Performance Analysis of Adaptive Fuzzy Spray and Wait Routing Protocol

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Abstract —Delay Tolerant networks (DTN) are Ad-hoc mobile networks that aim to avoid traditional Internet limitations in difficult environments that are identified by intermittent connectivity, power outages, and difficult topographies by following the Store-Carry-and-Forward mechanism. In the present work, we are comparing Adaptive Fuzzy Spray and Wait routing protocol to other famous DTN routing protocols in terms of delivery rate, overhead ratio and latency average. During the simulations we are analyzing the impact of changing nodes buffer sizes and a bunch of DTN drop policies on the above metrics.

Index Terms—Buffer management, Delay Tolerant Networks, Drop policy, Mobility models, Network Simulator (ONE), Scheduling

I. Introduction

The standard networking and internet scheme [1] is based on end-to-end communication, which expects a safe path between the source and the destination and a very large the bandwidth. This classic architecture cannot be applied in some all environments, for example the lack of end-to-end path between source and destination, limited bandwidth interplanetary or underwater networks. For those very hard circumstances, a new networking architecture starts taking place. This new model is called DTN (Delay Tolerant Networks) [4].

DTN networks are based on Store carry and Forward mechanism, therefore, each node owns a local buffer where incoming messages are stored until a delivery or forward opportunity arises. A common issue with DTN network is related to the fact that storage buffer size is very limited, and receiving too many messages (bundles) may congest the node. In order to reduce the congestion of nodes, researchers have developed a bunch of buffer management policies or drop policies. In the current work we compare some existing DTN drop policies to different routing protocols and for various buffer sizes.

We have organized the rest of this work as the following: Section II contains the state of the art where we give brief definition of Delay tolerant networks, the bundle protocol and routing mechanism. Section III describes the congestion control and buffer management policies in DTNs. While section IV summarizes our simulation results and analysis. Then finally, we reserved Section V for conclusion and future work.

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II. State of the Art

When communication systems based on Internet have faced many limitations, for instance intermittent connectivity, the long or variable Delay, asymmetric data rates and the high error rate. Researchers have proposed as a solution to reduces these communication issues, DTN network that are based on the Store-and-Forward mechanism [3], and are an implementation of the Bundle protocol which is a new layer over the transport layer.

A. *The Bundle Layer and the Bundle Protocols*

The Bundle Protocol (BP) [16] is a message-based experimental protocol for environments that are described by intermittent connectivity, massive error rates and huge delays. The BP is designed to act as an application-layer overlay on top of network layer over existing internet networks, it provides end-to-end path between two endpoints where no continuous end-to-end link ever existed.

The data units of this protocol are called bundles. The bundles have a time to live (TTL), and they will be destroyed from all nodes after expiration their TTL. Moreover, when a bundle cannot be transmitted or router to another destination, BP keeps it on the current node and waits for scheduled or opportunistic contacts. [12]

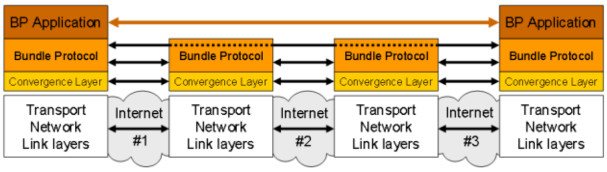

Fig. 1. The bundle protocol architecture. [11]

B. *Routing*

Routing refers to providing the routes that data bundles take on their way to a predefined destination. This term can be applied to data traveling on the Internet, over 3G or 4G networks, or over delay tolerant networks used for mobile and other digital communications architectures. Routing can also be applied within private networks.

In the ad hoc architecture, every node can act as a router. These networks are also known as MANETs (Mobile Ad Hoc Networks): [14] they don't have any central infrastructure, thus, they are very robust against isolated attacks or node failures. Moreover, as these networks do not rely on any external infrastructure they can be quickly set up anywhere. These aspects, on one hand, make MANETs the most suitable solution for many applications, but on the other hand, they cause a challenging networking problem.

