Performance Analysis of the Impact of Time to Leave on Different Drop Policies for Delay Tolerant Networks

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Abstract: Delay Tolerant Networks (DTNs) are intermittently connected networks, where there is no guaranteed end-to-end connectivity between the source and destination. The link between the pair of nodes in the DTNs environments is frequently disrupted, due to the fast mobility of nodes, dissemination nature, and power outages. Due to the absence of contemporaneous paths between the nodes, the opportunities for message forwarding in DTNs usually are limited. To obtain high data delivery, the DTNs use innovation of the Store-Carry and Forward (SCF) technique which allows data transmission to successfully proceed to the destination despite the absence of continuous end-to-end paths. However, the SCF approach arises various issues such as buffer congestion and message drop which are caused due to growing number of carried messages in restricted network resources. Therefore, buffer management techniques are required to manage the buffer capacity of the nodes by deciding how to effectively drop the messages and how to schedule the messages in the node's buffer in a perfect way. This paper evaluates the performance of six buffer management policies, namely First-In-FirstOut, Last In First Out, Drop Largest, Drop Youngest, Evict Shortest Lifetime First and Evict Most Forwarded First, with MaxProp and Spray & Wait routing protocols under variable message's Time-To-Live (TTL) values (60 to 300 minutes with step-change 60 minutes). This study uses an Opportunistic Network Environment (ONE) simulator that is utilized for evaluating the performance of the dropping policies, where it is considering five performance metrics (delivery ratio, overhead ratio, average latency, hop count, and message drop). The evaluation results of each buffer management policy are explained by these metrics briefly and shown that at 60 minutes of TTL values with the Spray & Wait gave the lowest delivery probability for all the six policies below 25%.

Keywords: Delay Tolerant Networks (DTNs); Store-Carry and Forward (SCF); Opportunistic Network Environment (ONE), Vehicular Delay-Tolerant networks (VDTNs).

1. Introduction

The Delay-Tolerant Network (DTNs) can be defined as one of the mobile ad hoc networks that are characterized as highly partitioned, high delay, dynamic topology, unreliable links, and limited network resources [1-3]. In DTNs, there is no complete path between source and destination. This may cause a long delay in the message's transmission. DTNs routing protocols could be used in various challenging environments such as military, wildlife tracking, deep space communication, sensing sensors, underwater, ocean networks, and Vehicular Delay-Tolerant networks (VDTNs) [4-6]. The problem is the low data delivery in DTN.

To obtain high data delivery in such challenging environments, Store Carries and Forward (SCF) techniques are commonly used to forward messages in DTNs [7]. Figure.1 shows the SCF technique that is typically used in DTNs to store the messages temporarily in the node's buffer and carry these messages until a suitable communication opportunity with the next relay node becomes available to forward these messages to their destination [8-10]. However, the SCF mechanism may cause a high overhead and dropped messages

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if more replications of messages are created in the networks without proper techniques to control the number of replicas. Thus, high-efficiency buffer management policies are required to ensure that the messages are delivered in proper time with less delay. Then, optimization of delivery to the destination would be needed to trade-off between delivery ratio, latency, and overhead with considering the availability of network resources.

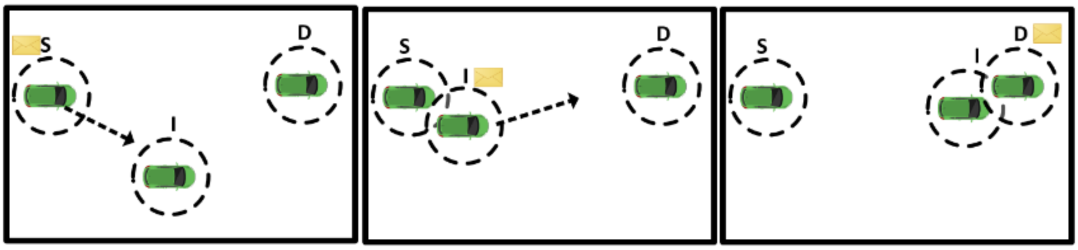

Figure 1. The Mechanisms of the Store- Carry and Forward.

