Journal of Theoretical and Applied Information Technology
31st December 2013. Vol. 58 No.3

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

ARE VDTN ROUTING PROTOCOLS SUITABLE FOR DATA COLLECTION IN SMART CITIES: A PERFORMANCE ASSESSMENT

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ABSTRACT

Vehicular Delay-Tolerant Networks (VDTNs) are composed of mobile nodes (vehicles) that communicate wirelessly to transfer data between nodes despite connectivity issues. It enables network connectivity in sparse or partitioned opportunistic networks, characterized by the low node density where the vehicular traffic is sparse and direct end-to-end paths between communicating parties do not always exist. Routing in such environments is challenging due to the absence, for nodes, of information about the state of the partitioned network, and because transfer opportunities between nodes are of limited duration. This paper focuses on the study of the performance of some well-known VDTN routing protocols in different scenarios to assess their suitability of use in the case of collecting sensor data in cities. In this paper we study the case of stationary nodes that represent urban sensor measuring different types of data, and transmitting collected information to stationary destination nodes, which are connected to the Internet. The transmission mechanism is performed through a set of mobile nodes in a VDTN context. We study the impact of different parameters on the routing protocols performances, using a large set of simulations and two scenarios. The results show that there is no perfect routing protocolthat is the best for all scenarios.

Keywords: *Vehicular Delay-Tolerant Networks, Routing, Performance Evaluation,ONE*

1. INTRODUCTION

One of the main issues of Smart Cities is the collection of data through the use of low cost sensors wirelessly. These sensors can be interconnected through different media, however the concept of “smart” leads essentially in the use of the infrastructure wisely and efficiently. As a consequence, the interconnection of the low cost sensors in Smart Cities should be solved using other networks than 3G, Wi-Fi, etc. Under this optic, Vehicular Networks could be a smart solution.

Vehicular Networks are a new class of wireless networks that are formed between moving vehicles equipped with wireless interfaces and can exchange traffic and road safety information with nearby cars and/or roadside units [1], [2], [3]. We often consider the introduction of car-to-car communication for the service they provide, with regard to safety and traffic management, thus the improvement of driving experience[4]. Nevertheless communicating cars and other vehicles (bus, tram, etc…) could also be considered a new class of wireless network and then offers a communication service for various kinds of applications. Due to the important issues that can be realized in such environment, vehicular networks have become popular research topic during the last years[5], [6], [7], [8].

Vehicular Ad Hoc Networks (VANETs) - a subclass of Mobile Ad Hoc Networks (MANETs) - face highly variable density of traffic, which affects drastically the connectivity of such networks. In rush hours, Vehicular networks attain high delivery probabilities, and when the traffic quiets down, end-to-end connections via intermediate nodes cannot be guaranteed any more. In such scenarios, researchers have proposed the use of Delay Tolerant Networks (DTN) [9], based on the store-carry-and forward paradigm to solve the problem of intermittent and opportunistic connectivity, which have lead to Vehicular Delay Tolerant Networks (VDTNs) as shown in figure 1.