1) Store and forward

In Delay tolerant networks, the transportation of a message from source to a destination may take a while, and nodes don't meet very frequently with each other.

Store carry and forward (Fig. 2) is a data transmission protocol in which a bundle or message transferred from a source node is kept at an midway device before forwarding to the destination node.

The store and forward mechanism enables remote hosts, data connectivity and transmission, even when there is no direct path between the source node and the destination.

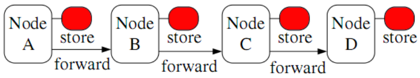

Fig. 2. Store and forward mechanism

Messages routing in DTN can be acheived in two methods Random routing or based on network topology information [9]. Researchers have proposed a set of several routing protocols and algorithms. For instance, Epidemic routing [19], Spray and wait [17], MaxProp [2], Rapid [1], First Contact [5] and Adaptive fuzzy spray and wait[15], and many others.

2) Epidemic routing

The Epidemic routing protocol [9] is based on replication. For this algorithm, each node transmits and share copies of its messages to new found node which do the same with its messages, in order to finally have both the same set of messages. Hypothetically, this algorithm needs boundless buffer size and limitless energy to result high deliverance rate, yet for all those intents and purposes this conditions are difficult to be applied.

3) First contact router

In order to lessen the weaknesses of epidemic approach, and to mitigate the spread of messages, the

First Contact routing protocol follows a very simple and very quick approach, for every message received or generated, this algorithm forwards a single copy of the bundle to the first node it meets in its path then it removes it from the local memory.

4) Spray & Wait Router (SnW)

Spray and wait protocol benefits from the high deliverance rate of replication based routing (Epidemic) and the resource consumption awareness of direct transmission and forward-based protocols. This router is composed of two stages. First, at the spray phase: for each message M at the source node, L copies of M are forwarded to L different relays (intermediate nodes). Then in the wait phase: if the destination is not present among those relays, each of them will keep the message copy until it meets the destination node or the TTL is reached. The L constant is to be defined at the beginning of the simulation.

5) Adaptable Fuzzy Spray & Wait Router(AfSnW)

Adaptive Fuzzy Spray and Wait (AFSnW) [15] is a routing system that incorporates fuzzy-based buffer management mechanism, roused by [18], with spray and wait routing protocol. It utilizes message size and forward transmission check (FTC) of a message to attach priority to messages. This message prioritization conspire is utilized at the time of message scheduling.

6) Max prop router

MaxProp utilizes a few procedures to characterize the way in which bundles are transmitted and dropped. At the center of the MaxProp protocol, there is a positioned set of the DTN nodes that stored messages dependent on a cost attached to every goal. This cost is a rating of delivery probability. Likewise, MaxProp uses affirmations sent to all nodes to alert them of bundle delivery. MaxProp designates a higher preference to new messages, and it likewise tries to anticipate gathering of a similar bundle twice.

C. Mobility Models in DTN

Movement models characterize how DTN nodes are walking inside the region of the simulation. In some models, nodes are moving in a random way, similar to the instance of Random walk or Random Waypoint. While some other models depend on gathered traces from real life circumstances, for example, ZebraNet or DakNet. At long last, DTN also supports some map-based mobility models.

For our present article we have chosen The Shortest Path Map-Based movement model. In this model we set a map area for the simulation and we draw path for nodes to follow using OpenJump. In order to calculate the most optimized path profiting from the intelligence of Dijkstra algorithm.

III. Buffer Management in DTN

Congestion control in Delay Tolerant Networks is defined as how to control the messages in the node's buffer, in plain English, it is how to manage node buffer. A buffer management strategy defines which packet to remove first if the buffer of a DTN node is full when a new packet is arriving.