The main task of buffer management is to manage the node's buffer which leads to improving the overall routing performance. The buffer management in DTNs can be divided into two categories that are the dropping policies and scheduling policies [9, 11]. The dropping policies use to determine which message is to be dropped in case of buffer overflow is occurring. While the scheduling policies are used to decide which message has to be forwarded first when the meeting has happened between nodes. Various buffer management schemes that can be adapted by different DTNs applications have been proposed in different studies [12-21]. As was highlighted, the buffer management methods require only a portion of or all of the network's information, for example, contact rate between nodes, shortest path knowledge among different nodes, and messages duplicated in the network. Secondly, buffer management methods that don't require global knowledge to select the message to transfer or/and drop instead of depending on the local information such as the message's size, arrival time, and Time-To-Live (TTL).

Eventually, the DTNs routing protocol and buffer management are the main aspects that affect the VDTNs performance. From the routing side, our previous published and scrutinized journal paper [22], has studied the performance of different DTNs routing protocols. It was focused on the impact of network density and buffer capacity on different routing protocols' performances. While from the buffer management side, the buffer management policies have a direct impact on the network performance by figuring out which messages should be transmitted first, and which messages should be discarded first. Hence, in this paper, the performance of different buffer management techniques First-In-First-Out (FIFO), Last In-First Out (LIFO), Drop Largest (DL), Drop Youngest (DY), Evict Shortest Lifetime First (SHLI), and Evict Most Forwarded First (MOFO) are evaluated with MaxProp and Spray & Wait routing protocols under variable TTL values.

The rest of this paper is organized as follows: section 2 presents the state of the art where the brief definition of two considered DTN routing protocols, different buffer management policies, and other characteristics of DTNs are discussed. The simulation results using Opportunistic Network Environment (ONE) and discussion are introduced in section 3. While section 4 summarizes the challenges and limitations of buffer management. The final section concludes the paper and describes the aspect of future works.

2. Delay-Tolerant Routing and Buffer Management Policies

This section has been divided into two subsections. In the first subsection, the main basic routing schemes that are considered in this study have been introduced briefly. While in the second subsection, the different buffer management policies that are implemented in this study have been described.

2.1. Description of DTNs Routing Protocols

The routing protocols are simply defined as the set of rules that determine how nodes are connected to one another and how data packets are delivered among them[23, 24]. Single copy routing protocols and multi-copies routing protocols are two types of DTNs routing protocols [25, 26]. Only a single copy of each message can be transmitted through the network using single-copy DTNs routing techniques, and this message has only a single path to reach the destination node. However, the single-copy protocols are experienced long delivery delays and are unable to recover the messages in case the message is lost due to contention [27]. But, multi-copies routing protocols, on the other hand, allow several copies of each message to be sent across all connected nodes, and each message can take various paths to reach its destination node [25, 28, 29]. Compared to the single routing protocol, the multi-copies routing protocol are delivered more messages than the single copy. Also, the delay with the multi-copies is less than the single copy. But, the multi-copies routing protocols have limitations as well where it is required a huge amount of network resources (energy, bandwidth, and buffer space) that may affect the overall network's performance and consume the network resources. This section shows a brief explanation of MaxProp and Spray & Wait routing protocols as these only two protocols are considered in our simulation.

A. MaxProp Routing Protocol

The MaxProp is one of the flooding-based DTNs routing techniques. MaxProp employs a method that reduces latency and increases the delivery rate. MaxProp uses a mechanism to determine the order in which packets are transmitted and discarded. Every node's buffer in the MaxProp protocol is divided into two parts to decide which messages should be dropped first and which ones should be sent first. One part is utilized to store the messages that have been ordered, depending on the hop count (from low to high hop count). This part occupies the head (front) of the buffer, while the other part occupies the tail (end) of the buffer where the messages have been ordered from low cost to high cost [11, 30]. When two nodes are encountered together, these nodes first exchange their node estimated meeting likelihood vectors. Every node shares a current vector from all other nodes that can be used to compute the shortest path [31]. Therefore, MaxProp chooses the shortest path in the network.

