# Message Routing in Vehicular Delay-Tolerant Networks Based on Human Behavior

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***Abstract*—Delay/Disruption-Tolerant Networks (DTNs) have been used in many different scenarios and are characterized by the high mobility of nodes, the constant disconnection, the high delays for message delivery and the frequent partitioning. The union of Vehicular Ad hoc Networks (VANETs) and DTNs has created a new research field in Vehicular Delay-Tolerant Networks (VDTNs) based on DTN's stored-carry-and-forward mechanism and applying it to the vehicular context. This mechanism allows messages to be routed to their destinations without the need of end-to-end connections. Due to the widespread availability of low cost on-board communication devices, message routing in VDTN has become an important research target. That is why many protocols can be found in the literature with the goal of overcoming the challenges encountered by applications developed for this context. Nevertheless, these proposed protocols do not take into consideration important requirements such as: no dependency on Road Side Units (RSU) and mechanisms to obtain information about the location of vehicles. This paper proposes and describes a message routing algorithm based on consciousness and human behavior in order to address the main demands of the VDTN environment.**

## I. Introduction

A large number of applications and services involving vehicular communication has been recently put forward. Intelligent Transportation System (ITS), for instance, proposes the development and use of advanced applications to provide innovative services to traffic management. These applications allow to improve road safety and provide more comfort to drivers. They are based on vehicular communication, where cars are equipped with wireless devices capable of exchanging information about traffic and road safety with other cars nearby [1]. Information exchanged among vehicles is used to detect different traffic levels [2], which can be used to reduce traffic jams, for example. This vehicle-to-vehicle communication model is termed *Inter-Vehicle Communication* (IVC). The results presented [3] show that IVC can reduce the number of secondary collisions caused by an accident by disseminating warning messages. Applications developed for the vehicular environment that use IVC can be classified into three categories: (1) road safety applications; (2) management and traffic efficiency applications; and (3) information, leisure and entertainment applications.

Therefore, an efficient communication strategy among vehicles is critical for applications developed to this environment. However, the high mobility levels and the velocity of the vehicles make the network topology highly dynamic, producing short contact windows between the vehicles which results in frequent disconnections. Another complexity factor in this environment is the existence of different operating contexts, like highly dense highways and areas with sparse traffic [4]. All these characteristics combined make data routing in vehicular networks particularly challenging.

The main routing protocols for vehicular environments are based on two premises, namely, information about the destination location and RSU support. They assume that the destination location is known to every vehicle and that RSUs are available along the streets to support communication. However, these assumptions are not realistic (since RSUs are not omnipresent) what makes the respective routing algorithms inefficient or even useless.

This paper presents a mathematical model to estimate the location of the destination node even when no RSUs are available. The estimated location is then used to make message routing decisions when contacts are established among vehicles.

## II. Vehicular Delay-Tolerant Network

Delay Tolerant Networks were initially designed to support interplanetary networking. The main shortcomings of such a challenging environment is the frequent connection interruptions and the high delays. DTN nodes use a technique known as *store-carry-and-forward*, literally carrying a message until it is delivered to its destination or another node with better conditions to route it to the destination. Vehicular Delay-Tolerant Networks (VDTNs) are a special case of Vehicular Ad hoc Networks (VANETa) where the DTN paradigm is used to solve problems such as frequent disconnections and network partitioning [4]. The DTN approach can be applied in various types of networks where there is no guarantee about the existence of end-to-end connectivity. Therefore, conventional routing protocols designed to VANETa – which assume fully interconnected environments and aims at establishing end-to-end connectivity between network nodes – do not apply when network traffic decreases (for instance, in sparse networks), since end-to-end connections through intermediate nodes cannot be established anymore.

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A new category of network – the VDTN – was then created applying the DTN environment paradigms to the vehicular context. Many routing protocol proposals can be found in the literature related to the VANETs (e.g., [5]). However, these protocols are built around specific routing issues of VANETs (e.g., existence of end-to-end connectivity), without regard to the main challenges of DTNs. This work focuses exactly on these issues presenting and evaluating a new solution to the routing problems found in VTDNs.

