Delivery Likelihood Based Spraying in Delay Tolerant Networks

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***Abstract*—Delay Tolerant Networks (DTNs) are intermittently connected mobile networks, in which a fully connected path from source to destination does not exist. Therefore in these networks, message delivery relies on opportunistic routing where nodes use store-carry-and-forward paradigm to route the messages. However, effective forwarding based on a limited knowledge of contact behavior of nodes is challenging. There exist schemes where the number of times a message can be replicated is pre-specified. Example includes Spray and Wait [4] that limits the total number of copies created initially (spray phase). A number of different spraying heuristics can be envisioned. Traditional spraying heuristics naively split copies between source node and encountered nodes. For instance, binary spraying halves copies, but do not necessarily use other available information. Moreover, these heuristics do not evaluate the encountered node in terms of delivery likelihood. If node *A* encounters node *B* which might have never contacted with any other nodes, handing over half of the copies to such a node means those copies will probably not be transmitted to the destination which is very inefficient. In this paper we propose two efficient spraying heuristics based on delivery likelihood.**

***Keywords*—Delay tolerant network, routing protocol, Spray and Wait.**

I. Introduction

Intermittently connected mobile networks are mobile wireless networks where most of the time there does not exist a complete path from a source to a destination or such a path is highly unstable and may change or break soon after it has been discovered (or even while being discovered). This situation arises when the network is quite sparse, in which case it can be viewed as a set of disconnected, time varying cluster of nodes. Intermittently connected mobile networks belong to the general category of Delay Tolerant Networks (DTN).

Several approaches have been adopted to achieve reliable communication in such challenged networks [7], [8], [9], [11], [12], [13]. The researchers have focused on various issues like reducing the delivery delay or increasing the delivery ratio. Optimizing resource usage, providing scalability etc. are also issues explored by various algorithms.

An important DTN routing scheme is one where node mobility is not under control of the routing algorithm. Epidemic routing [3] is the most basic of these methods that replicates messages whenever a node meets another node which has not received the message so far. PROPHET [1] uses delivery predictability as a metric to evaluate the likelihood of one node to reach the destination. A node carrying a message delivers it to all the neighbors with delivery predictability higher than its own. The queuing and replication techniques are the same as Epidemic (FIFO and unlimited), but forwarding is based on delivery predictability and it is thus history based.

The NECTAR protocol [5] uses contact history to create a neighborhood index. The scheduler of NECTAR uses the neighborhood index (contact history) to select the message to be forwarded.

The MaxProp [2] is a protocol designed for vehicle based DTNs. Such a DTN is characterized by large storage capacity and energy source but short contact duration. Hence it discusses prioritization of packets to be forwarded and dropped. These priorities are decided by path likelihood. Thus it becomes a controlled flooding.

Spray and wait [4] combines the speed of epidemic routing with the simplicity and thriftiness and reliability of direct transmission, and makes an effort to perform fewer transmissions by controlling the number of packet copies in spray phase and utilizing direct transmission in wait phase. The operation of Spray and Wait consists of two phases: the spray phase and the wait phase. In the spray phase, when a node generates a packet, it makes L copies of the packet, and spreads it to relay nodes. When a node meets the other node, the node checks L. If L is larger than 1, then the node sprays $\frac{L}{2}$ copies of the packet to its neighbor and revises L. When there is only single copy left, it comes to the wait phase and the direct transmission routing is used to send the single copy to the destination directly, each of N nodes carrying a message copy performs the direct message transmission until it successfully delivered the message to the destination. While in some scenarios with some kind of mobility model (like community-based mobility), the direct transmission based wait phase has low efficiency in delivery delay and predictability. To address this problem, the Spray and Focus [10] has been proposed to enhance the ability of Spray and Wait routing. The spray phase in the Spray and Focus adopts the same message dissemination scheme as the Spray and Wait routing and the utility-based forwarding is similar to the Seek and Focus, which is used to improve the delivery predictability.

However, Spray and wait does not evaluate the encountered node in terms of delivery likelihood. If node A encounters node B which might have never contacted with any other nodes, handing over half of the copies to such a node results in a great deal of inefficiency. In this paper, we propose two spraying heuristics based on delivery likelihood.