B. Spray & Wait Routing Protocol

The Spray & Wait routing protocol is one of the quotas DTNs routing protocols that limited the message copies to achieve a good message delivery. As it is clear from the name, there are two stages: the spray stage and the waiting stage. Firstly, in the spray stage, a node will start to flood (spray) a message that is created from the node itself up to L copied messages. Then, when the spray stage is finished, the protocol shifts to the waiting stage. In the waiting stage, every node keeps its message in the buffer until reaching its destination [32]. The advantage of the Spray & Wait protocol is lowering the overhead and buffer overflow by reducing the excessive packet forwarding in networks that exists in the flooding routing protocol like Epidemic. The characteristics of Spray & Wait are the high delivery probability, high scalability, and simple protocol operation. However, the Spray & Wait routing protocol depends strongly on parameter L. To select the optimal value of the L parameter, the mobility of nodes, the node distribution, and network density must take into consideration.

2.1. Buffer Management Policies

In DTNs, the messages do not discard the node's buffer unless the TTL of these messages is expired (TTL equal to zero) [3]. As a result, when the node's buffer is full, it is important to have an effective mechanism to determine which messages will be dropped to free up space in the node's buffer to accommodate another incoming message [33]. Therefore, buffer management (including dropping policies and scheduling policies) is very important to manage the node's buffer which can help to tackle the buffer congestion problem and reduce the losses of messages. According to these aspects, in this paper, the performance of six drop policies is evaluated. Also, their impact on the different DTNs routing protocols is analyzed based on various metrics that are overhead ratio, delivery probability, latency, hop count average, and bundle drop. The following sections have presented the list of the six policies that are considered in this study. These policies are FIFO, LIFO, DL, DY, SHLI, and MOFO which are explained below.

First-In-First-Out (FIFO)

The FIFO policy is also called the drop-front policy. With the FIFO buffer management technique, the message in the buffer that entered the queue first will be chosen to be dropped first [11, 33].

Last In, First Out (LIFO)

The LIFO policy can also be called drop-tail or drop last policy. LIFO drops the newly arrived message, which means the message that arrived last will be chosen to be dropped first [33, 38].

Drop Largest (DL)

The message in the buffer that has the largest size will be chosen to be dropped first when the buffer overflows have occurred. To free more space to accommodate incoming messages, the DL aims to drop a few big-size messages rather than drop a lot of small-size messages.

Drop Youngest (DY)

When using this policy, the youngest message which is the one with the longest remaining TTL is the first message to be discarded from the node's buffer when buffer overflows happen [13, 39].

Shortest Life Time First (SHLI)

Each message in DTNs architecture has a timeout value TTL. This value specifics when the message is no longer useful in the network and should be discarded [13]. When using the SHLI policy, the message with the smallest time TTL is discarded first.

Evict Most Forwarded First (MOFO)

The MOFO drop policy requires the routing agent to keep track of how many times each message has been forwarded. Then if the node's buffer is congested, the message that has been forwarded the most times will be selected to discard first [13]. The main aim idea of the MOFO policy is to provide more chances for the message that has a lower forward time to be forwarded. The message that has been forwarded to most nodes, will be the first message to be deleted.

3. Simulation Works and Acquired Results

The performance of various buffer management policies with MaxProp and Spray & Wait routing protocols is analyzed using ONE simulator. The ONE is a Java-based open-source simulator that is designed especially for DTNs. The ONE simulator's main functions include modeling node mobility, inter-node communications via different interfaces, routing, message handling, and application interactions [40]. The Graphic User Interface that is provided by the ONE simulator allows for visualization of the node's movement during the simulations, which facilitates the understanding of the simulation [41]. In addition, visualization, reporting, and post-processing tools can be accomplished by ONE and we can collect and analyze data [40]. The ONE simulator has suitable simulation tools that are designed in particular for evaluating the DTN routing protocols. ONE simulator uses a map of Helsinki and includes various mobility models, such as shortest path map-based movement, map-based movement model, map-based movement model, and random waypoint model [8]. Also, various DTNs routing protocols are available in ONE simulator.

