The Impact of Message Transmission Scheduling in DTN Message Delivery Across Multiple Islands

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***Abstract*—DTN have been employed widely to support various applications but among them, vehicle-based DTN on transportation infrastructure to deliver data is promising. In addition to routing protocols, message transmission scheduling is also very influential on DTN performance. Since nodes have a mobility and usually moving, a limited radio range and a limited duration of contact time can involve bottlenecks on message transmission in DTN. In this paper, we investigate the impact of message transmission scheduling on DTN message delivery across multiple islands that reflect a real example situation in Indonesia. We use our previous proposed A-SnHD as routing protocol, and evaluate the impact of message transmission scheduling by combining it with different scheduling schemes. One is a version of our previous proposed message scheduling called TTL-Loc modified to fit in the multiple island case. Other two are popular schemes, i.e., FIFO and Random. Two scenarios are examined. In 1s-to-2d scenario, a single source node sends different messages to two destination nodes located in different islands; not by multicast but by two different unicast deliveries. In the 2s-to-1d scenario, two source nodes located in different islands send different messages to a common destination node by two different deliveries. In both scenarios, our proposed TTL-loc scheduling is shown to have a better performance compared with FIFO and Random in terms of the amount of delivered messages before TTL-expiration. However the benefit of TTL-loc and its sensitivity differ depending on traffic load as well as the deliver scenarios.**

***Index Terms*—DTN, transmission, scheduling, multiple, island**

I. INTRODUCTION

Delay tolerant network (DTN) provides a remote message delivery where no end-to-end connectivity exists due to node mobility, temporal failure, and so on. In order to deliver messages in such a condition, DTN uses the store-carry forward (SCF) strategy. Each message generated in the source node will be forwarded to contacted intermediate nodes, it will be carried by the intermediate node along, and it will be exchanged between contacted intermediate nodes until it reaches the destination node or it is discarded for some reason, e.g., buffer overflow and time-to-live (TTL) expiration. DTN have been employed widely to various applications but among them, vehicle-based DTN on transportation infrastructure to deliver data is promising and have attracted much attention such as DAKNet [4] and UsMassDiseselNet [5].

In SCF approach in DTN, there are three important controls for DTN performance, e.g., to deliver as many messages as possible to the destination before the deadline (TTL expiration). The first one is which messages should be forwarded to the contacted node, referred to as message routing in this paper. The second one is which messages should be forwarded first within a limited number of messages being forwarded in one contact, referred to as message transmission scheduling. Since nodes have a mobility and usually moving, limited radio range and limited duration of a contact time can involve bottlenecks on message transmission in DTN. The last one is which messages should be dropped when the node buffer becomes full.

In our previous work [1], we developed a message transmission scheduling scheme called TTL-loc, based on the node location dependent remaining TTL, which is shown to achieve good performance in the two islands scenario where a single source sends messages to a single destination in a different island. Then in [2], we proposed a routing protocol called A-SnHD to fit in the four islands case with simple FIFO message transmission scheduling. In this paper, we will evaluate the impact of message transmission scheduling to improve the performance of our proposed A-SnHD routing protocol in the four island case. The evaluation scenario consists of four islands where each of our islands employs cars and buses as nodes and ferryboats to connect each island. This case is based on situation in Indonesia. The largest archipelago country in the world, in which some islands are small, some are remote, and some do not have a high-speed data communication infrastructure due to its high-cost for deployment.

The scenarios, message transmission scheduling, and routing protocol are implemented in ONE Simulator [3]. As message transmission scheduling, a version of TTL-Loc is used, which is modified from one we developed in [1] to fit in the multiple island cases. Two popular message scheduling schemes in DTN are also used, i.e. First in First Out (FIFO)

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and Random.

The remainder of this paper is organized as follows: Section II Existing message transmission scheduling strategies and improved version of our proposed message transmission scheduling is presented. In section III our proposed routing protocol explained. Section IV describes the evaluation scenario and the simulation results. Finally, the conclusion and directions for future work are described in Section V.

II. Message Transmission Scheduling Strategies

Message transmission scheduling is a strategy to allocate the order of transmitting messages between nodes during a duration of each contact. In DTN, the duration of each contact time is unpredictable and may end before the message transmission is completed, due to mobility at each node. Implementing an effective message transmission scheduling is expected to reduce the message delivery delay or/and increase the success probability of message delivery.

