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Routing in a Many-to-One Communication Scenario in a realistic VDTN

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Abstract.

In this paper, we evaluate and compare the performance of different routing protocols in a many-to-one communication within a Vehicular Delay Tolerant Network (VDTN). Seven groups with three stationary sensor nodes sense the temperature, humidity and wind speed and send these data to a stationary destination node that collect them for statistical and data analysis purposes. Vehicles moving in Tirana city roads in Albania during the opportunistic contacts will exchange the sensed data to destination node. The simulations are conducted with the Opportunistic Network Environment (ONE) simulator. For the simulations we considered two different scenarios where the distance of the source nodes from the destination is short and long. For both scenarios the effect of node density, ttl and node movement model is evaluated. The performance is analyzed using delivery probability, overhead ratio, average latency, average number of hops and average buffer time metrics. The simulation results show that the increase of node density increases the delivery probability for all protocols and both scenarios, and better results are achieved when shortest-path map-based movement model is used. The increase of ttl slightly affects the performance of all protocols. By increasing the distance between source nodes and destination node, delivery probability is decreased almost 10% for all protocols, the overhead for sprayandwait protocol does not change, but for other protocols is slightly increased and the average number of hops and average latency is increased.

Keywords: Opportunistic network, DTN, VDTN, Routing protocol, ONE Simulator

1. Introduction

Vehicular networks are characterized by the lack of an end-to-end multi-hop path most of the time, which is caused by a highly dynamic network topology and network partitioning due to low node density and large distances. In such network environments, a complete path from source to destination does not exist most of the time.

In order to deal with these connectivity constraints, opportunistic networks, DTNs and VDTNs (Vehicular Delay Tolerant Networks) are introduced. VDTNs are an emerging class of Delay Tolerant Networks (DTNs). DTNs are a class of networks that enable communication where connectivity issues like sparse connectivity, intermittent connectivity, high latency, long delay, high error rates, asymmetric data rate, and even no end-to-end connectivity exists.

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In order to handle disconnections and long delays in vehicular network scenarios, VDTN uses a store-carry-and-forward approach. VDTNs have the potential to interconnect Vehicles in regions that current networking technology cannot reach.

VDTNs aim to support a class of vehicular network applications characterized by delay tolerant and asynchronous data traffic. VDTN is supposed to be one of the effective methods to transmit significant data even under poor network conditions. In VDTN the communication is asynchronous, bundle-oriented, and a store-carry-and-forward routing paradigm is used. Instead of working end-to-end, in VDTNs, a message-oriented overlay layer called Bundle layer employs a store-carry-and-forward message switching paradigm that moves messages from node to node, along a path that eventually reaches the destination.

In this paper, we evaluate the effect of node density and node movement model in a VDTN. We compare the performance of three different routing protocols in a many-to-one communication network. Two scenarios were designed with short and long distance of source nodes from the destination. For the simulations we use the Opportunistic Network Environment (ONE) [1] simulator.

ONE is a simulation environment, capable of generating node movement using different movement models. ONE offers various DTN routing algorithms for routing messages between nodes. Its graphical user interface visualize both mobility and message passing in real time. ONE can import mobility data from real-world traces or other mobility generators. It can also produce a variety of reports from node movement to message passing and general statistics.

Performance evaluation results, based on simulation, show that the increase of node density increases the delivery probability for all protocols and both scenarios, and better results are achieved when shortest-path map-based movement model is used. The increase of ttl slightly effects the performance of all protocols. The increase of the distance between source nodes and destination node decreases the delivery probability almost 10% for all protocols. The overhead for sprayandwait does not change, but for other protocols is slightly increased and the average number of hops and average latency is increased.

The remainder of this paper is as follows. Section 2 introduces DTN and routing protocols. The simulation system design and description is presented in Section 3. In Section 4 are shown the simulation results. Finally, the conclusions and future work are presented in Section 5.

2. DTNs and Routing Protocols

2.1. DTN Overview

DTN are occasionally connected networks, characterized by the absence of a continuous path between the source and destination [2], [3]. The data can be transmitted by storing them at nodes and forwarding them later when a link is established. This technique is called message switching. Eventually the data will be relayed to the destination. DTN is the “challenged computer network” approach that is originally designed from the Interplanetary Internet, and the data transmission is based upon the store-carry-and-forward protocol for the sake of carrying data packets under a poor network environment such as space [2]. Different copies of the same bundle can be routed independently to increase security and robustness, thus improving the delivery probability and reducing the delivery delay. However, such approach increases the contention for network resources (e.g., bandwidth and storage), potentially leading to poor overall network performance.

