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Performance evaluation of a cooperative reputation system for vehicular delay-tolerant networks

João AFF Dias[1], Joel JPC Rodrigues[1*], Lei Shu[2] and Sana Ullah[3]

Abstract

In the last decade, both scientific community and automotive industry enabled communications among vehicles in different kinds of scenarios proposing different vehicular architectures. Vehicular delay-tolerant networks (VDTNs) were proposed as a solution to overcome some of the issues found in other vehicular architectures, namely, in dispersed regions and emergency scenarios. Most of these issues arise from the unique characteristics of vehicular networks. Contrary to delay-tolerant networks (DTNs), VDTNs place the bundle layer under the network layer in order to simplify the layered architecture and enable communications in sparse regions characterized by long propagation delays, high error rates, and short contact durations. However, such characteristics turn contacts very important in order to exchange as much information as possible between nodes at every contact opportunity. One way to accomplish this goal is to enforce cooperation between network nodes. To promote cooperation among nodes, it is important that nodes share their own resources to deliver messages from others. This can be a very difficult task, if selfish nodes affect the performance of cooperative nodes. This paper studies the performance of a cooperative reputation system that detects, identify, and avoid communications with selfish nodes. Two scenarios were considered across all the experiments enforcing three different routing protocols (First Contact, Spray and Wait, and GeoSpray). For both scenarios, it was shown that reputation mechanisms that punish aggressively selfish nodes contribute to increase the overall network performance.

Keywords: Vehicular delay-tolerant networks; Cooperation; Reputation system; Selfish nodes; Simulation; Performance evaluation

1 Introduction

Vehicular networks have been emerging as a suitable solution to enable communications in different kind of scenarios using vehicles (i.e., cars, buses, trams, etc.). Several architectures, like vehicular *ad hoc* networks (VANETs) [1] and delay-tolerant networks (DTNs) [2], were proposed to solve several issues in such networks. Vehicular delay-tolerant networks (VDTNs) [3] appeared as a breakthrough DTN-based solution that tries to overcome several issues found in other vehicular architectures, such as long delays and sporadic connections. To support communications, VDTNs propose an architecture based on three design principles: (i) an Internet Protocol (IP) over VDTN approach, (ii) an end-to-end, asynchronous, and variable-length bundle-oriented communication; (iii) a separation between control and data planes performing out-of-band-signaling.

VDTNs follow a store-carry-and-forward paradigm similar to the one that is implemented by DTNs. This approach allows VDTNs to solve several problems caused by intermittency, disconnection, and long delays. However, it distinguishes itself from DTNs by introducing the bundle layer under the network layer. This approach also assumes two logical planes (a control and a data plane). At the control plane, nodes exchange signaling messages in order to reserve resources (to be used at the data plane) and perform several routing decisions. At a given node, if there are bundles to exchange, the data plane is activated during the estimated contact duration time, and functions like queuing, scheduling, or

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* Correspondence: joeljr@ieee.org
[1]Instituto de Telecomunicações, University of Beira Interior, Covilhã 6201-001, Portugal
Full list of author information is available at the end of the article

traffic classification are performed. Data bundles aggregation/de-aggregation is performed at the edge of the network. This approach is very important because it not only ensures the optimization of the available data plane resources (e.g., storage and bandwidth) but also allows power saving, which is very important for energy-constrained network nodes, such as stationary relay nodes [3,4].

VDTNs consider three types of nodes: terminal, relay, and mobile. Both fixed and mobile nodes can act as terminal nodes. Fixed nodes work as access points to the VDTN and may act as traffic source and traffic sinks. Stationary relay nodes, with store-and-forward capabilities, are placed at road intersections and interact with mobile nodes in order to improve the number of contact opportunities that contribute to increase the overall network performance [5]. Mobile nodes can be the source or destination of data, but usually they carry data among different nodes (both fixed and mobile). Although in the already conducted studies, VDTNs still present a large number of technical challenges that should be overcome. One of these open issues is cooperation between network nodes. Previous studies on this topic [6] show that enforcing cooperation in VDTNs is not an easy task. For example, it is important to stimulate nodes to cooperate in order to create an optimal cooperative system that provides quality of service (QoS) to increase the overall network performance without compromising or deteriorating data. One way to achieve this issue is to afford nodes with sophisticated schedulers. These schedulers should take into account that cooperative networks should assume two types of nodes: selfish and cooperative. Selfish nodes are unwilling to cooperate and in most cases they receive bundles forwarded by other nodes to drop them immediately. This behavior contributes to a huge waste of network resources (e.g., power). Contrary to selfish nodes, cooperative nodes share their own resources to store-and-forward bundles from others. However, the behavior of selfish nodes may affect their performance.

In order to reduce the impact of selfish nodes, an optimized reputation system for VDTNs that considers nodes reputation scores calculated through nodes performance is proposed. For example, each time nodes successfully deliver a bundle, their reputation increases. However, each time they drop a bundle without sending it at least once, their reputation decreases. This system considers four different ways to penalize nodes with a selfish behavior. All four approaches distinguish itself from others by the way they reward/penalize nodes by their behavior. Then, the main contributions of this paper are the following:

- A review of the state of the art, considering the most relevant contributions on cooperation and reputation systems for vehicular networks
- Proposal of an optimized version of the reputation system already proposed for VDTNs with four different strategies to identify and avoid selfish nodes
- Exhaustive studies to evaluate the network performance improvement considering the proposed reputation system on VDTN nodes, using two different scenarios and the most relevant routing protocols

The remainder of this paper is organized as follows. Section 2 focuses on the cooperation problem and presents a review of the state of the art on cooperation and reputation systems for vehicular networks. Section 3 describes the proposed optimized reputation system and how it can be enforced in VDTNs, whereas Section 4 presents the experimental settings considered on the performance studies. The performance assessment of the proposed reputation system in VDTNs considering an urban scenario is presented on Section 5, while Section 6 emphasizes the obtained results by the proposed reputation system when deployed on a rural environment. Finally, Section 7 concludes the paper providing a final summary of the study and suggests further research topics.

2 Related work

In challenging environments characterized by long delays and sporadic connections, it is very important to ensure that nodes cooperate with each other in order to carry messages from the source to destination. Ensuring cooperation between network nodes may be a tough task due to the misbehavior of network nodes. Nodes may diverge from the protocol to save their own data and resources. Then, nodes may also diverge from the protocol and be unwilling to cooperate due to a selfish behavior. Selfish nodes may belong to individual users (nodes) that are not interested to share their own resources to forward messages from other users (nodes). In both conditions, this selfish behavior severely affects the overall network performance [7].

A possible solution to minimize the effects of misbehavior nodes is to create sophisticated reputation systems that allow nodes to detect, identify, and avoid such nodes. Several approaches were already been proposed for VANETs. For example, CONFIDANT scheme [8,9] was proposed to incentive nodes to cooperate by detecting and isolating misbehavior nodes. To accomplish such task, this scheme implements a system composed by four components: a monitor, a trust manager, a path manager, and a reputation score. The monitor, in conjunction with the trust manager, detects any misbehavior node and uses the collected information to make routing decisions. Based in the routing decision made by the monitor, the path manager calculates the optimal path avoiding misbehavior nodes. To calculate the optimal path, the reputation score of each node is considered. The CORE scheme, proposed in [10], considers the following three different kinds of mechanisms to select which node can use network services: (i) subjective, calculated based on direct observation, (ii) indirect reputation calculated according to information provided by other nodes, and (iii) functional reputation calculated using a specified function. In [11], authors propose a reputation system that encourages nodes to cooperate between them and punish misbehavior nodes. This system works under the principle that cooperation between nodes is performed by forwarding packets without any loss or network performance degradation. To avoid misbehavior nodes, this scheme detects and punishes nodes using a reputation management system (RMS) as an extension of the source routing protocol (SRP) [12].