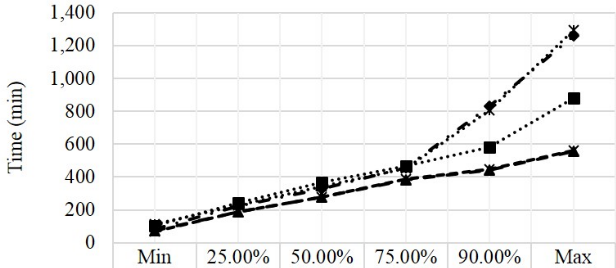
To evaluate the performance of message transmission scheduling, in this paper we focus to evaluate two popular scheduling strategy with one scheduling strategy that we have developed in our previous research [1]. Each scheduling strategy is independent of each routing protocol, meaning that any scheduling strategy can be tested on multiple routing protocols, but in this paper we only focus to our proposed routing protocol (i.e., Adaptive Spray and Hop Distance routing protocol (A-SnHD) [2]).

A. First in First Out (FIFO)

This is a simple and widely use scheduling strategy based on a first-come and first-serve approach. The messages are ordered to be transmitted in a duration of contact, based on their arrival time at the nodes buffer storage. The oldest message is transmitted first, then the second oldest and so on. The expected effect is that older message will be transmitted first although the Time to Live (TTL) value of message will expire soon, and it cannot reach the destination using the available TTL and will resulting high overhead. Another version is Last in First Out (LIFO), the opposite strategy of FIFO. The youngest message that received in node buffer will be transmitted first, and maybe the old messages are not transmitted at all in congestion condition because newer messages are always preferred. This strategy will decrease the average latency and increase the probability of delivered messages in shorter path condition.

B. Random Scheduling

Random scheduling reorders message in the buffer storage queue based on a uniformly distributed random function. This scheduling strategy does not improve anything although in some scenario it has a good performance. It will increase computing overhead, which means if we prefer low power consumption device, this scheduling strategy is not acceptable.



	Min	25.00%	50.00%	75.00%	90.00%	Max
mdr1	102	243	368	467	582	883
mdr2	74	188	278	382	442	557
mdr3	69	186	279	387	448	562
mdr4	114	230	343	451	805	1294
mdr5	84	222	328	456	833	1262

Fig. 1: Message delivery reports for each node location

C. Node Location dependent remaining TTL-based (TTL-Loc)

This scheduling strategy uses a Time To Live (TTL) value in combination with global knowledge about the network as a decision for message transmission. Each message in DTN has a TTL value that indicates the timer to limits the lifetime of a message in the network. Global knowledge about network in general increase the performance of message delivery although it is difficult to get some global knowledge accurately and promptly [6]. Therefore, in a real system, we can only use global knowledge that can be estimated easily (e.g., estimated independently in each closed region)and is not changed rapidly in time. In addition, a system that utilizes some global knowledge should not be too sensitive to the estimated global knowledge.

The scheduling TTL-Loc uses the estimated message delivery time within each island as global knowledge about the network. Figure 4 shows the network topology consisting of four islands we considered. Figure 1 shows the estimated distribution (percentiles) of message delivery time between two vantage stationary locations on each island. They were obtained by measurement in a simulation of A-SnHD routing protocol with random message scheduling over 819.2 MB of generated messages. In a real system, such information can be obtained by repeatedly monitoring the messages delivered by the currently running routing protocol with the currently running message scheduling over some number of messages or some duration. Although such information is expected to obtain at some vantage points, how to distribute the information into other nodes in an island should be considered; it is our future work.

In this paper, for simplicity of investigation and to get baseline results, we use the above single data set shown in Fig. 1, which was measured in the fixed condition. We use five the estimated message delivery times according to node location as follows:

- Estimated message delivery time from Source node to the Station A in the City Island *(mdr1)*.
- Estimated message delivery time from the Station B in the Island 1 to Station E in the same island *(mdr2)*).

- Estimated message delivery time from Station B in the Island 1 to Station C in the same island *(mdr3)*.
- Estimated message delivery time from the Station D in the Island 2 to the destination 1 node in the same Island *(mdr4)*.
- Estimated message delivery time from Station F in the Island 3 to the destination 2 node in the same Island *(mdr5)*.