II. RELATED WORK

Daru Pan et al. [14], proposed the Spray and Wait with Probability Choice (SWPC) routing, where continuous encounter time is used to describe the encounter opportunity. A delivery probability function is set up to direct the different number of copies to the destination during the spray phase and a forwarding scheme is implemented in the wait phase. In the spray phase, any active node will hand over half of its copies to encountered node if its delivery probability is greater than a prespecified threshold. Otherwise the source node will hand over only one copy to the encountered node. In the wait phase, if a node with the last one copy encounters another node having larger delivery probability, then that node will hand over the last copy to the encountered node.

III. BACKGROUND

Spray and Wait routing decouples the number of copies generated per message, and therefore the number of transmissions performed, from the network size. It consists of two phases:

- spray phase: for every message originating at a source node, *L* message copies are initially spread - forwarded by the source and possibly other nodes receiving a copy- to *L* distinct "relays".
- wait phase: if the destination is not found in the spraying phase, each of the *L* nodes carrying a message copy performs direct transmission (i.e. will forward the message only to its destination).

Spray and Wait combines the speed of epidemic routing with the simplicity and thriftiness of direct transmission. It initially "jump-starts" spreading message copies in a manner similar to epidemic routing. When enough copies have been spread to guarantee that at least one of them will find the destination quickly (with high predictability), it stops and lets each node carrying a copy perform direct transmission. In other words, Spray and Wait could be viewed as a tradeoff between single and multi-copy schemes.
The above definition of Spray and Wait leaves open the issue of how the *L* copies are to be spread initially. A number of different "spraying" heuristics can be envisioned. For example, the simplest way is to have the source node forward all *L* copies to the first *L* distinct nodes it encounters ("Source Spray and Wait"). A better way is the following which is known as Binary Spray and Wait: The source of a message initially starts with *L* copies; any node *A* that has $n > 1$ message copies (source or relay), and encounters another node *B* (with no copies), hands over to *B* $\lfloor \frac{n}{2} \rfloor$ and keeps $\lceil \frac{n}{2} \rceil$ for itself; when it is left with only one copy, it switches to direct transmission.

IV. DELIVERY LIKELIHOOD BASED SPRAYING

The definition of Spray and Wait(SAW) leaves open the issue of how the *L* copies are to be spread initially. However, existing spraying heuristics does not use the knowledge of delivery likelihood. We propose some techniques and show how these information can be used in split decision.

A. Delivery likelihood calculation

We calculate delivery likelihood using the technique of MaxProp. MaxProp assigns link weights as follows.
Let the set of nodes in the network be s. Each node, $i \in s$, keeps track of a probability of meeting peer $j \in s$. We estimate this probability f_j^i as the likelihood that the identity of the node we connect to next will be *j*. For all nodes, f_j^i is initially set to $1/(|s|-1)$. When node *j* is encountered, the value of f_j^i is incremented by 1, and then all values of *f* are re-normalized. Using this method, often called incremental averaging, nodes that are seen infrequently obtain lower values over time. In MaxProp, each time two peers meet, they exchange these values with one another.
With other nodes values in hand, a local node calculates a cost, $c(i, i+1, ..., d)$, for each path possible to the destination *d*, up to *n* hops long. The cost for a path using nodes $i, i+1, ..., d$ is the sum of the probabilities that each connection on the path does not occur, estimated as one minus the probability that each link does occur:

$$c(i, i+1, ..., d) = \sum_{x=i}^{d-1} [1 - f_{x+1}^{x}] \quad (1)$$

The cost for a destination is the lowest path cost among all possible paths. In practice, this calculation among all possible paths is fast because paths monotonically increase in cost during a depth first search. Once the cost for a path is worse than the current best path, the search can stop.

B. Spraying heuristics

We can define a spraying algorithm in terms of a function $f : N \to N$ as follows :
when an active node with *n* copies encounters another node, it hands over to it *f(n)* copies, and keeps the remaining *1-f(n)*. Any spraying algorithm (i.e. any *f*) can be represented by the following binary tree with the source as its root: assign the root a value of *L*; if the current node has a value $n > 1$ create a child with a value of 1-*f(n)* and another one with a value of *f(n)*; continue until all leaf nodes have a value of 1.
The various choices of f correspond to various spraying heuristics. For example, $f = 1/2$ is Binary SAW, $f = 1/L$ becomes Source SAW.
Traditional spraying heuristics naively split copies between encountered nodes (for example, binary SAW halves copies), but do not necessarily use other available information such as delivery likelihood. We propose two techniques and show how these information can be used in split decision.

