A Context-Aware Method Decoupled from Protocol for Adapting Routing Process in DTN

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Abstract. Several routing protocols for Delay-Tolerant Networks (DTNs) can be found in the literature. All these protocols have strengths and weaknesses depending on the usage scenario. Nevertheless, in DTNs, messages are forwarded hop-by-hop autonomously, without an on-line path connecting the source and the destination. This unique characteristic of DTNs allows the routing protocol to be changed on-the-fly while a message traverses the network. The only limitation is that each pair of nodes must share the same routing protocol. If each node is able to choose the best routing protocol based on its context and on the available routing protocols, it is possible to minimize the weaknesses of the chosen protocols. In this way, this article proposes an on-the-fly context-aware routing adaptation method. Each node, independently, chooses the routing protocol to forward a message, based on its own context information and on the routing protocols available at the possible next hops. Thus, in order to explore the strengths of all protocols and reduce their weaknesses, every message can be forwarded from the source to the destination through several different routing protocols, one for each hop if necessary. The feasibility and the efficiency of the proposed method are evaluated through simulations, and the results demonstrate that it is possible to increase the delivery ratio and reduce the delay with a small increase on the overhead.

Keywords: DTN · Routing · Performance analysis · Network parameters

1 Introduction

Delay Tolerant Networks (DTNs) are opportunistic networks mainly composed by mobile nodes without a persistent connection between them. Routing represents a challenge for DTNs since the communication path from a source to a destination is intermittently connected; the message delivery relies on a predicted sequence of communication opportunities, which is defined as a ***contact***. Thus, routing protocols should be able to forward, store, and deliver messages

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without any contact guarantee, aiming at maximizing data delivery and minimizing delay. A key factor for routing protocols in DTNs is the selection of the best candidate node to store and carry messages towards the destination.

Traditional routing protocols for DTNs, such as *Epidemic* [19], *Spray-And-Wait* (SPW) [17], and *Probabilistic Routing using History of Encounters and Transitivity* (PRoPHET) [10], consider contact history or the amount of messages in the network as parameters to choose the best next hop to forward each message. While these context information is not sufficient to achieve a satisfactory view of the network, forwarding messages without considering the node's willingness to contribute in the delivery process may waste network resources with unnecessary overhead. Moreover, all these protocols focus on achieving good performance under specific scenarios/contexts and may behave below expectations on different ones. On the other hand, context-aware routing protocols [3] consider that network context information, as geographic position and link quality, may impact on routing performance. Such information is used in order to choose the best next hop candidate to forward the messages. Several approaches such as [9,13,14,16] have shown that a context provides consistent and optimized information for routing protocols, adapting critical values according to a certain threshold, thus reflecting the importance of context information into a decision making.

In DTNs, messages are forwarded hop-by-hop autonomously, without an online path connecting the source and the destination. This unique characteristic of DTNs allows the routing protocol to be changed on-the-fly while a message traverses the network, i.e. each hop can forward the message using a different routing protocol, decoupling the source-destination path from the routing protocol. If each node is able to choose the best routing protocol based on its context and on the available routing protocols, it is possible to minimize the weaknesses of the chosen protocols. Thus, this paper proposes the first on-the-fly Context-Aware Routing Protocol Adaptation (CARPA) Method for DTNs. It aims at optimizing the network resources while ensuring specific routing metrics. At each contact opportunity, CARPA determines the "best" suitable routing protocol based on the current network state vision of the node, expressed as a context. This process is run at each hop transmission of each message, adapting the routing protocol and its parameters to the actual network context, searching the "best" suitable values at every moment. This is the first work applying multiple routing protocols into a trajectory of a single message in DTNs, without altering the routing protocol.

Simulation results show that CARPA significantly achieves a good performance trade-off among several metrics. It outperforms protocols such as Epidemic and PRoPHET on delivery, delay and overhead ratio and SPW about delay, mainly at sparse networks. Moreover, these results are achieved using only these three protocols for CARPA to choose.

This paper is organized as follows: Sect. 2 reviews the context-aware routing protocols for DTNs; the system model, assumptions, and the proposed method are described in Sect. 3; Sect. 4 evaluates the impact of different contexts over routing protocols in DTN; the experimental results about the feasibility of the proposed method are shown in Sect. 5; finally, conclusions and future work are presented in Sect. 6.