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

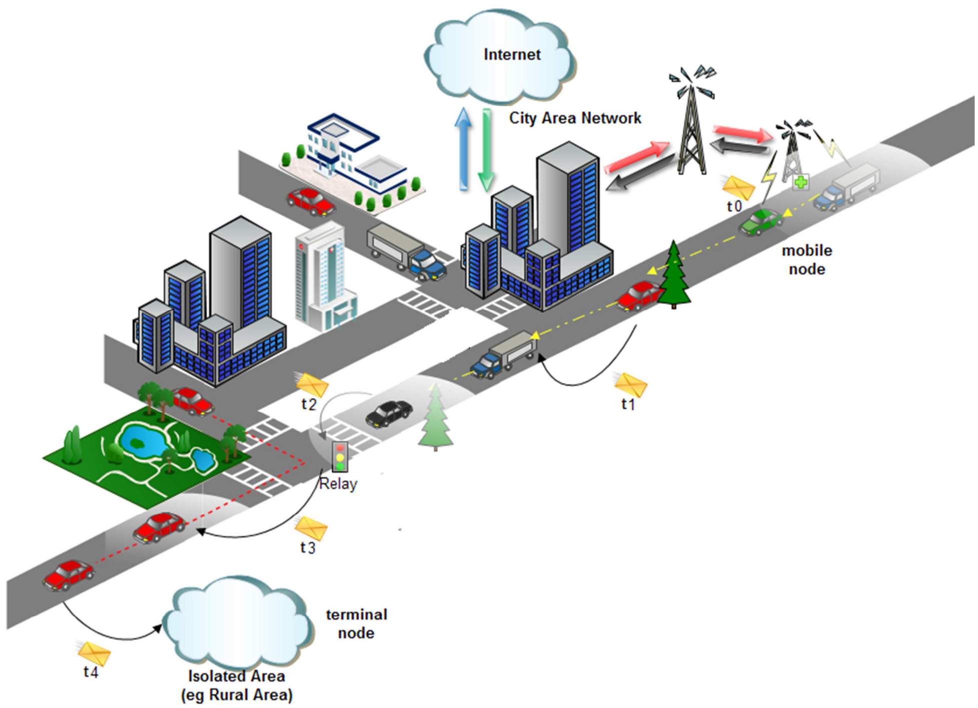

Figure 1: VDTN Scenario

One of the major concerns in such environment is the persistence/absence of connectivity between communicating parties. Due to nodes density and traffic variations, highly dynamic topology, short contact durations, limited transmission ranges, radio obstacles, and interferences, these networks are prone to intermittent connectivity, and significant loss rates[7]. As a consequence, the use of conventional ad hoc routing protocols designed for connected networks become inadequate. In fact, Routing in vehicular networks presents a particularly challenging problem due to the unique characteristics of these networks [10].

In this paper, our objective is the study of the performances of some well-known VDTN routing protocols in different scenarios. Through the present study, our concern is the evaluation of these protocols when the number of mobile nodes becomes small which leads to sparse and disconnected networks. This study focuses on the case of stationary nodes that represent urban sensor measuring and transmitting different types of data, to stationary destination nodes, which are connected to the Internet. Sensors are supposed to present no complexity in their operation mode. Thus, the transmission mechanism is performed through a set of mobile nodes in a VDTN context, and we suppose a one-way communication between sensors and gateways. We do not care about the gateway used in a given transmission: the first gateway reached in the best. We study the impact of different parameters on the routing protocols performances, using a large set of simulations and two scenarios. The results show that no protocol among those we have studied performs significantly better than others in all scenarios we used. This confirms the intuition that each protocol exhibits good performances in very specific situation it has been designed to operate in.

The remainder of this paper is organized as follows. Section 2 is an overview of DTNs and VDTNs focusing on routing protocols used in such networks. Section 3 describes the scenarios used in our present study and all related parameters. Section 4 provides the performance assessment part of the paper and is divided into two parties: one for network setting and the second one presents simulations results and a comprehensive discussion and interpretation of graphics. Finally Section 5 concludes the paper and suggests further research works.

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

2. DELAY TOLERANT NETWORKS OVERVIEW

DTNs, are a kind of networks which have been taking a huge attention and been the subject of many researches in the last years, because of their challenging applications[11], [12], [8]. They were designed for the first time for the interplanetary networking (IPN) [13], to establish communication between nodes on the different solar system planets after the failure of traditional protocols used in the internet communication for many reasons, then spread across several applications in many critical environments such as military networking, sparse sensor networks [8], vehicular networks, which is one of the growing field of DTNs.

DTN take part of the wireless ad hoc networks with new added features that make it suitable for these applications[14]. The transfer of data is based on a topology where it exist intermittent connection, high node mobility, and no end to end path between nodes this exchange can be done only if the nodes are in the same transmission range.

2.1 The architecture of DTN

The DTN architecture was the center of interest for researchers and network designers, during the last ten years. The DTN Research Group (DTNRG) has designed a complete architecture to support various protocols in DTNs[11].
DTN architecture was targeted to support the network connection disruption, and also to offer structure that deal with the heterogeneity of various regions by the addition of an overlay called bundle layer between transport and application layer[12]. In other words, the bundle layer consists of forming an overlay network to transfer the messages/bundles by using the hop-by-hop transfer. The buffer corresponding to nodes supposed to be large to allow the storage of bundles[13].
With all those capabilities, DTNs are considered strong enough to connect isolated heterogeneous regions together with a good interoperability between them, regardless of their technologies or region features.

2.2 Store-Carry-Forward routing paradigm

To deal with the new challenging situations, the traditional store-and-forward paradigm used in the Internet was not required anymore because of the lack of infrastructure in such networks, but it is store-carry-forward (SCF) routing which used [7], [8], [14], [15].

The idea behind SCF is simple, the message (bundle) will be stored in the buffer of an intermediate node when the next hop is not available, until it finds the opportunity to be forwarding to another host and so on. The process continues till the bundle reaches the destination or its time to live (TTL) expires and the message get dropped. It should be noted that the message could be not only stored but also replicated by multiple nodes before reaching its destination.

2.3 Routing protocols in DTNs and VDTNs

The vehicle delay tolerant network make opportunistic communications by utilizing the mobility of vehicles, the node makes delay tolerant based on the paradigm of "store-carry and forward" to deliver packets to the destination, which implies some degree of cooperation among nodes, as nodes route other node messages, or pick them in one place and deliver them in another. In order to overcome the lack of end-to-end paths, the protocols replicate messages, if necessary, in each contact.

