Adaptive Spray: An Efficient Restricted Epidemic Routing Scheme for Delay Tolerant Networks

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***Abstract*—In Delay Tolerant Networks, there is no guarantee that a fully connected path between source and destination exists any time. In this context, the limited hop count scheme which allows a message to travel at most k hops is considered as a basic routing scheme. However, there are no significant works offering an efficient method to identify a proper value for k. In this paper, we propose a new approach, named Adaptive Spray (AS-scheme). Instead of identifying a strict value k, it heuristically identifies a real-value coefficient to improve the network performance while eliminating the computational complexity. By leveraging only local knowledge like messages remaining time and nodes meeting rate, AS-scheme is highly scalable. Simulation results reveal that the proposed approach can quickly identify an appropriate coefficient and outperforms Epidemic algorithm in terms of increasing delivery rate, reducing overhead ratio and average latency, especially in dense networks.**

I. Introduction

Due to the mobility and limited resources of nodes in Delay Tolerant Networks, a fully connected path between source and destination does not always exist. In this situation, limited hop count scheme (LH-scheme) allows a message to traverse at most k hops with the expectation of reducing the number of transmissions while keeping reasonable delivery rate. However, searching a proper value of k is a challenging problem because the affections of limited buffer size on the number of copies are not clearly defined in mathematical formulas.

Despite a large number of existing protocols, this paper proposes an extremely simple routing scheme named *Adaptive Spray (AS-scheme)*. It makes use of local knowledge: (i) message's remaining time, (ii) node's meeting rate and (iii) message's hop count to adjust the total copies of a message which should be replicated without dropping copies of other messages. The main contributions of this paper can be summarized as follows:

- The simulation results show that the proposed scheme outperforms Epidemic, PRoPHET, Spray and Wait in terms of delivery rate, average latency.
- The proposed scheme works without any accurate or estimated global knowledge such as the number of nodes [1] in the whole network. It is highly scalable and adapts to the network changes.

II. Related Work

The weaknesses of Epidemic such as resource hungry, high average latency are examined in [1] [2] [3]. Therefore, several restricted epidemic routing algorithms *(RERs)* are proposed to diminish the number of copies such as two-hop-copy [4], k-hop-copy [5] [6]. By using static and time-aggregated graphs, the work in [7] realizes that second hop brings most of the benefits of *k-hop* routing, while the optimal paths are achieved at further hops. Theoretical analysis in [8] observes the performance of *k-copy* limited flooding over *Markov and Random graph Hierarchic Model (MRHM)* and concludes that when $k = 3$, the performance of *k-copy* limited flooding is very close to Epidemic. However, the above routing algorithms miss important observations as k is a real number, for example, $k = 3.5$. LH-scheme produces high delivery rate and low average latency by delivering messages in infectious diseases fashion. However, more copies mean more traffic, more dropped copies and more time to deliver. According to the above analysis, this paper proposes the AS-scheme which limits the number of copies by adjusting a specific coefficient a to cover all possible situations of LH-scheme. The coefficient a is described in the next section.

III. Adaptive Spray Scheme

AS-scheme is described as follows: at node x, message i in the buffer maintains a list of variables:

- n_i is the hop count of message i at calculation time. $n_i = 0$ at source node.
- R_i is the remaining time of message i at calculation time. $R_i = 0$ then message i is dropped.
- λ_x is the meeting rate of node x under the given mobility model.
- $a \in [0, \infty)$ is a coefficient used to apply limitation to the number of message copies.

With the above problem settings, when node x encounters another node which has not already received message i it runs Algorithm 1 against message i to determine a proper action: *replicate message i to the encounter* or *keep message i in the buffer then directly transfer to the destination*. During the lifetime of node x, it encounters n different nodes. Then λ_x is estimated as follows:

$$\lambda_x = \frac{n}{\sum_{i=1}^{n} \frac{1}{\lambda_i}} \tag{1}$$

λ_x is updated every time x encounters other nodes.

