On the Performance of VDTN Routing Protocols with V2X Communications for Data Delivery in Smart Cities

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Abstract: VDTN concept and V2X communications capabilities can be utilised for an efficient data collection and delivery in smart cities. Here we present performance comparison of four lightweight VDTN routing protocols: First Contact, Epidemic, Spray and Wait, and MaxProp in terms of its percentage of message delivered, latency, overhead ratio, and hop counts. Overall results show that Spray and Wait and MaxProp show high performance in most of the scenarios, while each also shows potentials for improvements. We also present simulation results where buses with predetermined routes were introduced to the network and observe that it generally increases the delivery performance. These results are our starting point towards a work-in-progress for a bus and cars assisted data delivery protocol for VDTN in smart cities.

Keywords: VDTN; routing protocols; V2X; smart cities; energy efficiency

1. Introduction

Low energy devices, such as wireless sensors and mobile devices have become an integral part of our daily lives, and their potential to extract data from their surroundings is only limited by their designed sensing capabilities and power sources. A very low power consuming sensor can acquire data such as temperature, humidity, and level of pollution for years without the need for maintenance. While on the other hand, a higher power consuming device can retrieve position, motion, and even image, before its battery needs to be recharged.

Typical ways to connect devices to the central systems are by using cellular networks (3G/4G), or dedicated networks such as SigFox, LoRa and Qowisio, which incur subscription cost. Yet, on the other hand, a common feature in the liveliness of a city is the population of vehicles, either public or private, roaming on the streets and highways. This together with the maturing technology of Vehicle-to-Everything (V2X) communications opens the possibility of utilising cars for data collection from devices and deliver them to the nearest sink for lower cost, or even for free.

The utilisation of vehicles to deliver data will be affected by the intermittent connection available due to the mobility. This is why the Vehicular Delay Tolerant Network (VDTN) concept need to be incorporated within the process of delivering data from the source to the sink. In this paper, we present performance evaluation of four VDTN routing protocols, namely: First Contact (FC), Epidemic (EP), Spray and Wait (SNW), and MaxProp (MP). Previous studies on similar performance evaluations can be found in [1], [2] and [3], but they do not consider different communication technologies. We improve upon this work by implementing and studying some of the latest wireless access technologies with farther communication ranges achievable today, Zigbee for the sensors and IEEE 802.11p for the vehicles. Another difference is that we additionally consider public vehicles and study their impact on the performance. We take into account the fact that well-established bus routes and schedules are common in most modern cities today. This predetermined mobility of buses in a smart city, among other potential functions that the buses can be assigned to, is one key factor that we will try to exploit in our work-in-progress towards a VDTN routing protocol for an efficient data collection in smart cities, which we name as ***Bus Assisted data deLIvery*** or **BALI** in short.

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2. Routing Protocols in VDTN

Store-carry-and-forward mechanism is used in scenarios with sparse and intermittent connectivity in VDTN [4]. The routing protocols that try to tackle these challenges have evolved from the simplest to the more elaborate in terms of message replication policy and process of clearing the networks from redundant messages which are already received by the intended destination. Here we describe and focus on four protocols that do not need priori knowledge of the network connectivity nor nodes coordinates.

First Contact, is a single copy forwarding approach where each node forwards messages randomly to the first node they encounter. Nodes erase messages that they already forwarded, which means only a single copy of a message exists in the network. This single copy of messages continues to hop until it reaches its destination.

Epidemic, is a multiple copy forwarding approach where each node keeps copies of every message while also forwarding them to every other nodes they encounter until the messages reach the destination. Each node receives messages that they do not already have, with their buffering capacity as the only limitation. This approach ensures that at least one copy of each message will reach its destination in the earliest possible time, with the expense of flooding the networks with redundancy.

Spray and Wait, is a more controlled multiple copy forwarding approach, where the number (L) can be assigned to the protocol to determine limit of copies that can be created per message by a node, as described in [5]. This protocol has two spraying phase modes: the normal mode and the binary mode. In the normal spray mode, each originating node that received a new message can have L copies of the message and forward each copies to other nodes until it has only the last copy when it switches to the wait phase. In the binary spray mode, the source node initially starts with L copies of a message. When the source node encounters another node which has no copies of the message, it forwards $L/2$ copies and keeps the other $L/2$ copies. When each of the nodes subsequently encounter another node, they forward half of copies that they still have and keep the other half. This process continues until each node is left with only the last copy when they switch to the wait phase. In the wait phase, each node carries the last copy until it reaches the destination.