A. Performance Assessment

As was pointed out, in DTNs, the buffered messages do not discard of the node's buffer unless the TTL of these messages is expired [3]. Thus, when the node's buffer is full, it is critical to have a mechanism that determines which messages are dropped to make free room in the node's buffer to accommodate other incoming messages. Therefore, the scenarios of our comparative research of various dropping policies FIFO, LIFO, DL, DY, SHLI, and MOFO are represented in this section.

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B. Simulation Scenario Parameters

In this section, we set various simulation configuration that is used for this study as listed in Table 1. We increased the bundles' TTL value from 60 to 300 minutes with a step-change of 60 minutes to realize the impact of the different TTL values on the different dropping policies. Here, we kept the node density constant at 200 nodes and fixed the buffer size to 5 MB. We compared the six dropping policies for MaxProp and Spray & Wait routing protocols only.

Table 2. Parameters of Stimulation.

No	Parameters	Value
1	Total Simulation Time	12 hours
2	World Size (meter)	4500 [m] X 3400 [m]
3	Movement Model	Random Walk Model
4	DTNs Routing Protocol	MaxProp, Spray & Wait
5	Buffer Size	5 MB
6	Number of Nodes	200 (-)
7	Interface Transmit Speed	2 Mbps
8	Message TTL	60,120,180,240,300 minutes
9	Node Movement Speed	Min=0.5 m/s Max=1.5 m/s
10	Message Creation Rate	One message per 25–35 seconds
11	Message Size	500 KB to 1 MB
12	Buffer Management Policies	FIFO, LIFO, DL, DY, SHLI, MOVO

C. Metrics for Performance Evaluation

Any network system's performance can be assessed by using a variety of metrics. When we are examining scenarios involving DTNs protocols, the following metrics are frequently employed:

1. *Packet Delivery Ratio*

The total number of packets delivered to their destination divided by the total number of packets generated is known as Packet Delivery Ratio (PDR) [3]. PDR can be computed by using eq. (1).

$$PDR = \frac{\sum Number\ of packets\ recived}{\sum Number\ of packets\ \ sent} \quad (1)$$

2. *Overhead Ratio*

Overhead Ratio (OR) is another metric for evaluating the performance of various DTNs routing protocols. It refers to the average number of copies of the same messages that are duplicated during the simulation time in specific networks.

3. *Delivery Latency*

The average time between when a message is created at a source and when it arrives at its destination is measured by delivery latency [42]. For better networking performance, average latency should be lower as possible.

4. *Hop Count*

The hop count indicates the number of hops that the message passes between the source node and the destination node [43]. For the stability of a network, the hop count is assumed to be low.

5. *Packet Drop*

Packet Drop (PD) is known as the difference between packets sent and the packets received over the network. The PD can be determined by eq. (2).