Dotzer et al. [13] propose a reputation system for VANETs called VARS. This scheme assigns a reputation score to network nodes based on an opinion generation and confidence of the decision. Each time a node receives a message from others it generates an opinion based on the trustworthiness of this message. To calculate this opinion, nodes may consider partial opinions attached to the message, opinions from other nodes (if the sender is known), or a combination of both. Next time this message is forwarded, the new opinion is attached to it. A long-term reputation system for vehicular networking is proposed in [14]. This system provides reliable reputation scores by taking advantages from nodes' daily trajectories. Based on this experience, roadside infrastructure could rely on repeated daily observations of the same set of passing-by vehicles to build long-term reputation scores. To be deployed in a vehicular network, this scheme only requires nodes to have a secret and verifiable certificate. Patwardhan et al. [15] propose a reputation management scheme for VANETs. To evaluate nodes' reputation scores this scheme considers cooperativeness and accuracy of peer-provided data. To calculate these tokens, the proposed scheme uses persistent identifiers, frequency of encounters, and a known set of anchored trustworthy sources to serve as nucleating points for building trust relationships with previously unknown devices. In addition, this scheme deploys an epidemic exchange protocol to ensure high reliability of data and stimulate proactive collaboration between nodes.

In the DTN literature, it is also possible to found several cooperative schemes to stimulate cooperation between network nodes. For example, cooperative ARQ scheme (C-ARQ) [16] tries to reduce the number of loss packets in transmissions between access points placed along roads and vehicles. Same authors propose another cooperative approach called DC-ARQ (delayed cooperative ARQ) [17]. This scheme is an optimization of the previous one. It realizes cooperation between vehicles until they are out of range of an access point, instead of a packet-by-packet cooperation approach. In [18] authors propose a new cooperative mechanism to encourage nodes to cooperate during a message exchange. To perform such task, this scheme gathers several contributions from a game-theory model. Conducted studies have shown that this cooperative mechanism contributes to a significant improvement of the overall network performance. A study about the impact of misbehavior nodes in DTNs is presented in [19].

Several preliminary studies to enforce cooperation in VDTNs were already conducted [6,7,20]. Most of them try to understand the impact of different cooperative strategies in the overall performance of this type of architecture. This section overviewed the most important contributions already proposed to deal with node reputation and selfish nodes in vehicular networks. All the above-described schemes contributed to the proposal of a reputation system for VDTNs. A preliminary version of a reputation system for VDTNs was presented in [21].

3 Reputation system

This section, divided into two subsections, describes the optimized reputation system proposed for VDTNs focusing on its main features. The first subsection overviews the main features of the reputation system presenting the system operation mode, while the second one details the four reputation mechanisms supported by the system.

3.1 System overview

As above-mentioned, VDTNs use out-of-band-signaling allowing the separation of the control and data planes. The control plane is used to determine and adjust the characteristics of a requested connection in order to ensure a high-quality transmission of the corresponding data bundles. The data plane exchanges data bundles among nodes, according to the contact time scheduled for the data plane. Based on this architectural behavior, a reputation system for VDTNs is proposed to provide a sophisticated tool that allows network nodes to detect, identify, and avoid contacts with selfish or misbehavior nodes. It is expected that a reputation system contributes to an optimization of the overall network performance.

The reputation system operation may be described as follows. At the beginning of its process, each network node initializes a reputation table and a reputation score. The reputation table will store information (e.g., node name and reputation score) about all the encounter nodes. Each time a contact opportunity is available, the encountered node is added to the reputation table (if it does not already exist) and the reputation score is updated using the VDTN out-of-band-signaling at the control plane phase. At this phase, nodes exchange control information (setup messages), such as node type, geographical location, route, speed, supported link technologies properties, energy status, and buffer status. When the reputation system is active, nodes also exchange their reputation score. Afterwards, the reputation system accepts or denies a contact opportunity based on the nodes' reputation score by comparing it with a network reputation threshold (α), which is equal to all the network nodes and is defined at the beginning of the system execution. Nodes are able to exchange bundles and perform other data plane functions if their reputation score is higher than α. At the end of each contact, the nodes' reputation score is updated based on their performance during the contact opportunity. To update the nodes' reputation score, the reputation system considers two variables: delivered and dropped bundles. Each time a node successfully delivers a bundle to its final destination, it is rewarded with an increase on its reputation score. On the other hand, each time a node drops a bundle without sending it at least one time, it is punished and its reputation score decreases. Each time a node has a reputation score lower than the network reputation threshold, it is marked as a selfish node and is added to a blacklist. Nodes that are presented in the blacklist are ignored.

In the proposed reputation system, the reputation score is not only used to add nodes to the blacklist or to accept or deny a contact opportunity. It is also used to set the node cooperative threshold. The cooperative threshold is used to set the amount of resources that nodes share with others network nodes. For example, if a node has a reputation score equal to 80%, it means that this node will reserve 80% of its buffer capacity to store bundles from others. It also means that this node will spend 80% of an available contact time sending messages from other nodes. With this approach it is expected that selfish nodes will be identified and isolated soon in order to improve the overall network performance. Figure 1 illustrates the reputation system workflow.

3.2 Reputation system update module

The reputation system update module defines how the reputation score will be updated. To perform such task, the following four different heuristics were created: (i) simple increment simple decrement (*SISD*), (ii) double increment simple decrement (*DISD*), (iii) simple increment double decrement (*SIDD*), and (iv) simple increment message hop decrement (*SIMHD*).

In the SISD heuristic, each time a node successfully delivers a bundle to its final destination, its reputation score increases k units, where k is a positive constant. By the other hand, each time a node drops a bundle without send it, at least, once, its reputation score decreases k units. This scheme punishes nodes in the same proportion that rewards them. The DISD and SIDD schemes are a variation from this first scheme. The main difference between them is how they reward/punish nodes. In the DISD scheme, nodes increase their reputation in $2\,k$ units each time a bundle is delivered to its final destination. Contrary to this, the SIDD scheme punishes nodes in $2\,k$ units each time a bundle is dropped without having been sent once. This scheme will allow to observe if it is most important to reward nodes or to punish them by their selfish behavior.

The SIMHD scheme considers the number of hops between bundle source and the node where the bundle is dropped (without been sent once) to punish nodes. This scheme is more aggressive than the other schemes in penalizing nodes by their selfish behavior. Each time a node drops a bundle without sending it once, its reputation score decreases $2\,k + h{*}k$, where h is the number of bundle hops between the source and the current node. The idea behind this scheme is to punish nodes by the effort of previous nodes to deliver bundles.

