay-Tolerant Networks (VDTNs) [1] are networks with a variable topology over time, in which there is no permanent path between the source and the destination for data routing. The main characteristics of VDTNs are: intermittent connectivity, long and variable delays, and high error rates in data transmission. Due to frequent network partitions, the usual routing protocols cannot find routes resulting in data transmission failures. Routing in VDTNs is done through cooperation between the vehicles (i.e., nodes) of the network. Messages are stored in the nodes' buffers and carried. When another node with better conditions to find the destination appears, the message is transferred, repeating the process until the destination of the message is eventually found.

One of the challenges of routing in VDTNs is the development of routing metrics that allow choosing the most appropriate node to which the messages are transferred. Since in VDTNs, contact opportunities between nodes may be scarce, the choice of the next node for carrying the message is important. The present work is about routing in VDTNs based on the nodes location and navigation information.

The use of routing metrics based on location information requires that the node with the message knows its position, the position of the node with which it communicates, and the localization of the message's destination. Location information related to the nodes in contact can be obtained using the Global Positioning System (GPS) and exchanged during the contact, but locating the message's destination requires a location system. Many existing geographic protocols assume that the network nodes know the exact location of all destinations (e.g. GeoSpray [2]) or the destination is stationary, not considering the associated delays for obtaining the information nor destination mobility. However, in a VDTN, location information may be very outdated due to mobility and network partitions.

Another issue is that most geographical routing protocols, for VDTNs, use their metric information from navigation systems, such as the node's destination or the estimated time to reach the destination. However, if it is common for mobile nodes to have GPS, it is not so common for them to have a navigation system and know their destination on the map, since it would require user's action and might change during the trip. Therefore, there is a high dependence of some protocols on the navigation system, which can affect its performance.

In this work, Spray and Locate that is a location-based routing protocol is proposed, as well as a node location system, known as VDTN-Locate. Spray and Locate is a hybrid protocol, which uses multiple copies and geographic mechanisms. The protocol has two operation phases: in the first phase, it disseminates a limited number of copies of the messages in the network and, in the second phase, it makes location-based routing of the created copies of the messages. To obtain the location of the nodes in the network, Spray and Locate uses the VDTN-Locate system. VDTN-Locate is a VDTN localization system, where each node of the network maintains a dictionary with the last known location information, direction and speed of movement of other nodes. When two nodes establish contact, they update their dictionaries.

The performance evaluation of our proposed approach, compared with geographic and non-geographic protocols, shows that the Spray and Locate protocol has a higher delivery rate and lower latency than the other protocols evaluated.

The rest of the article is organized as follows. Section II describes some related work. Section III presents the proposed localization system for VDTNs. Section V presents the Spray and Locate routing protocol and its principles of operation. Section V focuses on the performance evaluation, i.e., the metrics and results for both: VDTN-Locate and Spray and Locate. Finally, Section VI presents concluding remarks and future work.

II. RELATED WORK

There are many routing protocols for DTNs and VDTNs in the literature [3][4]. Some of these protocols are presented here, and they differ in the number of message copies generated and the type of knowledge used to forward messages. These protocols are: Greedy-DTN [3], MoVe [5], Epidemic [7], Spray-and-Wait [8] and PRoPHET [9]. The first two routing protocols use a single-copy strategy, which means that there is only one copy of each message in the network. The remaining protocols use a multi-copy strategy, thus creating multiple copies of messages in the network.

Motion Vector (MoVe) is a geographic routing protocol that leverages the knowledge of relative velocities of nodes to estimate the closest distance that they are predicted to get to the destination of the messages, following their current trajectories. The node whose estimated trajectory goes closest to the destination is the best forwarding node.

The Greedy-DTN protocol is a geographic routing protocol that forwards the message to the node that is closest to the destination. The protocol is an adaptation, for DTNs, of the geographical routing protocol for Ad-Hoc networks, GPSR [6]. When the network is dense enough for end-to-end connectivity, the message is forwarded hop-by-hop, to nodes that minimize distance to the destination. When a local maximum occurs, so there is no neighboring node that is closer to the destination, than the node that holds the message, the node carries the message stored in its buffer, until there is a better contact opportunity.

Epidemic is a replication routing protocol, which disseminates an unlimited number of messages copies on the network, so that one of the copies will eventually find the best path to the destination of the message. When two nodes establish contact, they exchange all messages they still not have in its buffer. The protocol is simple and fast, but it overloads the network quickly.