A. Drop Policies

The current section is for presenting a brief definitions of a couple of well-known DTN drop policies:

1) Last In First Out (LIFO)

By applying this drop policy in the DTN network, the node is strategized in the order of first in first out. Hence, the message which is queued last is dropped first. [13]

2) First in First Out (FIFO)

In opposite of LIFO, the node in this policy is strategized in the order of last in first out. So the message which is queued last is the first one to be dropped. [20]

3) Drop Youngest (DY)

In opposite of the SHLI, in this drop policy the messages which will be chosen first to br removed is the one with the highest TTL value, which is in fact the youngest message of the stack. [20]

4) Drop Largest (DL)

In DTN and in all other communication networks every message or packet has a size which may differ from other messages. For this policy, the message that reserves more memory space is the first message to be dropped. [13]

5) SHLI: Evict shortest lifetime first

Every message existing in the network keeps a bunch of information about its source, its destination, the nodes it traversed as well as the Time to Live (TTL) value. After this time has been exceeded, the message is no longer useful and should be discarded. Thus, here the message with the shortest lifetime is dropped first. [10]

6) Most Forwarded first (MOFO)

The message that is forwarded to the most number of network nodes is the first message to be dropped in order to the give the less forwarded messages the chance to be forwarded and delivered. The node has to track information about the number of times a message has been forwarded. [8]

IV. Simulation and Results

A. The ONE Simulator

The simulation tool we are using for the present paper is the: Opportunistic Network Environment (ONE) Fig. 3 differently to other DTN simulators, which usually focus only on simulating routing protocols, the ONE combines mobility modeling, DTN routing and visualization in one package that is easily extensible and provides a rich set of reporting and analyzing modules [6].

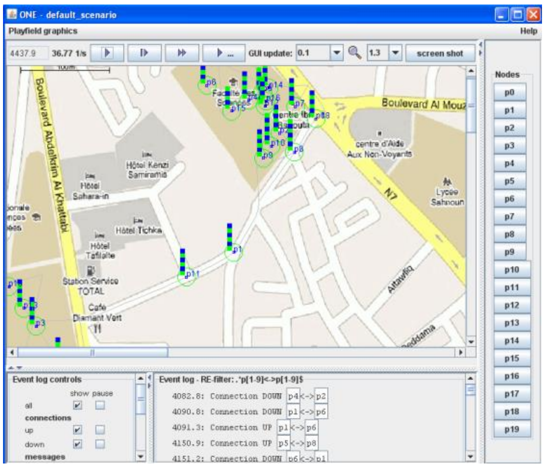

Fig. 3 Screenshot: The ONE simulator GUI

The main functions of the ONE simulator are the modeling of node movement, inter-node contacts, routing and message handling. Result collection and analysis are done through visualization, reports and post-processing tools.

A detailed description of the simulator, the ONE simulator project and the source code are available in [6], [7] and [18] respectively.

B. Metrics of Performance Evaluation

The next couple of variables are commonly considered metrics when evaluating and judging algorithms and protocols in the DTN networks. [15]

1) Delivery rate

Presume that **M** is the set of all messages created in the network during our simulation time and $\mathbf{M_d}$ is the set of all delivered messages. Then, the delivery ratio is measured by:

$$M_d/M \tag{1}$$

2) Overhead ratio

The Overhead ratio is the average number of copies of the same message that are created during the simulation.

Let r_i be the number of replications of any message $M_i \in M$. Then the overhead ratio is determined as:

$$\sum_{i=1}^{M}(r_i - M_d)/M_d \tag{2}$$

3) Latency average

Now let the i^{th} delivered message was created at time c_i and delivered at time d_i. Then the average message delivery latency is computed as:

$$\sum_{i=1}^{M_d}(d_i - c_i)/M_d \tag{3}$$

C. Simulation Environment

In our simulations, we tried to experience various environments by swinging between many simulation parameters like routing protocols, Buffer size and DTN drop policies When other parameters are kept the same for the whole simulations such as area size, movement model and TTL value ... The Table I bellow encapsulates the important variables of our experiments.

TABLE I. Environment Parameters of Our Simulations

Parameter	Value
Movement Model	Shortest Path Map Based Movement
Router	Epidemic - Spray & Wait - Adaptable Fuzzy Spray & Wait
Buffer Size	100k - 250k - 500k - 1M
Drop Policy	FIFO - LIFO - DL - DY - SHLI - MOFO
Message TTL	300 minutes
Messages size	500k,1M
World Size (meters)	4500, 3400

D. Delivery Rate

The first metric we are measuring here is the Delivery rate which helps us decide either a protocol or a policy is suitable for an environment or not. Figures bellow show Delivery rates for different routing protocols.