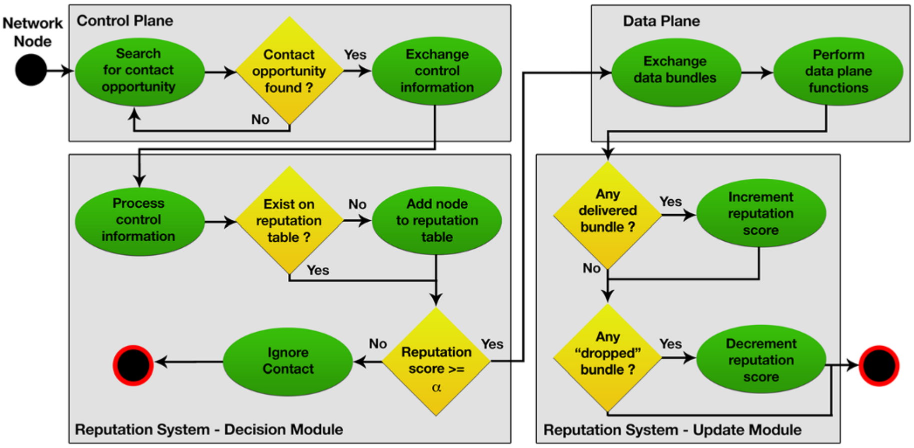


Figure 1 Optimized VDTN reputation system workflow.

4 Simulation setup

This section focuses on the simulation setup considered for the performance evaluation studies. Simulation studies were conducted using the VDTNsim tool [22]. This tool is an extension of the ONE simulator [23,24] and allows simulating the VDTN architectural approach, which comprehends the store-carry-and-forward overlay network below the network layer. This section is divided into three subsections. The first one describes how the urban network scenario was setup, as well as all the corresponding considered parameters. The second subsection elaborates on a rural network scenario presenting the network setup for this scenario, while the third presents the performance metrics and all the routing protocols considered for the performed simulation studies.

4.1 Urban network scenario

For an urban scenario, the simulation considers a map-based model representation of the Dakar region in Senegal, Africa (Figure 2). A cooperative opportunistic environment is considered without knowledge of the traffic matrix and contact opportunities for a period of 24 h. Twenty-seven terminal nodes, acting as traffic sources, represent real-world clinic locations. Each terminal node has a 125-MB (megabyte) buffer and generates bundles using an inter-bundle creation interval in a range of 15 to 30 min, which is uniformly distributed using random values. Each bundle has a size range between 500 KB and 2 MB. All the bundles exchanged in the simulations have an infinite time-to-live (TTL). Their destination address is the terminal node connected to the Internet that acts as the traffic sink.

Seven relay nodes, each one with a 250-MB buffer, are placed at the selected crossroads presented in Figure 2. All the network nodes connect to each other using the standard IEEE 802.11b with a data rate of 6 Mbps and a transmission range of 350 m using omni-directional antennas. Finally, 100 vehicles move along roads with a 50-MB buffer and at random speed between 30 and 80 km/h. When a vehicle reaches a terminal node, it randomly waits from 15 to 30 min. Then, it randomly selects its next destination node. From these 100 mobile nodes, 25 will act as selfish nodes, receiving bundles from other nodes and dropping them immediately after that. The remaining 75 mobile nodes act as cooperative nodes, sharing their resources depending on their reputation score.

4.2 Rural network scenario

For the rural scenario, the performance experiments consider a real map of Serra da Estrela region, Portugal (Figure 3). In this scenario, 25 terminal nodes acting as traffic source and traffic sink are placed at real-world sparse villages with a buffer capacity of 250 MB. Bundles, with a size ranging from 500 K to 2 MB, are created without TTL with a creation interval in the range of 15 to 30 min. Six relay nodes, with a buffer capacity of 500 MB, are placed at the most important crossroads in order to increase the number of contact opportunities. Contrary to the urban scenario, in this scenario, relay nodes' buffer capacity is increased due to the low density of mobile nodes, which results in fewer contact opportunities between network nodes. With this approach, relay nodes can store a larger number of bundles, in order to increase the bundle delivery probability [25]. Bundles are transported between terminal nodes by 40 mobiles nodes, which move along roads with a buffer capacity of 125 MB and a velocity in the range of 30 to 80 km/h. When a mobile node reaches a terminal node, it randomly waits between 15 and 30 min. Thus, a new random terminal node is chosen to be the next destination point. To study the impact of the proposed reputation system, from the 40 mobile nodes, 10 of them will act as selfish nodes. All the network nodes are equipped with the standard IEEE 802.11b interface to allow communications with other nodes and a data rate of 6 Mbps.

Figure 2 **Dakar region (Senegal) representing map roads and the location of terminal (clinics) and relay nodes.**

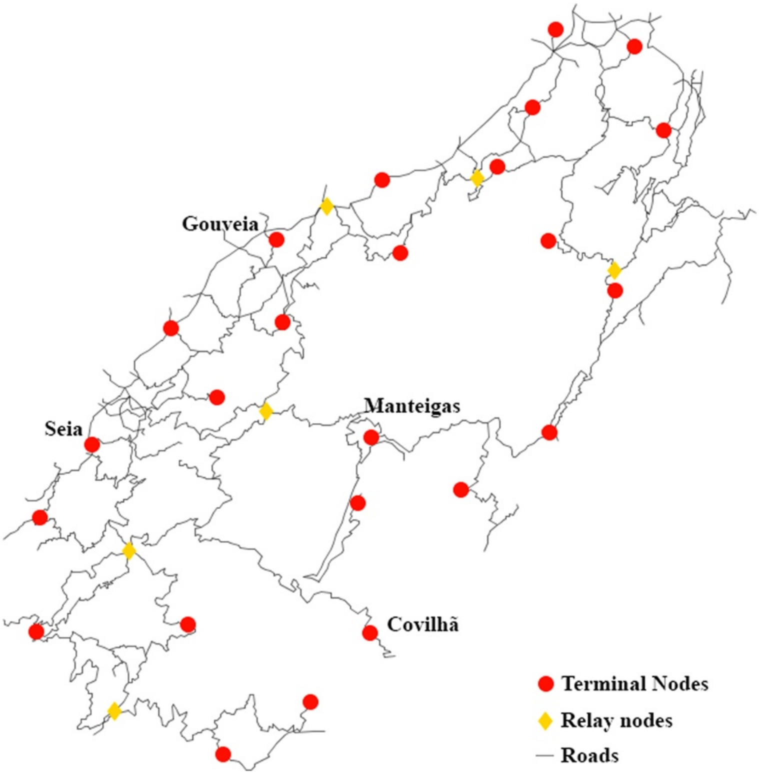


Figure 3 Serra da Estrela region (Portugal) representing map roads and location of terminal and relay nodes.

4.3 Performance metrics and routing protocols

The performance metrics considered in this study are the bundle delivery probability, the bundle average delivery delay, and the percentage of dropped bundles. The bundle delivery probability (D_{P}) is defined as the ratio between the number of unique bundles (i.e., it does not count bundle replicas) that have reached the final destination node(s) and the total number of unique bundles that were created at the source node(s). It is calculated according to Equation 1, where D_{P} is the bundle delivery probability, D_{B} is the total number of unique delivered bundles, and C_{B} is the total number of unique created bundles.

The bundle average delivery delay (D_{D}) is defined as the average time between bundles creation and their delivery. It is calculated according to Equation 2, where D_{D} is the bundle average delivery delay, $T\mathrm{d}_i$ is the time when the bundle i was delivered, $T\mathrm{c}_i$ is the time when the bundle i was created, and D_{B} is the total number of unique delivered bundles.

