Effects of Buffer Size and Mobility Models on the Optimization of Number of Message Copies for Multi-Copy Routing Protocols in Scalable Delay-Tolerant Networks

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***Abstract*—In Delay-Tolerant Network (DTN), there exists a lack of direct path from source to destination, and it is also featured by extremely high bit error rate, unwanted delay, limited resource, etc. For such network, we have investigated the effects of buffer size and mobility models on the optimization of the number of message copies for multi-copy routing protocols such as Spray-and-Focus (SNF) and Spray-and-Wait (SNW). This investigation is essential for providing us with the insight on the number of message copies that would provide better delivery, lower latency and lower overhead considering the effects of buffer size and mobility models in scalable delay-tolerant networks. In this investigation, we have considered three performance metrics, namely delivery probability, average latency, and overhead ratio. Simulation is done using Opportunistic Network Environment (ONE) simulator, which is designed basically for evaluating the performance of DTN routing strategies. Here we have considered three mobility models, namely Shortest Path Map Based (SPMB) movement, Random Walk, and Random Direction. Simulation results show that for increasing buffer size and number of nodes on these considered mobility models for a particular value of number of message copies, indicated by L, SNF routing exhibits satisfactory performance, especially in the case of SPMB movement using only L = 2 copies. Since our purpose is to provide a satisfactory performance, i.e., higher delivery, lower latency and lower overhead, SNW routing shows overall good performance using L = 10 copies. Therefore, it would be a good optimization using Shortest Path Map Based movement model using L = 2 copies for SNF routing, and L = 10 copies for SNW in scalable DTN scenario, where there may be a high possibility of varying buffer size with number of mobile nodes.**

***Keywords*—intermittently connected mobile networks; delay-tolerant networks; routing; opportunistic network environment simulator; buffer size; mobility models; average delay; delivery probability; overhead ratio**

I. Introduction and Related Works

In Delay-Tolerant Networks (DTNs), there is no persistent route from source to destination due to scarce network resources and mobility models; this type of networks can be characterized by extremely high bit error rates, unwanted delays, fixed resources, etc. [1−2]. DTNs are also referred to as Intermittently Connected Mobile Networks (ICMNs) [3], which are featured by intermittent connectivity and temporarily broken links [4]. It uses "store and forward" mechanism for providing the route of messages where a message is successively moved from the source to the next available node and stored in respective node's buffer which is forwarded to other nodes with an aim to reach the destination [5−7]. DTNs have been extensively used in many areas including interplanetary networks [8], underwater networks [9], satellite communication [10], wildlife tracking sensor networks [6], military networks, and vehicular ad-hoc networks [11], etc.

In our previous work [22], we have investigated the optimization of number of message copies for two multi-copy routings, namely Spray-and-Wait (SNW) and Spray-and-Focus (SNF) with the variation of number of nodes. From the investigation, we have seen that SNF routing shows better performance using L = 2 copies while for SNW it needs about L = 10 copies. In the present work, we have included the impacts of varying buffer size and mobility models on their performance.

The rest of this paper is organized as follows: Section II describes the considered routings used in a scalable DTN. Section III includes the discussion of mobility models. Section IV introduces the simulation tool and setup. Section V discusses the simulation results. Section VI concludes this research work.

II. Investigated Routings in DTN

In this paper, we have considered two routings, Spray-and-Wait (SNW) [12], and Spray-and-Focus (SNF) [13].

SNW routing shows better performance than Epidemic [14], PRoPHET [15] as discussed in [16] by limiting the number of message copies. There are two versions, namely vanilla and binary. In case of vanilla, a single message is forwarded from source to the first L distinct nodes it encountered. On the other hand, in binary version source node containing L copies forwards L/2 to the first node it encountered. Each node then forwards half of its copies to future nodes they meet having no copy in common. When a node has only a single copy, then it is in wait phase and tries to communicate directly to the destination.

In the focus phase of SNF routing, messages are not routed using direct transmission (i.e. forwarded only to their destination) [4, 17], rather copies can be forwarded to another

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node having better probability to deliver them to the destination using a single-copy utility based routing.

III. Mobility Models

In this research work, three mobility models, namely Random Walk (RW), Random Direction (RD), and Shortest Path Map Based (SPMB) movement have been used.

In RW, each node moves randomly towards a new node's location. Although random direction with speed is assigned to every node within a predefined range, nodes in a network are independent from each another [18]. Whenever a node reaches to the destination, a new direction is again assigned from predefined ranges.

