Impact Analysis of the Shortest Path Movement Model on Routing Strategies for VDTNs in a Rural Region

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Abstract — **Vehicular Delay-Tolerant Network (VDTN) appears as a particular application of the Delay-Tolerant Network (DTN) concept to transit networks. In this paper we analyze the use of a VDTN to provide asynchronous Internet access on a rural remote region scenario. Through simulation we evaluate the impact of a shortest path based movement model on the performance of four DTN routing protocols in respect to message delivery probability and message average delay.**

I. INTRODUCTION

Over the last years the problem of providing data communications to undeveloped remote areas has been addressed by several projects with approaches that focus on asynchronous (disconnected) messaging in order to reduce the cost of connectivity. The DakNet project [1] aimed to provide connectivity to the Internet to rural villages in India at low-cost. In this project Mobile Access Points (MAPs) are mounted on vehicles, and when they are in contact with kiosks that are located in villages, data is exchanged between them. Afterwards, MAPs can use an Access Point to download/upload information to the Internet.

The Saami Network Connectivity (SNC) project [2] focused on providing Internet connectivity to the Saami population of the reindeer herders, who live in Lapland and move from their villages through the year, following the migration of reindeers. The Wizzy Digital Courier service [3] was designed to provide Internet access to schools located in remote villages of South Africa. This system is based on a courier using a motorbike, equipped with a USB storage device, which travels from a village school to a large city with broadband Internet connectivity. The Message Ferry project [4] aimed to develop a data delivery system in disconnected areas. In this system, mobile nodes called message ferries (e.g. cars, buses, boats, etc), move around the network and collect messages from source nodes.

All the networks above-mentioned are based on the concept of Delay Tolerant Network (DTN). DTNs address challenging connectivity issues enabling communication on scenarios having sparse connectivity, intermittent connectivity, long or variable delay, asymmetric data rate, high latency, high error rates and even with no guarantee of end-to-end connectivity [5]. In this type of network, a source node originates a message and stores it while a contact is not available. The message will be forwarded when the source node is in contact with an intermediate node thought for being more close to the destination node. Afterwards, the intermediate node stores the message and carries it while a new contact is not available. This process is repeated and the message will be relayed hop by hop until reaching its destination [6].

Vehicular Delay-Tolerant Network (VDTN) is a particular application of a mobile DTN where vehicles are opportunistically exploited to offer a message relaying service. It intends to provide low-cost connectivity in scenarios where the telecommunications infrastructure is unreliable or not available due to disconnected areas, natural disaster, or emergency situations. This paper presents a scenario where a VDTN is applied on a rural region. It considers that mobile nodes move in accordance to a shortest path movement model, and evaluates the impact of this mobility model on existing DTN routing protocols, comparing their performances.

The remainder of this paper is organized as follows. Section II introduces the VDTN architecture and the shortest path movement model, identifying our contribution. Section III presents the simulation scenario and analyzes the obtained results. Section IV concludes the paper and provides guidelines for future work.

II. VEHICULAR DELAY-TOLERANT NETWORKS

This work considers the use of a Vehicular Delay-Tolerant Network to provide low cost asynchronous Internet access on a rural remote region without network infrastructure. Figure 1 presents the VDTN node types: *terminal nodes*, *mobile nodes*, and *relay nodes*. *Terminal nodes* are located in isolated regions (villages) and provide network connection to end-users. At least one of the *terminal nodes* may have access to the Internet. *Mobile nodes* (e.g., vehicles) physically carry data between *terminal nodes*. They can move along the roads following predefined routes or randomly. *Relay nodes* are store-and-forward stationary devices located at crossroads. They allow *mobile nodes* that pass by to collect and leave data on them. *Mobile nodes* can also exchange information with one another.

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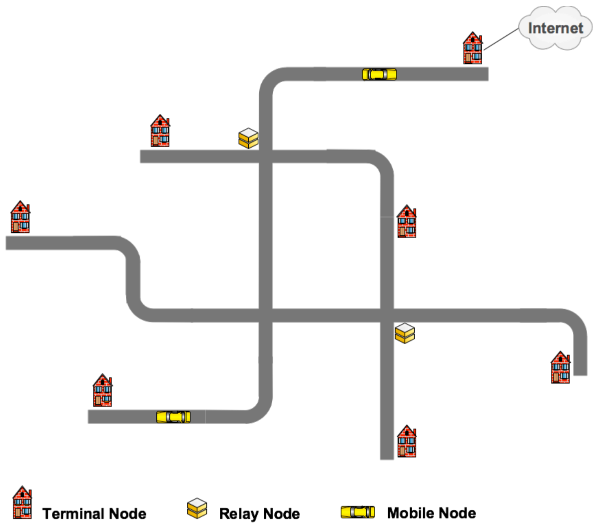

Fig. 1. Example of Vehicular Delay-Tolerant Network nodes.