The percentage of dropped bundle (P_{DB}) is defined as the ratio between the total number of dropped bundles and the total number of bundles that was created at the source node(s). It is calculated according to Equation 3, where P_{DB} is the percentage of dropped bundles, N_{DB} is the number of dropped bundles, and N_{CB} is the total number of created bundles.

$$D_{\mathrm{P}} = \frac{D_{\mathrm{B}}}{C_{\mathrm{B}}} \tag{1}$$

$$D_{\mathrm{D}} = \frac{\sum_{i=1}^{D_{\mathrm{B}}} (T\mathrm{d}_i - T\mathrm{c}_i)}{D_{\mathrm{B}}} \tag{2}$$

$$P_{\mathrm{DB}} = \frac{N_{\mathrm{DB}}}{N_{\mathrm{CB}}} \tag{3}$$

For all the simulation experiments, the following three routing protocols are considered: First Contact [26], Spray and Wait [27], and GeoSpray [28]. First Contact is a single-copy forwarding routing protocol that maintains at most one copy of a bundle in the entire network. Contrary to the previous protocol, Spray and Wait routing protocol is a flooding-based routing protocol. It limits the number of copies of each bundle in the network. In studies that consider this protocol, the binary version assumes the use of a limited number of copies equals to 5 ($N = 5$). With this approach, binary version of Spray and Wait reduces some overhead of the pure epidemic diffusion. GeoSpray is a multiple-copy geographic routing protocol designed specially for VDTNs.

This protocol exploits the mobility of vehicles and the location information provided by position devices (e.g., Global Positioning System), to support routing decision-making process. GeoSpray was designed to perform into sparse scenarios where communication opportunities are sporadic. It also follows a hybrid approach inspired on GeOpps [29] and the binary version of Spray and Wait. GeoSpray and Spray and Wait protocols were chosen because they were the best performing protocols in previous studies focused on cooperation in VDTNs [6].

Across all the experiments, the impact of selfish nodes in the overall performance is evaluated as well as how the reputation system can help to identify and isolate them. Six different reputation thresholds (0, 10, 20, 30, 40, and 50) were studied along the simulation experiments.

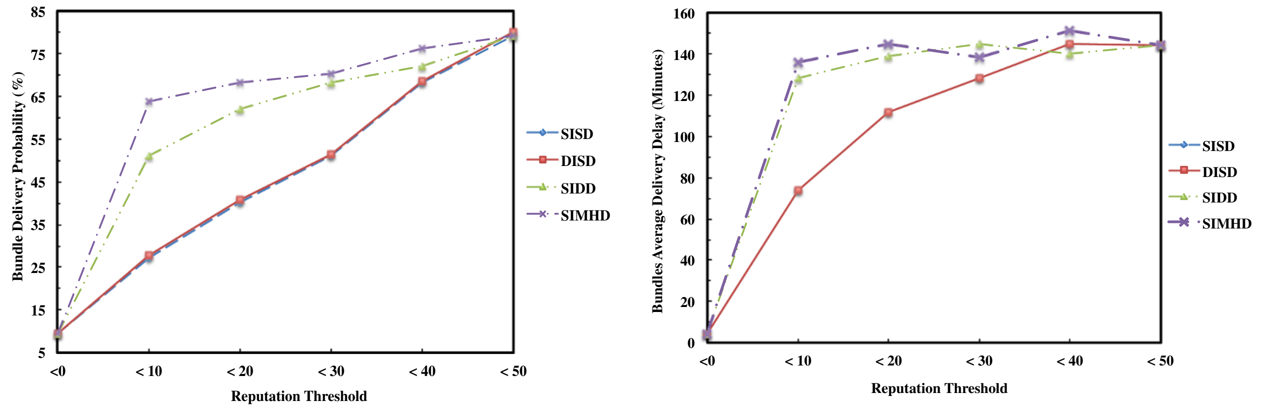
5 Performance analysis of the VDTN reputation system in an urban environment

This section focuses on a deep performance analysis of the above-presented reputation system enforced in an urban environment and its impact on the performance of VDTNs. Considering the presented heuristics used on the reputation system update module presented at the end of the Section 3, this section is divided into four subsections. The impact of the proposed reputation system in a single-copy routing protocol, called First Contact, is presented in the Subsection 5.1. The Subsection 5.2 focuses on the performance of the same reputation system when enforced in Spray and Wait routing protocol, while the Subsection 5.3 presents a discussion about the obtained results for GeoSpray routing protocol. Finally, the last subsection discusses the obtained results for this urban environment.

5.1 Impact of VDTN reputation system on First Contact routing protocol

This study starts with the results observed in simulation experiments with First Contact routing protocol. As this routing protocol is a single-copy forwarding routing protocol, it is very important to select the best nodes to forward bundles in order to increase their delivery probability. The results observed shown the importance of introducing a reputation system to identify selfish nodes in the network. Figure 4a shows that all the considered reputation mechanisms help to reduce the impact of selfish nodes by increasing the number of delivery bundles. The same figure also shows that mechanisms that are more aggressive in penalizing selfish nodes (SIMHD and SIDD) outperform those who do not have this approach (SISD and DISD). More accurately, SIMHD presents gains of approximately 37%, 28%, 19%, and 8% (for cooperation threshold equals to 10, 20, 30, and 40, respectively) when compared to the SISD reputation mechanism. When compared to the DISD mechanism, it presents gains of approximately 36%, 27%, 19%, and 7%. SIMHD and SIDD mechanisms have a very similar performance. However, SIMHD slightly outperforms the performance of SIDD mechanism.

Figure 4b shows the results observed by the same protocol for the bundle average delivery delay. As expected, by identifying and avoiding selfish nodes, the number of available nodes to forward bundles will decrease, which will force bundles to stay more time in nodes buffer and, consequently, it will increase the bundle average delivery delay for routing protocols with a single-copy approach. The SISD approach delivery bundles approximately 62, 33, 10, and 7 min sooner (for cooperation threshold equals to 10, 20, 30, and 40, respectively) when compared to the SIMHD approach.



(a) (b)

Figure 4 Bundle delivery probability and bundle average delivery delay for First Contact routing protocol. Bundle delivery probability **(a)** and bundle average delivery delay **(b)** for First Contact routing protocol as function of the reputation threshold, considering SISD, DISD, SIDD, and SIMHD reputation mechanisms.

When compared to the SIDD, the same heuristic delivers bundles approximately 54, 27, 17, and 4 min sooner. The DISD approach delivery bundles approximately at the same time of the SISD approach.

5.2 Impact of VDTN reputation system on Spray and Wait routing protocol

Contrary to First Contact, Spray and Wait is a routing protocol with a flooding approach. This means that each time a bundle is forwarded to a node, the sender node keeps a copy of this bundle on its buffer until the bundle is discarded by buffer congestion. As expected, Spray and Wait performs better than First Contact presenting better delivery probabilities across all the experiments. This assumption is confirmed comparing the results presented at Figures 4a and 5a.

The effect of cooperation, as an effective strategy to increase the bundle delivery probability, is even more pronounced in this routing protocol. Figure 5a shows that when a reputation system considers the SIMHD heuristic, the bundle delivery probability increases approximately 6%, 4%, 2%, and 1% (for cooperation threshold equals to 10, 20, 30, and 40, respectively) comparatively to the SISD approach. When compared to the DISD approach, the SIMHD approach presents gains of 5%, 3%, 2%, and 1%. Finally, when compared to the SIDD, the SIMHD heuristic presents gains of 1%, 1%, 1%, and 1%, respectively.