### A. Motivation and Challenge

Recent research on routing protocols in the the context of VDTNs [1] raises the need to address shows some shortcomings that need to be addressed, such as:

*1) The need of an infrastructure-based operation: Roadside Units* (RSUs) are devices installed on the road sides with the goal of supporting IVC. Many protocols designed for VDTN assume that there are RSUs along the roadways that provide communication support. This assumption is, however, impractical since the installation and maintenance of RSUs can be very costly. For this reason, connection through RSUs is implemented only in very limited areas along roadways. Therefore, this is a demand that must be considered by the routing model proposed in the new research.

*2) Node Location:* Information about the location of the nodes has been frequently used by the proposed protocols for VDTN. This information provides a promising metric to classify protocols in accordance with the routing method used [4]. On the other hand, the acquisition of the information about the location of the destination is particularly complex when the nodes are moving constantly (which is the case in VDTNs). *Beacons* containing the location information could be exchanged between connected nodes. A mechanism like this allows the cars to store local information about other nodes, and use it as metric to estimate the location of the destination vehicles. This approach will guide message routing in VDTNs.

*3) Tradeoff:* The *tradeoff* between message delivery rates and the use of network resources is a constant challenge in VDTNs. Message replication is a common mechanism used by the routing algorithms to increase their message delivery rates. Such an approach increases considerably the number of message transmissions, causing congestions and quickly consuming the available network resources. New researches focused on VDTNs should consider this and propose innovative methods to deal with this issue. The simulation of human behavior by using techniques of context awareness and artificial intelligence seems to be very promising in this context [1].

The use the DTN communication paradigm for IVC critical applications (e.g., road safety) can be problematic, due to a higher possibility of transmission failures. This topic is treated elsewhere [6] and is considered out of scope of this paper. Nonetheless, considering the challenges and demands presented above, a new routing model based on human behavior called HBR will be presented in more detail in Section IV.

## III. Routing Protocols

Many routing algorithms designed for DTNs can be found in the literature (e.g., *Epidemic* [7] e *Spray and Wait* [8], *PRoPHET* [9] and *MaxProp* [10]). The most relevant routing protocols for DTNs can be classified into two groups: (1) *Random Routing Model* protocols (of which *Epidemic* and *Spray and Wait* are representatives), and (2) *Deterministic Routing Model* protocols (represented by *PRoPHET* and *MaxProp*). Table I compares the behavior of these protocols, based on the main forwarding metrics of the DTN environment.

TABLE I
Comparative View – DTN Protocols.

| | **Type** | **Copies** | **Replication rate** |
|---|---|---|---|
| **Epidemic** | Flooding | multiple | Very High |
| **Spray and Wait** | Controlled flooding | single and multiple | Medium |
| **PRoPHET** | Probabilistic | multiple | Medium |
| **MaxProp** | Flooding | multiple | High |

The second column of Table I shows the classification of the protocols according to the routing model they adopt. The third column shows that all these protocols use message replication as the method to increase the delivery rate. Replication is justified because it allows a message to follow more than one path to its destination. However, as seen in Section II-A3, message replication consumes network resources.

Once all these limitations are taken into account and considering a recent research contribution presented in [1], this paper defines a mathematical model that mimics the decision making process used commonly by people when routing an object from a person to another person, as they see and look for other people as they move. The methodology proposed assumes that the object cannot be duplicated. In other words, message replication does not apply. This assumption prevents an excessive growth in the number of message transmissions, thus decreasing considerably the consumption of network resources and, consequently, the network congestion. However, in order to do so, an efficient routing strategy is required. The model that simulates this human behavior is presented in detail in Section IV.

### A. VDTN Routing Protocols

Recently, many protocols and routing algorithms have also been proposed for Vehicular Delay-Tolerant Networks. The most important works are summarized in Table II, where their characteristics are discussed considering the main metrics in the context of VDTNs.

The second column of Table II reveals that protocols designed for VDTNs use a particular set of data to define how the message forwarding will occur. The information needed is composed of: speed, contact window, location and network density. The algorithm proposed in this paper considers these data (time, location, speed and contact window) within a mathematical model that attempts to capture a common human behavior when routing an object.

TABLE II
COMPARISON OF THE MAIN VDTN PROTOCOLS.

| | Forwarding metrics | Infra-structure? | Location Info? |
|---|---|---|---|
| **PBRS [12]** | Velocity-based probability | Yes | Yes |
| **ACSF [13]** | Minimum outage time of node | Yes | Yes |
| **DARCC [14]** | Location of destination moving direction of nodes | Yes | Yes |
| **GeOpps [16]** | Density of nodes | Yes | Yes |
| **GeSpray [17]** | Density of nodes and different data size | Yes | Yes |

The third column of Table II shows that one of the requirements discussed in Section II-A – the infrastructure-based operation – is not contemplated by most of the VDTN protocols. This observation legitimates the search for new methodologies which are infrastructure-independent. That is the reason behind the decision of not using RSUs in the proposed model. The fourth column shows that all routing protocols consider information about the location of the nodes in order to determine how message routing will happen.