In [4], authors have studied this model and found that it can provide substantial capacity at little cost, and that the use of a DTN model often doubles that capacity compared with a traditional end-to-end model. The main assumption in the Internet that DTNs seek to relax is that an end-to-end path between a source and a destination exists for the entire duration of a communication session. When this is not the case, the normal Internet protocols fail. DTNs get around the lack of end-to-end connectivity with an architecture that is based on message switching. It is also intended to tolerate links with low reliability and large delays. The architecture is specified in RFC 4838 [5].

Bundle protocol has been designed as an implementation of the DTN architecture. A bundle is a basic data unit of the DTN bundle protocol. Each bundle comprises a sequence of two or more blocks of protocol data, which serve for various purposes. In poor conditions, bundle protocol works on the application layer of some number of constituent Internet, forming a store-and-forward overlay network to provide its services. The bundle protocol is specified in RFC 5050. It is responsible for accepting messages from the application and sending them as one or more bundles via store-carry-and-forward operations to the destination DTN node. The bundle protocol runs above the TCP/IP level.

2.2. Routing Protocols

In order to handle disconnections and long delays in sparse opportunistic vehicular network scenarios, VDTN uses a store-carry-and-forward approach. A network node stores a bundle and waits for a future opportunistic connection. When the connection is established, the bundle is forwarded to an intermediate node, according to a hop-by-hop forwarding/routing scheme. This process is repeated and the bundle will be relayed hop-by-hop until reaching the destination node. In [6], [7], [8], [9], [10], [11], [12], [16], [17], [18], [19] authors deal with routing in DTNs.

In this work, we will use three widely applicable DTN routing protocols Spray and Wait [14], Maxprop [15] and Prophet [16].

Spray and Wait routing protocol: Spray and Wait [14], is a routing protocol that attempts to gain the delivery ratio benefits of replication-based routing as well as the low resource utilization benefits of forwarding-based routing. The Spray and Wait protocol is composed of two phases: the spray phase and the wait phase. When a new message is created in the system, a number L is attached to that message indicating the maximum allowable copies of the message in the network. During the spray phase, the source of the message is responsible for "spraying", or delivery, one copy to L distinct “relays”. When a relay receives the copy, it enters the wait phase, where the relay simply holds that particular message until the destination is encountered directly. The same authors also introduce an improvement called Binary Spray and Wait scheme, in which each node transmits half of their bundles they have to any encountered nodes. For example, a source node with L = 10 will transmit five bundles to another node-A, and keeps five bundles for itself. This process is then repeated for any nodes that the source and node-A meet in the future. Their experiments involving 100 nodes show that with L increasing from five to 20 the delivery delay decreases by approximately 42%. Under the same condition, Binary Spray and Wait has a higher performance, where delivery delay ranges from 3500 to 1500 seconds. The main limitation with this protocol is that a maximum of two hops is used to deliver bundles. Hence, in large DTNs, a bundle may incur a significant delay as it can only be delivered when a relay or source node encounters the destination.

Maxprop routing protocol: Maxprop [15], is based on prioritizing both the schedule of packets transmitted to other peers and the schedule of packets to be dropped. These priorities are based on the path likelihoods to peers according to historical data and also on several complementary mechanisms, including acknowledgments, a head-start for new packets, and lists of previous intermediaries. This protocol also includes three principal complementary mechanisms, namely: head start for new bundles, lists of previous intermediaries, and system-wide acknowledgments. In order to guarantee that all bundles have a chance of being propagated in the network, a “head start” is given to new bundles. This means that priority is given to the transmission of these bundles. Lists of previous intermediaries are maintained to prevent bundles of being sent to the same node again. System-wide acknowledgments are propagated through the network in order to notify nodes to eliminate redundant copies of the bundles that have already been delivered to their destination.

Prophet routing protocol: Prophet (Probabilistic Routing Protocol using History of Encounters and Transitivity) [16] is a variant of the epidemic routing protocol for intermittently connected networks that operates by pruning the epidemic distribution tree to minimize resource usage while still attempting to achieve the best case routing capabilities of epidemic routing. Prophet tries to compute routes by dynamically learning about link and node availability and uses previously learned information to schedule future transmissions. Delivery probability is calculated

Fig. 1. Tirana city map imported from osm.

based on: aging, encounters and transitivity It uses a probabilistic metric: delivery predictability, that attempts to estimate, based on node encounter history, which node has the higher probability of successful delivery of a message to the final destination. When two nodes are in communication range, a new message copy is transferred only if the other node has a better probability of delivering it to the destination.