Contrary to the observed results for First Contact routing protocol (Figure 4b), with the integration of a reputation system, heuristics that aggressively punish nodes deliver bundles sooner (Figure 5b). Comparatively with the SISD, the SIMHD scheme delivers bundles approximately 3, 3, 2, and 1 min sooner (for cooperation threshold equals to 10, 20, 30, and 40, respectively). When compared to the DISD, the same scheme delivers bundles 2, 2, 1, and 1 min sooner. SIMHD and SIDD have a very similar performance in terms of bundle average delivery delay.

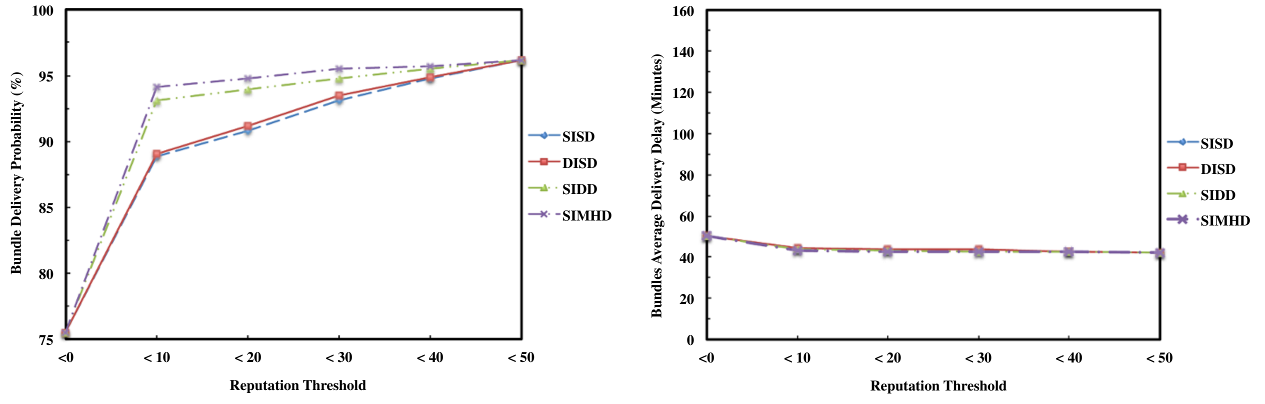
5.3 Impact of VDTN reputation system on GeoSpray routing protocol

As may be seen in Figure 6a,b, GeoSpray has a similar performance in this resource-constrained network scenario, when compared to Spray and Wait. As shown in Figure 6a when nodes follow the SIMHD scheme, the bundle delivery probability increases compared with other schemes. When compared with the SISD scheme, it increases to approximately 9%, 6%, 5%, and 2% (for reputation threshold equals to 10, 20, 30, and 40, respectively). It also performs better than the DISD, by delivering approximately 9%, 6%, 5%, and 2% more (for reputation threshold equals to 20, 30, and 40, respectively). Finally, SIDD delivers 3%, 2%, 2%, and 1% less, respectively, when compared with the SIMHD scheme.

In terms of bundle average delivery delay, the performance of GeoSpray presents significant gains when compared to Spray and Wait. SISD and DISD schemes deliver bundles later and present a similar performance. However, SIMHD delivers bundles approximately 2, 2, 1, and 1 min sooner (for reputation threshold equals to 10, 20, 30, and 40, respectively) when compared to the SIDD scheme. Figure 6b also shows that the bundle average delivery delay tends to decrease as the cooperation threshold value increases.

5.4 Discussion

This subsection overviews and discusses the results obtained for all the conducted studies, considering different reputation mechanisms in an urban environment.



(a) (b)

Figure 5 Bundle delivery probability and bundle average delivery delay for Spray and Wait routing protocol. Bundle delivery probability **(a)** and bundle average delivery delay **(b)** for Spray and Wait routing protocol as a function of the reputation threshold, considering SISD, DISD, SIDD, and SIMHD reputation mechanisms.

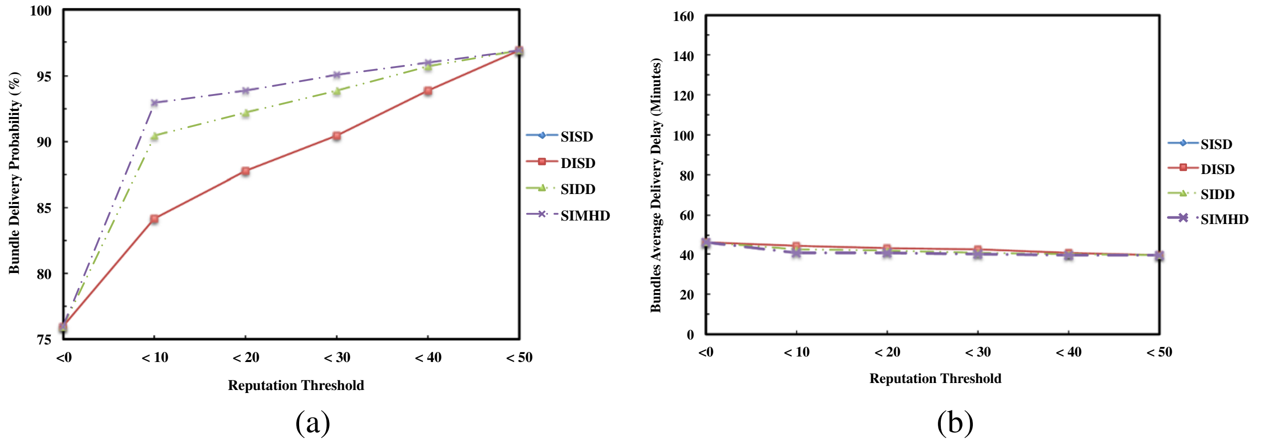


Figure 6 Bundle delivery probability and bundle average delivery delay for GeoSpray routing protocol. Bundle delivery probability **(a)** and bundle average delivery delay **(b)** for GeoSpray routing protocol as function of the reputation threshold, considering SISD, DISD, SIDD, and SIMHD reputation mechanisms.

For all the considered routing protocols, reputation functions that penalize selfish nodes in a more aggressive way contribute to improve the overall network performance by increasing the number of delivered bundles. As a consequence of increasing the number of delivered bundles in flooding-based approaches, a decrease of the bundle average delivery delay was observed. This network improvement may also be confirmed taking into account the percentage of dropped bundles for a reputation threshold of 40 (Figure 7).

As may be seen in the same figure, GeoSpray presents the lower percentage of dropped bundles. Considering the SIMHD heuristic, it drops 11% less of the bundles when compared to the Spray and Wait routing protocol, and 12% of the bundles when compared to the First Contact routing protocol. Regarding the SIDD approach, GeoSpray drops less 11% of bundles when compared to the same heuristic when enforced on the Spray and Wait routing protocol. When compared to First Contact, GeoSpray drops 15% less considering the SIDD heuristic. The other two heuristics (SISD and DISD) have a similar performance in all the considered routing protocols. However, when applied to GeoSpray, it drops 11% less of the bundles when compared to Spray and Wait and 18% when compared to First Contact.