Although the adequate use of this information is very important in VDTNs, as seen in Section II-A, the method used to acquire the location information of mobile nodes is not discussed in the corresponding literature. This gap also needs to be addressed.

## IV. HUMAN BEHAVIOR-BASED ROUTING — HBR

As presented in Section II-A, the VDTN environment has a set of requirements that still need to be better met by the existing routing protocols. Our view is that there is room for improvement in the routing process in the context of VDTNs by the definition of an efficient mechanism for estimating the location of the nodes and by removing the dependence on an RSU infrastructure. From this point view, we call *Human Behavior-based Routing* (HBR) the computational model that mimics human behavior in obtaining location-related information about of the network nodes.

The protocol is based on three questions, namely:

1) *"If someone has already met the destination node, how long ago did the encounter occur?"*. This question allows the node carrying the message, say node $C$, to identify the best (i.e., most recent) information about the last known location of the destination node.
2) *"What is the last known location of the destination node and where was it going to?"*. At this time, $C$ already knows who has the latest information about the destination node, say node $D$, and, therefore, it needs now to determine which is the most recent information about $D$'s location, speed and direction. The answers of questions 1 and 2 make it possible to estimate the current location of $D$ (assuming a uniform motion)
3) *"When node $C$ is in contact with other nodes, which one going to the $D$'s estimated location?"*. This question allows to identify between $C$'s current neighbors (and $C$ itself) which one will most likely be in a position of delivering the message to its destination.

The computational model defined in the following is based on these questions and satisfies the main requirements of VDTNs. It will be shown that it is possible to estimate the location of the nodes without using message replication. This clearly reduces network resources consumption (and thus avoiding the *tradeoff* dilemma).

### A. Context Awareness

*Last Encounter Routing* (LER) is a known technique based on the node's history of encounters, and the underlying assumption is that each node holds information about the time, place, speed and direction of other nodes. In VDTNs, the information kept in the node's table is obtained when two vehicles are close enough. In order to be able to obtain this data, vehicles running the HBR protocol broadcast their information through *beacons*, allowing neighboring vehicles to store it. From a typical LER routing table, it is possible to obtain the time and the place where a vehicle was found. However, this is not enough in order to estimate future locations. Thus, the table needs to be extended to store further information, namely, the speed and direction of the vehicles.

The new table defined by HBR is called *Table of Contact Awareness* (TCA), since it contains "contextual" information about other nodes. The TCA can be seen in Figure 1, where:

- $ID$ it is the identifier of the contacted node;
- $T$ is the time (local clock) or the moment at which a contact was established with that node;
- $P_x$ e $P_y$ are the last known coordinates of node $ID$ (the last contact established with it); and
- $V_x$ e $V_y$ are the last known speed of node $ID$ in the plane axes $x$ and $y$, respectively (i.e., latitude and longitude).

| ID | T | $P_x$ | $P_y$ | $V_x$ | $V_y$ |
|---|---|---|---|---|---|
| 9 | 94 | 8 | 7 | 1 | -1 |
| 8 | 94 | 6 | 6 | 0 | 2 |

Fig. 1. The structure of the TCA.

From the TCA the following information can be computed:

**(1)** Using the time at which the contact occurred, it is possible to have an estimation of the geographical location of the destination node, since the smaller the age of the contact – $IC$ – (elapsed time), the higher the probability that the node is still in the same region where it was found last time. This information answers the first question. Since the time when the vehicle has been viewed is stored in the $T$ column of the table, the elapsed time can be obtained by subtracting the current time from the stored time.