2.4 Classifications of Routing Protocols In DTNs

Different classifications [16], [17], [18], [19], [20]have been done by researchers for routing protocols in DTNs, there are many advantages and disadvantages to each approach, the use of the appropriate approach is probably dependent on the scenario at hand. Based on the methodology used to find destinations, and whether replication of messages is used or not, routing in DTN can be classified according to several categories:

2.4.1 Flooding or Forwarding

Flooding strategy: In flooding strategy, messages are replicated to enough nodes so that destination nodes must receive it so it increases the probability of message delivery to the destination but Flooding based approach increases the contention for network resources like bandwidth and storage, and thus can not cope with network congestions and does not scale well [21].

Forwarding-based: In this approaches there are much less wasteful of network resources, as only a single copy of a message is stored in the network at any given time. Knowledge about network is used to select the best path to the destination (Fig 2). This category is also known as knowledge-based[22].

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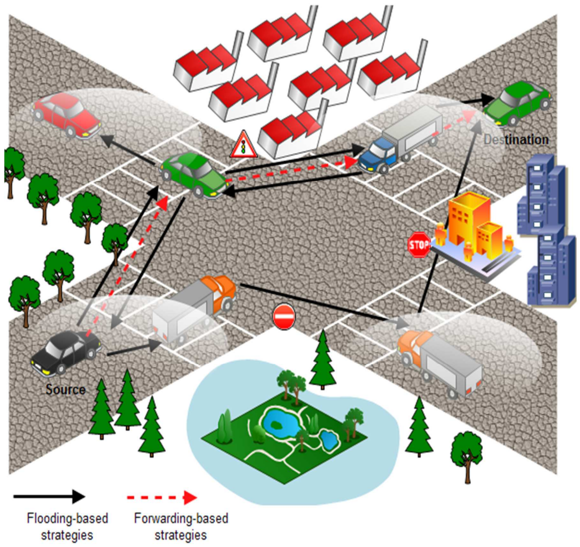

Figure 2 : Illustration Of Flooding Based And Forwarding Based Strategies

2.4.2 Single copy or multiple copies

Single-copy category maintains a single copy of a bundle in the network that is forwarded between network nodes.

Multiple-copy category replicates bundles at contact opportunities.

2.4.3 Deterministic or stochastic DTN routing

Deterministic routing is characterized by the knowledge of the current topology and future changes can be predicted.

Stochastic DTN routing is generally used when node movement is random or unknown and nodes know very little or nothing about the future evolution of the topology.

2.5 VDTN routing Protocols

Prophet (Probabilistic Routing Protocol using History of Encounters and Transitivity) uses a probabilistic metric: delivery predictability y, 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[23]. 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.

Direct Delivery are single copy DTN routing protocols where only one copy of each message exists in the network[24]. In Direct Delivery, the message is kept in the source and delivered only to the final destination, if the nodes meet. In First Contact, the message is forwarded to the first node encountered and deleted. The message is forwarded until it reaches the intended destination[25].

Epidemic Routing protocol [26]is flooding-based protocol, where nodes continuously replicate and transmit messages to newly discovered contacts that do not already possess a copy of the message. Consequently, epidemic routing protocol minimizes the delivery delay and maximizes the delivery ratio as messages may reach the destination on multiple paths, but spoils storage and bandwidth in comparison with other protocols[10].

Spray and Wait [27]is an n - copy routing protocol with two phases: (1) spray phase, where a message created by the source node is initially spread by the source to encountered nodes until the n copies are exhausted ; (2) wait phase, where every node containing a copy of the message performs a direct delivery to the destination. There are two variants of the protocol: normal mode, where a node gives one copy of the message to each node it discovers that does not have the message; and binary mode, where half of the n copies are given in each encounter.

MaxProp protocol attempts to transfer all messages not held by the other node, when it is in communication range[28]. The protocol uses acknowledgments to clear the remaining copies of a message in the network when the destination node receives it. When nodes discover each other, MaxProp exchanges messages in a specific priority order, taking into account message hop counts and the delivery likelihood to a destination based on previous encounters. New packets are assigned higher priority, and the protocol attempts to avoid reception of duplicate packets.

RAPID (Resource Allocation Protocol for Intentional DTN), routing packets are opportunistically replicated until a copy reaches the destination node[29]. The protocol models DTN routing as a utility - driven resource allocation problem. The routing metric is a per-packet utility function. When nodes are in communication range, RAPID replicates the packet that results locally in the highest increase in utility. The corresponding utility Ui of packet I, is defined as the expected contribution of i to the given utility routing metric.

A comprehensive surveys related to routing protocols in VDTN can be found in [7], [8], [10]. Table 1, summarizes some specific characteristics of these protocols.