The main idea is to give a high priority to a message in buffer queue that arrives in a node according to its location. The priority is based on W variable that determined by node location and the message delivery time. W is expected minimum normal time for a message to reach its destination. In order to fit in the multiple island case, we modified the formula that has been considered in [2] according to multiple island condition. Here is formulation to determine W.

- Node in the City Island

$$W = (X\text{-tile of } mdr1) + (50\text{-tile of } FT) + (X\text{-tile of } Avg(mdr2 : mdr3)) + (50\text{-tile of } FT) + (X\text{-tile of } Avg(mdr4 : mdr5)) \quad (1)$$

- Station A in the City island,

$$W = (50\text{-tile of } FT) + (X\text{-tile of } Avg(mdr2 : mdr3)) + (50\text{-tile of } FT) + (X\text{-tile of } Avg(mdr4 : mdr5)) \quad (2)$$

- Station B and node in the island 1,

$$W = (X\text{-tile of } Avg(mdr2 : mdr3)) + (50\text{-tile of } FT) + (X\text{-tile of } Avg(mdr4 : mdr5)) \quad (3)$$

- Station C node in the island 1,

$$W = (50\text{-tile of } FT) + (X\text{-tile of } mdr4) \quad (4)$$

- Station E node in the island 1,

$$W = (50\text{-tile of } FT) + (X\text{-tile of } mdr5) \quad (5)$$

- Station and node in the island 2,

$$W = (X\text{-tile of } mdr4) \quad (6)$$

- Station and node in the island 3,

$$W = (X\text{-tile of } mdr5) \quad (7)$$

Here, $mdr1, mdr2, mdr3, mdr4, mdr5$ is the message delivery time for each location of the node. In our scheme, we use a X-tile of the expected delivery time value as the moderate normal time to deliver a message from each location to the destination, and set X to various values. FT is the duration the ferry travels between the station on the small island and the station on the large island, including the waiting time at the stations. We define FT as a fixed value, the wait time in the stations is $[0, 30]$ min, and the travel (sailing) time is 15 min. So "the wait time + travel time" is $[15, 45]$. Then, 50-tile is expected to be about 30 min. For each incoming message from another node, it will be arranged according to W value. Figure 2 shows the flowchart of TTL-Loc scheduling. The messages in buffer storage are sorted according to it remaining TTL value and W value. There are two priority we used in this scheduler, the messages in the high priority queue will be sent according to its delivery time in the buffer storage, the latest incoming message will be sent first. In case of there is no message in the high priority queue, the message with large remaining TTL will be sent first.

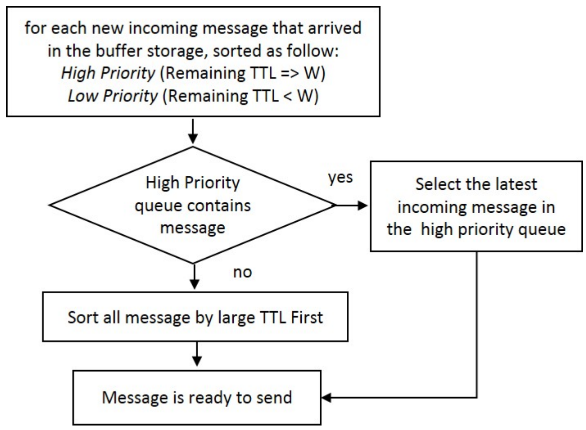


Fig. 2: Flowchart of TTL-Loc.