1) Simple Spraying Heuristic: Let, node *A* encounters node *B* and *L* be the initial number of copies. Let, *D* be the destination node.
Now, let f_D^B be the likelihood that node *B* next connects to node *D*. Simple probabilistic spraying splits *L*, in the following way:
The number of copies left for node *A*, $L_A = (1 - f_D^B)L$
The number of copies for node *B*, $L_B = f_D^B L$

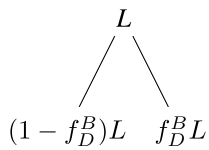

Fig. 1. Binary tree corresponding to Simple Spraying Heuristic.

2) Proportional spraying heuristic: Let, node A encounters node B and L be the number of copies. Let, D be the destination node.
Now, let f_D^A be the likelihood that node A next connects to node D and f_D^B be the likelihood that node B next connects to node D. Proportional spraying heuristic splits L in the following way:
The number of copies left for node A, $L_A = \frac{f_D^A}{f_D^A + f_D^B} L$
The number of copies for node B, $L_B = \frac{f_D^B}{f_D^A + f_D^B} L$

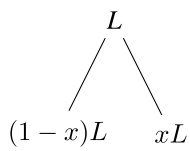

Fig. 2. Binary tree corresponding to Proportional Spraying Heuristic where x is $\frac{f_D^B}{f_D^A + f_D^B}$.

V. Simulation Environment

Simulations play an important role in analyzing the behavior of DTN routing protocols. With sparsely distributed nodes, DTN simulations abstract from the details of wireless link characteristics and simply assume that two nodes can communicate when they are in range of one another. This allows focusing on the evaluation of the DTN routing protocols. DTN routing and application protocol's performance is highly dependent on the underlying mobility and node characteristics. Evaluating DTN protocols across many scenarios requires suitable simulation tools. We used the Opportunistic Network Environment (ONE) simulator which is specifically designed for evaluating DTN routing algorithms.

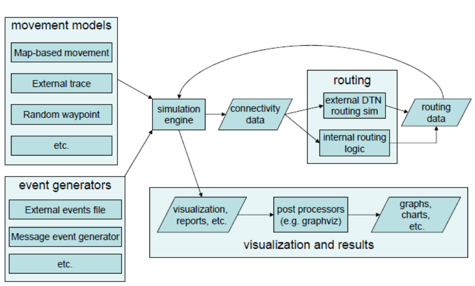

Fig. 3. Overview of ONE simulator environment [6].

At its core, ONE is an agent-based discrete event simulation engine. At each simulation step the engine updates a number of modules that implement the main simulation functions. The main functions of the ONE simulator are the modeling of node environment, inter-node contacts using various interfaces, routing, message handling and application interactions.
The message routing capability is implemented similarly to the movement capability: the simulator includes a framework for defining the algorithms and rules used in routing and comes with ready implementations of Spray and Wait and other well-known DTN routing protocols. To evaluate our proposed spraying technique in the simulator we created a new routing module.

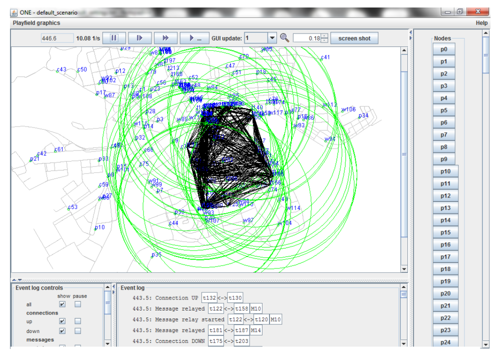

Fig. 4. Screenshot of the ONE simulators GUI.