Journal of Theoretical and Applied Information Technology
31st December 2013. Vol. 58 No.3

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

Table 1:DTN and VDTN Routing Protocols And Their Characteristics.

Routing Protocols	single/multiple or n Copy	Replication Rate	Functions, Objectives
Epidemic	unlimited-copy	Very High	Rapid propagation of data
Direct Delivery	single-copy	none	Source moves and delivers the bundle directly
Prophet	unlimited-copy	Medium	Probabilistic
SprayAndWait (SnW)	n-copy	Medium	Sets a limit on the number of copies
MaxProp	unlimited-copy	High	use of the delivery likelihood as a cost assigned to each destination
Resource Allocation Protocol for Intentional DTN (Rapid)	unlimited-copy	hight	attempt to limit replication

3. PERFORMANCE ASSESSMENT

This section presents a study with the performance comparison of some well known routing protocols in the context of VDTN: MAXPROP, SPRAY and WAIT, EPIDEMIC and PROPHET. Also, some routing protocols have not been included in our simulations like First Contact (FC) and Direct Delivery (DD). In fact, DD protocol cannot be used in our case since the source and destination node will never meet. They are stationary nodes. FC protocol has been discarded from the current study due to its poor performances in regards to delivery probability and Latency as it has been studied in[30].

Furthermore, Six performance metrics are considered. The number of initiated bundle transmissions is defined as the number of started transmissions between nodes. The number of dropped bundles is defined as the number of bundles that have been discarded from the nodes' buffers due to overflow or TTL expiration. The delivery probability is measured as the relation of the number of unique delivered bundles to the number of bundles created. It tells the percentage of successfully received bundles among all sent. The average delivery delay is defined as the average time between bundles generation and bundles delivery. The overhead ratio measures how many transfers are needed for each bundle delivery. Finally, the average hop count is defined as the average number of hops counts between the source and the destination node of bundles.

The aim of the present simulations is to show different key performances of used routing protocols. The simulation study was performed using the Opportunistic Network Environment (ONE) simulator[31], which is one of the major simulation tools used to validate DTN routing protocols [32], [33] . It is a JAVA based simulator, which uses the Helsinki city map and allows node movement modeling, inter-node opportunistic contact using different interface types. The ONE offers a framework for implementing routing protocols in DTN environment, and permits graphical visualization of mobile nodes. Furthermore, we have observed some memory limitations of ONE when the number of nodes exceeds 300. However, the choice of using the ONE simulator still one of the best provided the number of nodes still below this limit, which is generally the case in DTN context.

4. NETWORK SETTINGS

The network scenario is based on a part of the city of Helsinki (Finland) presented in Fig.1 the total number of all nodes in all simulations has been kept fix and equal to 100. Ten stationary destination nodes and ten stationary source nodes are placed at the map positions presented in this figure. Fig.3 shows the localization of all stationary nodes before running the simulation. In Fig.4, we can see all nodes of the present simulations. Source nodes represent sensors used in urban area to collect different types of information and measures, whereas destinations nodes are gateways connected to Internet. The use of VDTN networks in such a context can be a promising low-cost solution for urban sensing and information/entertainment applications.

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

Figure 3: The Position Of Sources And Destinations Nodes In The Helsinki City Map

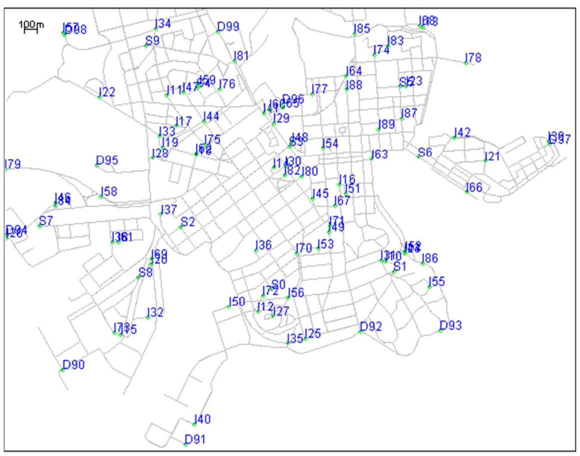

Figure 4: The Position Of All Nodes In The Network

All nodes in the network have a 5M in their buffer size. During the simulated 12 hours period of time, the group of mobile nodes (vehicles) moves along the map roads with a speed ranging from 10 km/h to 50 km/h, between random locations. Simulations were done using two mobility models, namely: the shortest path map based movement model, and the map based movement model. Mobility models define the algorithms and rules that generate the vehicle movement paths. Three types of synthetic movement models are included in the ONE simulator: 1) random movement, 2) map-constrained random movement, and 3) human behavior based movement. Since we did not find significant differences between simulation results in the two different mobility models, we just present results related to the shortest path map based movement model.