$$PD = Total\ packets\ created\ \ - Total\ packets\ recived \quad (2)$$

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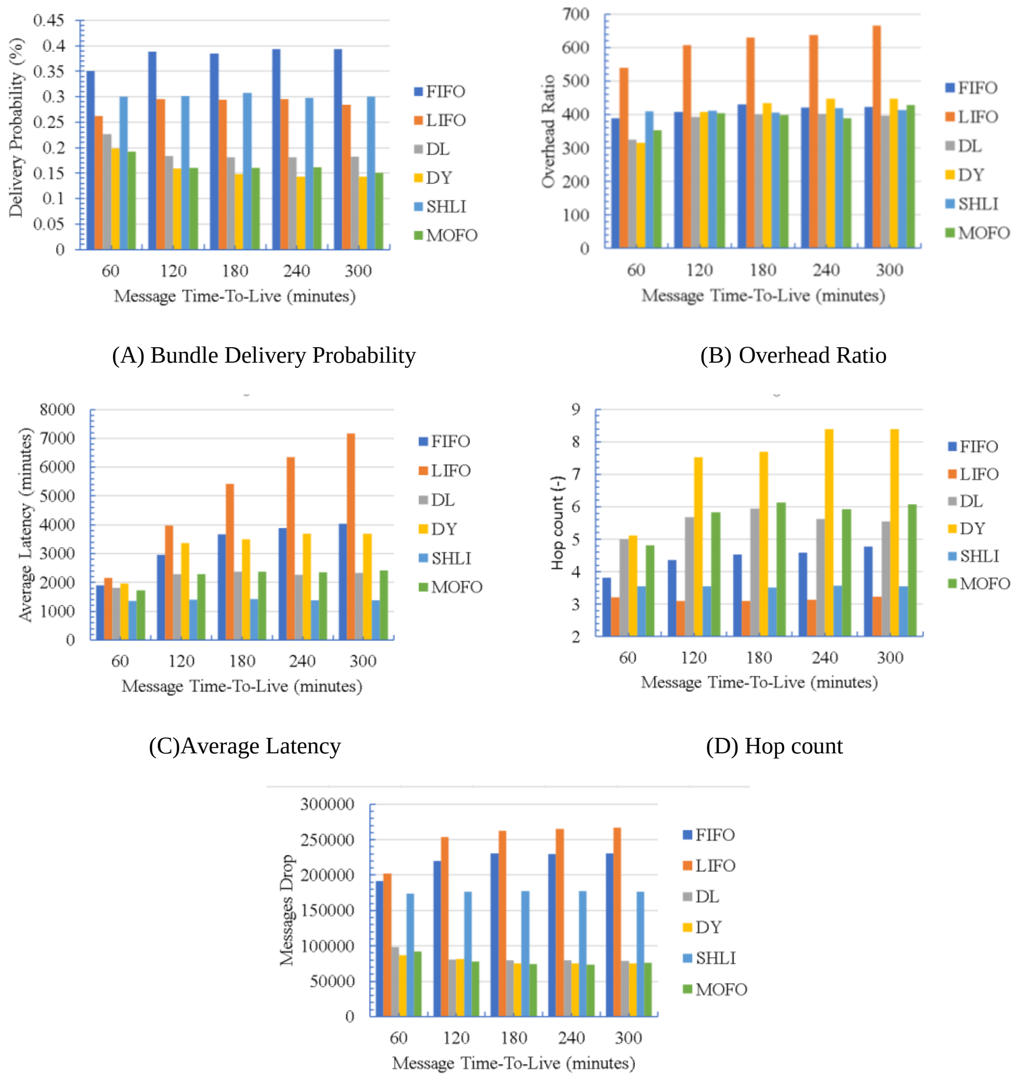
4. Performance Analysis and Results Discussion

A. *Impact of Varying the Bundles' TTL on MaxProp Routing Protocol with Different Drop Policies*

The effect of the six previously mentioned policies has been implemented on the MaxProp routing protocol whereas the acquired results are analyzed based on the different performance metrics as shown in Figure 2.



(A) Bundle Delivery Probability (B) Overhead Ratio

(C)Average Latency (D) Hop count

(E) Messages Drop

Figure 2. The Performance of various Drop policies on MaxProp routing protocol with different TTL values.

Delivery Probability

The change in the deliver ratio illustrates in Figure 2 (A) when the TTL value is between 60 and 300 minutes. As we can note from Figure 2 (A) the highest delivery ratio is achieved by the FIFO policy followed by SHLI where this policy depends on the remaining TTL value. The results of SHLI and LIFO are rough to the same at the start of the TTL=120 minutes and above. While the worst delivery ratio was given by DY and MOFO joined it when TTL=300 minutes.