Spray-and-Wait is a replication protocol that limits the number of message copies created to a configurable maximum value. The protocol has two distinct phases: the Spray phase and the Wait phase. In the Spray phase, for every message originating at a source node, L message copies are initially spread to L distinct relays. In the wait phase, if the destination was not found in the spray phase, each of the L nodes carrying a message copy will forward the message only to its destination. There are two different versions of the protocol, which differ in how the L copies of the message are spread. The simplest version is Source Spray-and-Wait, in which the source node forwards all L copies to the first L distinct nodes it encounters. The second version is Binary Spray-and-Wait, where any node that has $n > 1$ message copies (source or relay) encounters another node with no copies, hands over $\lfloor n/2 \rfloor$ copies and keeps $\lceil n/2 \rceil$ copies for itself. When a node has only one copy left, it switches to the wait phase.

PRoPHET is a probabilistic routing protocol that replicates message copies based on node's encounter history. The protocol uses the node's contact history to calculate a probabilistic metric called delivery predictability, which indicates how likely it is that a node will be able to deliver a message to the destination. Contacts increase the delivery predictability meanwhile time passed without contacts decreases it. A message is replicated to another node if the delivery predictability of the destination of the message is higher at that node.

Epidemic, Spray-and-Wait and PRoPHET do not have features specific of vehicular networks, therefore presenting a sub-optimal performance in such networks. On the other hand, despite Greedy-DTN and MoVe being geographical routing protocols, they are single copy, suffering from outdated geographic information in sparse networks. Spray and Locate uses multiple copies to improve delivery probability with limited overhead and all known location information, that is, position, movement direction and age.

III. THE VDTN-LOCATE SYSTEM

In this section, we present the VDTN localization system that was designed for geographic routing in VDTNs.

A. *The principle of operation*

In VDTNs, there is no permanent connectivity and communication is made when contact opportunities occur, hence a centralized localization system is ineffective.

VDTN-Locate is a decentralized localization system based on epidemic operating principles that disseminates information in the network. Nodes maintain a dictionary with the last localization information of known nodes and update it by exchanging information whenever a contact occurs. The localization information stored is called *GeoInfo* and its structure is shown in Figure 1. For a given node, it consists in the node identification, last location position coordinates, direction of movement angle, speed and time at which the information was created.

Nodes use a GPS receiver to get their location and time information. The VDTN-Locate system obtains this data and calculates the speed and direction of the angle of movement.

Node ID	Location	Direction	Speed	Info Time

Figure 1. The structure of GeoInfo

B. *Dictionary update*

The algorithm for the exchange of dictionaries between nodes is shown in Figure 2. It was considered that all the nodes in the network have the VDTN-Locate system implemented. First, each node updates its dictionary, so that information is deleted if it is too old. This allows to saves nodes' data storage space, which is a limited resource. The maximum value of the information age is a configurable parameter. When nodes are in contact, they should update their GeoInfo, and then exchange their updated dictionaries. When a node receives its neighbor's dictionary, it updates its dictionary as follows: for each GeoInfo received, it checks whether the information is already in its dictionary. If the information is in its dictionary, it only updates it if the time of acquisition of the information in the dictionary of the neighboring node is more recent. If the information is not present, it adds this information to its dictionary.

Algorithm for updating dictionaries

- Delete GeoInfos from dictionary with very old information
- Get my current GeoInfo and put it in my dictionary
- Send my dictionary to neighbor node
- Receive the neighbor's dictionary
- For each node ***i*** in the received dictionary different from me
  - If ***i*** is in my dictionary
    - If neighbor's information is more recent, update ***i***
  - Else
    - Add ***i*** to my dictionary

Figure 2. Algorithm for exchanging dictionaries between nodes when a contact occurs.

IV. The Spray and Locate Routing Protocol

Spray and Locate is a geographic routing protocol for VDTNs that uses the routing strategy of both single- and multi-copy protocols. The Spray and Locate protocol employs the Spray phase concept of the Binary Spray-and-Wait protocol, in which a predetermined quantity of copies of a message is disseminated in the network. According to the authors in [8], the binary version of the Spray-And-Wait algorithm is the one with the best mechanism to minimize the distribution time of the copies of the messages in the Spray phase. However, in the second phase of operation, instead of waiting to find the messages destination, as done in Spray-and-Wait, Spray and Locate forwards the message to a node that moves towards the destination of the message.