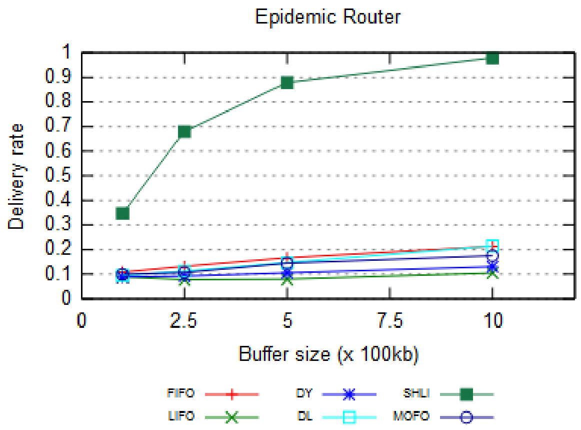

Fig. 4. Delivery rate of epidemic router

For Epidemic routing protocol, SHLI drop policy has the highest and while it is reaches a value near 100%, about the rest of other policies, they stuck between 10% and 20%. This result is normal while Epidemic protocol is not suitable for very long simulations.

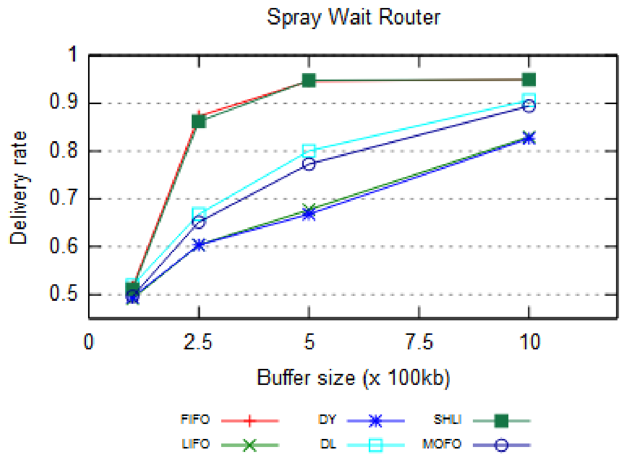

Fig. 5. Delivery rate of spray and wait router

In the case of Spray and Wait router, the increasing of the buffer size impacts positively the Delivery rate and increases it also. The SHLI algorithm keeps having the best score and this time FIFO also get the highest result while LIFO and DY have the lowest rates.

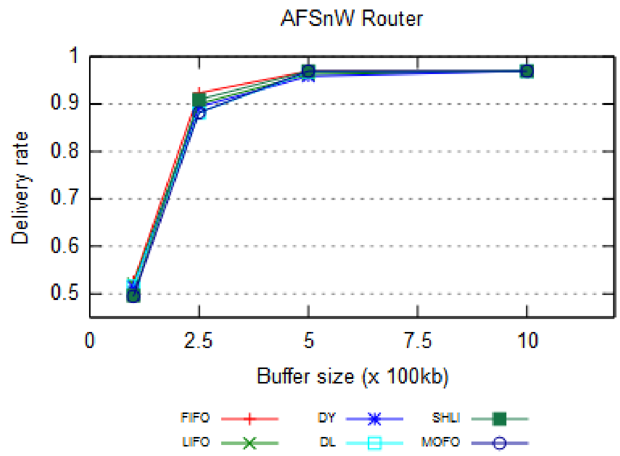

Fig. 6. Delivery rate of adaptive fuzzy spray and wait router

The Fig. 6 shows the Delivery rate per buffer size for Adaptable Fuzzy Spray and Wait router, in this graphic we can perceive easily that all drop policies have nearly the same delivery rate and it is very high compared to other routing protocols. This rate is very close to 100% for big buffer memory.

D. *Overhead Ratio*

The overhead ratio is a metric that gives an idea about the number of copies is created for each message in the network. This means that the objective of every DTN algorithm is to lessen the average of this metric.