TABLE I. Simulation Parameters

Parameter	Value
Total Simulation Time	12 Hours
World size	4500 × 3400 m
Movement Model	ShortestPathMapBasedMovement
Routing Protocol	Spray and Wait (for both spraying heuristics)
Node Buffer Size	5M
No of Nodes	215
Interface Transmit Range	10m
number of initial message copies	15, 20, 25, 30, 35, 40
Time To Live(TTL)	200, 250, 300, 350, 400 (in minutes)
Node Movement Speed	Min=0.5 m/s Max=13.9 m/s
Message Creation Rate	One Message Per 25-35 sec
Message Size	500 KB to 1 MB

VI. Simulation Results and Evaluation

We have investigated the performance of Binary Spray and Wait and our proposed spraying algorithm by varying message Time To Live (TTL) and number of initial message copies. The performance is analyzed on three metrics: Delivery ratio, Overhead ratio and Average latency.
In the simulation environment, we have focused on comparing the performance with regard to the metrics mentioned above. The simulation results presented here are obtained by running the simulations as per the parameters defined in Table 1.

A. Performance in terms of Delivery Ratio

It is the fraction of generated message that are correctly delivered to the final destination within a given time period. It is defined as:

$$\frac{Number of Packets Delivered}{Number of Packets Created} \tag{2}$$

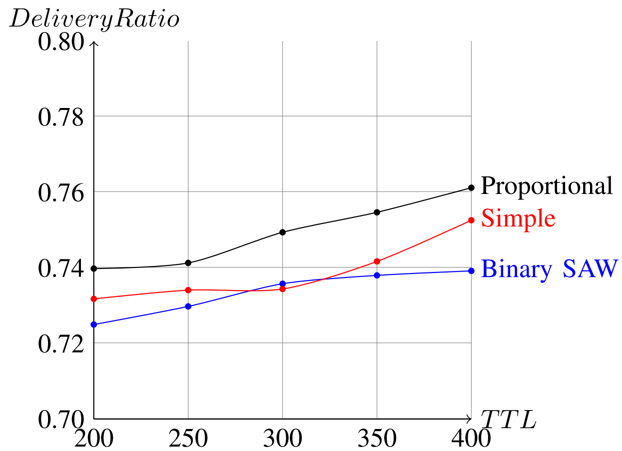

Fig. 5. Effect of TTL on delivery ratio.

From simulation results, it is evident that delivery likelihood based spraying heuristics(Simple and Proportional) outperform Binary SAW in terms of delivery ratio. Simulation was performed by varying both TTL and number of initial copies.

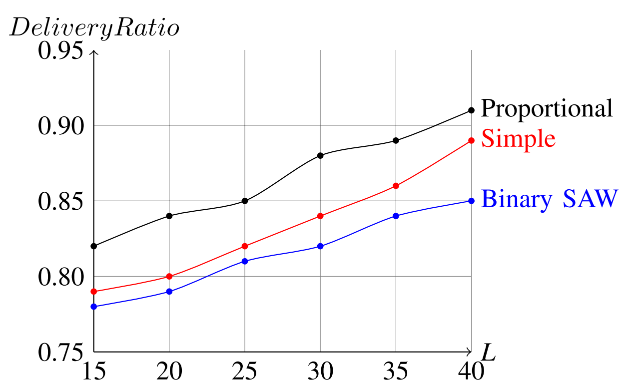

Fig. 6. Effect of number of initial copies on delivery ratio.

B. Performance in terms of Overhead Ratio

This metric is used to estimate the extra number of data packets needed by the routing protocol for actual delivery of the data packets. It is defined as:

$$\frac{Number of Packets Relayed - Number of Packets Delivered}{Number of Packets Delivered} \tag{3}$$

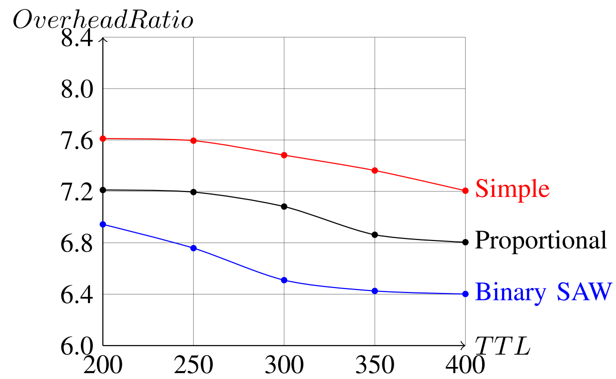

Fig. 7. Effect of TTL on overhead ratio.