2 Context-Aware Routing Protocols for DTN

The first context-aware routing protocols consider only one context to adapt the routing method. All of them modify the routing protocol, proposing a new one which must be used for the entire network. The RAPID protocol [2] treats the routing as a resource allocation problem, based on utility. It calculates the replication effect on the routing metric while accounting for resource constraints. However, only one metric can be satisfied at a time. In the HiBOp protocol [4], context is a collection of information which describes the user's community and social relationship. Nodes share information to learn the context, resulting on a qualitative classification about the accuracy of the attribute class. However, routing data in HiBOp depends on widely available context information in the network. The Context-Aware Routing Protocol for Opportunistic Network (CARTOON) [13] switches dissemination between Epidemic and PRoPHET protocols based on three parameters: density, contact time and the available buffer size for each node. Nevertheless, CARTOON requires high processing at nodes, being indicated for unlimited resources networks, and low mobility. The Opportunistic Routing with Window-Aware Replication (ORWAR) [16] considers the average message transmission rate and contact window size to adapt routing. Although the ORWAR is concerned about network resources including energy and bandwidth, it may loose the opportunity to replay messages due to the use of fixed number of message copies. The Context-Aware Routing (CAR) protocol [11] periodically measures some information about the nodes to determine the best forwarding node. Without previous acknowledgment about routes, the replication is proportional to the frequency and the time of nodes' contacts. CAR deals exclusively with unicast, though the definition and management of context information is not addressed. The context is only exploited to evaluate probabilities for the destinations that the node is aware of.

Different solutions were proposed to adapt the routing to multiple contexts in DTN. In [3], the definition and implementation of a middleware that collects and provides information on the context and the social interaction of users is explored. The context is defined by two functions: utility and cost. The middleware is integrated to the Haggle platform [12], and become able to share context information with all the interested components independent of the services and protocols. However, this middleware only supplies the interested services with network information; it neither analyzes nor decides which routing protocol is the best for the current context. A similar approach is proposed in [15]. It uses a passive adaptation context through a framework called Context-Aware Network Coding (CANC). It implements an adaptation portal to a context agent which collects and processes context information to reconfigure the router behavior. The context agent is independent of any routing protocol, however, CANC behavior can cause overhead due to sharing network view by epidemic protocols.

Related work analysis shows that current solutions are composed by protocols or a mechanism to provide a context for routing in DTN, based on different context information, such as density, energy, bandwidth, social relationships, contact time, and buffer size. However, most of the proposals consider only a few context information or just supply context information for other layers, leaving the decision of which protocol is the best suited for the current context an open issue. The CANC [15] is an exception: it aims to integrate context information with router module, but only for coding networks. On the other hand, the method proposed in this paper explores the ability of nodes to decide which protocol to use according to the interested context and current network conditions. Thus, multiple network information is exploited to identify the node's context, and then apply it to choose the most suitable protocol to the current context.

3 The On-the-fly Context-Aware Routing Protocol Adaptation Method for DTN

This section details the CARPA, the first on-the-fly Context-Aware Routing Protocol Adaptation Method. The identification of a context requires specific rules to detect and analyze the network status information in order to enable decision making. The context is composed by a set of attribute-value pair of information which may impact on routing performance. A context is formally defined as a vector c of attributes $c = (c_1, \ldots, c_n)$, where $c_1 \in C_i$ and $C = C_1 \times \cdots \times C_n$ representing the potential search space values. In DTN, context may consider several attributes as buffer size, density, remaining energy, network bandwidth, etc.

The context C_i is composed by two parts, α which is the message attributes and β which is the current locally collected network context. α is defined by the source of each message, and it represents the attributes that this message should perceive, for example, message m must be forwarded with the smallest delay possible. On the other hand, β represents the actual node context, such as bandwidth, size of the buffer, etc.

In this paper, DTN is modeled as a graph $G_t(V, E)$, composed by a finite set V of nodes $N = |V|$ and a dynamic set E of connections (contacts) between these nodes during time t. Nb_n represents the neighbor set of node n. Nodes are heterogeneous, and they have a finite buffer. Transmissions occur whenever a node is in the transmission range of another node. Any node $n \in V$ stores a set of messages $M_n = \{m_1, \ldots, m_k\}$, such that $k \in [1, m_k]$.