MaxProp, is also another multiple copy forwarding approach with explicit mechanism of sending acknowledgements to clear redundant messages left on the network once a copy is received by the destination [6]. MaxProp also uses messages ordering policy in the buffer to give priority of transfer and deletion. The ordering policy includes the calculation of delivery likelihood based on nodes encounters.

3. Performance Evaluation

We evaluate the performance of the four routing protocols for VDTN by using the Opportunistic Networking Environment (ONE) simulator [7]. We use the city of Helsinki's map, with an area size of 4500m x 3400m, to set up our smart city data collection scenario, where data from one sensor on one side of the city is needed to be delivered to an Access Point at the other side of the city. We replicate the scenario three times, each with different placement of sensor and Access Point, but identical vehicles mobility. We then accumulate all results for the performance evaluation to avoid isolated outcomes. A sensor which has a Zigbee connection (250m communications range and data rate of 250kbps) transmits data with a varying size of 10kB – 100kB once every minute during the 12 hours simulation time and a Time to Live (TTL) of 5 hours. Each car with pseudo-random initial placement and mobility, has an identical Zigbee connection with the sensor to communicate, and also has an 802.11p connection (500m communications range and data rate of 6Mbps) for V2X communications. The destination Access Point has an identical 802.11p connection with the cars for communications. We only implement 5MB of buffer size for the cars to evaluate the performance of the routing algorithms under strict constraint, since messages only come from one sensor. We also evaluate the scenario with the increasing number of cars roaming the city, from 10 up to 100 with an increase of 10 each time.

TABLE I. THE ROUTING ALGORITHMS PERFORMANCE COMPARISON FOR A DENSITY OF 100 CARS

	First Contact	Epidemic	Spray & Wait	MaxProp
Delivery Percent.	81.20	42.04	81.76	81.72
Latency (s)	1118	722	729	194
Overhead Ratio	46	634	3	249
Hop counts	46	4	3	6

All the performance comparison results for a density of 100 cars are summarised in Table I. The results on the **Percentage of Messages Delivered**, show that FC, SNW, and MP can deliver slightly above 81% of messages, while EP delivered only 42%. These results show that EP performance relies heavily on buffer size, where 5MB of buffer rapidly becomes full and lots of messages are dropped. The results on **Latency** show that MP has the lowest latency of around 3 minutes, while EP and SNW have around 12 minutes, and FC has the highest latency of around 18 minutes. The results of latency combined with the **Hop Counts**, where FC had 46 hop counts on average, suggested that messages are being forwarded back and forth between cars a lot of times, although in the end about 81% of them finally reach the destination. On the contrary, EP, SNW and MP had average hop counts of as little as 4, 3, and 6 respectively. On the **Overhead Ratio** results, where the value of this parameter gives indication on how many copies of a message were relayed on the network before it reaches its destination, SNW has the lowest value of 3, while EP has the highest value of 634, FC has 46, and MP has 249. These results show that SNW is the most efficient in term of limiting useless replication, and that MP needs to be improved on this.

In the next simulation scenario, we include a bus route where the buses will pass the Sensor and the Access Point on their way. The buses have the same specification as the cars, with the exception of the lower maximum speed and the larger buffer size of 25MB. The comparisons of Delivery Percentage for MaxProp routing algorithm, between the cases where buses were included in the network and the previous simulations without buses, can be seen in Figure I. It shows that delivery percentage is increasing in most of the cases where buses were included. This emphasises the potential for improvement if the bus network is considered in the algorithm design.

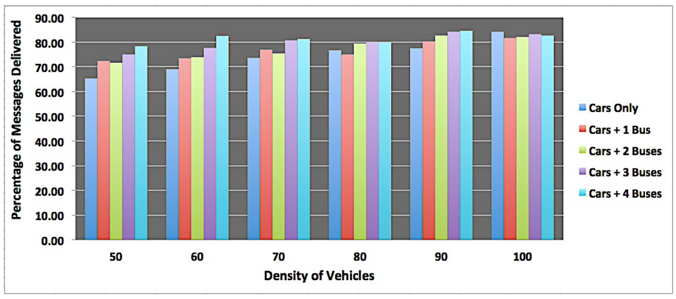

FIGURE I. THE EFFECT OF BUSES ON THE PERCENTAGE OF MESSAGES DELIVERED USING MAXPROP

4. Conclusion and Future Works

In this paper, we present the performance comparison of four basic VDTN routing protocols and identify some parameters that can be improved. We also show that the inclusion of buses with predetermined routes in the network has the potential to improve the performance. This is our starting point towards a work-in-progress on ***BALI***, a ***b***us ***a***ssisted data de***li***very protocol for VDTN in smart cities.

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