A. *The principle of operation*

The Spray and Locate protocol has two phases of operation:

1) *1st phase - Spray*

In the Spray phase, the source node sets the maximum number of copies of a message in the message header. Any node that has more than one copy of a message and finds another node that has no copies, gives half of the copies to the encountered node hence keeping half to itself. If the message is not delivered in this first phase, and a node is left with only one copy, it changes to the second phase of the protocol.

2) *2nd phase - Locate*

In the second phase, nodes that have only one copy of the message, route it geographically to the destination node. To do this, whenever they establish contact with another node, they must evaluate if it is going in a direction closer to the destination than itself. If so, they transfer the message to the other node. Since nodes are in contact, they are relatively close, and since VDTN are usually sparse, it is preferable to forward the message to the node that is going in a closer direction towards the destination. If both nodes have the same angle of the direction of movement relative to the destination, the node that minimizes the distance to the destination is selected to carry the message. The protocol is therefore greedy in order to take advantage of the multi-hop communication opportunities, if they exist, which are expected to result in lower latency, than if the message is simply carried by a node.

B. *Direction of movement calculation*

To calculate the nodes' direction of movement angle relative to the destination, it is considered the location of the node, its movement direction, and the location of the destination. Given the Node **X's** direction of movement vector $\overrightarrow{v_X}$, and the vector $\overrightarrow{XD}$ originating from node **X** to the known location of the destination **D**, the direction of the movement angle of **X** relative to **D** is

$$\theta = \cos^{-1}\left(\frac{\overrightarrow{XD}.\overrightarrow{v_X}}{|\overrightarrow{XD}|.|\overrightarrow{v_X}|}\right) \quad (1)$$

C. *Spray and Locate algorithm*

The algorithm of the protocol is shown in Figure 3. When node **X** encounters node **Y**, they begin to exchange the respective location dictionaries. Then, node **X** accesses its list of stored messages and verifies if there is any message whose destination is node **Y**. The next phase (Spray) is to check among the stored messages which ones have a number of copies larger than one so that they can be replicated to **Y**. Node **X** updates the number of copies in the message header to half of the present value and creates a copy to deliver to node **Y**. Finally, in the Locate phase, it verifies the remaining messages that only have one copy in the message header to evaluate if **Y** is a better carrier of these messages. Node **X** calculates its movement direction angle and its distance relatively to the message destination. Next, **X** performs the same calculations for **Y**. The message must be delivered to node **Y** if its movement direction angle relative to the destination is less than the angle of **X**. If a situation occurs where nodes have equal angles, the message is only delivered to **Y** if its distance from the destination is less than that of **X**. Messages forwarded to **Y** are deleted from **X**'s buffer when successfully transferred.

V. Performance Evaluation

This section presents the performance evaluation of the VDTN-Locate system and the Spray and Locate routing protocol. The simulations were performed on the Opportunistic Network Environment [10] (ONE) simulator. The map of Helsinki city, with dimensions of 4.5 km by 3.4 km, was used.

A. *Evaluation of the VDTN-Locate system*

A set of simulations, with different seeds for the movement pattern, were performed to analyze the error associated with the data at the nodes' dictionaries. The goal was to evaluate the speed of information acquisition, the age of the information, the position error and the relative speed error. For each metric evaluated, the average of the data collected from all nodes in the simulation was calculated. Samples were collected every fifteen minutes during over four hours.

1) *Performance metrics*

The dictionary size as a function of time is the amount of GeoInfos in the dictionary of a node. It allows knowing how the information propagates in the network. The age of information allows us to know how long ago the information was created and hence how outdated it is. It is the difference between the current time and the time when the information was generated, which is given in seconds. The position error is the distance between the position in the dictionary and the actual position of the node, in meters. The relative error of the speed is given in percentage and allows to analyze the error associated with the speed information present in the dictionaries.