6 Performance assessment of the VDTN reputation system in a rural environment

This section presents the observed results when proposed VDTN reputation system is enforced on a rural

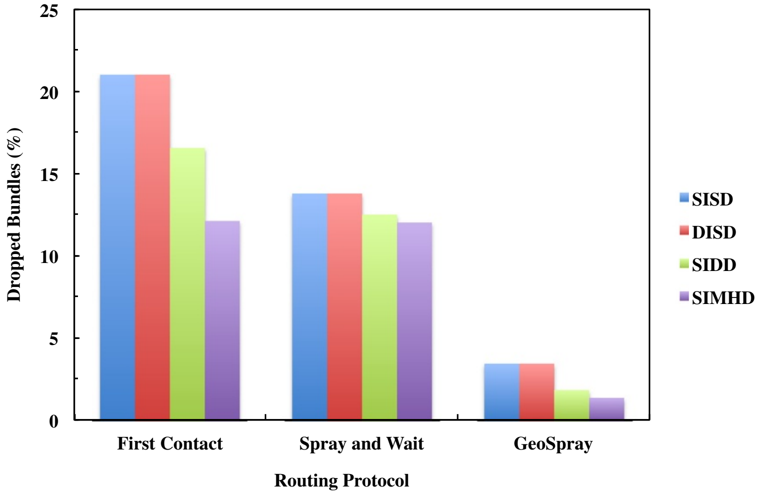
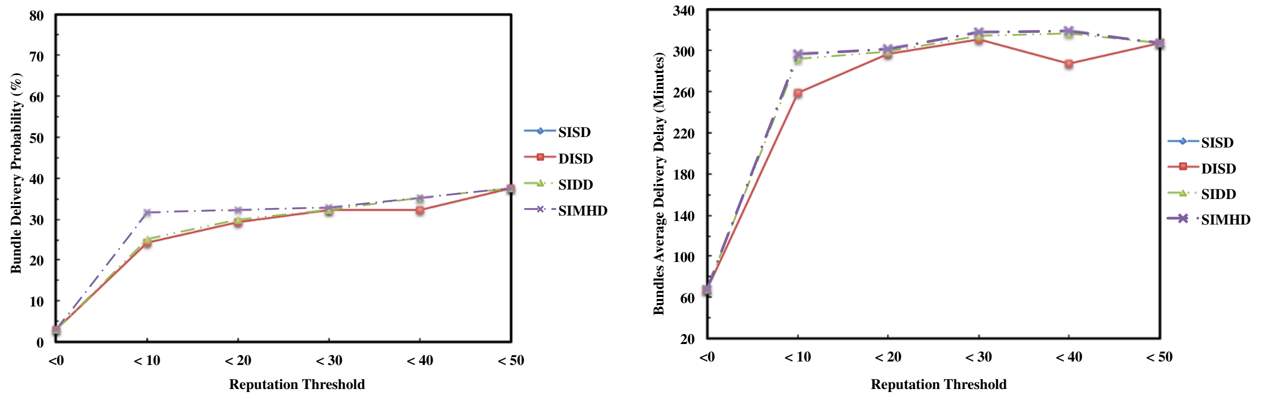


Figure 7 Percentage of dropped bundles as function of the reputation threshold. SISD, DISD, SIDD, and SIMHD reputation mechanisms for First Contact, Spray and Wait, and GeoSpray are considered.



(a) (b)

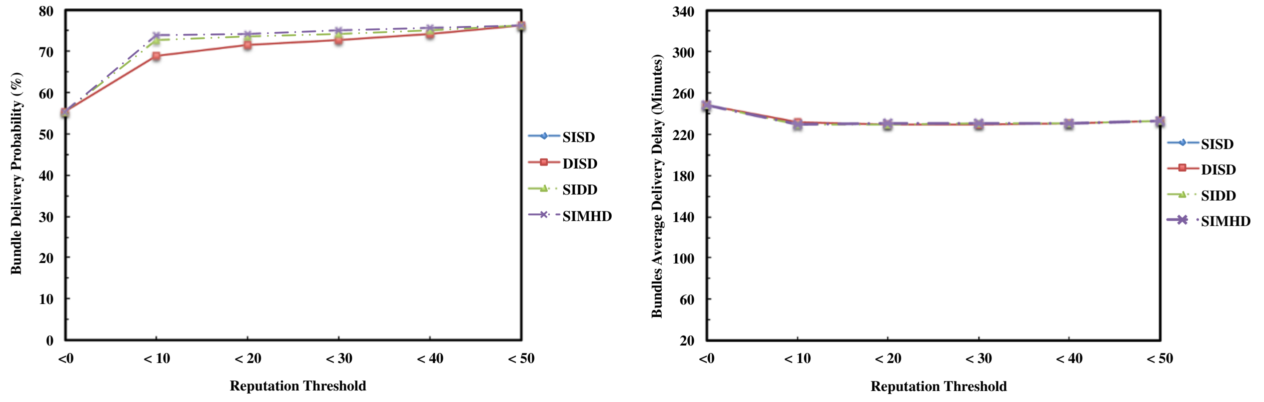
Figure 8 Bundle delivery probability and bundle average delivery delay for First Contact routing protocol. Bundle delivery probability **(a)** and bundle average delivery delay **(b)** for First Contact routing protocol as a function of the reputation threshold, considering SISD, DISD, SIDD, and SIMHD reputation mechanisms.

environment. Following the same approach of the previous section, this section considers four subsections. It starts to present the observed results for the First Contact routing protocol. Afterwards, the performance of the same reputation system when enforced in Spray and Wait and GeoSpray routing protocols is studied. Finally, several considerations are fixed about the conducted studies in a rural environment.

6.1 Impact of VDTN reputation system on First Contact routing protocol

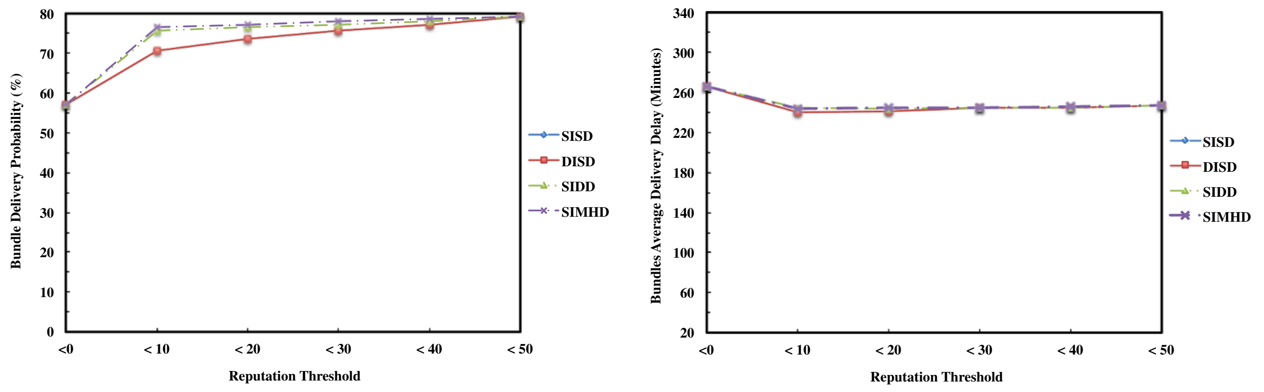
The results observed for the First Contact confirm those obtained for the urban scenario. Introducing a reputation system to detect, identify, and avoid selfish nodes contributes to increase the bundle delivery probability (Figure 8a). The SIMHD heuristic presents gains of approximately 8%, 3%, 1%, and 3% (for cooperation threshold equals to 10, 20, 30, and 40, respectively) when compared to the SISD reputation mechanism. When compared to the DISD mechanism, it presents gains of approximately 7%, 3%, 1%, and 2%, while the SIDD heuristic delivers approximately 6%, 2%, 1%, and 1% less bundles.