Overhead Ratio in case of delivery likelihood based spraying heuristics is slightly higher than Binary SAW.

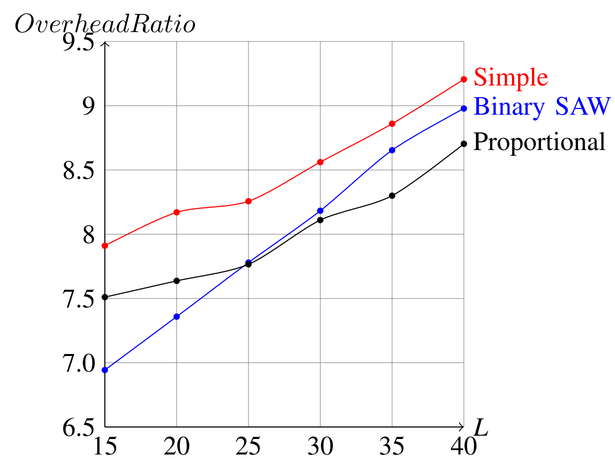

Fig. 8. Effect of number of initial copies on overhead ratio.

C. Performance in terms of Average Latency

It is the measure of average time between messages is generated and when it is received by the destination.

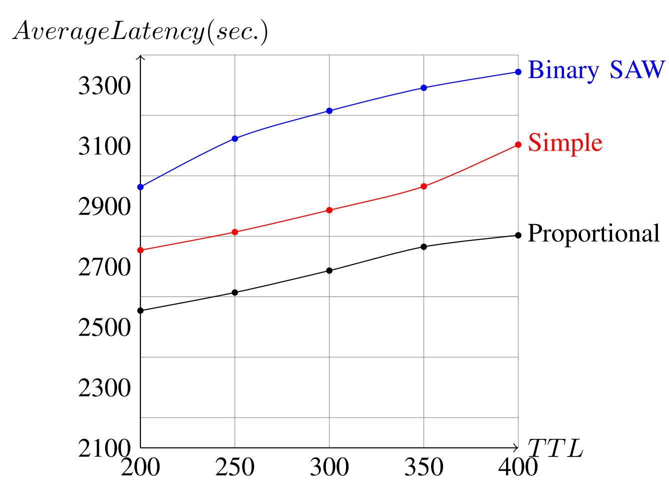

Fig. 9. Effect of TTL on average latency.

The overall latency increases with TTL because as lifetime of the packet increases packet has to wait in the buffer before it is either delivered to the destination or being discarded due to lifetime expiry.
But as the number of initial copies increases, latency decreases.

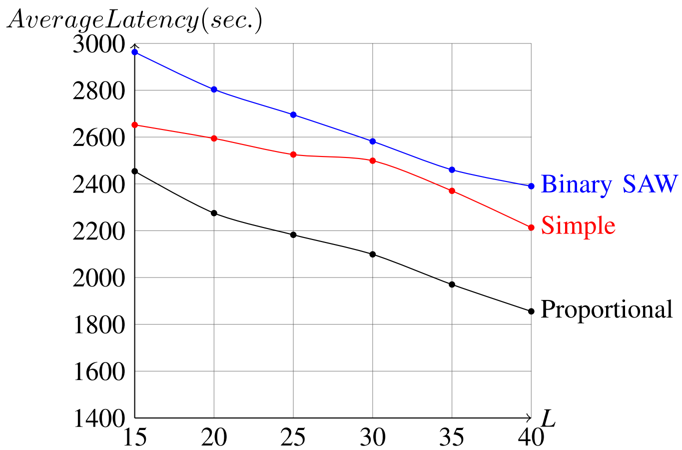

Fig. 10. Effect of number of initial copies on average latency.

VII. CONCLUSION

This paper presents spraying heuristics based on delivery likelihood for Spray and Wait routing protocol. We evaluated the proposed heuristics using the ONE simulator in different scenarios. Simulation results show that delivery likelihood based heuristics outperforms Binary Spray and Wait in terms of the delivery ratio and average latency.
We will focus on introducing a few more metrics that all independently capture the network behavior from different perspectives and then merge them together.

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