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Overhead Ratio

Figure 2 (B) shows that the overhead ratio increases gradually with an increase in the TTL values. This is because when the TTL for the messages is high, it will increase the chance of duplicating the same messages and also save all the messages for a long time even the messages that do not get any chance to be transmitted. The LIFO policy gave the highest overhead ratio which is considered the worst result.

Latency Average

The change in the average latency when the TTL value is between 60 and 300 minutes can be illustrated in Figure 2 (C). As we can note in Figure 2 (C), average latency increases in accordance with the increase in the TTL values for FIFO, and LIFO. There is no effect of the TTL on the SHLI. SHLI achieved the lowest latency (the best result) compared with the other policies. Latency with MOFO and DL is still stable at TTL=120 minutes and above. On the other hand, the highest average latency was given by LIFO.

Hop Count Average

The hop count of all drop policies is minimum at TTL=60 minutes and maximum at TTL=300 minutes. From Figure 2 (D), the hop count of DY is the maximum as compared to the other five drop policies. While the lowest hop count is performed by LIFO followed by SHLI. The hop count with DL increases gradually until TTL=180 minutes and then starts to drop at TTL=240 and above.

Messages Drop

From Figure 2 (E), it can be seen that at different TTL, the LIFO policy drops the highest amount of dropped messages, followed by FIFO and SHLI policies respectively. The other three policies, on the other hand, approximately dropped the same amount of the messages, which started with a high drop amount at 60 minutes and start to drop gradually at 120 minutes then stayed stable even when the TTL value increased. Because these policies (DL, DY, MOFO) do not rely on the lifetime for dropping the messages.

B. Impact of Varying the Bundles' TTL on Spray & Wait Routing Protocol with Different Drop Policies

To observe the impact of varying the packet's TTL values on the Spray & Wait routing protocol, we increased the TTL value up to 300 minutes from an initial value of 60 minutes with a step change of 60 minutes. The effect of the six previously mentioned policies has been investigated on the Spray & Wait routing protocol and the acquired results are analyzed based on the different performance metrics as shown below in Figure 3:

Delivery Probability: We first evaluate each policy in terms of delivery probability and show their comparison in Figure 3 (A). All the dropping policies start with the same delivery probability at TTL=60 minutes which was 0.25 and then the delivery probability increase with all the policies at the TTL value was 120 minutes. As we can note from Figure 3 (A), the Spray & Wait gives a good delivery probability and this rate is impacted positively by the increase of the TTL value. The message delivery success rate is increased because it takes advantage of the restricted copy of message forwarding. The highest delivery ratio was performed with FIFO and SHLI followed by the DL which start to reduce the delivery probability at the TTL value of 240 minutes and above. While the lowest delivery probability was given by MOFO policy. LIFO, DY, and MOFO continue

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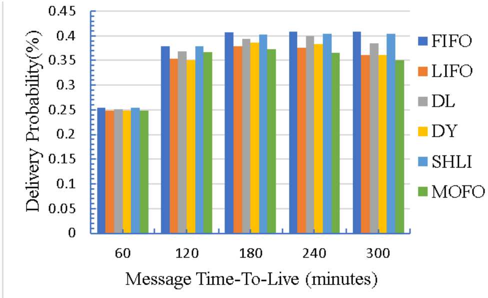
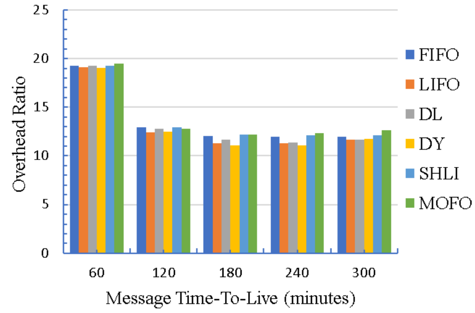
to increase with the increase of the TTL then TTL=240 starts to decrease the delivery probability.