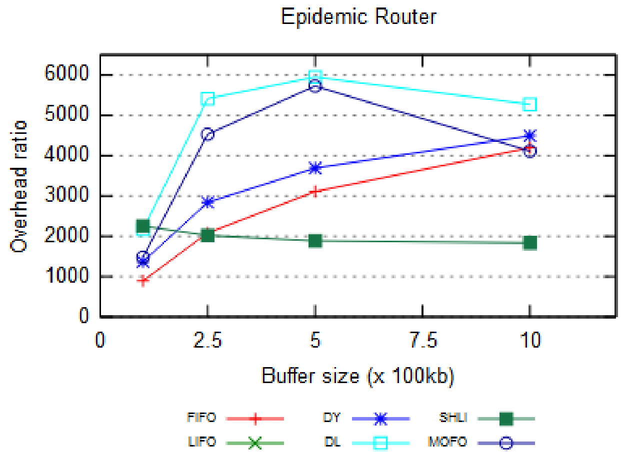

Fig. 7. Overhead ratio of Epidemic router

From Fig. 7 we observe that the overhead is very high for all DTN drop policies, it is varying between 1000 and 6000 copies per message. Even if the SHLI has the lower overhead ratio, (between 1000 and 2000) whatever buffer size is, this ratio still very high compared to other routing protocols.

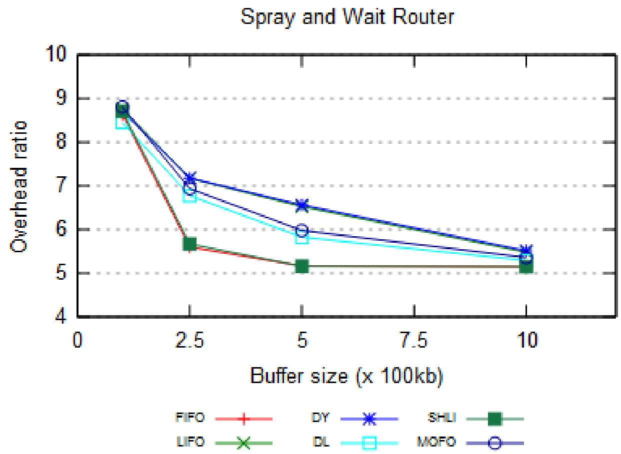

Fig. 8. Overhead ratio of Spray and Wait router

In contrary to the Epidemic Router, Spray and Wait presents a very low Overhead ratio, which range between 5 and 9, also the difference between policies is minimized. This result is due to the intelligence of this algorithm because it doesn't broadcast messages to all the network nodes like what Epidemic do.

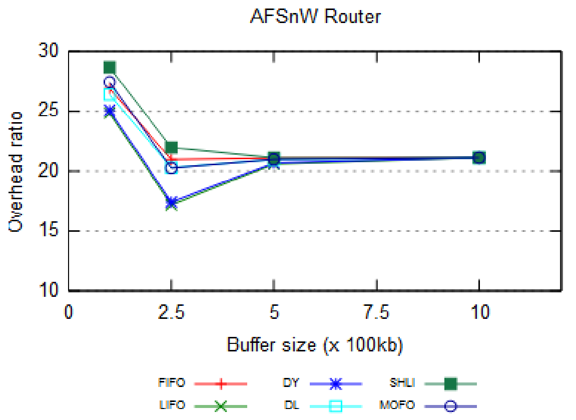

Fig. 9. Overhead ratio of adaptive fuzzy spray and wait router

The overhead for AFSnW is a little bit higher than spray and wait router. But the positive point is that it normalizes all drop policies and as we can easily notice, there is almost no difference between overhead ratios.

E. Latency Average

As we have cited above, the average latency represents the average time difference between messages creation and messages delivery. A lower latency determines a better drop policy.