CARPA evaluates the network context during the routing process. It receives as input the actual context of the current node, and the summarized context of the estimated next hop. Then it evaluates them, and suggests the most appropriate available routing protocol. Note that, the information about the next hop includes the routing protocols it understands. Moreover the chosen protocol must be known by the both nodes as messages are processed according to the policy of the used routing protocol policy. This decision is taken on every node before

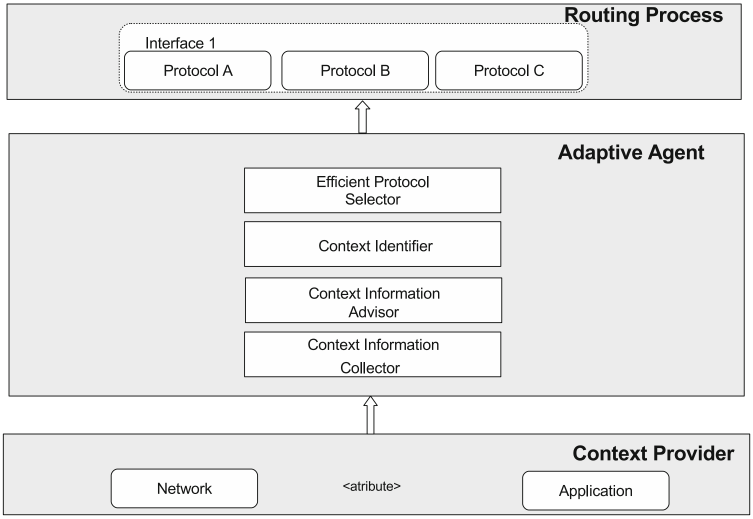

Fig. 1. CARPA Overview.

forwarding a message. Figure 1 illustrates the proposed context-aware model. It is composed by three processes: *context provider*, *adaptive agent*, and *routing process*. The *context provider* is responsible for feeding the *adaptive agent* (AA) with the actual context of the node. The context provider may gather any type of information from the network interfaces, users and/or applications, depending on the user allowance. The AA is in charge of acquiring and selecting network attributes, defining the context type, and making the decision to select the "best" available routing protocol. The *routing process* is a set of standard routing protocols, which are not altered by CARPA. The routing process receives the decision from the method and sets this protocol as active. The message is then forwarded using this routing protocol.

The *context provider* process analyses and defines certain thresholds, for example the minimal delivery ratio, maximum delay or limits on the resource consumption. These parameters are defined based on the actual network configuration and on the available routing protocols, as each protocol has distinct thresholds about different network attributes. The output of the context definition process is β.

The AA processes derives an heuristic (H), which guides the selection of attributes to form a context, as an utility function over the attributes. Figure 2 summarizes the AA process. The heuristic returns the "best" suitable routing protocol for the context requirements, as the trade-off between performance and constraint. Every DTN node constructs its own context by using instantaneous attributes collected by the *context provider* process. The heuristic used in this paper is a simple one, it is based on the results provided on Sect. 4. The best protocol for each simulated context is set as the "best" protocol for this context on CARPA. Future work consists in creating a swarm intelligence based heuristic to implement the AA process.

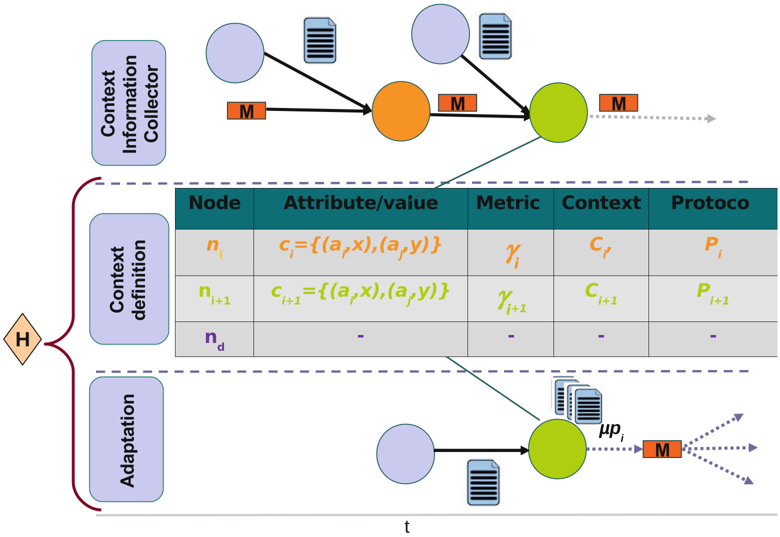

Fig. 2. CARPA - Adaptive Agent.