In RD, a mobile node gets a movement degree randomly and moves in a particular direction until it touches the destination boundary of simulation area with a specified speed. When it travels to boundary area, it stops for a specified pause time before choosing a new direction to move again [19].

In SPMB movement, all nodes travel to a certain destination in the map and follow Dijkstra's shortest path algorithm [20] to discover the shortest path to the destination.

IV. Simulation Tool and Setup

In this section, we will discuss opportunistic network environment (ONE) simulator and simulation setting.

ONE [20−21] is an agent-based discrete event simulation engine, which is basically designed for evaluating the performance of DTN routing protocols. At each simulation step, ONE combines mobility modeling, inter node contacts, DTN routing, message handling and visualization in one package that provides a rich set of reporting and analyzing modules.

Simulation configuration for varying percentage of L copies in a scalable network is shown in table I. Two groups of nodes namely cars and pedestrians have been considered. Both groups have equal number of nodes.

TABLE I. Simulation Environment Parameters

Parameters		Value
Simulation Time		12 hours
Number of Nodes		50, 100, 150, 200
Pedestrians	Speed	0.5-1.5 m/s
	Group id	p
Cars	Speed	2.7-13.9 m/s
	Group id	c
Interface		Bluetooth Interface
Transmit Speed		250 kbps
Transmit Range		10 m
Buffer Size		5, 10, 20, 30 MB
Message Generation Rate		2, i.e., one message in 25-35 seconds
Message TTL		300 minutes
Mobility Models		SPMB, RW, RD
Message Size		500 KB – 1 MB
Number or Percentage of L Copies		2, 5, 10, 20

V. Results and Discussion

In this investigation, we have used three mobility models and varied buffer size to achieve the optimum number of message copies for the considered routing protocols in a scalable DTN scenario based on their performance.

A. Performance Analysis on Delivery Probability

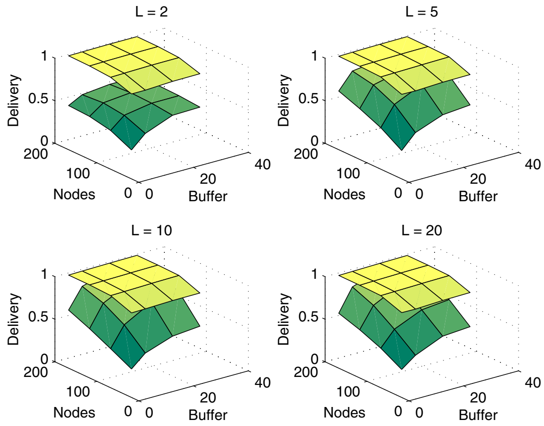

Fig. 1. Delivery probability with varying number of nodes and buffer size for L copies using shortest path map based movment mobility model

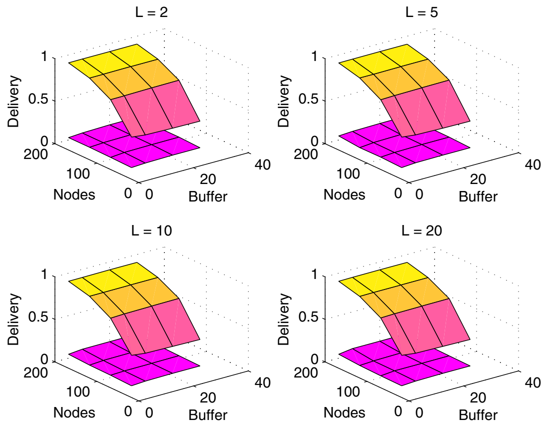

Fig. 2. Delivery probability with varying number of nodes and buffer size for L copies using random direction mobility model

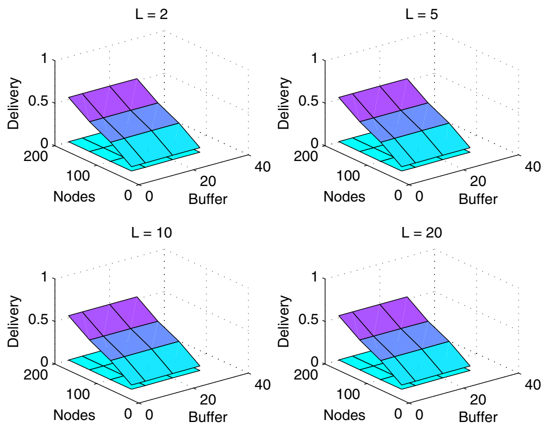

Fig. 3. Delivery probability with varying number of nodes and buffer size for L copies using random walk mobility model