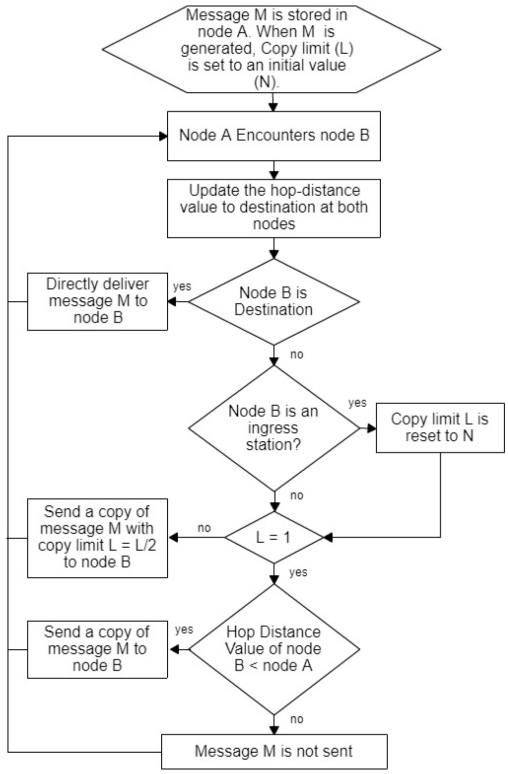


Fig. 3: Flowchart of A-SnHD.

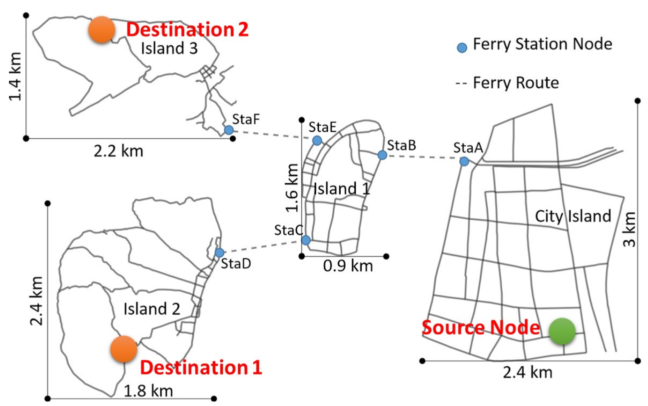


Fig. 4: Simulation scenario.

TABLE I: Simulation parameter

Parameter	Value
Simulation time	28 h
Node buffer size	Mobile = 200 MB Stationary = 2000 MB
Transmission speed	4.5 Mbps
Transmission range	30 m
Message TTL	14 h
Node speed	Bus = 5-20 km/h Car = 10-30 km/h
Total size of Generated messages	204.8 MB, 409.6 MB 819.2 MB, 1638.4 MB, and 3276.8 MB
Message creation duration	8 h
Message size	0.4 MB
Warm up time	60 min
Initial value of L of A-SnHD	3 messages
Message drop policy	Drop Oldest

III. Adaptive Spray and Hop Distance Routing Protocol (A-SnHD)

This protocol was proposed in our previous research [1]. An improved version of Spray and Wait routing protocol with two new features: 1) adaptive binary-spray; and 2) hop distance based forwarding. Adaptive binary-spray is an improved version of binary spray. Each generated message has a copy limit (L) as the permitted number of copy each message in the network. In A-SnHD the value of copy limit (L) will reset to the initial value when it reaches in station node on each island. A message with copy limit of n (n>1), in the transmission to another node that does not have a copy of a message, copy limit (L) change to half (n/2). For a message with copy limit of 1 it switched to hop distance based forwarding. In hop distance based forwarding phase, the message only forwarding to a node that has lower hop distance value to the destination. For each node that encountered to the destination node, it hop distance value will set to 1. However, a node that encounters with destination node once and never goes back again will have high hop distance value. This routing decision will reduce unnecessary message transmission. Figure 3 shows the flowchart of A-SnHD Protocol.

IV. Performance Evaluation

A. Simulation Scenario

The objective of the evaluation is to investigate the impact of message transmission scheduling in the multi-hop island case. For performance comparison, we use three metrics i.e., amount of delivered messages, average latency, and overhead ratio. We also show the number of delivered messages on each island. This scenario is based on the condition in Indonesia in which consists of four islands with two message delivery scenarios.

Message delivery on the island is consists of Car and Bus, then the ferries for message delivery between the island (Fig. 4). A similar type of scenarios can be seen in [7], that considered segmented island-hopping scenarios where nodes located in three geographically separated groups that connected by three mobile traveler nodes. During 28 h of simulation time, cars and buses are moving using car movement model along the map on each island, while each ferry node moves according to its route between islands. Total of 97 mobile nodes (e.g. car, bus, and ferry) move on the map road with the warm-up time of 1 h. The car speed is 10-30 km/h, and bus speed is 5-20 km/h. The traveling time (sailing) of ferry nodes is 15 minutes and waiting time on each island is 30 minutes. Ferry stations and ferry node need to have a buffer that is about ten times or larger than mobile nodes. Note that, as the limitation of the ONE simulator, the maximum node buffer size is 2000 MB. In our scenarios, We used some scaling in which we select 200 MB buffer for Car and Bus nodes, 2000 MB for ferry stations and ferry.