4 Impact of Different Contexts over Standard Routing Protocols in DTN

This section demonstrates the impact of different contexts on three standard routing protocols in DTN: Epidemic, PRoPHET and SPW. The analysis of these protocols has two implications: *i* to demonstrate each protocol outperforms the other in specific scenarios; and *ii* to create the heuristic which is used in the CARPA demonstration.

All routing protocols are implemented and simulated on the ONE simulator [7], according to parameters shown on Table 1. The network is composed by mobile nodes equipped with a WiFi 802.11 network interface with the transmission speed of 1375 Kbps and transmission ranges of 50 m and 150 m. Two movement models are used in the simulations: the *Shortest Path Map-Based Movement* (SP) [6] model, which uses the shortest path algorithm to move the nodes on the Helsinki city map, and the *Random Waypoint* (RW) model, in which nodes randomly move to the given destination along a zig-zag path. Sources are randomly selected and they generate messages in an interval from 1 to 10 s until the amount of 11914 is reached. Messages size range from 1 KB to 200 KB. All results are the average of 24 different simulation runs.

The protocols are evaluated using three metrics: message delivery ratio, average delay and overhead ratio. Delivery ratio is defined as the ratio of the successfully received packets at the destination divided by the total packets generated at the sources [1], average delay denotes the average end-to-end delay for all successfully received packets at the destination, and overhead ratio is calculated as the number of messages introduced in the network by the protocol in order to deliver the messages [2]. Messages are discarded when they reach their TTL deadline.

Table 1. Scenarios parameters.

Parameters	Values
Area ($m \times m$)	$800 \times 800, 1000 \times 1000, 1500 \times 1500, 2000 \times 2000, 5000 \times 5000$
Duration (sec)	2115, 43200, 86400, 172800
Host	30, 70, 90, 120
Buffer Size(MB)	1, 2.5, 5, 10, 20
Message Size(KB)	1, 100, 200
TTL (min)	10, 100, 1000

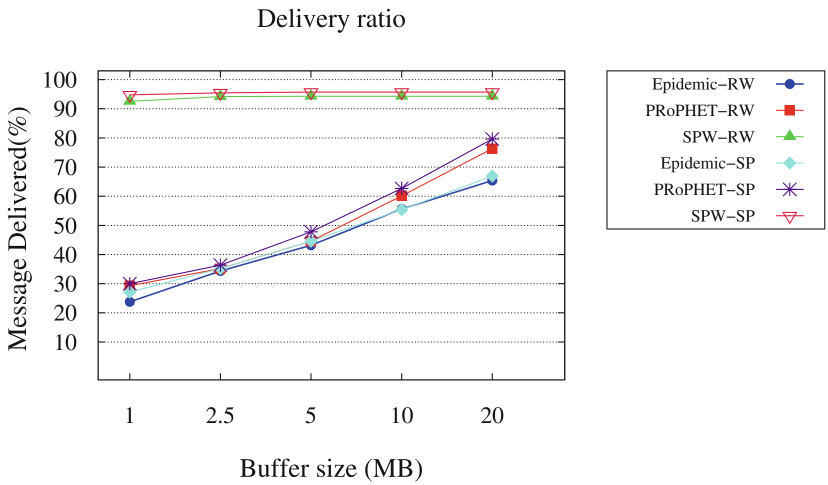

Fig. 3. Protocols performance for delivery ratio over different scenarios.

4.1 Scenario A: Buffer Size Effect

Figure 3 presents the delivery ratio for each protocol varying the movement model and buffer size from 1 MB to 20 MB. Due to page limitation, only the results for 80 nodes with communication range of 50 m spread over a 800m × 800m network area are shown. However, the results for other parameters follow the same pattern. SPW limits the number of copies (L) in 8.