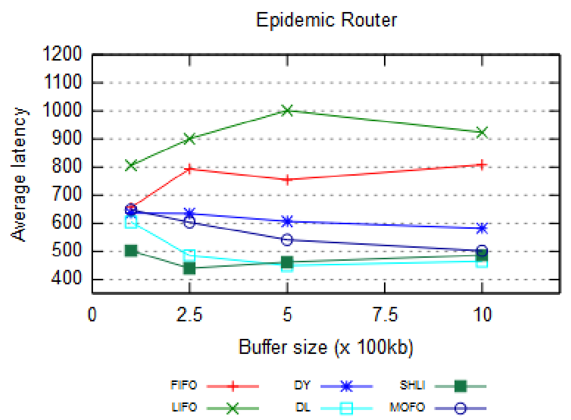

Fig. 10. Latency average of epidemic router

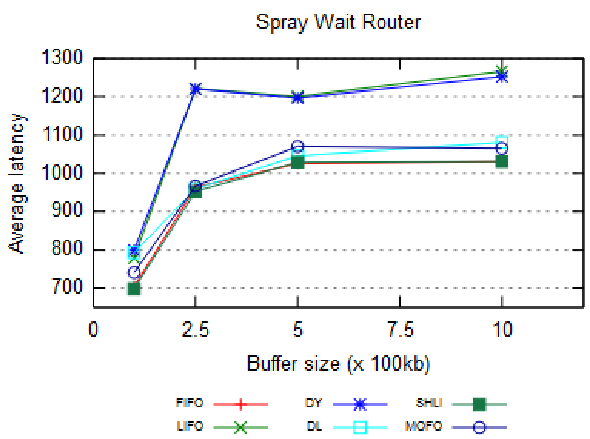

Fig. 11. Latency average of of Spray and Wait router

The chart in Fig. 10 shows the average latency in second for the Epidemic routing protocol. You notice that the buffer size has no influence on the latency time for all drop policies, and you can also note that the best drop policy is SHLI and the worst one is LIFO (Last in First Out).

For Spray and wait router, we perceive that always the best latency is obtained by SHLI and the worse is provided by LIFO. The difference here is that the average latency for all policies is higher than Epidemic and that the increase of buffer size has a negative impact on this metric.

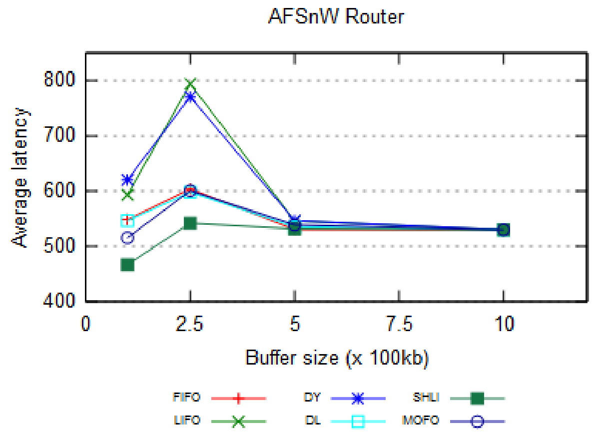

Fig. 12. Latency average of Adaptive Fuzzy Spray and Wait router

In the case of AFSnW the average Latency is lower than Spray and Wait an again the best advantage about this fuzzy protocol is that it normalizes the Latency for all DTN drop policies and the difference is almost null.

V. Conclusion

According to the result presented above, we can easily confirm that the intelligence of Adaptive Fuzzy Spray and Wait is making the point and this routing protocol is the suitable router for DTN because it gives better result in terms of delivery rate, overhead ratio and Latency average. The best point about this router is that it normalizes the obtained result for all drop policies and it is influenced positively by the increasing of buffer size.

The results obtained by this routing protocol are a consequence of the fact that it associates two considerable factors. From one side, it is based on the intelligent approach of Spray and Wait router. And from the other side, the AFSnW benefits from the powerful capabilities of the Fuzzy logic mechanism.

In future works we are planning to focus our researches on the energy consumption of this routing algorithm in comparison with other DTN routing protocols in order to analyze which is the economic and environment friendly router and eventually proposing some optimized approach for the AFSnW protocol.

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