To clearly explain AS-scheme, we define a simple scenario where a message i is generated at node A and traverses through

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Algorithm 1 Adaptive Spray

Input: n_i, R_i, λ_x, a
Output: An action: *keep* or *replicate*
  $U_i \leftarrow \lambda_x R_i - a \times n_i$
  if $U_i \geq 0$ **then**
    return *keep*
  else
    return *replicate*
  end if

B, C, D with the expectation of reaching G. The scenario is completely described in Figure 1.

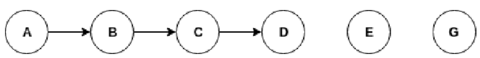

Fig. 1. The delivery path of the message i

Table I describes the calculation processes at nodes {*A, B, C, D, E*} of message i with $a = 1$. $U_i > 0$ at {*A, B, C*} and thus i is replicated. D accidentally encounters E but $U_i(B) < 0$ and thus i is kept in D's buffer and attempts to approach the destination.

TABLE I
DECISION MAKING ON A DELIVERY PATH OF THE MESSAGE i

Node	λ	R_i	U_i	Decision
A	0.05	200	$200 \times 0.05 - 0 = 10$	Replicate i to B
B	0.025	180	$180 \times 0.025 - 1 = 3.5$	Replicate i to C
C	0.02	140	$140 \times 0.02 - 2 = 0.8$	Replicate i to D
D	0.015	90	$90 \times 0.015 - 3 = -1.65$	Keep
E	0.01	-	-	-

In summary, AS-scheme is easy to implement because it depends on local knowledge, $\{n_i, R_i, \lambda_x\}$.

A. Algorithm Analysis

Let TTL be time to live, message i takes $\{T_{i1}, T_{i2}, ..., T_{in}\}$ to deliver i from source to hop n^{th}, λ_n be meeting rate at hop n^{th} where $\lambda_n = \frac{1}{T_n}$, upper bound function U_i at hop n^{th} is given by $U_i = \lambda_n(TTL - \sum_{j=1}^{n} T_{ij}) - a \times n > 0$. For the special case where $\{\forall j \in [1, n], T_{ij} = T_n = T\}$ then

$$n < \frac{TTL}{(a+1) \times T} \tag{2}$$

Equation (2) is a tight upper bound of n. With fixed TTL and stable T, we can control the maximum hop count of individual messages by adjusting coefficient a.

1) $a \leq 0$, AS-scheme is the Epidemic algorithm
2) $a \to \infty$, AS-scheme is the *1-hop* algorithm

In summary, by adjusting $a \in [0, \infty)$, AS-scheme covers all situations of LH-scheme

IV. Evaluations

To evaluate the performance of AS-scheme, we have conducted various simulations on the-one [9] simulator. Figure 2 describes the delivery rate of AS-scheme (Spray $a = 0.1$) in comparison with other algorithms with respect to the different number of moving nodes. It is clearly that AS-scheme outperforms all other algorithms, even more than 20% compared to the closest algorithm (Epidemic).

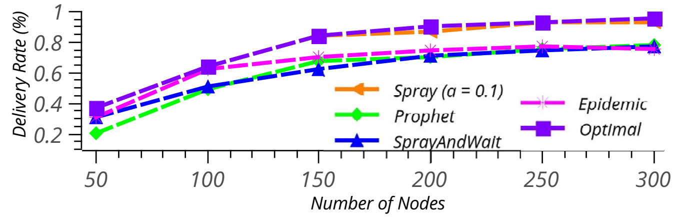

Fig. 2. Delivery rate of the AS-scheme in comparison with other algorithms

V. Conclusion

In this paper, we discussed a flexible routing scheme named the AS-scheme. Despite its simplicity, the theoretical analytics, and the simulation results show that AS-scheme produces near-optimal results with proper values of coefficient a. In the future, we will continue investigating a solid method to quickly find $a_{optimal}$ in order to completely propose optimal algorithms.

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