It is possible to notice that the performance of Epidemic and PRoPHET suffers from the buffer size limitation. Their delivery ratio is directly proportional to the buffer size. Moreover, the performance of Epidemic for this context is worse than PRoPHET due to the fact that Epidemic retransmits messages to all neighbors, leading to a buffer exhaustion. Nevertheless, SPW is not affected and provides a delivery ratio higher than the others.

Figure 4(a) shows the delay for the scenario. The delay of Epidemic and PRoPHET varies with the buffer size. This follows the delivery ratio variation, with limited buffer. These protocols deliver fewer messages but faster.

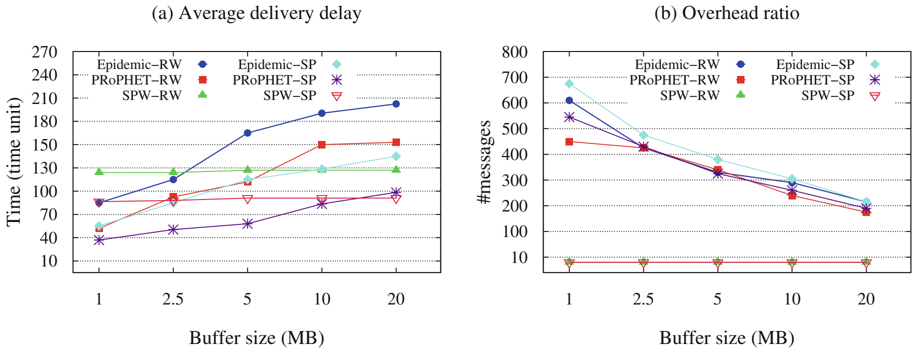

Fig. 4. Protocols performance for message delivery cost over different scenarios.

However, in sparse networks it can be observed that the buffering time increases as the delivery ratio decreases, implying in delay.

Figure 4(b) indicates that the overhead is inversely proportional to the delivery ratio and buffer size for the Epidemic and PRoPHET. This is because the more messages delivered, the less redundancy is generated by the protocols. As observed, the SPW outperformed the other protocols in several contexts, in terms of consumption of resources, delivery and delay ratio. This behavior is due to its dynamic mechanism for limiting the number of forwarded messages. However, SPW has several variations [5,8,18,20] as its performance depends on the network scenario.

4.2 Scenario B: The Influence of Density

This scenario is used to demonstrate the influence of node density on the Epidemic, PRoPHET and SPW protocols. The simulation area is then varied in order to examine its impact on the effectiveness of the protocols. In the first scenario settings, considered as dense, the area is set to 2 km $\times$ 2 km, while the sparse scenario, the second one, is composed by a 5 km $\times$ 5 km area. The transmission range is fixed in 50m.

As reported in Fig. 5, the performance of all protocols shows that they have poor efficiency in very disconnected areas. In this case, a few copies are spread out. As a result, it may take a long time for a message to traverse the network and reach the destination or it may never meet it. Thus, the sparser the scenario, the lower the delivery ratio is.

The evaluation of the simulation results indicates that all protocols have similar behavior for sparse networks, the delivery ratio decreases and the delay increases following the connectivity. Also, the buffer size represents a sensitive attribute for the protocols, which increases their delivery ratio in accordance with its size.

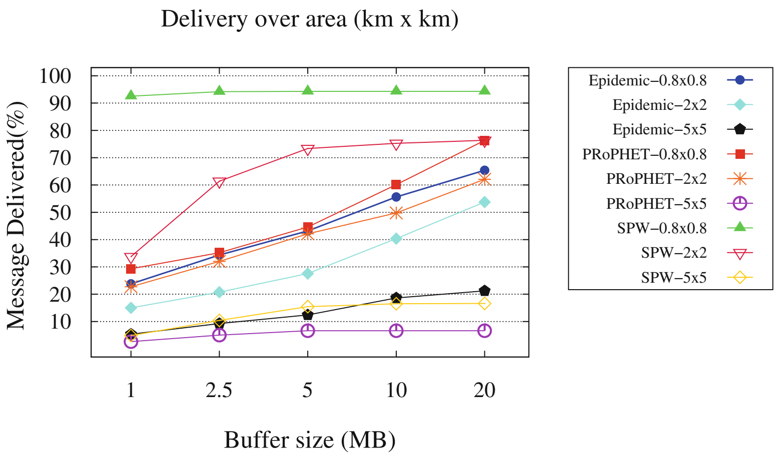

Fig. 5. Delivery from density.