The algorithm of the Spray and Locate routing protocol

- Node **X** establishes communication with node **Y**

/* VDTN-Locate dictionaries are exchange between **X** and **Y** */

- **X** updates the GeoInfo in its dictionary with current data and sends to **Y** its updated VDTN-Locate dictionary
- **X** receives **Y**'s VDTN-Locate dictionary and updates its dictionary with the latest received information

/* Delivery of messages whose destination is **Y** */

- For each message stored in **X**'s buffer and destined for **Y**
    - **X** delivers the message to **Y** and deletes it from its buffer

/* Replication/forwarding of the remaining messages */

- For each message ***i*** in **X**'s buffer
    - If ***i***'s number of copies ***L*** is greater than 1
        - **X** delivers to **Y** ***L*/2** copies of ***i*** and keeps ***L*/2** copies
    - Else
        - **X** accesses its VDTN-Locate dictionary to get the GeoInfo for **X**, **Y** and destination node **D**.
        - If the destination's GeoInfo is in the dictionary
            - **X** calculates its distance and the angle of the direction of its movement relative to **D**
            - **X** calculates **Y**'s distance and the angle of the direction of **Y**'s movement relative to **D**
            - If **Y**'s angle is smaller than **X**'s angle
                - **X** delivers ***i*** to **Y** and deletes it from its buffer
            - Else
                - If **X**'s angle is equal to **Y**'s angle and **Y**'s calculated distance is smaller than **X**'s distance
                    - **X** delivers ***i*** to **Y** and deletes it from its buffer
        - Else **X** keeps ***i*** in its buffer and moves on to the next message

Figure 3. The Spray and Locate routing algorithm when a contact occurs between node X and Y.

In the VDTN-Locate evaluation, three scenarios with different node densities were considered: with 50, 150 and 300 nodes. The nodes speed varies in the interval from 10 km/h to 50 km/h. The movement model is SPMBM (Shortest Path Map-Based Movement), included in the ONE simulator: nodes randomly choose a destination and move there by the shortest path.

2) Results

For all node densities, at 900 s (15 min), the nodes' dictionaries are almost filled with information about all existing nodes in the network. The information dissemination is fast, and after 30 min, the nodes have location information in their dictionaries for all the other nodes in the network. The high speed of the vehicles increases the frequency of contacts between nodes in the network, which increases the information dissemination speed across the network.

Figure 4 presents the results for the average age of the information existing in the nodes' dictionaries. By comparing these graphs, one can conclude that the information is more outdated in scenarios with lower node density. The dictionary of a given node is updated whenever contact occurs between two nodes. In low-density node environments, contact opportunities are rarer than in denser node environments, therefore the information in the dictionary is updated less frequently.

By observing Figure 5 and Figure 6, which correspond to the average location error and the average relative speed error, respectively, it is possible to see that the average errors are lower in the higher density scenarios as there are more contact opportunities.

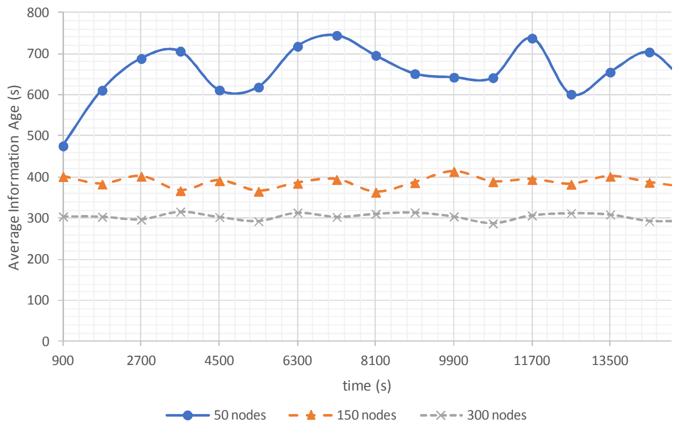

Figure 4. Average information age, in seconds.

The information in the dictionaries has low accuracy. As an example, the scenario with 300 nodes has 850 m average position error (Figure 5) for information with an average age of 5 min (Figure 4). This will have effects on the routing protocols, which can be very significant, if they are based on very outdated information. The relative speed error is significant, as nodes frequently stop and change speed. However, it should be noted that the results presented are the average for all nodes. Naturally, the errors for a particular node are smaller near that node, because the information is spread from each node through an epidemic update mechanism.