Figure 8b shows the results observed by the same protocol for the bundle average delivery delay. As expected, the bundle average delivery delay for this routing protocol increases as the reputation threshold increases. The SISD approach delivery bundles approximately 38, 4, 7, and 32 min sooner (for cooperation threshold equals to 10, 20, 30, and 40, respectively) when compared to the SIMHD approach. When compared to the SIDD, the same heuristic deliver bundles approximately



(a) (b)

Figure 9 Bundle delivery probability and bundle average delivery delay for Spray and Wait routing protocol. Bundle delivery probability **(a)** and bundle average delivery delay **(b)** in the rural environment for Spray and Wait routing protocol as a function of the reputation threshold, considering SISD, DISD, SIDD, and SIMHD reputation mechanisms.



(a) (b)

Figure 10 Bundle delivery probability and bundle average delivery delay for GeoSpray routing protocol. Bundle delivery probability **(a)** and bundle average delivery delay **(b)** in the rural environment for GeoSpray routing protocol as function of the reputation threshold, considering SISD, DISD, SIDD, and SIMHD reputation mechanisms.

33, 2, 3, and 29 min sooner. The DISD approach delivery bundles approximately at the same time of the SISD approach.

6.2 Impact of VDTN reputation system on Spray and Wait routing protocol

As expected, Spray and Wait performs better than First Contact not only in terms of bundle delivery probability but also in terms of bundle average delivery delay. Figure 9a shows that when a reputation system considers the SIMHD heuristic, the bundle delivery probability increases approximately 5%, 3%, 2%, and 1% (for cooperation threshold equals to 10, 20, 30, and 40, respectively) comparatively to the SISD approach. When compared to the DISD approach, the SIMHD approach presents gains of 4%, 2%, 2%, and 1%. Finally, when compared to the SIDD, the SIMHD heuristic present gains of 1%, 1%, 1%, and 1%, respectively.

Contrary to the single-copy approach, with the integration of a reputation system, heuristics that aggressively punish nodes deliver bundles sooner in Spray and Wait (Figure 9b). Comparatively with the SISD, the SIMHD scheme delivers bundles approximately 2, 1, 1, and 1 minute sooner (for cooperation threshold equals to 20, 30, and 40, respectively). When compared to the DISD, the same scheme delivers bundles 1, 1, 1, and 1 min sooner. SIMHD and SIDD have a very similar performance in terms of bundle average delivery delay.

6.3 Impact of VDTN reputation system on GeoSpray routing protocol

GeoSpray has a similar performance when compared to Spray and Wait in this resource constrained network scenario. Figure 10a shows that when nodes follow the SIMHD scheme, the bundle delivery probability increases when compared with other schemes. When compared to the SISD scheme, it presents gains of approximately 6%, 4%, 2%, and 2% (for reputation threshold equals to 10, 20, 30, and 40, respectively). It also performs better than the DISD, by delivering approximately 6%, 4%, 2%, and 2% more (for reputation threshold equals to 20, 30, and 40, respectively) of the bundles. Finally, SIDD delivers 1%, 1%, 1%, and 1% less of the bundles, when compared with the SIMHD scheme.

In terms of bundle average delivery delay, the performance of GeoSpray presents significant gains when compared to Spray and Wait. SISD and DISD schemes deliver bundles later and present a similar performance. However, SIMHD delivers bundles approximately 1, 1, 1, and 1 min sooner (for reputation threshold equals to 10, 20, 30, and 40, respectively) when compared to the SIDD scheme. Figure 10b also shows that the bundle average delivery delay tends to decrease as the cooperation threshold value increases.

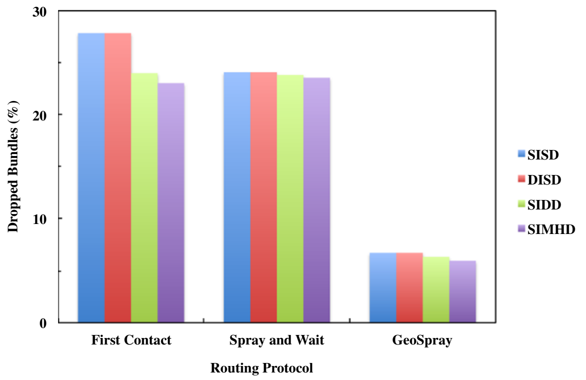


Figure 11 Percentage of dropped bundles as function of the reputation threshold. SISD, DISD, SIDD, and SIMHD reputation mechanisms for First Contact, Spray and Wait, and GeoSpray routing protocols are considered.

6.4 Discussion

In a rural environment, where the number of contact opportunist is sparse, it is very important to forward bundles to nodes that are able to deliver them. It was shown that a reputation system that punishes nodes by their selfish behavior contributes to improve the overall network performance. Although the results presented in the previous subsections, this network improvement may also be confirmed, taking into account the percentage of dropped bundles for a reputation threshold of 40 (Figure 11).

From all the considered routing protocols, GeoSpray is the one that presents the lower percentage of dropped bundles. Considering the SIMHD heuristic, it drops less 18% of the bundles when compared to the Spray and Wait routing protocol, and 17% of the bundles when compared to the First Contact routing protocol. Regarding the SIDD approach, GeoSpray drops less 18% of the bundles when compared to the same heuristic when enforced on the Spray and Wait routing protocol. When compared to First Contact routing protocol, GeoSpray drops less 18% considering the SIDD heuristic. The other two heuristics (SISD and DISD) have a similar performance in all the considered routing protocols. However, when applied to GeoSpray, it drops less 17% of the bundles when compared to Spray and Wait and 21% when compared to First Contact.

7 Conclusions

In the last years, vehicular architectures have been the focus of research not only by the scientific community but also by the automotive industry. VDTNs have been proposed as a possible solution to overcome the most challenging issues of vehicular communications. However, VDTNs still face several challenges on data communications due to sparse and intermittent connectivity or even the absence of an end-to-end path between the source and destination nodes.

This paper focuses on nodes' cooperation and how selfish nodes may influence the overall network performance. To reduce the impact of such nodes, an optimized version of a VDTN reputation system was proposed and enforced on VDTNs. This system includes four different ways to reward/punish nodes, and their performance was evaluated considering three different protocols (First Contact, Spray and Wait, and GeoSpray). It was shown that schemes that penalize selfish nodes in a more aggressive way contribute to increase the overall network performance (the number of delivered bundles increases and the number of dropped bundles decreases). This can be observed by the significant increase of the performance of First Contact routing protocol. From the two considered flooding-based routing protocols, GeoSpray has the best performance. Comparing the observed results for Spray and Wait and GeoSpray with the performance results in [21] for the same routing protocols, we can conclude that the reputation system improvement contributes to an increase of the bundle delivery probability. This was accomplished through the implementation of a more accurate function to calculate nodes' cooperative threshold.

This work may be used as a base to develop more complex reputation strategies that contribute to an increase of the overall network performance. Monitoring and management strategies may also be developed to help nodes in saving network resources. Mechanisms to incentive selfish nodes to cooperate in order to reactivate them to be considered in the network may also be proposed. All the above-presented proposals may be suggested for further research works.

Competing interests

The authors declare that they have no competing interests.

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Author details

[1]Instituto de Telecomunicações, University of Beira Interior, Covilhã 6201-001, Portugal. [2]Guangdong University of Petrochemical Technology, Guangzhou 51000, China. [3]CISTER Research Center, ISEP, Polytechnic Institute of Porto (IPP), Porto 4200-135, Portugal.