3. Simulation System and design

The network scenario is based on the map-based model of a part of Tirana city (Albania). The map was imported from Open Street Map [20] (see Fig. 1). Simulations are carried out using the ONE simulator. We simulated an urban scenario where vehicles move on the map roads with a speed between 10-50 km/h during 4 hours period of time. There are 7 groups with 3 nodes each group that sends data to a destination node (many-to-one communication). These 21 nodes can be sensors that gather information about temperature, humidity and wind speed and sends their data to a node that collects these data for statistical purposes. Source and destination nodes are stationary and have a 100 MB buffer. Other nodes are vehicles equipped with a 100 MB buffer. We considered two scenarios: in the first one the distance of the source nodes is between 400 m - 1000 m and the second one where the distance is 800 m - 2000 m. The initial position of all the nodes for the first scenario are shown in Fig. 2(a).

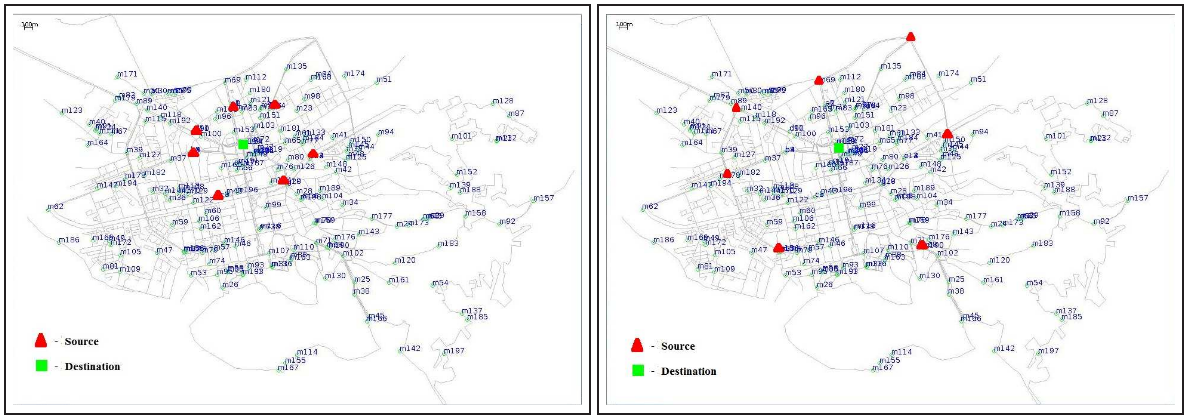
All network nodes use a WiFi link connection with a transmission data rate of 250 KBps and the transmission range is considered 20 m. We use shortest-path map-based movement model for the vehicles. This model, initially places the nodes in random places but selects a certain destination in the map for all nodes and uses Dijkstra‘s shortest path algorithm to find the shortest path to the destination.

The event generator is responsible for generating bundles with sizes uniformly distributed in the ranges [10kB, 50kB]. A bundle is created every 30 s. We vary the data bundles ttl from 15 to 60 min. The simulation parameters are shown in Table 1. We made extensive simulations considering ttl 30 and two different node densities and movement models.

We consider a network with 200 vehicles and evaluate the performance of the system for 3 different routing protocols: Spray and Wait, Maxprop, Prophet.

We use the following metrics to measure the performance of different routing protocols: delivery probability, overhead ratio, average latency, and average number of hops.

- **Delivery probability** is the ratio of number of delivered messages to that of created messages.
- **Overhead ratio** is the difference relayed and delivered messages upon the number of delivered messages.
- **Average latency** is the average time elapsed from the creation of the messages at source to their successful delivery to the destination.



(a) First scenario (b) Second scenario

Fig. 2. Nodes initial positions for both scenarios.