Delivery probability is the ratio of the total number of messages delivered to the destination over the total number of messages created at the source. In the following figures, upper layer shows the performance of SNF routing and lower layer the SNW routing. We see that with increasing buffer size and number of nodes, delivery of SNF and SNW routings is better in case of SPMB movement than RD and RW. For clarification (considering only the highest value), SNF routing shows a delivery ratio 1 (approx.) in case of SPMB while for RD and RW, delivery ratios are less than 1 and 0.5, respectively. SNW routing shows approximately the same performance in RD and RW model. Hence, we see that SNF routing shows higher delivery when L = 2. On the other hand, in case of SNW routing, we see the better delivery for L = 10.

B. *Performance Analysis on Average Latency*

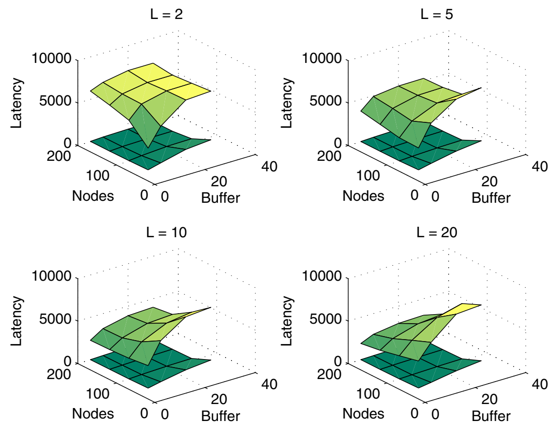

Fig. 4. Average latency with varying number of nodes and buffer size for L copies using shortest path map based movment mobility model

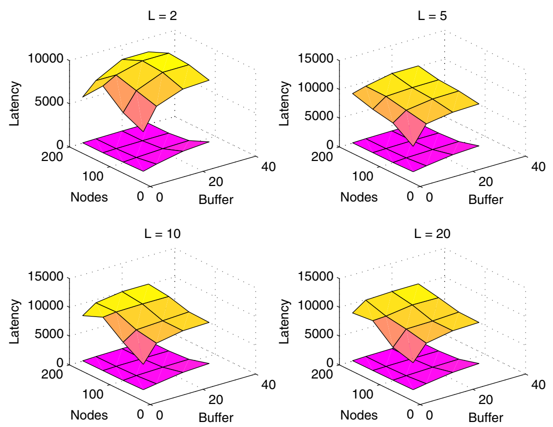

Fig. 5. Average latency with varying number of nodes and buffer size for L copies using random direction mobility model

Average latency is the measure of average time between messages generated and messages received to destination. In the following figures, upper layer shows the performance of SNW routing and lower layer the SNF. Average latency increases gradually in accordance with the increase of number of nodes and buffer size. Hence, in case of SNF routing, average latency is approximately same for varying L copies. For SNW routing, L = 10 shows lower latency than L = 2 and L = 5. Therefore, we can give a standard (L = 10) with its higher delivery probability. That is, SNF routing gives lowest latency using only 2 copies but SNW requires 10 copies to obtain its optimization.

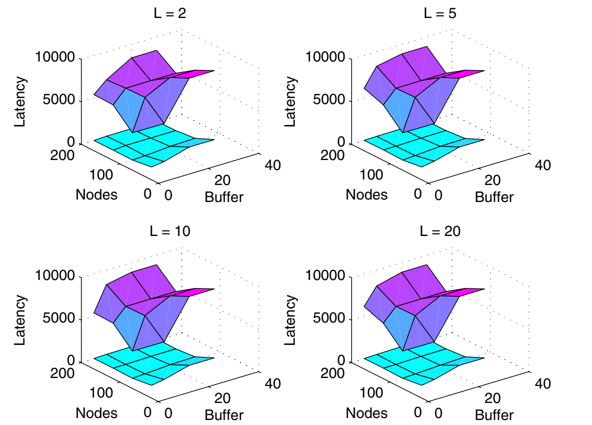

Fig. 6. Average latency with varying number of nodes and buffer size for L copies using random walk mobility model