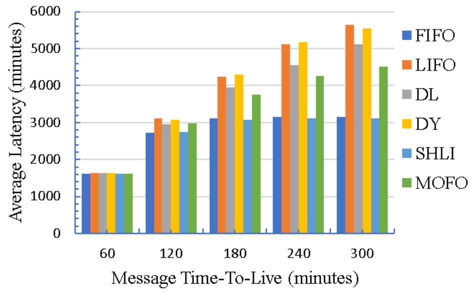
Overhead Ratio: The overhead ratio of Spray & Wait keeps decreasing with the increase of TTL. Figure 3 (B) shows the overhead ratio of the six dropping policies starting to be high at TTL=60 minutes and then decreasing until TTL=120 minutes. The overhead ratio is approximately equal to SHLI and FIFO whatever the TTL value is. The DY policy provides a little less overhead ratio than the other five policies. The DY policy provides a little less overhead ratio than the other five policies. The Spray & Wait protocol is lowering the overhead and buffer overflow by reducing the excessive packet forwarding.



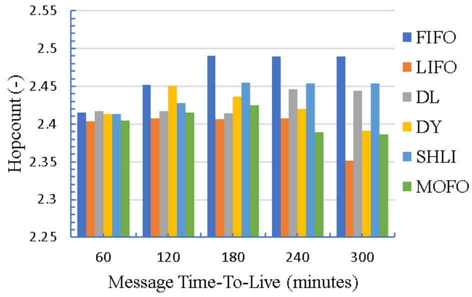
(A) Bundle Delivery Probability



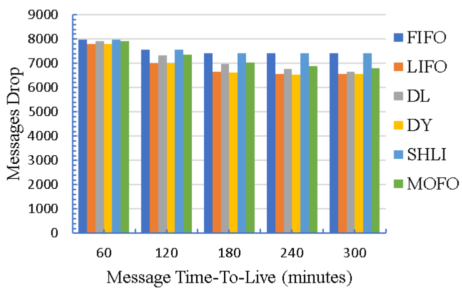
(B) Overhead Ratio



(C) Average Latency



(D) Hop count



(E) Messages Drop

Figure 3. The Performance of various Drop policies on Spray & Wait routing protocol with different TTL values.

<u>*Latency Average*</u>

Figure 3 (C) shows the comparison of the six policies in terms of average latency. It shows that the average latency ratio is increasing with the increasing TTL value with all the dropping policies that start with the same average latency at TTL value =60. The latency average of SHLI and FIFO is markedly lower than the other four policies they remain almost steady near 1500 seconds whatever the TTL value is. Also, we can note

that from Figure 3 (C), the LIFO and DY gave the same average latency which is considered to be the highest average latency (the worst result) compared with the other four dropping policies.

Hop Count Average

It can be observed from Figure 3 (D), that the hop count for the FIFO and SHLI is increased at TTL=180 minutes and then it stays without any change at the TTL value above 180 minutes. LIFO stays stable until TTL=240 minutes and then the hop count decreases when the TTL is increased to 300 minutes. The best result was obtained by LIFO at TTL= 300 minutes. While the worst result was achieved by FIFO at TTL=180 minutes and above. With DY the hop count decreases gradually at TTL=180 minutes and above.

Messages Drop

In Figure 3 (E) at TTL= 60 minutes, all the policies gave the same amount of message drop then the dropping message started to reduce gradually with all the policies. The DY dropped the least amount of messages forwarded by LIFO. While the FIFO and SHLI policies on the other hand dropped the highest amount of messages followed by the MOFO and the DL respectively.

5. Challenges and Limitations of Buffer Management

It can be observed from the literature review that, there are still a lot of gaps in the area of buffer management in DTN routing protocols that need more attention. The main challenges and issues in buffer management policies are summarized as follows:

1- Various buffer management policies depend only on computing a single metric to drop the message [33, 34, 44, 45]. However, a serious weakness in these arguments, however, is that a fair selection of the message to drop cannot be accomplished by a single metric.