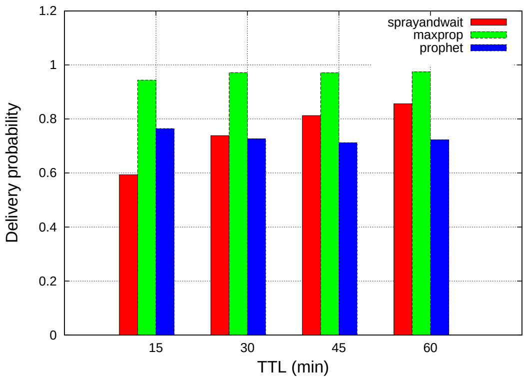


Fig. 3. Simulation results of delivery probability for the first scenario.

- **Average number of hops** is the average number of hops counts between the source and the destination node of bundles.

In the second scenario, we increased the distance between the source nodes and the destination node. The initial position of all the nodes for the second scenario is shown in Fig. 2(b). All other simulation parameters are the same with the first scenario.

4. Simulation Results

In this section, we present the simulation results of the above described routing protocols. In Fig. 3, Fig. 4, Fig. 5 and Fig. 6 are shown the simulation results for the first scenario where the distance between source nodes and destination node is short and we use different ttl values. In Fig. 3 are shown the simulation results of delivery probability vs. ttl for all considered routing protocols. The simulation results show that best performance is achieved for Maxprop routing protocol. With the increase of ttl the performance of sprayandwait protocol is improved, but for other protocols the performance does not change. This is related with the fact that the buffer becomes full and cannot accept new packets so the packets are dropped.

The simulation results of overhead ratio are presented in Fig. 4. The increase of ttl leads to higher overhead for prophet protocol, but for sprayandwait and maxprop it does not change. Sprayandwait has the lowest overhead

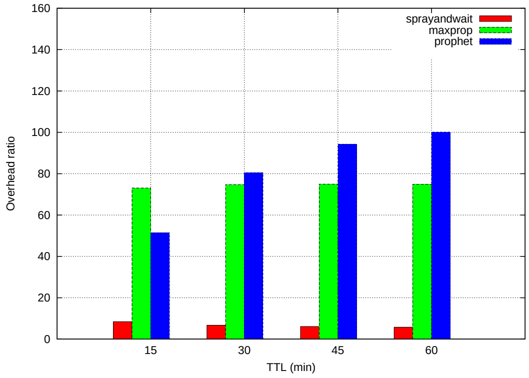


Fig. 4. Simulation results of overhead ratio for the first scenario.

Table 1

Simulation Parameters and their values.

Parameters	**Values**
Number of nodes	200
Simulation time	14400 s
Map size	5 km *x* 3.5 km
Movement Model	Map-based, Shortest-path map-based
Buffer size	100 MB
Interface type	WiFi
Interface Transmission Speed	250 MBps
Interface Transmission Range	20 m
Message TTL	15, 30, 45, 60 min
Vehicles speed	10-50 km/h
Message size	10k, 50k
Warm up time	100 s
Events interval	30 s

ratio and this is related with its direct transmission mechanism. This protocol limits the number of bundle copies created per bundle in order to control flooding.

In Fig. 5 are presented the results for average latency. From the figure it can be noticed that Maxprop protocol achieves the lowest latency compared with other protocols.

The results in Fig. 6 show that the increase of ttl does not change the average number of hops.

In Fig. 7, Fig. 8, Fig. 9 and Fig. 10 are shown the simulation results for the second scenario where the distance between source nodes and destination node is longer and evaluate the effect of increasing ttl values.

In Fig. 7 are shown the simulation results of delivery probability vs. ttl for all considered routing protocols when the distance of communicating nodes is long. The simulation results show that best performance is achieved for Maxprop routing protocol. The increase of ttl slightly increase the delivery probability of all protocols.

Comparing the results of the first scenario (Fig. 3) with the second scenario (Fig. 7) we can notice that when the distance is increased, the delivery probability is decreased almost 10% for all protocols.

In Fig. 8, ttl does not effect the overhead for sprayandwait and maxprop. The increase of ttl increases the overhead ratio for prophet.

Comparing the results with Fig. 4, we can see that the overhead for sprayandwait does not change, but for other protocols is slightly increased.

The increase of ttl makes the bundles stay for longer time in the buffers and the average latency is increased for all protocols (see Fig. 9).

In Fig. 10 longer ttl does not change the number of hops for all protocols.