Thus, even if the Random Way Point mobility model exhibits slightly different results for all simulations in comparison to the two other models, it is not relevant for our use case.
The number of mobile nodes in the first scenario is 80 representing a dense network while in the second scenario this number is 20. The idea is to assess different performances of VDTN protocols in cases where usually the vehicle density is low (rural area) and a city where the traffic is dense.

Data bundles are originated at specific stationary source nodes and are destined to specific stationary terminal nodes. No random transmissions have been used in all simulations. Furthermore, we have used external event generator to create 1000 messages with sizes varying from 100KB to 1MB. Those messages are created in an interval time between the start of the simulation and 900s. Data bundles TTL changes between 50, 100, 150, 200, 300, 400, and 500 minutes, across the simulations. Increasing the TTL will lead to contention for network resources. All network nodes use a Bluetooth link connection with a transmission data rate of 2 Mbps and an Omni-directional transmission range of 10 meters. The configuration of PRoPHET protocol parameters is set according to the default values proposed in default setting and the number of copies parameter (L) of Spray and Wait is equal to 15% of the total nodes. The different parameters are grouped in the table below.

Table 2 : Summarization Of The Different Parameter Used In The Scenario

Simulation time	43200 seconds
Buffer size	5 M
Movement Model	Shortest Path Map Based Movement; Map Based Movement
TTL	[50;100;150;200;300;400;500]
Routing protocol	[MaxProp; Epidemic; Prophet; Spray And Wait]
Interface type	Simple Broadcast Interface
Number of nodes	100 nodes (10 sources, 10 destinations, 80 and 20 mobile nodes (respectively for the first and second scenario)
Velocity of mobile nodes	2.7, 13.9
Size of bundles	100KB, 1MB
Event used	External Event Queue
Size of map	4500m, 3400m
Transmission range	10 meters
Transmission speed	2 Mbps
Number of copies (L)	15, the binary mode = true

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

We ran thirty separated simulations using differentseeds for each protocol in each scenario, and the results were averaged. Simulations in ONE, run much faster than in real-time. It should be noted thatsome simulations take much time than others depending on the number of nodes used, and also on the protocol being simulated. Simulation speeds are ranging from 3 to 35 min per simulation, and these values can greatly change depending on physical resources of the computer used. Fig. 5 shows the different paths of the bundles sent from source node S8 to destination node D96, using Maxprop protocol.

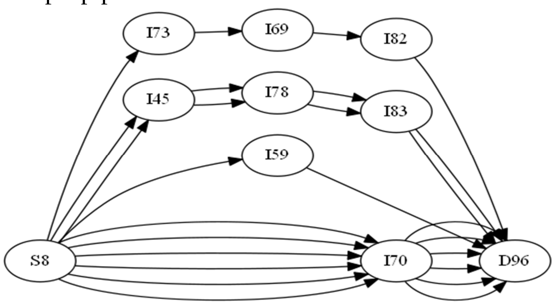

Figure 5: Example Of Message Paths From Node S8 To D96

5. RESULTS ANALYSIS

As it should be expected, the number of mobile nodes in the simulation area has a direct effect on all measurable metrics.

Figure 6-a shows the performances of the four studied protocols in terms of delivery probability vs. the time to live (TTL). Increasing TTL values leads to hold bundles in buffers for longer time while waiting for the opportunity to forward or deliver them.

Maxprop protocol shows the best delivery probabilityresults when the number of nodes is high, followed by Spray and Wait. However, in terms of Latency, fig. 6-b shows that Maxprop has the worst performances comparing to the other protocols, for both scenarios, and Prophet protocol comes first exhibiting the lowest Latency average overall.

Maxprop can play an important role in our case study, since it shows the best results in terms of delivery probability and addresses scenarios in which either transfer duration or buffer sizes are a limited resource in the network[28]. However, one of the main characteristics of this protocol is the use of acknowledgements sent from the destination to the source and network-wide. This component of the protocol is not needed in our scenarios since we are mainly interested by a low-coast sensors (static nodes) and a one-way communication: sensor to Internet gateway.

In the other hand, Prophet presents a great overhead ratio comparing to the rest of protocols, as we can see in Fig. 6-c, followed by epidemic, as both protocols make multiple copies of a given bundle to deliver it to the final destination. The same message generation period for all sources requires higher message traffic and thus a larger number of transmissions. Consequently, the overhead ratio increases when the number of sources increases.

Spray and Wait exhibits the lowest magnitude in term of overhead ratio, because of its direct transmission mechanism. This protocol limits the number of bundle copies created per bundle in order to control flooding.

In addition, the hop count is a factor, which contributes to the overall end-to-end delay. It is an important metric that allows us to get a better understanding of how a routing protocol should be designed so that it can deliver acceptable performances. Fig 6-d shows the performance of the studied routing protocols regarding hop count metric. Epidemic protocol exhibits the highest values for the dense scenario. Indeed, as the network becomes dense, the hop count values increase. This is due to the nature of this protocol consisting on duplicating bundles to reach the final destination as fast as possible.