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References

1. J Jakubiak, Y Koucheryavy, State of the art and research challenges for VANETs, in *Fifth IEEE Consumer Communications & Networking Conference (CCNC'2008) - 2nd IEEE Workshop on Broadband Wireless Access* (Las Vegas, Nevada, 2008), pp. 912–916
2. V Cerf, S Burleigh, A Hooke, L Torgesson, R Durst, K Scott, K Fall, H Weiss, Delay-tolerant networking architecture. http://www.rfc-editor.org/rfc/rfc4838.txt. Accessed August 2013
3. VNGJ Soares, F Farahmand, JJPC Rodrigues, A layered architecture for vehicular delay-tolerant networks, in *The Fourteenth IEEE Symposium on Computers an Communications (ISCC'09)* (Sousse, 2009), pp. 122–127
4. N Banerjee, MD Corner, BN Levine, An energy-efficient architecture for DTN throwboxes, in *26th IEEE International Conference on Computer Communications (INFOCOM 2007)* (Anchorage, Alaska, 2007), pp. 776–784
5. JJPC Rodrigues, VNGJ Soares, F Farahmand, Stationary relay nodes deployment on vehicular opportunistic networks, in *Mobile Opportunistic Networks: Architectures, Protocols and Applications*, ed. by MK Denko (USA, Auerbach, CRC, 2010)
6. JAFF Dias, JJPC Rodrigues, L Zhou, Performance evaluation of cooperative strategies for Vehicular Delay-Tolerant Networks, in *Transactions on Emerging Telecommunications Technologies*, 2014. doi:10.1002/ett.2683
7. JAFF Dias, JJPC Rodrigues, JNG Isento, J Niu, The impact of cooperative nodes on the performance of vehicular delay-tolerant networks. Mobile Networks and Applications (MONET) **18**, 867–878 (2013)
8. S Buchegger, JYL Boudec, Performance analysis of the CONFIDANT protocol, in *Proceedings of the 3rd ACM International Symposium on Mobile Ad Hoc Networking & Computing* (Lausanne, 2002), pp. 226–236
9. Z Safaei, M Safaei, F Torgheh, An efficient reputation-based mechanism to enforce cooperation in MANETs, in *International Conference on Application of Information and Communication Technologies (AICT 2009)* (Azerbaijan, Baku, 2009), pp. 1–6
10. P Michiardi, R Molva, CORE: A collaborative reputation mechanism to enforce node cooperation in mobile *ad hoc* networks, in *IFIP TC6/TC11 Sixth Joint*

Working Conference on Communications and Multimedia Security: Advanced Communications and Multimedia Security (Portoroz, 2002), pp. 107–121

11. T Anantvalee, J Wu, Reputation-based system for encouraging the cooperation of nodes in mobile *ad hoc* networks, in *International Conference on Communications (ICC 2007)* (Glasgow, Scotland, 2007), pp. 3383–3388
12. ZG Al-Mekhlafi, R Hassan, Evaluation study on routing information protocol and dynamic source routing in ad-hoc network, in *7th International Conference on Information Technology in Asia (CITA11)* (Kuching, Sarawak, 2011), pp. 1–4
13. F Dotzer, L Fischer, P Magiera, VARS: a vehicle ad-hoc network reputation system, in *Sixth IEEE International Symposium on a World of Wireless Mobile and Multimedia Networks (WoWMoM)* (Taormina, Giardini Naxos, Messina, 2005), pp. 454–456
14. S Park, B Aslam, CC Zou, Long-term reputation system for vehicular networking based on vehicle's daily commute routine, in *IEEE Consumer Communications and Networking Conference (CCNC)* (Las Vegas, Nevada, 2011), pp. 436–441
15. A Patwardhan, A Joshi, T Finin, Y Yesha, A data intensive reputation management scheme for vehicular *ad hoc* networks, in *3rd Annual International Conference on Mobile and Ubiquitous Systems - Workshops* (San Jose, California, 2006), pp. 1–8
16. JM Pozo, O Trullols, JM Barceló, JG Vidal, A cooperative ARQ for delay-tolerant vehicular networks, in *The 28th International Conference on Distributed Computing Systems (ICDCS'2008)* (Beijing, 2008), pp. 192–197. June 17–20
17. JM Pozo, O Trullols, JM Barceló, JG Vidal, *Evaluation of a cooperative ARQ protocol for delay-tolerant vehicular networks, Wireless Systems and Mobility in Next Generation Internet, Lectures Notes in Computer Science* (Springer Berlin, Heidelberg, 2008), pp. 157–166. vol. 5122
18. L Buttyán, L Dóra, M Félegyházi, I Vajda, Barter-based cooperation in delay-tolerant personal wireless networks, in *IEEE International Symposium on a World of Wireless, Mobile and Multimedia Networks (WOWMOM 2007)* (Helsinki, 2007), pp. 1–6
19. U Shevade, HH Song, L Qiu, Y Zhang, Incentive-aware routing in DTNs, in *The 16th IEEE International Conference on Network Protocols (ICNP 2008)* (Florida, 2008), pp. 238–247
20. VNGJ Soares, JJPC Rodrigues, Cooperation in DTN-based network architectures, in *Cooperative Networking*, ed. by S Misra (John Wiley & Sons, Ltd, 2011), pp. 101–115. doi:10.1002/9781119973584.ch7
21. JA Dias, JJPC Rodrigues, L Shu, S Ullah, A reputation system to identify and isolate selfish nodes in vehicular delay-tolerant networks, in *13th International Conference on ITS Telecommunications (ITST)* (Tampere, 2013), pp. 133–138
22. VNGJ Soares, F Farahmand, JJPC Rodrigues, VDTNsim: a simulation tool for vehicular delay-tolerant networks, in *IEEE International Workshop on Computer-Aided Modeling Analysis and Design of Communication Links and Networks (IEEE CAMAD 2010)* (Miami, 2010), pp. 101–105
23. JOA Keränen, T Kärkkäinen, The ONE simulator for DTN protocol evaluation, in *Second International Conference on Simulation Tools and Techniques (SIMUTools 2009)* (Rome, 2009)
24. A Keränen, T Kärkkäinen, J Ott, Simulating mobility and DTNs with the ONE. J Commun (JCM), Academy Publisher **5**(2), 92–105 (2010)
25. VNGJ Soares, F Farahmand, JJPC Rodrigues, Improving vehicular delay-tolerant network performance with relay nodes, in *5th Euro-NGI Conference on Next Generation Internet Networks (NGI 2009)* (Aveiro, 2009)
26. S Jain, K Fall, R Patra, Routing in a delay tolerant network, in *Conference on Applications, Technologies, Architectures, and Protocols for Computer Communications (ACM SIGCOMM 2004)* (Oregon, 2004), pp. 145–158
27. T Spyropoulos, K Psounis, CS Raghavendra, Spray and Wait: an efficient routing scheme for intermittently connected mobile networks, in *ACM SIGCOMM 2005 - Workshop on Delay Tolerant Networking and Related Networks (WDTN-05)* (Philadelphia, PA, 2005), pp. 252–259
28. VNGJ Soares, JJPC Rodrigues, F Farahmand, Performance assessment of a geographic routing protocol for vehicular delay-tolerant networks, in *Proceedings of IEEE Wireless Communications and Networking Conference (WCNC 2012)* (Paris, 2012), pp. 2553–2558
29. I Leontiadis, C Mascolo, GeOpps: geographical opportunistic routing for vehicular networks, in *IEEE International Symposium on World of Wireless, Mobile and Multimedia Networks (WoWMoM 2007)* (Helsinki, 2007), pp. 1–6

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