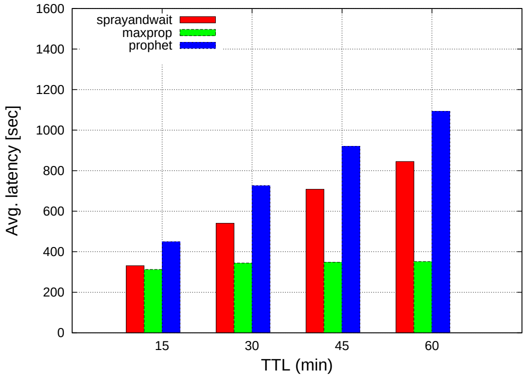


Fig. 5. Simulation results of avg. latency for the first scenario.

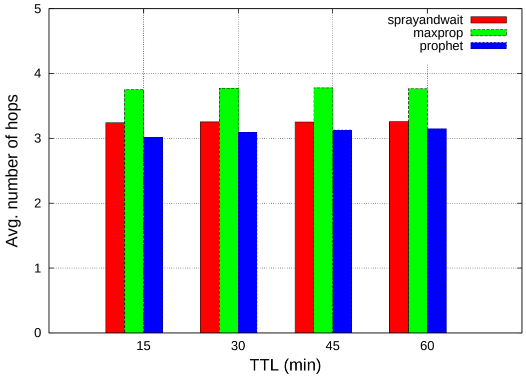


Fig. 6. Simulation results of avg. number of hops for the first scenario.

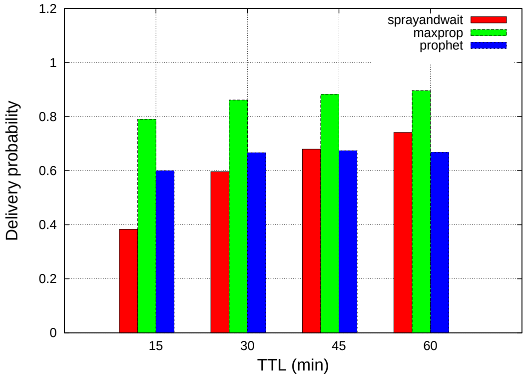


Fig. 7. Simulation results of delivery probability for the second scenario.

Because the distances from source nodes to destination node are longer in the second scenario, the average number of hops and average latency is increased.

We made extensive simulations for ttl 30 and evaluated the performance of the system for different node densities and two different movement models.

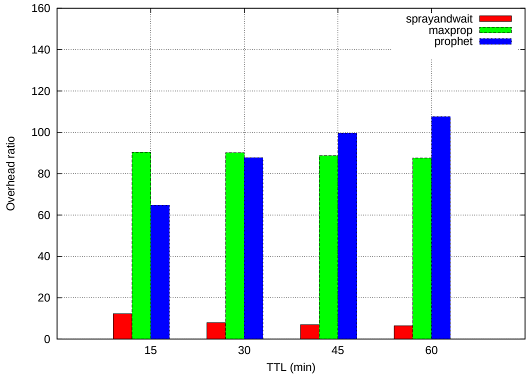


Fig. 8. Simulation results of overhead ratio for the second scenario.

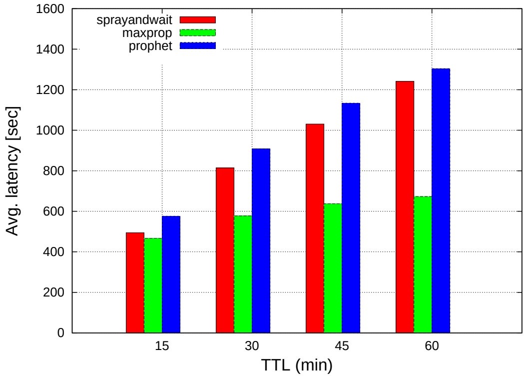


Fig. 9. Simulation results of avg. latency for the second scenario.