Furthermore, as expected, Epidemic protocol shows the maximum started messages since each packet will be duplicated in each contact opportunity. Fig. 6-e shows that the number of mobile nodes in the simulation area has a clear effect on the number of initiated bundles transmissions due to the increased number of contact opportunities. The number of dropped and started messages is high in the case of Epidemic protocol (Fig. 6-f), which is a direct consequence of duplication mechanism of this protocol and the limited size of the buffer. If we increase the buffer capacity the number of dropped bundles will be significantly reduced. However, the buffer capacity should be small, at least moderated in our case, to remain in the low-cost sensors category.

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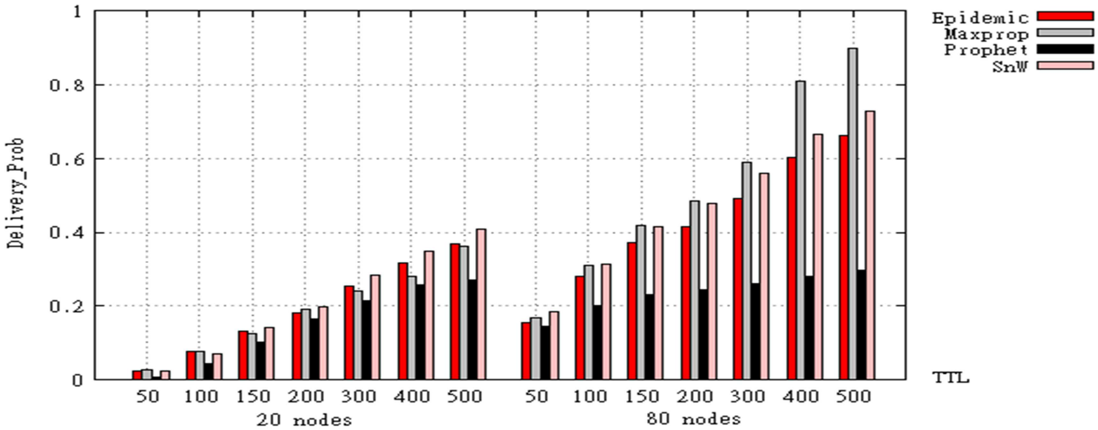

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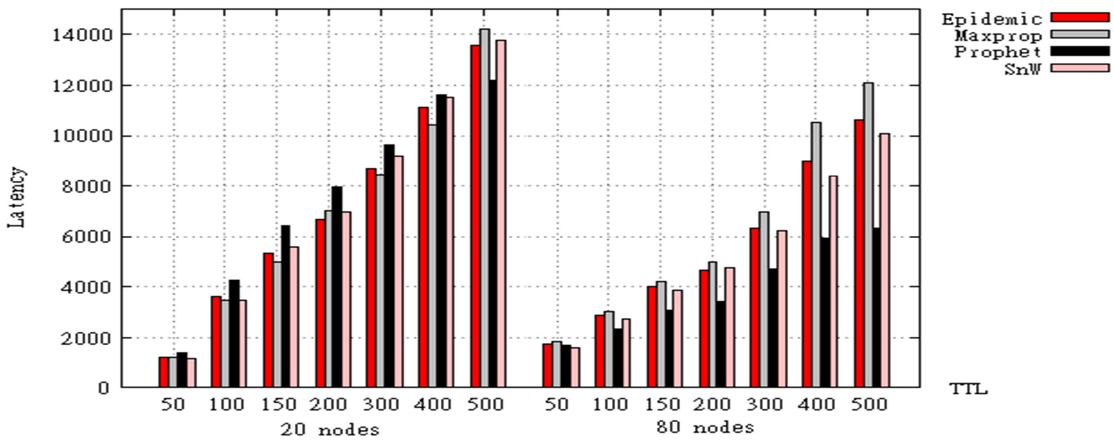