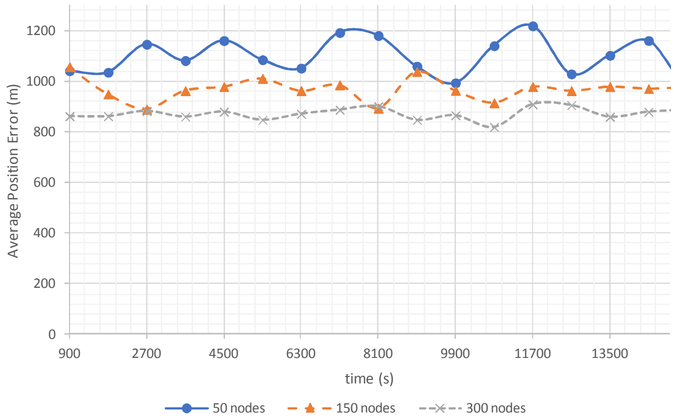

Figure 5. Average position error, in meters.

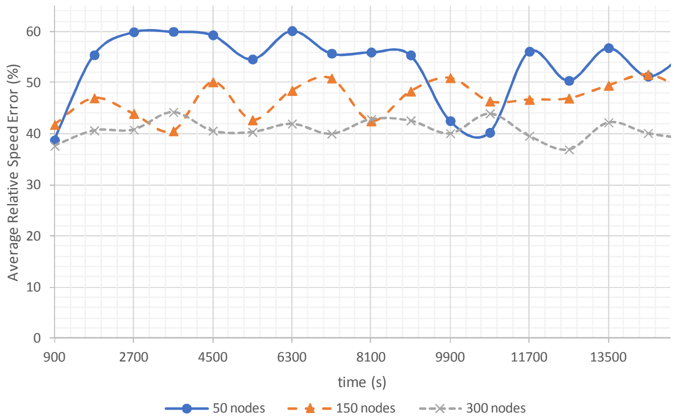

Figure 6. Average relative speed error, in percent.

B. *Evaluation of the Spray and Locate routing protocol*

This section describes the simulation model and results for our proposed routing protocol.

The evaluation of the Spray and Locate routing protocol was done with three multi-copy routing protocols that do not use geographic information (i.e., Epidemic, PRoPHET, Spray-and-Wait) and two single-copy geographic routing protocols (i.e., MoVe and Greedy-DTN). First, an optimal setup, where nodes have exact knowledge of the position of all the nodes in the network, will be considered. Then, a more realistic setup, where, as nodes do not know where exactly the message destinations are, use the VDTN-Locate system to estimate the latest known location, will be considered.

1) The simulation setup and performance metrics

The simulation takes place during a period of 12 h, in a scenario with 150 nodes, of which 105 are cars and 45 are buses. Cars have a buffer size of 20 MB and move on roads, according to the SPMBM model. The speed of movement of cars varies between 10 km/h and 50 km/h, with pauses in the range of 0 s to 120 s. Buses have a buffer size of 50 MB and move on pre-programmed routes, according to the Route Map Based Movement (RMBM) model. Their speed of movement varies between 25 km/h to 36 km/h, with pauses between 10 s to 30 s. The wireless communication interface of the nodes has a range of 30 m and a transmission rate of 4.5 Mb/s. Nodes randomly generate messages to a random destination, with an interval ranging between 25 s to 35 s. The size of the generated messages range between 500 KB and 1 MB.

The parameters of PRoPHET were $P_{init} = 0.75$, $\beta = 0.25$ and $\gamma = 0.98$. They were set according to [7]. Spray-and-Wait and Spray and Locate use the binary scheme with the number of copies equal to 6. This limit was chosen to avoid overloading the network. The buffer management policy used by the routing algorithms is the First In, First Out (FIFO). Thus, the first messages to be discarded when buffer congestion occurs are the oldest messages.

Simulations were performed by varying the value of the Time-To-Live (TTL) parameter of messages, aiming to vary the load on the network. The TTL determines the period of validity of a message in the network, that is, when the configured TTL value ends, the message is deleted from the node's buffer. The values chosen for the TTL were 60 min, 120 min, 180 min, 240 min and 300 min. The metrics used to evaluate the protocols were delivery rate, average delay, and overhead. Each simulation was executed 8 times using different random seeds. The results presented are the average values of the performance evaluation metrics and the respective 95% confidence intervals.