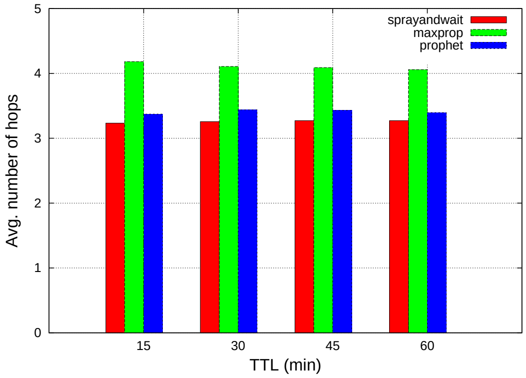
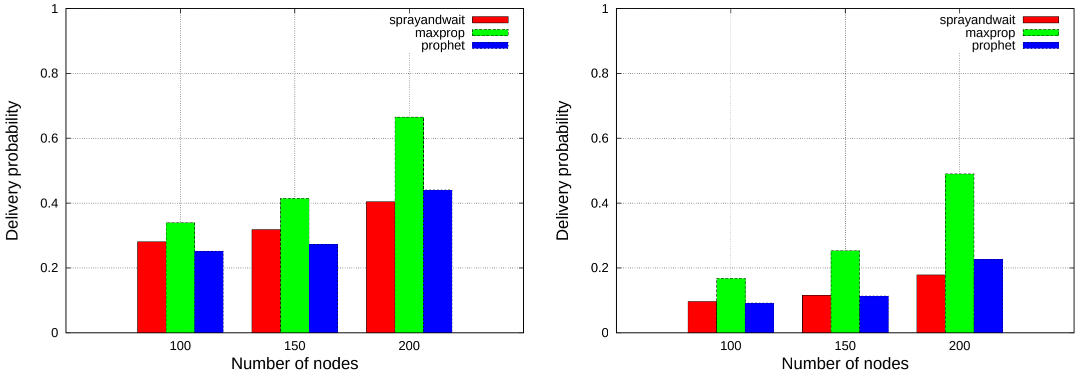


Fig. 10. Simulation results of number of hops for the second scenario.

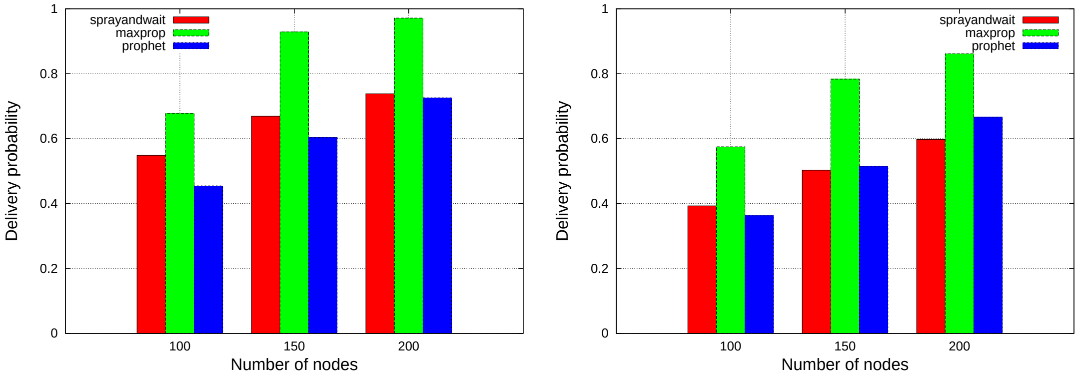
We use the following metrics to measure the performance of different routing protocols: delivery probability and average latency.

In Fig. 11 are shown the simulation results of number of nodes vs. delivery probability for all considered routing protocols when map-based movement model is used. For both scenarios, the increase of node density increases the



(a) First scenario (b) Second scenario

Fig. 11. Results of number of nodes vs. delivery probability for map based movement.



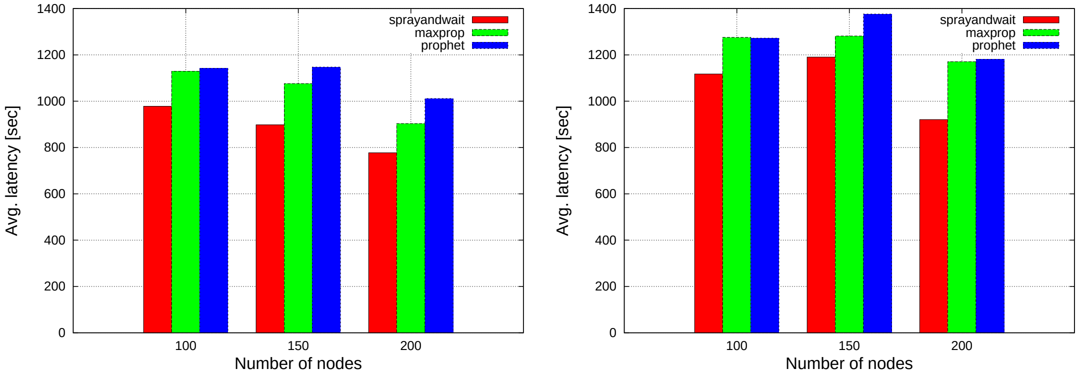
(a) First scenario (b) Second scenario

Fig. 12. Results of number of nodes vs. delivery probability for shortest path map based movement.