All messages are generated randomly and uniformly over 8 hours. Messages are originated depending on the message delivery scenario: first, from one source in city island to two destinations node in island 1 and island 2 (1s-to-2d); second, from two sources in island 1 and island 2 to one destination in city island (2s-to-1d). Each source node generates a number of messages to one of destination. The message size is 0.4 MB with five cases of the total size of generated messages; 204.8 MB, 409.6 MB, 819 MB, 1638.4 MB, and 3276.8 MB. A large total size implies a high message generation rate (i.e., a high network congestion level). In all simulation scenarios, A-SnHD (copy limit L) value of A-SnHD as 3 messages. Details of the simulation parameters are presented in Table 1.

B. Performance Metric

We use the following three metrics to compare the performance of three routing protocols:

1) *Total Size of Delivered Messages*, this metric is the measure of the message size multiplied by the number of messages successfully delivered to the destination before TTL expiration.
2) *Overhead Ratio*, is defined how many additional copies of messages were relayed for each delivered message, it represents the efficiency of message transmission and desirable to have a low overhead ratio.
3) *Average Latency*, this measure is another important concern in DTN routing evaluation, it represents an average time difference between the message generation

time at the source and the message received time at the destination over all successfully delivered messages.

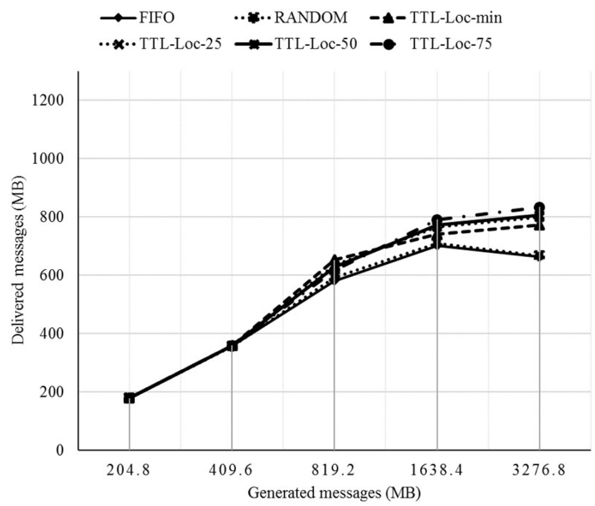
C. Performance Analysis

1) One Source to two destinations (1s-to-2d): In this scenario messages are originated in the city island and destined to island 1 and island 2. Figure 5(a) shows the comparison of delivered messages of three message transmission scheduling (FIFO, Random, and TTL-Loc and four different of percentile value of message delivery report in TTL-Loc (i.e., TTL-loc-min, TTL-loc-25, TTL-loc-50, and TTL-loc-75). TTL-Loc-min means that the W value compute according to its location and minimum value of message delivery time, TTL-loc-25 means that the W value compute according to its location and 25-tile of message delivery time, and so on.

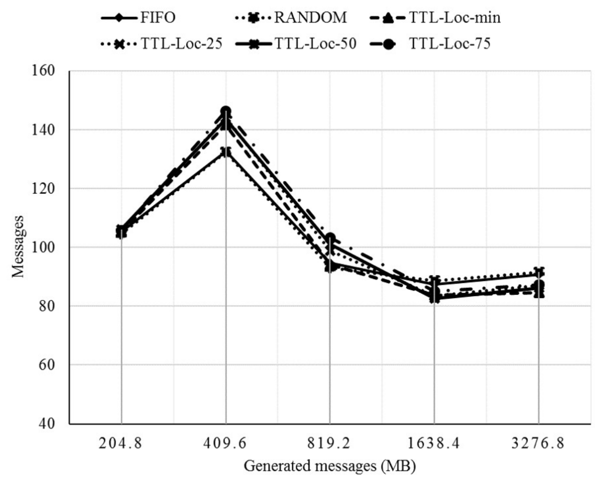
Figure 5(a) shows that the TTL-loc achieved better performance than FIFO and Random at high amount of generated messages, i.e., from 819.2 MB or greater. The W value gives a threshold according to TTL value of message in buffer queue; the messages that have a TTL value lower than the W value will be sent only after all other messages have been sent in the current contact. This prioritization will suppress to send messages that has an insufficient remaining TTL value and is not surely expected to reach the destination within TTL when the contact duration is short compared with the number of messages to be sent. This may help to work robustly in high message loads. On the other hand, by FIFO and Random scheduling, the number of delivered messages becomes being saturated at 1638.4 MB of generated messages. As for the sensitivity of the percentile value of TTL-Loc scheduling on the performance, TTL-Loc-75 achieved better performance than the other TTL-loc scheduling at high message loads. A larger W value gives a high priority to messages that have a larger remaining TTL value, which means the priority will be given to the newer messages in the network.