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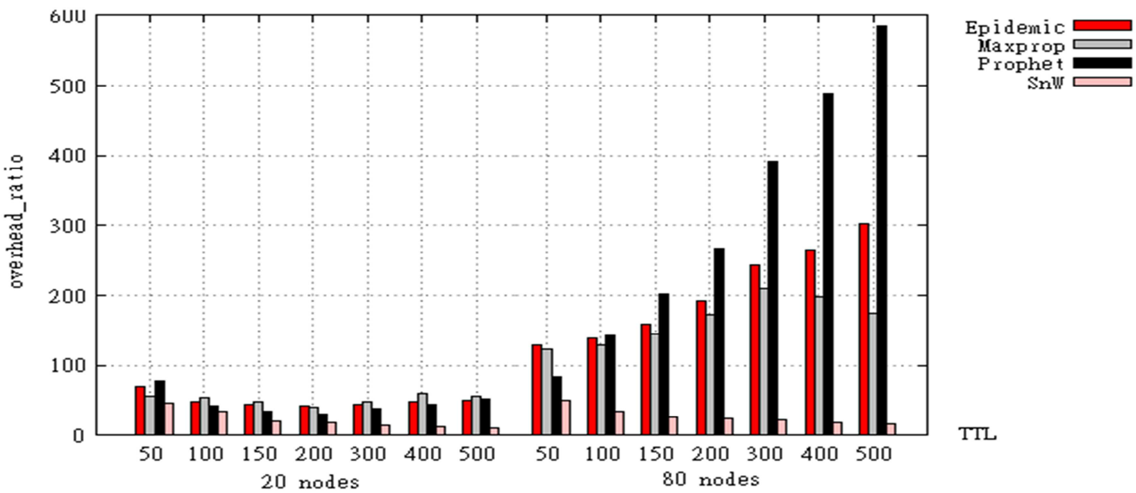

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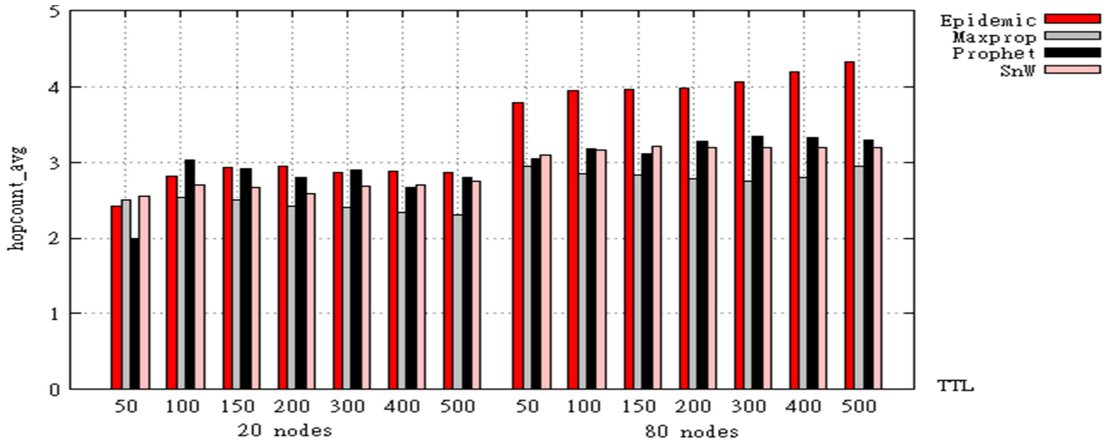

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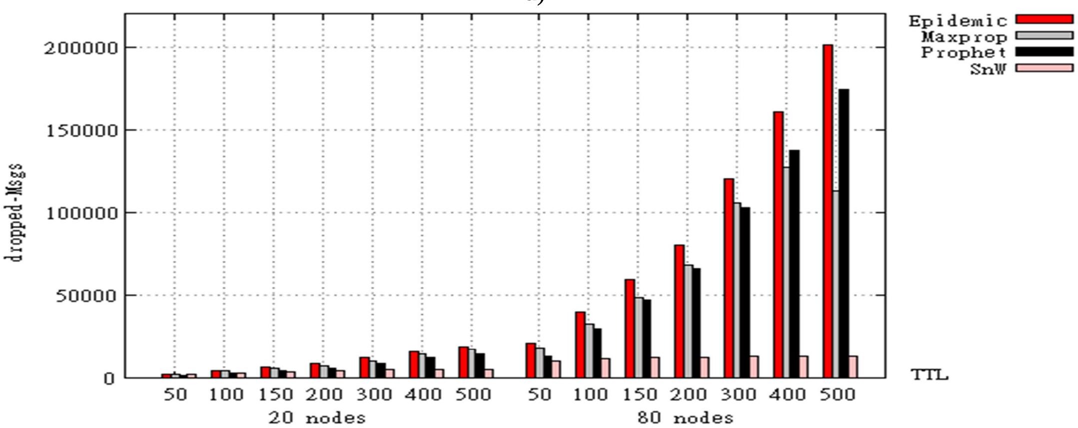
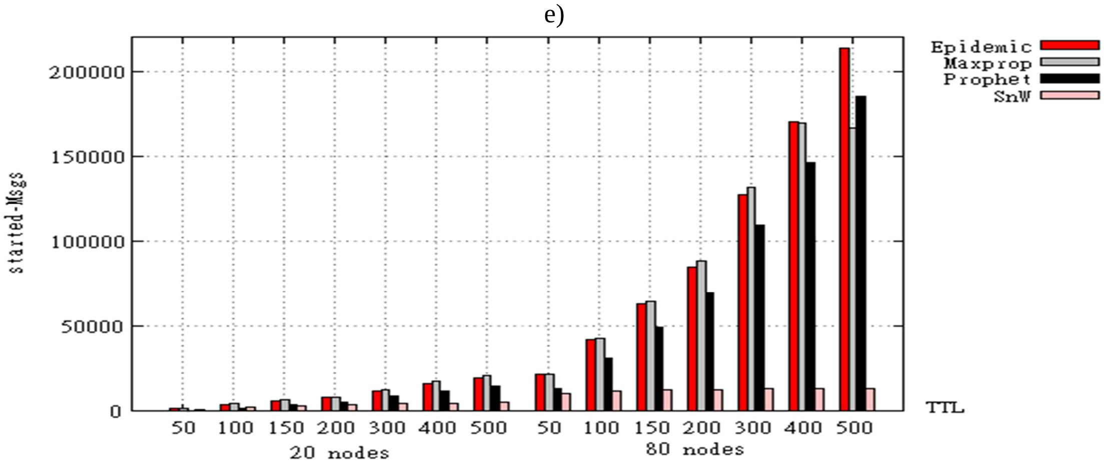