In the context of this work we use a shortest path based movement model that will control the way *mobile nodes* move in the simulation map scenario. It will provide destination coordinates, speeds, pause times, and shortest path calculation. In addition, the map data contains two groups of Points of Interest (POIs). A group includes the terminal nodes (the *traffic sources*), whereas the other one contains the terminal node connected to the Internet. This terminal node will be the *traffic sink*. Based on the application of different probabilities to the POI groups, we are able to introduce variations on the mobility model, since it will use these probabilities to determine which POI will be the next destination for a *mobile node*.

We are interested on impact evaluation of varying POI group probabilities on the following four DTN routing protocols: Epidemic [7], Prophet [8], MaxProp [9], and Spray-and-Wait (binary variant, with 20 message copies) [10]. Epidemic is a flooding-based routing protocol where the nodes exchange the messages they don't have. Prophet is a probabilistic routing protocol that considers a history of encounters and transitivity. MaxProp prioritizes the schedule of messages transmitted to other nodes and also the schedule of messages to be dropped. Finally, the Spray-and-Wait protocol creates a number of copies to be transmitted per message. At each message transfer, the number of copies left is reduced to half. Performance metrics considered in this study are the overall message delivery ratio (measured as the relation of the number of unique delivered messages to the number of messages sent), and the message delivery delay (measured as the time between message creation and delivery).

III. PERFORMANCE EVALUATION

To analyze the impact of the above described movement model over the performance of a VDTN network, we run several simulations using the Opportunistic Network Environment (ONE) Simulator [11]. For the simulation scenario we develop a real-world map-based model representation of the *Serra da Estrela Region* (Fig. 2), and consider a simulation time of 12 hours (we are interested in message delivery for example from 8:00 to 20:00). We select 24 real-world village locations to place the *terminal nodes* that act as *traffic sources*. Each of the *terminal nodes* has a 125 Mbytes FIFO message buffer, and generates messages using an inter-message creation interval in the range [15, 30] minutes of uniformly distributed random values. Each message has a size in the range [500 KB, 2 MB] of uniformly distributed random values. All the messages 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*.

We consider three *mobile nodes* all having a 250 Mbytes FIFO message buffer, and moving in the map roads. Once a *mobile node* reaches a destination, it randomly waits 15 to 30 minutes. Then, instead of selecting any random location for the next destination, our movement model is configured to give a new destination in accordance to a probability. Afterwards, a random speed between 30 and 80 km/h is selected, and the *mobile node* moves there using the shortest path. Our map data contains two groups of Points of Interest (POIs). One of the POI groups contains the *terminal nodes* that are the *traffic sources*, and the other one contains the *terminal node* that is the *traffic sink*. For each simulation we associate different probabilities to the POI groups (Table I). This allows us to introduce variations in the *mobile nodes* movement model, and to study its implications on the performance of the VDTN network.

Table I – Points of Interest Group Probabilities

Traffic Sources POIs	**Traffic Sink POI**
85%	15%
80%	20%
75%	25%
70%	30%

For example, consider the first case reported on Table I. There is an 85% probability for the movement model to select a random village (*traffic source*) as the next destination for the *mobile node*. Intuitively, increasing the *traffic sink* POI selection probability, it will increase the overall message delivery ratio, so will *relay nodes* still being necessary? To answer to this question, on the second simulation scenario, we deploy six *relay nodes* with 500 Mbytes FIFO message buffer, placing them at randomly selected crossroads on the positions presented on Fig. 2.

All the network nodes connect to each other using 802.11b with a data rate of 6 Mbit/s and a transmission range of 350 meters. *Terminal nodes* and *relay nodes* exchange data only with *mobile nodes*. In addition, *mobile nodes* can communicate between themselves. Given the movement model of *mobile nodes* there isn't any knowledge about the transfer opportunities. Finally, we run a series of simulations for each combination of the parameters using different random seeds, and report the mean values.