5 CARPA Performance Evaluation

By definition, most of the DTNs are expected to operate in sparse and stressed environments. Nevertheless, in many situations the network designer or the application itself might impose certain performance requirements to the routing protocols (e.g. maximum delivery, maximum delay, minimum throughput, etc.). For example, a message sending over a DTN, notifying a number of peers about a catastrophe, would obviously be of no use if it arrived after the disaster time. Despite a large number of existing proposals, there is no routing protocol that outperform the others in all scenarios.

To assess the feasibility of the proposed method and demonstrate that the best option is an on-the-fly combination of routing protocols to achieve the desired performance in a specific scenario, simulations are performed using an extended version of the ONE simulator. In this version, each node runs CARPA, and before forwarding messages, nodes share their network attributes with their own one hop neighbors.

CARPA's decisions are based on the node's own instantaneous context information, the message context and the routing protocols available. The CARPA heuristic was defined based on the results presented in 4.1 and 4.2. Table 2 summarizes the heuristic. Note that heuristic can be changed without altering the rest of CARPA.

This analysis considers the context information regarding the number of messages, free buffer size, and density degree, and it focuses on achieving the highest message delivery ratio with the smallest delay. Thus, CARPA is examined under two network scenarios: dense and sparse networks. The first scenario is evaluated using the scenario 4.1 with a few modifications: there are 200 nodes with infinite buffer, moving according to the RW movement model in an 800 m × 800m network area. The transmission range is switched among 50 m, 100 m and 150 m.

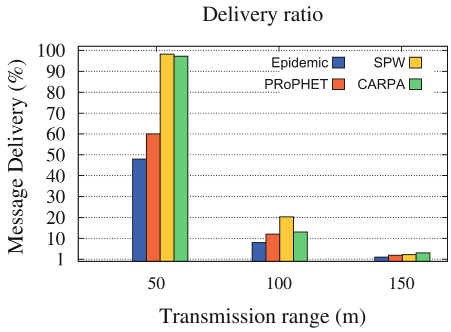

Fig. 6. Delivery for dense scenario.

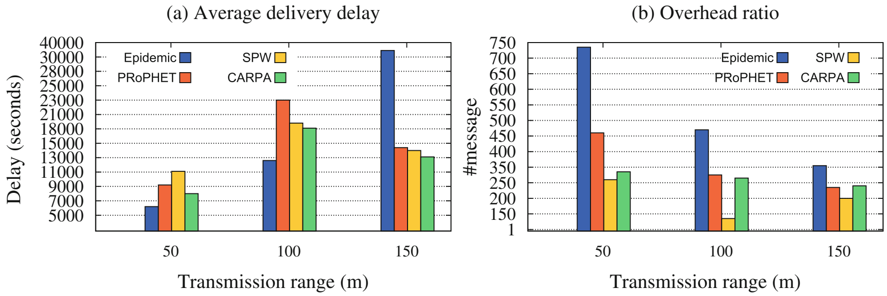

Fig. 7. Delay and cost for dense scenario.

The second scenario exploits limited resources and a sparse network. For this, 200 nodes randomly move in three different network areas: 5 km × 5 km, 10 km × 10 km and 20 km × 20 km. In both scenarios, messages are generated every five seconds.

All results presented here consist of four data: (*i*) using the standard Epidemic protocol during all messages routing; (*ii*) using standard PRoPHET to route all messages; (*iii*) using Spray-and-Wait to route all messages; (*iv*) using CARPA on all nodes, at each hop CARPA chooses the "best" suitable routing protocol for the context (among Epidemic, PRoPHET and SPW) and uses this protocol for this hop transmission.

Figures 6 and 7 show the performance evaluation of the protocols under different transmission ranges. In these dense scenarios, as the density and the traffic load are high, the available bandwidth decreases and the buffer occupancy increases proportionally, which reduces the performance of all protocols, especially for the Epidemic and PRoPHET. The Epidemic produces the largest delay and requires a higher number of transmissions compared to all the other schemes. The PRoPHET produces a high overhead. CARPA achieves the same delivery ratio as SPW with a lower delay for less density, but higher overhead.