TTL-loc scheduling achieved higher overhead ratio compare with FIFO and Random in the small size of generated messages (409.6 and 819.2 MB) as shown in Figure 5(b), the message that has lower remaining TTL value than W value will not send until all message with remaining TTL larger than W value is sent. Note that, we used drop oldest as a default buffer management policy, in which will drop the oldest message in the buffer storage. Affected the copy of a message with remaining TTL is larger than W value is increased as increased of the occupancy of buffer storage. On the other hand, in 1638.4 MB or greater, the overhead ratio of TTL-loc scheduling is lower than FIFO and Random. In this high network congestion condition, the capacity of buffer storage in the network is not enough, the priority of W value affected the new message that has large remaining TTL value will be transmitted first.

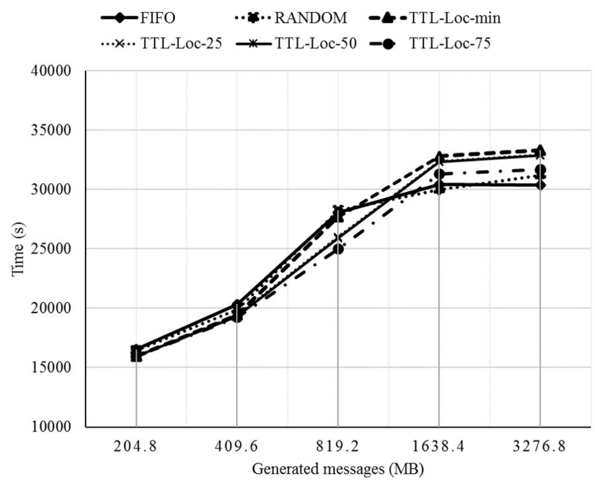
Figure 5(c) shows the latency average of 1s-to-2d scenario. In general, since the total size of generated message is 1638.4 MB or greater, latency average of TTL-Loc is higher than FIFO and Random. Then for the various TTL-Loc latency average is depends on the percentile value of message delivery



(a) Total size of delivered message



(b) Overhead ratio



(c) Average Latency

Fig. 5: Simulation result of 1s-to-2d scenario

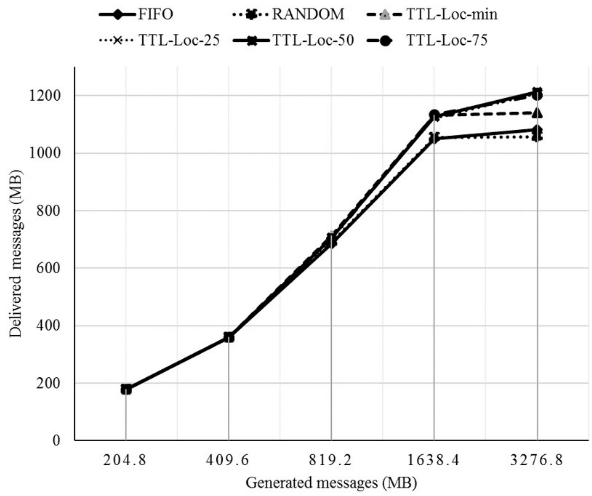
report. TTL-loc min, 25, and 50 achieved higher latency average than TTL-Loc-75. TTL-loc-75 used 75 percentile of message delivery report, in which affected this scheduling only forward large of remaining TTL value or newer message compare with the other TTL-loc.