C. *Performance Analysis on Overhead Ratio*

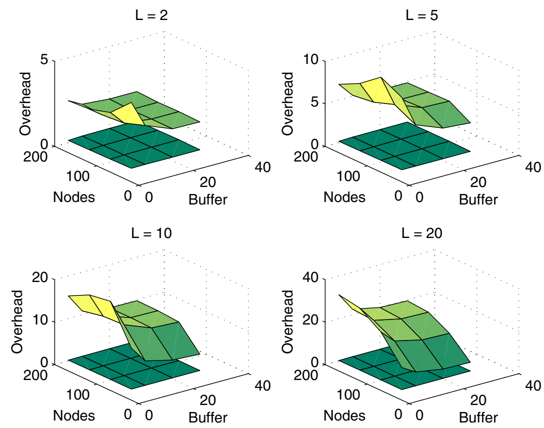

Fig. 7. Overhead ratio with varying number of nodes and buffer size for L copies using shortest path map based movment mobility model

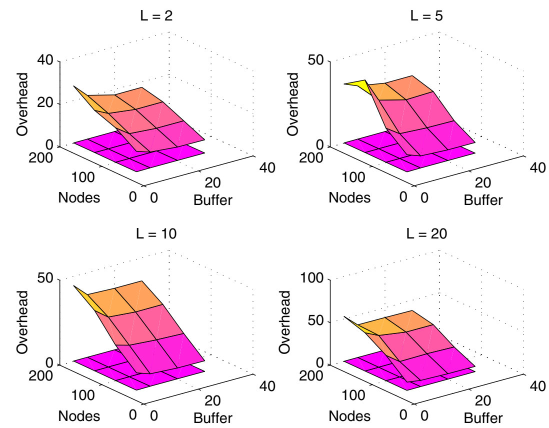

Fig. 8. Overhead ratio with varying number of nodes and buffer size for L copies using random direction mobility model

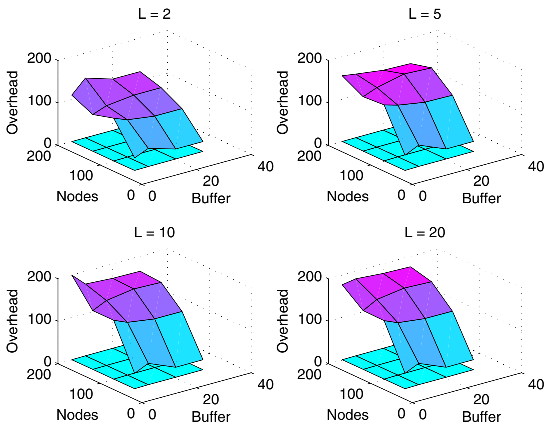

Fig. 9. Overhead ratio with varying number of nodes and buffer size for L copies using random walk mobility model

The overhead ratio defines how many redundant packets are relayed to deliver a single packet. It simply reflects the cost of transmission in a network. In the following figures, upper layer shows the performance of SNW routing and lower layer the SNF. With increase of number of nodes and buffer size we see that overhead ratio increases for SNW routing. Although SNW routing shows lower overhead for L = 2 and L = 5 than L = 10 and 20. We have considered L = 10 as a standard considering its delivery probability. SNW shows lower overhead for L = 10 compared to L = 20. On the other hand, SNF routing shows very low (approximately zero) overhead ratio for L = 2 copies. So we can say that SNF routing shows lower overhead with only L = 2 copies.

VI. CONCLUSIONS

In this paper, we have investigated the effects of buffer size and mobility models, i.e. Shortest Path Map Based (SPMB) movement, Random Walk, and Random Direction, for optimizing the number of message copies for multi-copy routings such as Spray-and-Focus (SNF) and Spray-and-Wait (SNW) in a scalable delay-tolerant network. The investigation demonstrates that for increasing buffer size and number of nodes on these considered mobility models for a particular value of number of message copies, indicated by L, SNF routing exhibits the satisfactory performance using only L = 2 copies, especially for SPMB. On the other hand, SNW routing shows overall good performance using L = 10 copies. Hence, in comparison to SNW, SNF routing shows better results because of using the single-copy utility-based algorithm for enhancing the message delivery. Therefore, it will be a good optimization using Shortest Path Map Based movement model using L = 2 copies for SNF routing, and L = 10 copies for SNW in such scalable DTN scenario where there may be a high probability of having variable number of mobile nodes with varying buffer sizes.

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