e)



f)

Figure 6: Bundle Delivery Probability (A), Latency (B), Overhead_Ratio (C), Hopcount_Avg (D), Number Of Dropped Bundles (E) And Number Of Started Bundles (F) As Function Of Bundles TTL In A Scenario With 20 And 100 Nodes Using Map Based Movement For Epidemic, Spray And Wait, Prophet And Maxprop Routing Protocols

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

A summary of simulations results have been grouped in Fig. 7, where one can notice the absence of the best routing protocol in all scenarios and for all metrics.

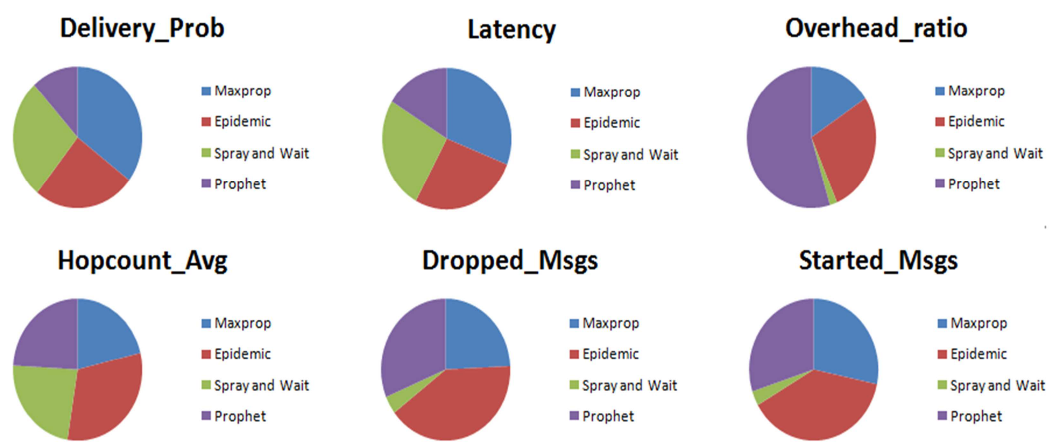


Figure 7 : Summary of the performances of the four VDTN routing protocols.

6. CONCLUSION

This paper evaluated the performances of different VDTN routing protocols using two scenarios: sparse and dense network. Our main goal is to decide if one of this routing protocols could be suitable for data collection in smart cities.

The ONE simulator was used for this study, which is a dedicated tool for DTN and opportunistic networks. The results observed show that there is no protocol adequate for all cases and contexts. Our simulations show that each protocol can exhibit good performances in some metrics but shows a different behavior regarding the other metrics, as studied protocols perform better or worse on different scenarios. Moreover, all the protocols we studied are probably too complex to be implemented in sensor and in all vehicles for the very simple usage we envision.

Maxprop shows the best delivery probability results when the number of nodes is high, and the worst latency values for sparse and dense traffic, while Prophet protocol shows best values in term of latency.

Maxprop can play an important role in our case study, however, due to its use of acknowledgements sent from the destination to the source and network-wide, this protocol cannot be a good candidate for our purpose since our focus is toward low-cost sensors and a one-way communication: sensor to Internet gateway.

Also, Prophet protocol presents a great overhead ratio followed by epidemic, as both protocols use multiple copies of bundles, while Spray and Wait exhibits the lowest values in term of overhead ratio.

This suggests the need for further research in the area, to develop a simpler routing protocol that can present good performances in terms of the different metrics used in this study, which can lead to its standardization in intelligent transport systems.

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