2) Two Source to One destinations (2s-to-1d): In this scenario, two source nodes located on different islands (island 2 and island 3) and a destination node located on city island. Figure 6(a) shows that the TTL-loc achieved better performance than FIFO and Random at moderate and high amount of generated messages, i.e., from 819.2 MB or greater. Each source node in different island generated half from the total size of generated messages, this affected the network resources (i.e., buffer storage and bandwidth) in this scenario is may be enough for 819.2 MB or smaller, in this condition, all message scheduling achieved almost the same performance. As for the sensitivity of the percentile value of TTL-Loc scheduling on the performance, the different percentile values achieved almost the same performance except for TTL-Loc-Min.

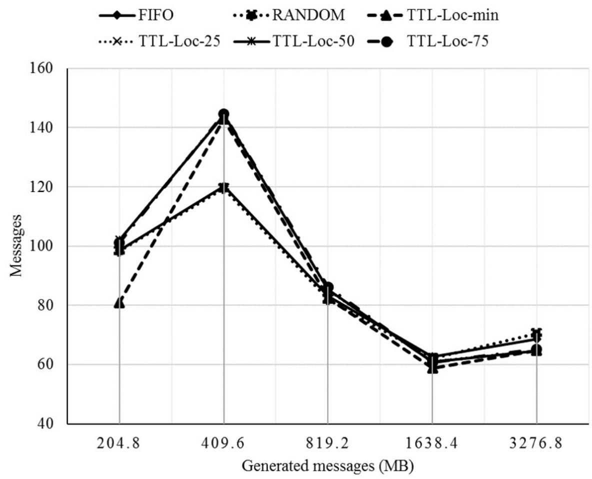
Figure 6(b) shows the overhead ratio of 2s-to-1d scenario, TTL-loc has higher overhead ratio when the number of generated messages is 409.6 MB. Note that, the usage of threshold in TTL-loc affected the number of message transmission is lower than FIFO and Random. The message that has remaining TTL is lower than the threshold will never be transmitted until it dropped from the buffer storage. Then the message that has remaining TTL is higher than the threshold will be transmitted to all encountered node. This affected the number of copy for each message is higher.

Latency average shows in Figure 6(c). The average latency of all message scheduling is diverse as the total size of generated message increases. TTL-Loc-min have a higher average latency in 819.2 MB and 1638.4 MB of generated messages. On the other hand, Random has lower latency average compare with the other message scheduling. Lower threshold value of TTL-Loc-min will gives more chance to forward message to the encountered node compare with the other version of TTL-Loc.

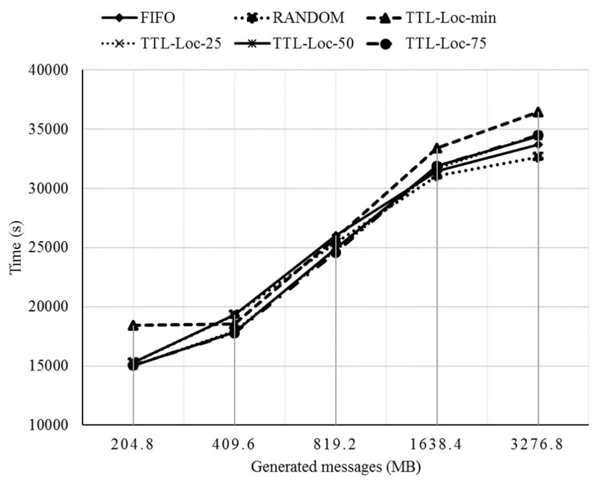
3) The Impact of Message Scheduling on Dropped message: In this comparison, to investigate the detailed difference between message scheduling schemes in two scenarios, we analyzed the dropped message due to buffer storage full with 3276 MB of generated messages. As shown in the figures 7(a) of 1s-to-2d scenario, in general, TTL-loc has a higher number of dropped messages (by buffer-full) than FIFO and Random. TTL-Loc gives a high priority to the messages that have remaining TTL values higher than the threshold value. In other words, the threshold value of TTL-loc determines the minimum of remaining TTL value of a message that is preferentially sent to the encountered node. With a higher value of threshold of TTL-loc, the number of the dropped message by buffer-full is increased. A higher threshold helps newly generated messages to be distributed more quickly, which may increase the number of different messages stored in two contacted nodes and thus the number of messages exchanged in contact. Then for 2s-to-1d scenario (Figure 7(b)),