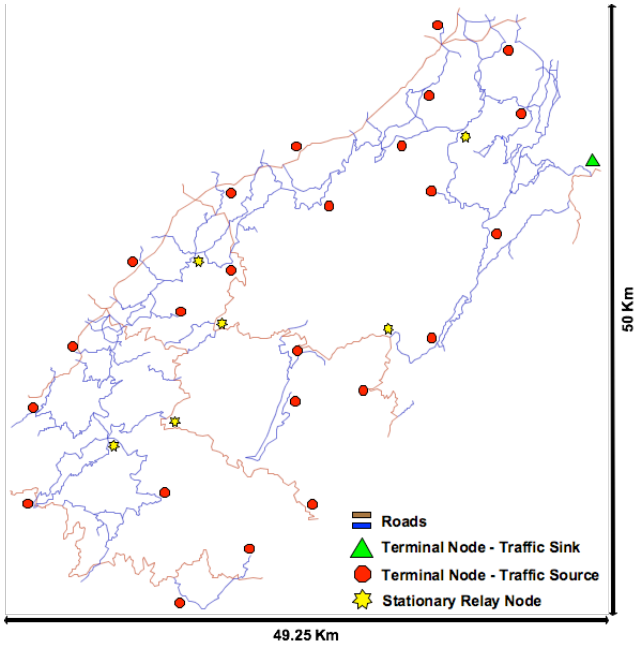

Fig. 2. *Serra da Estrela Region* simulation area with the locations of the terminal nodes and the relay nodes.

A. Simulation Scenario without Relay Nodes

In order to evaluate if increasing the *traffic sink POI selection probability* will, in fact, increase the message delivery ratio, and to analyze if the relay nodes will still improve the network performance, we start our evaluation by simulating of the network scenario without the presence of *relay nodes*. Fig. 3 shows that all routing protocols have a low message delivery probability. This is not strange since we are using a scenario that covers an area with large dimensions (approximately 2500 Km^2), only three *mobile nodes* are used, and the simulation finishes after 12 hours.

It can be surprising that increasing the *traffic sink POI selection probability* from 15% to 20% causes the message delivery probability to drop on all protocols. This change on the movement model increases the number of times that *mobile nodes* will drive to the *terminal node* that is the *traffic sink* instead of visiting villages (*traffic sources*), so they will collect, carry and deliver less messages. This effect is not aggravated when increasing the *traffic sink POI selection probability* further. We can also observe that the Spray-and-Wait routing protocol performs better than the others in respect to the delivery probability. The Prophet protocol performs poorly in this performance metric.

Due to the sparse and intermittent connectivity of this environment it is not strange to register large message delivery delays as the ones presented on fig. 4. For the same reasons presented above, the average delay drops when the *traffic sink POI selection probability* increases from 15% to 20%. On the first case, *mobile nodes* move more times between villages collecting more messages that are kept in buffers during larger periods of time until being delivered, augmenting the overall message average delay. We observe that the Epidemic and MaxProp protocols have similar values and perform better in this performance metric. Prophet and Spray-and-Wait also register similar average delays.

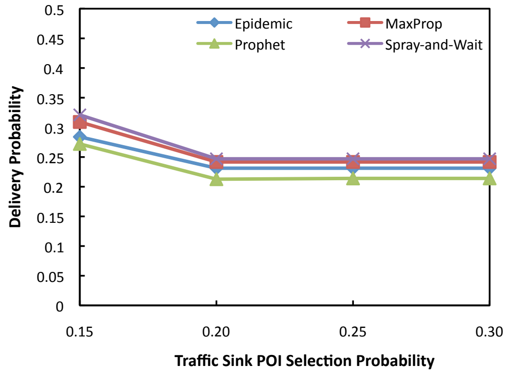

Fig. 3. Message delivery probability without relay nodes.

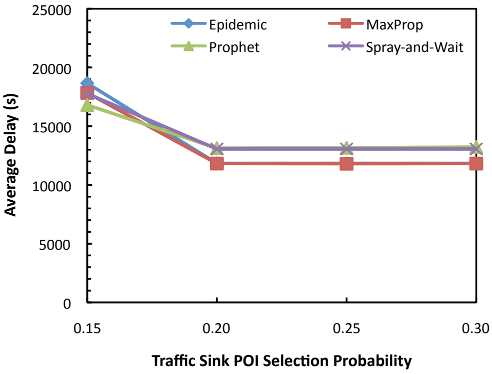

Fig. 4. Message average delay without relay nodes.