2) Results

Figure 7a) presents the average message's delivery rate. Spray and Locate has the highest average delivery rate for different TTL values. The second protocol with the highest average delivery rate is Spray-and-Wait. These two protocols have an equal dissemination phase, in which they place multiple copies of the messages circulating in the network, increasing the probability that eventually one of these copies will find the destination of the message. However, in the second phase of operation Spray-and-Wait waits until it finds the destination to deliver the message, while Spray and Locate forwards copies of messages to nodes that are moving towards the destination. The delivery rate of Greedy-DTN and MoVe grow with the increase of the TTL. Since these are protocols where there is only a single copy of each message in the network, with more time to deliver messages, the right path to the destination is more likely to be found. Epidemic and PRoPHET have different behavior from the remaining protocols with the TTL variation. In both, the number of copies circulating in the network is unlimited hence, the increasing of TTL results in an increased congestion and increased message drop, which results in a lower delivery rate. In Figure 7b), it is possible to see that the average message's delivery rate of Spray and Locate, when using VDTN-Locate differs from the average delivery rate for the optimal setup, only for the 60 minutes of TTL, remaining practically the same for the remaining TTL values. As for MoVe and Greedy-DTN, the difference between the average delivery rates in the optimal and real setups are more significant. For example, for the 60-minute TTL, the difference in the MoVe average delivery rate is equal to 24.4%. Spray and Locate distributes a limited number of copies of each message in the network and then forwards the copies using geographic routing metrics, meanwhile MoVe retains only one copy of each message circulating in the network. VDTN-Locate is a decentralized location system, thus the information present in the node dictionary and associated errors are not the same. Consequently, the different copies of the messages circulating in the network are subject to different circumstances imposed by VDTN-Locate.

Figure 7c) presents the message delivery latency. In general, with the increase of TTL there is an overall increase in the latency due to the increase of network congestion. Single-copy protocols, such as Greedy-DTN and MoVe, have higher latency than multi-copy ones. Replication is the means used to distribute multiple copies of a message in the network, and it increases the likelihood of one of these message copies reaching the destination. It is possible to see that Spray and Locate is the protocol with the lowest latency, which is due to its hybrid nature. That is, its Spray phase allows to distribute a limited number of copies of a message, which are able to explore different paths, and its Locate phase routes these message copies towards the destination.

Figure 7d) shows the latency in the scenario using VDTN-Locate. The three geographic routing protocols have higher latency when using VDTN-Locate. The inaccurate node location information causes more latency in message delivery. In the optimal setup, the metrics are calculated by always considering the current position and as a result, the message is being carried towards the destination. In the real setup that uses VDTN-Locate, the message suffers more deviations when it is transported to outdated positions.

By observing Figure 7e), one may conclude that multi-copy routing protocols are those that have higher overhead, except for Spray-and-Wait as it only generates 6 copies of each message during the Spray phase. When entering the Wait phase, the number of transmissions is very close to this value. Epidemic and PRoPHET generate an unlimited number of message copies, resulting in higher overheads. Geographic routing protocols have a Greedy behavior, i.e., they always transmit to any node that is closer to the destination, therefore increasing the number of transmissions. Figure 7f) shows that the overhead of geographic routing protocols increases when VDTN-Locate is used. Since these protocols have higher latency, messages circulate for longer period in the network, causing more transmissions.

VI. CONCLUSIONS AND FUTURE WORK

This article proposed a geographic routing protocol, named Spray and Locate, and a VDTN localization system, called VDTN-Locate, for routing in vehicular networks. Spray and Locate makes routing decisions based on geographical location information and moving direction of nodes. VDTN-Locate provides information of the location of nodes used by the protocol.

Simulation results showed that the Spray and Locate protocol outperformed other routing protocols considered in this article. That is, it has the highest average delivery rate and the lowest average latency, in both optimal and real setups.

The hybrid strategy used by our proposed approach allows it to obtain good results. Spray and Locate performs better than single-copy geographic routing protocols because in the first phase (Spray) it controlled the replication of messages. Consequently, there is a limited number of copies of a message circulating in the network, exploring different paths to find the destination. This latter allowed increasing the likelihood of finding the destination. In the second phase (Locate), the forwarding of copies of messages to nodes that move towards the destination improves its latency compared to other multi-copy based routing protocols.

Furthermore, the comparative analysis of the performance of the geographical routing protocols between the optimal and real setups showed that the inaccuracy of the VDTN-Locate information has more impact on the single-copy geographic protocols. As each node in the network maintains its own VDTN-Locate dictionary, the information present in each dictionary and the associated errors are not the same. They are only similar when there is a contact between two nodes and they update their dictionaries. Therefore, the different copies of different messages circulating in the network are subject to different contexts and the errors decrease as these messages approach the destination.