Figure 8 shows that under sparse scenario, CARPA can achieve a higher delivery ratio than the Epidemic and PRoPHET. Note that even with infinite

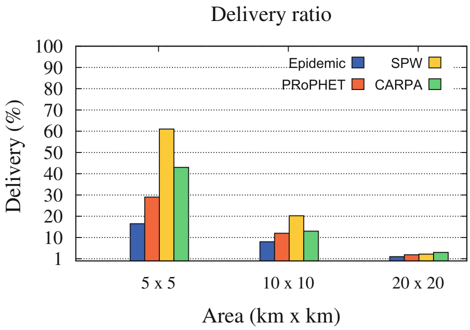

Fig. 8. Delivery ratio for sparse scenario.

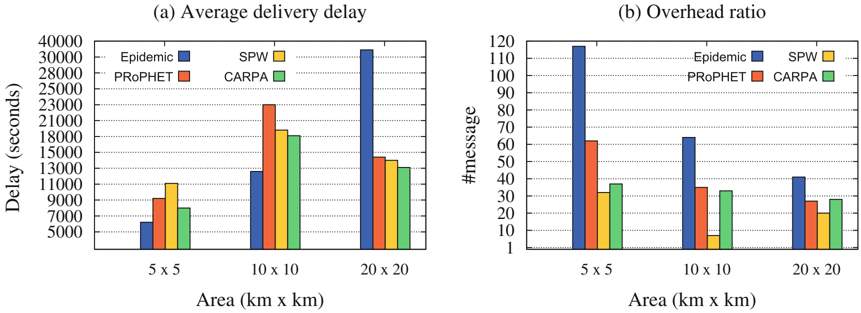

Fig. 9. Delay and cost for sparse scenario.

Table 2. Relation between context information and protocols.

C_i	*Range*	*Protocol*
Degree density	$1 \;=\; \lvert Nb_n \rvert$	Epidemic
	$2 \;\leq\; \lvert Nb_n \rvert \;\geq\; 10$	SPW
	$\lvert Nb_n \rvert \;<\; 10$	PRoPHET
Number of messages	$\lvert M_n \rvert \;< 20$	SPW
Free buffer size	$\tilde{B}_{free} \;\geq 90\,\%$	PRoPHET

buffer the delivery ratio is low due to the very sparse network. Also, Fig. 9(a) and 9(b) show that the delay and overhead ratio are proportionally improved. The two metrics are better observed in the 5 km × 5km network area, while the delivery ratio of CARPA is about 45 % better than Epidemic and PRoPHET. Even though its delay is greater then the Epidemic, it is much smaller than the PRoPHET and SPW. Likewise, the overhead ratio obtained by CARPA is 70 % less than the Epidemic, about 45 % less than the PRoPHET and 35 % smaller than SPW. On the other hand, the results show that the SPW outperforms the proposed method for the overhead and delivery, except over a 20 km × 20 km network area in which CARPA's performance is better.

The results suggest that CARPA takes full advantage of the strengths of the routing protocols and reduces their weaknesses. The performance of CARPA highly depends on the snapshot network. Even though the method in this article is composed by simple heuristics, it is possible to visualize the effectiveness of CARPA. The next step consists in improving the heuristic, which will have a direct impact on CARPA's performance.

6 Conclusion

This paper presented the first on-the-fly Context-Aware Routing Protocol Adaptation method (CARPA) for DTN. The method evaluates the network context before each hop transmission and chooses the "best" suitable routing protocol to use. The purpose of the context is to evaluate the requirements of the network which influence the performance of protocols towards a metric. Thereby, several different protocols can compose the message trajectory from the source to the destination.

The feasibility and the efficiency of CARPA were evaluated through simulations. Results demonstrate that it outperforms protocols such as Epidemic and PRoPHET in delivery, delay and overhead ratio and SPW in delay, using only these three protocols for the hop transmissions. This demonstration shows significant performance gains, mainly at sparse networks. Future work includes a swarm intelligent heuristic to improve the decision making of CARPA.

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