delivery probability for all protocols. This is related with the increase of the number of opportunistic contacts between nodes. Better results are achieved in the first scenario where the distance between sources and the destination is short. The simulation results show that best performance is achieved for Maxprop routing protocol. The simulation results of number of nodes vs. delivery probability for shortest-path map-based movement are presented in Fig. 12. Shortest-path map-based movement model is a more sophisticated model compared with map-based movement model and for both scenarios it achieves better delivery probability. Maxprop performance is higher compared with sprayandwait and prophet. Best results are for dense network with 200 nodes where delivery probability is 98%.

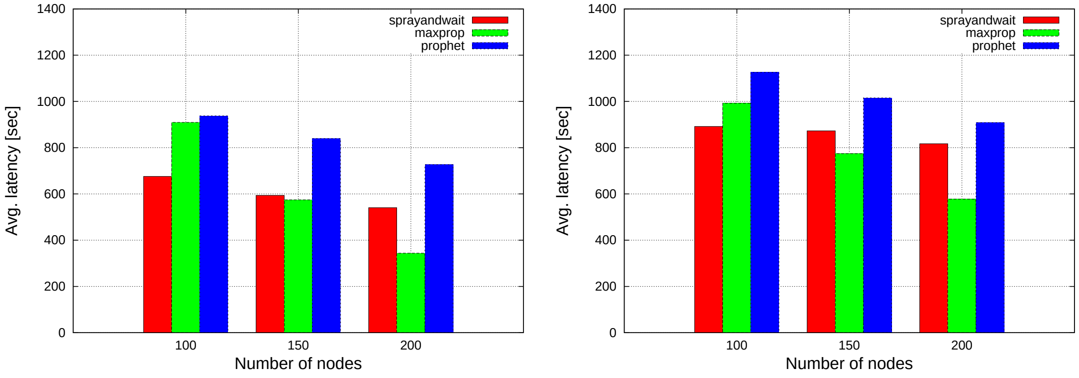
In Fig. 13 are presented the results for avg. latency when map-based movement model is used. From the figure it can be noticed that the avg. latency is shorter for the first scenario because the distance between the communicating nodes is shorter. Spray and wait results in lower latency than other protocols. Low avg. latency results are achieved for dense networks for all protocols. In dense mobile networks the probability of nodes to encounter other nodes is high and opportunistic contact happens often.

The evaluation results of number of nodes vs. avg. latency when the shortest-path map-based movement is used are shown in Fig. 14. The avg. latency of all protocols is lower compared with map-based movement model because the Dijkstra algorithm finds the shortest path to the destination. In both scenarios, best results are for dense network where maxprop is used.



(a) First scenario (b) Second scenario

Fig. 13. Results of number of nodes vs. avg. latency for map based movement.



(a) First scenario (b) First scenario

Fig. 14. Results of number of nodes vs. avg. latency for shortest path map based movement.

5. Conclusions

In this work, we evaluated and compared the performance of three routing protocols (maxprop, sprayandwait and prophet) in a many-to-one communication opportunistic network scenario for short and long distances between source and destination nodes. For evaluation we considered delivery probability, overhead ratio, latency and average number of hops metrics. We evaluated the effect of ttl on the performance of protocols. The performance study showed that the increase of ttl from 15 min to 60 min slightly effects the performance of all protocols.

When the distance between source nodes and the destination node is increased:

- The delivery probability is decreased almost 10% for all protocols.
- The overhead for sprayandwait does not change, but for other protocols is slightly increased.
- The average number of hops and average latency is increased.

We made extensive simulations to evaluate the effect of node density and movement model. For evaluation, we considered delivery probability and avg. latency metrics.

The results showed the following.

- For both scenarios, the increase of node density increases the delivery probability for all protocols.

- Better results of delivery probability are achieved in the first scenario where the distance between sources and the destination is short.
- In both scenarios, best performance in terms of delivery probability is achieved for Maxprop routing protocol.
- Shortest-path map-based movement model is a more sophisticated model compared with map-based movement model and for both scenarios it achieves better delivery probability.

In this work, we considered a communication network with multiple sources and a single destination node. In the future, we would like to consider multiple sources and destinations and make extensive simulations to evaluate the performance of different routing protocols considering different scenarios and parameters.

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