B. Simulation Scenario with Relay Nodes

Now, we deploy the *relay nodes* over the map. By increasing the number of contact opportunities, *relay nodes* augment the connectivity on this sparse rural region. As it can be observed, comparing Fig. 3 to Fig. 5, Epidemic protocol, that performs flooding, presents delivery probabilities 0%, 5%, 5%, and 11% greater than the ones registered in the case of no relay node usage. The MaxProp protocol that does flooding but implements explicit message clearing after delivering, increases its message delivery probability approximately 0%, 6%, 6%, and 16% (for each of the *traffic sink POI selection probabilities* that we are varying on the simulations). Prophet, that also performs a variant of flooding, only takes advantage of the use of relay nodes in the case of a *traffic sink POI selection probability* equal or superior to 25%, increasing the delivery probability in 3% and 13%. It performs worse on the other variations of the mobility model. Finally, Spray-and-Wait that creates a number of copies per message (20 in our case) presents gains approximately of 2%, 10%, 9%, and 15% across the simulations. It can also be observed that all routing protocols register the largest message delivery probabilities for a *traffic sink POI selection probability* of 30%. For that specific case, MaxProp and Spray-and-Wait perform better and have similar delivery probabilities. Epidemic and Prophet also have similar delivery probabilities.

Notice that we deploy the six relay nodes randomly on the map crossroads. We assume that the traffic matrix and the contact opportunities are unknown. If we knew this information in advance, then the relay nodes could be positioned in order to further increase the overall VDTN performance. Minimizing the message average delay lowers the time that messages spend in the network and reduces the contention for resources in the network. In this work, we consider small message sizes, sufficiently large buffers, and inter-message creation intervals, which minimize the probability of message drops due to buffer overflows. Given the dimensions of this scenario and the sparse connectivity also caused by the limited number of *mobile nodes*, we think that the performance evaluation should focus in the delivery probability metric. Nevertheless, the analysis of Fig. 6 allows us to conclude that Spray-and-Wait registers the lowest average delays, except for the case of a *traffic sink POI selection probability* of 25%. MaxProp and Epidemic protocols registered similar average delays for the first two simulations. For a *traffic sink POI selection probability* of 30%, Prophet and Epidemic protocols have an equal delivery probability and a similar average delay.

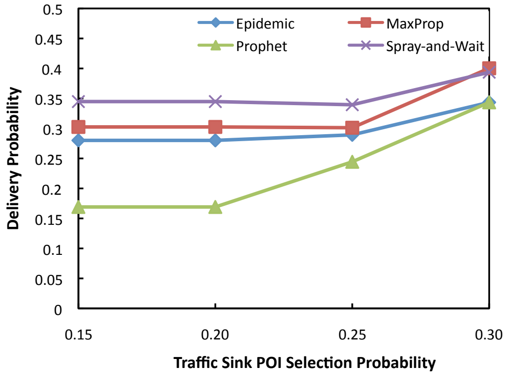

Fig. 5. Message delivery probability using 6 relay nodes.

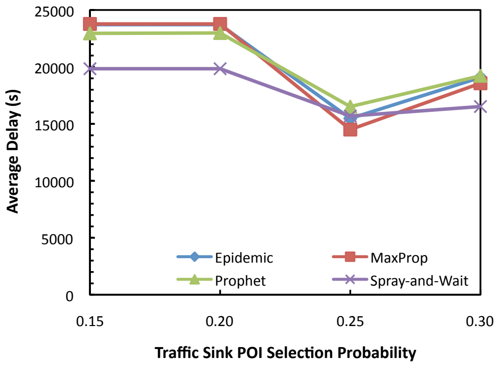

Fig. 6. Message average delay using 6 relay nodes.

IV. CONCLUSIONS AND FUTURE WORK

This paper presented how a VDTN can be applied on a sparse region enhancing the rural connectivity. It was assumed a cooperative opportunistic environment without knowledge of the traffic matrix and contact opportunities. Several experiments were performed to evaluate if introducing variations on the mobile node movement model will affect the overall performance in terms of message delivery probability and average delay. As expected, it was observed that relay nodes have an important role in the network. Despite of the variations done on the movement model, they improve the message delivery probability on the routing protocols. Our interests for future work are focused on evaluating the VDTN overall performance considering further mobility scenarios like random waypoint and route based (e.g., a bus) movement models.

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