**(2)** From the speed vector, it is possible to estimate where the destination node currently is, by considering the time elapsed since the last contact – the "age" of contact. These data allows to answer the second question. To reduce the processing demand, the mathematical model assumes that the vehicle's velocity is kept constant and that its direction does not change (Equations 1 and 2).

$$E_x(t) = V_x(t) \cdot IC + P_x(t) \quad (1)$$

$$E_y(t) = V_y(t) \cdot IC + P_y(t) \quad (2)$$

**(3)** Since the information about velocity and direction of all met nodes is available, it is possible to estimate which nodes will be inside the destination's communication range in the future. No only can the distance from the destination node be estimated, but also when it will happen. This information answers the third and last question. In order to perform all this computation, a mathematical model was created using the distance variation between two points as time passes by.

Using the information available at each node, it is possible to estimate: (a) the network topology; (b) the geographic location of vehicles; and (c) which of them will encounter the destination node in the future. This "context awareness" will be used to make routing decision.

### B. Mathematical Model

As discussed above, the information about the position and velocity of nodes is obtained using *beacons*. Additionally, the speeds of the nodes are assumed to be constant. Because of this, Equations 1 and 2 can to used to estimate the current location of destination vehicle. Nevertheless, the computation of how close two nodes will be in the future is also necessary. Consider the following definitions:

1) $X_0 = x_t - x_n$, where $x_t$ and $x_n$ represent, respectively, the $x$ coordinates of target (i.e., destination) and neighboring nodes;
2) $Y_0 = y_t - y_n$, where $y_t$ and $y_n$ represent, respectively, the $y$ coordinates of target and neighboring nodes;
3) $V_x = v_{dx} - v_{nx}$ where $v_{dx}$ and $v_{nx}$ represent, respectively, the speeds of the target and the neighboring nodes in the $x$ axis;
4) $V_y = v_{dy} - v_{ny}$ where $v_{dy}$ and $v_{ny}$ represent, respectively, the speeds of the target and the neighboring nodes in the $y$ axis.

Also, let $V = \sqrt{V_x^2 + V_y^2}$. Equations 3 to 6 are then derived to compute where the neighboring nodes are moving and how close each of them will be to the estimated destination location.

$$O_{coef} = X_0 \cdot V_x + Y_0 \cdot V_y \quad (3)$$

$$S_{min} = \left|(Y_0 \cdot V_x - X_0 \cdot V_y)\right| / V \quad (4)$$

$$T_{io} = \frac{-O_{coef}}{V^2} \pm \frac{\sqrt{O_{coef}^2 - V^2 \cdot (X_0^2 + Y_0^2 - R^2)}}{V^2} \quad (5)$$

$$T_{cw} = T_s - T_e \quad (6)$$

The *Oncoming Coefficient* – $O_{coef}$ – allows to identify if the analyzed system is physically acceptable. In other words, if the vehicles follow a trajectory that converges to the destination. If $O_{coef} > 0$, then the system is *not* physically acceptable, because a negative time would be necessary for the moment of the encounter. Actually, it means that the encounter between the analyzed vehicles may have occurred in the past. Therefore, when $O_{coef}$ is greater than zero, the node that carries the message will not pass it on to the neighbor analyzed because its trajectory will not reach the destination vehicle.

When $O_{coef} \leq 0$, the system is physically acceptable and the nodes follow intersecting trajectories. This allows the estimation of the *Minimum Distance* – $S_{min}$ – between vehicles (destination and neighbor). From this, it is also possible, using the *Input and Output Time of a Node Range* – $T_{io}$ – and the *Contact Window Time* – $T_{cw}$ –, to predict the moments in which the destination enters and leaves a node's communication range and the contact window time.

### C. HBR Operation

By employing the mathematical model presented in Section IV-B, HBR can simulate human behavior from the following data: the vehicle, amongst all encountered, that has the latest information about the destination, its position and its speed. Such awareness is possible because in each contact this information is stored in the Tables of Contact Awareness (TCA), which are exchanged during the contact.

Using the equation $\vec{V_m} = \Delta x / \Delta$ to compute the average velocity of the anchor node (the one that currently has the custody of the message), it is possible to estimate where the destination is now. And, using the position and velocity information shared by the neighbors (beacons), it can identify if and how long it will be in contact with the destination node. A better understanding about HBR operation is possible through the situation problem shown in Figure 2.

Notice that: (a) vehicle 1 obtained awareness (beacons) from/about destination node (where it was going to), thus storing information on its TCA; (b) vehicle 1 establishes a contact with the anchor node, transmitting the stored information about the destination node. This step corresponds to the questions (1): "Has someone seen or encountered the destination lately, and (if it is the case) how long ago did it occur?" and (2): "Where was the destination node and where was it going to?".