As future work, additional studies of the protocol's performance in other scenarios such as different node densities, node speeds and city maps, will be conducted to study the scalability of the protocol and influence of the scenario on the localization system. The comparison with other routing protocols in the literature [3][4] and the integration of VDTN-Locate with maps to improve the location forecast accuracy will also be considered.

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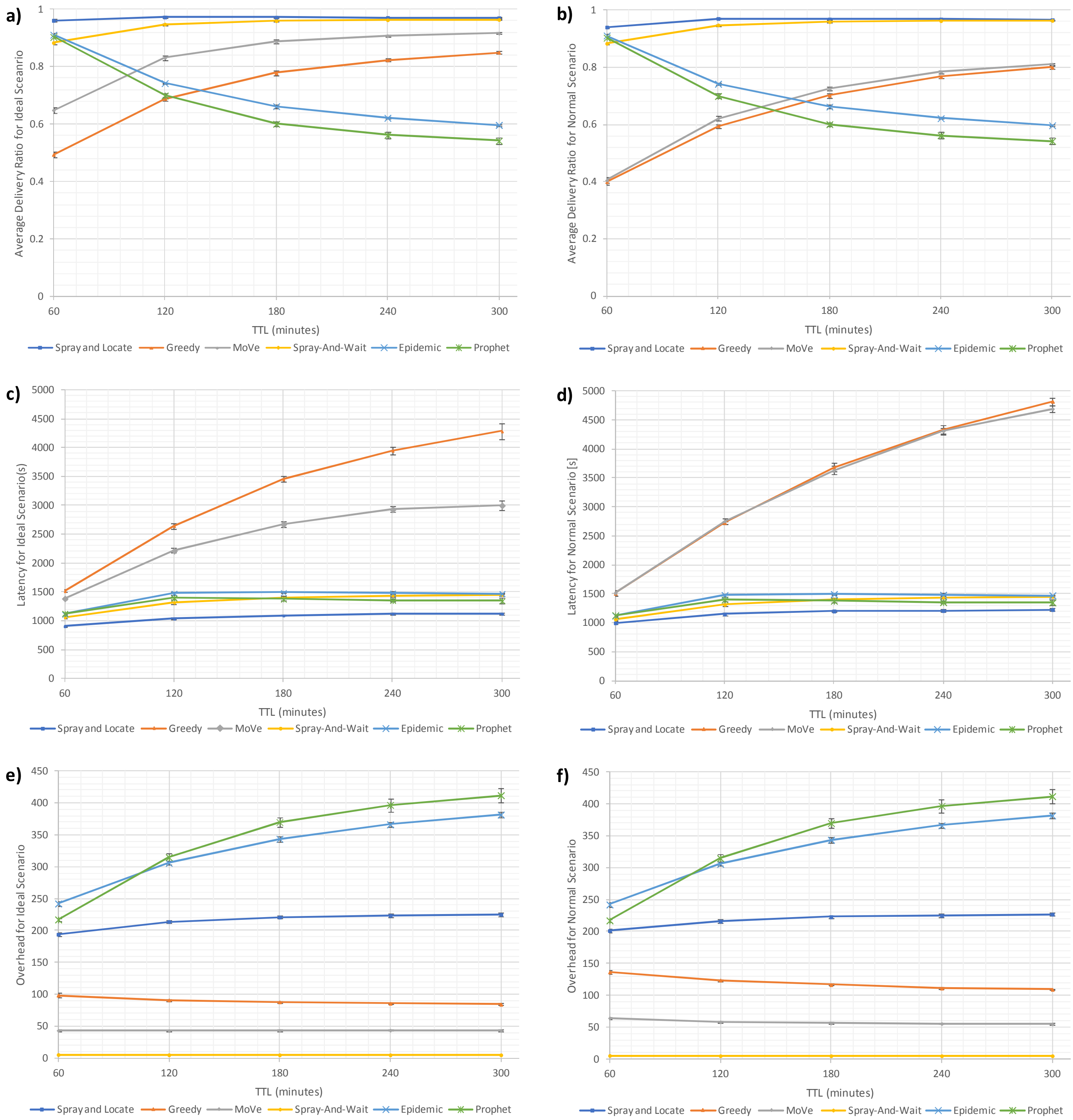

Figure 7. Simulation results in an ideal scenario and in a real scenario.