(a) Total size of delivered message

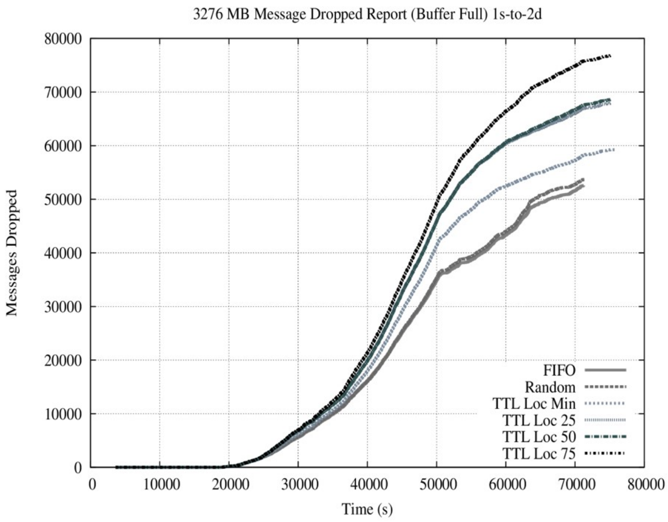


(b) Overhead ratio

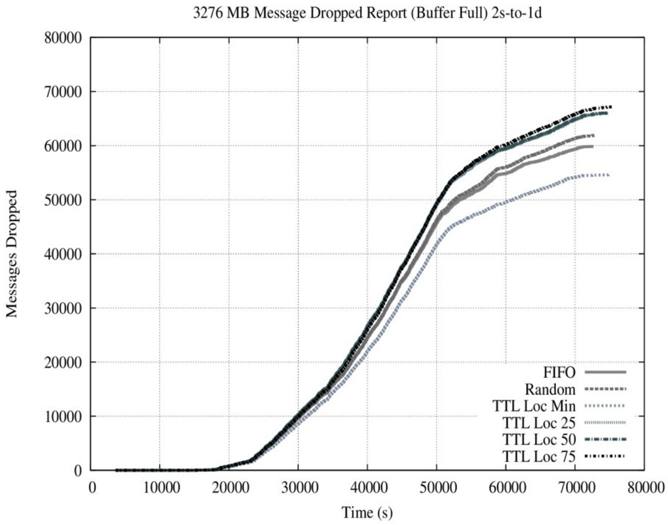


(c) Average Latency

Fig. 6: Simulation result of 2s-to-1d scenario



(a) 1s-to-2d scenario



(b) 2s-to-1d scenario

Fig. 7: Message dropped report due to buffer full

in general, TTL-loc 25, 50, and 75 have higher numbers of dropped messages than FIFO and Random. Surprisingly, however, TTL-Loc min has the lowest dropped messages for 3276 MB case. This uniqueness of TTL-Loc min should be investigated more.

V. Conclusion and Future Work

In this paper, we have investigated the impact of message transmission scheduling on the performance of DTN message delivery across multiple islands in conjunction with routing protocol A-SnHD that we proposed in [2]. In two message delivery scenarios, i.e., 1s-to-2d and 2s-to-1d, a modified version of message transmission scheduling TTL-Loc [1] is compared against two popular schemes, i.e., FIFO and Random. The evaluation results show that, in the 1s-to-2d scenario, TTL-Loc achieves a better performance (i.e., a larger amount of delivered messages) compared with FIFO and Random with middle and high-level loads. In addition, this advantage increases as the messages load becomes higher. In 2s-to-1d scenario, TTL-Loc achieves a better performance only with a high-level load. Moreover, the relationship of the parameter W of TTL-Loc on the delivery performance and on the number of messages dropped by buffer overflow is evaluated. Note that W is a threshold of the remaining TTL to give a low scheduling priority to the message, and represented by a percentile value of the message delivery delay averaged in a located island.

For future work, we should more clarify the detail reasons of TTL-Loc impact on the performance by changing many related simulation conditions. In particular, it is essential to examine different source-destination relation scenarios in different island conditions.

Acknowledgment

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