In Figure 2, it is possible to observe that the anchor node gets connected to vehicle 2 and becomes aware of its direction and that it is going towards node $D$'s estimated location. The anchor node then forwards the message to vehicle 2, that now becomes the new anchor node. This procedure answers question (3): "Which neighbors is heading towards the estimated location of node $D$?".

However, although the initial anchor node has forwarded the message to vehicle 2 (that was going to the last known location of the destination node), node $D$ changed direction (turning right on the next corner) just after sharing its speed

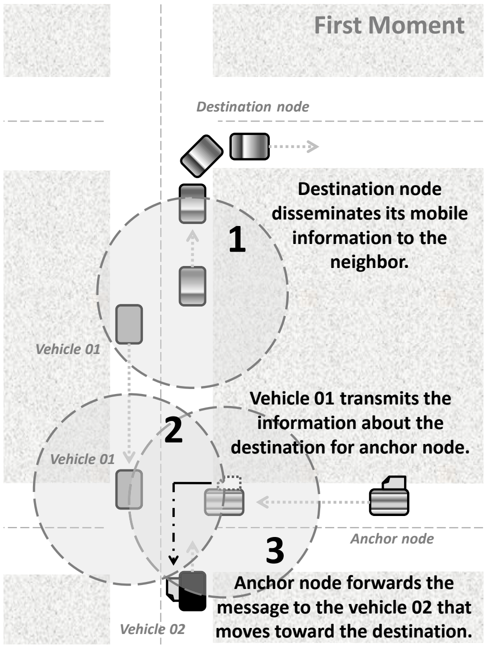


Fig. 2. Situation Problem (First Moment) – HBR Operation.

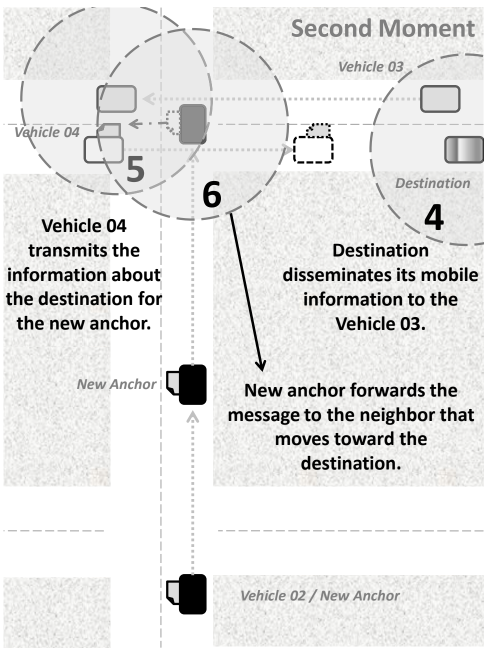


Fig. 3. Situation Problem (Second Moment) – HBR Operation.

and direction with vehicle 1. Notice that, in this case, the HBR protocol refines the estimated location in each message hop, as shown in Figure 3. This figure illustrates the behavior of HBR in a second moment, when the destination vehicle changes its direction. Notice that, even after changing it s direction, node $D$ still keeps announcing its contextual information to the new neighbors (vehicle 3 in Figure 3). This dynamics allows the new anchor node (vehicle 2) to obtain an updated information about the destination, and thought the mathematical model proposed IV-B, to choose new neighbors (vehicle 4, in the example) to forward the message to (based on the new estimated direction of vehicle $D$).

## V. SIMULATIONS AND PRELIMINARY RESULTS

The environment used for simulation was a city map (real scenario) containing the main features of VDTN: low density (sparse network), high mobility and frequent disconnections. Given these premises and in order to define the main simulation parameters, some previously used environments aimed at VDTN were investigated, as shown in Table III.

Based on the information shown in Table III, it was chosen a simulation set defined by an area of 4.5 x 3.4 square kilometers within the city map of Helsinki, Finland, and 100 vehicles moving at a speed ranging from $10km/h$ to $50km/h$. In order to simulate, we considered an initial "warm-up" time interval in which the nodes running the HBR protocol exchange information about their neighbors so to fill in their TCA up to a certain degree. Results were then gathered for the next 4 hours (considered the maximum amount of driving time).