2- The TTL directly affects the delivery of messages in the DTN. As a result, the DTN established a deadline for the transmission of message copies [46, 47]. The message is automatically deleted from all nodes if it is not delivered within the TTL. Nevertheless, the TTL based on some of the buffer management policies does not keep track of the lifetime of the message in the nod's buffer. Thus, to improve the performance and avoid network congestion, it is good to remove the messages that do not have any transmission opportunity.

3- Another issue with the existing buffer management is maintaining the replicating of the message until the TTL expired without providing any method to compute how many copies have been transmitted so far. Hence, the benefits of the threshold limit are very helpful to drop the messages that have been transmitted a greater number of times than the threshold value.

4- Continuing to carry and save the messages in the node's buffer even if these messages are already delivered to their destination causes buffer congestion and will cause reduce the chance for the other messages to be delivered [8]. Therefore, employing an acknowledgment mechanism that leads to a reservation of the node's buffer is useful and it is required.

6. Conclusions

The Store Carry and Forward (SCF) technique is employed in the Delay-Tolerant Networks (DTNs) to recover from network partitions and deal with node sparsity. The SCF technique allows nodes to keep bundles in their buffers while they wait for contact opportunities to transfer the bundles to intermediate nodes or the destination node. However, the message(s) from the source node may have to wait for a long time in one or more intermediate nodes before the connection is formed which might cause buffer congestion.

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This congestion in DTNs can result in major network delays or message loss. When the buffer of nodes is over-utilized, congestion control in the DTNs becomes an important task. Hence, the scheduling and dropping buffer management policies are becoming essential in DTNs to manage the node's buffer by adapting transmit priority during the contact time and efficiently dropping priority during the buffer is congested.

In this paper, we evaluated the performance of six buffer management policies, namely First-In-First-Out, Last In First Out, Drop Largest, Drop Youngest, Evict Shortest Lifetime First and Evict Most Forwarded First, with MaxProp and Spray & Wait routing protocols under variable message's Time-To-Live (TTL) values. The acquired results show the clear benefits of increasing the TTL value for delivery probability and overhead ratio in the Spray & Wait routing protocol. This implies that the Spray & Wait was impacted positively by the increase of the TTL value and gave a better delivery probability and overhead ratio with the six policies compared to the MaxProp routing protocol. The reason behind this is that Spray & Wait routing protocol limits the copy of the message and does not consume the network resources. On the other hand, the MaxProp drops the message amounts lower than Spray & Wait for some of the dropping policies. The reason behind this is that MaxProp employs an efficient scheduling mechanism for forwarding packets to relay nodes. That is meant that the MaxProp includes both efficient buffer management and high-quality routing tasks in contrast to the Spray & Wait routing protocol which does not specify or considered the buffer management policy. Also, the chance for the message to be delivered to the destination is high when the TTL is large. While in contrast, the latency, hop count, and message drop are impacted negatively by increasing TTL because the store time for the messages will be longer and cause high latency and also it can cause messages to drop. In addition, for both the MaxProp and Spray & Wait routing protocols, we perceive that the latency result is almost the same, where always the highest latency is obtained by LIFO and the lowest latency is provided by SHLI. The little difference in MaxProp where the average latency for SHLI is between 1000 and 2000 which is lower than Spray & wait. Also, with two protocols, the best delivery ratio is given by FIFO followed by SHLI. But, with the MaxProp the overhead ratio increases with the growing TTL value that occurs because the MaxProp is a flood-based protocol where too many messages are contending for limited shared resources.

In future work, we will combine several message attributes that can improve the buffer management decision. Also, more than one buffer management policy can be combined to improve overall network performance, whereas the first policy will be used predominantly, and the second policy can be used only when a tie break is required between messages with the same eviction priority as the primary policy. The DTN dropping policies and protocols will be tested and verified on real networks, if possible, as part of future works.

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