TABLE III
TOPOLOGY AND IMPLEMENTATION USED BY VDTN PROTOCOLS

| | Topology Assumption | Implementation |
|---|---|---|
| **PBRS [12]** | 20 km one way road. Vehicle inter arrival time: 5-120 seconds | Java-based simulator |
| **ACSF [13]** | Not Available | Numerical analysis |
| **DARCC [14]** | 100 vehicles in a 3000mx3000m area. Each road has 4 lanes. Average speed of a node is 60km/h. | The One |
| **GeOpps [16]** | 260,000 vehicles 15km x 15km area | OMNet++ |
| **GeSpray [17]** | 100 mobile nodes with an average speed of 50 km/h city of Helsinki, time: 6hrs | VDTNSim |

The first metric analyzed was the message delivery average rate, which is the main goal of any routing algorithm designed for delay and disconnection-tolerant environments. Figure 4 shows the results obtained for the five protocols studied.

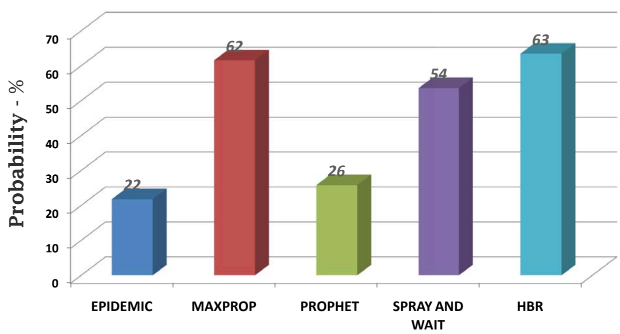


Fig. 4. Average rate of message delivery.

Figure 4 shows that the HBR's mathematical model was capable of attaining an average message delivery rate slightly superior to the other routing protocols analyzed (even when choosing not to use message replication). This shows that the method was successful in estimating good routes for message delivery. And this was done without needing additional infrastructure (RSUs), thus complying with this requirement. The second metric analyzed was the number of message transmissions initiated by each protocol (resource consumption) because, by increasing the number of transmissions of messages to increase the delivery rate, the protocols create traffic congestion. In other words, they do not comply with the tradeoff demand. Figure 5 shows the average transmissions produced by each of the five protocols during the four hours of simulation.

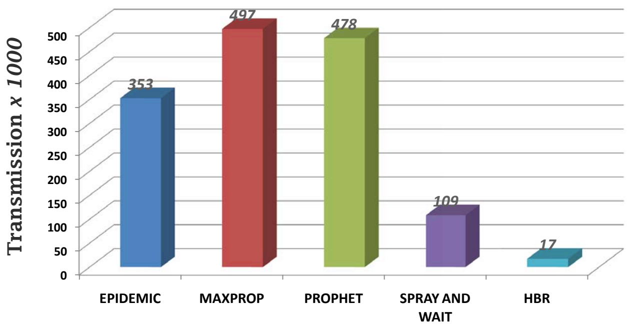


Fig. 5. Number of transmissions Started Messages.

According to the graph showed on Figure 5, it is possible to note that the number of transmission produced by the other protocols is extremely high when compared with the HBR protocol. This shows that, at the VDTN environment, where the network density is low, the unconscious increase of replication messages does not produces the expected increase in the message delivery rate. During the whole simulation time, the HRB protocol used 17800 message transmissions and a delivery rate of 63%, while MaxProp protocol used 497000 message transmissions and a delivery rate of 62%. That is, the MaxProp protocol produced 2.850% transmissions more than HRB protocol did, while it delivered fewer messages. Therefore, the HBR protocol, when compared with other protocols, complied with the tradeoff demand.

## VI. Conclusion and Future Works

The Vehicular Delay-Tolerant Network has peculiar features that bring the challenges of DTN environments into the vehicular networks. The non existence of an end-to-end connection (DTN) and the high mobility of nodes (VANETs) bring the need for new protocols that should be designed in order to accomplish new environment demands. The protocol here presented (HBR) draws attention to the possibility of developing new techniques that simulate consciousness and human behavior in order to comply with these demands. The results show that an appropriate mathematical model capable of estimating and obtaining information such as the location of nodes, with an efficient method for packet replication, or not using replication at all, may be a promising way to overcome challenges such as obtaining information about the location of nodes without the use of additional infrastructures (RSUs), reducing the number of packet transmission and congestion. Ongoing work includes integrating message path estimations into HBR and detailed performance analysis by the definition of new simulation scenarios and comparison with other VDTN protocols.

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