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CONTENTS

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Title

AN EFFICIENT ROUTING SCHEME FOR ICMN

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ABSTRACT:

In this paper, intermittently connected mobile networks are sparse wireless networks where most of the time there does not exist a complete path from the source to the destination. These networks fall into the general category of Delay Tolerant Networks. There are many real networks that follow this paradigm, for example, wildlife tracking sensor networks, military networks, inter-planetary networks, etc. proposed efforts to significantly reduce the overhead of flooding-based schemes has often been Plagued by large delays. With this in mind, we introduce a new routing scheme, called Spray and Wait because it “sprays” a number of copies into the network, & then “waits” till one of these nodes meets the destination. Using theory and simulations we show that Spray and Wait outperforms all existing schemes with respect to average message delivery delay and number of transmissions per message delivered; its overall performance is close to the optimal scheme. Furthermore, it is highly scalable retaining good performance under a large range of scenarios, unlike other schemes.

Keywords: Intermittently connected mobile networks, Delay Tolerant Networks

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. This situation arises when the network is quite sparse, in which case it can be viewed as a set of disconnected, time-varying clusters of nodes. There are many real networks that fall into this paradigm. Intermittently connected mobile networks belong to the general category of Delay Tolerant Networks, that is, networks were incurred delays can be very large and unpredictable.

Since in the ICMN model there may not exist an end to-end path between a source and a destination, conventional ad-hoc network routing schemes, such as DSR, AODV, etc., would fail. Specifically, reactive schemes will fail to discover a complete path, while proactive protocols will fail to converge, resulting in a deluge of topology update messages. However, this does not mean that packets can never be delivered in such networks. Over time, different links come up and down due to node mobility. If the sequence of connectivity graphs over a time interval is overlapped, then an end-to-end path might exist. These implies that a message could be sent over an existing link, get buffered at the next hop until the next link in the path comes up, and so on and so forth, until it reaches its destination.

This approach imposes a new model for routing. Routing consists of a sequence of independent, local forwarding decisions, based on current connectivity information and predictions of future connectivity information. In other words, node mobility needs to be exploited in order to deliver a message to its destination. However, there mobility is exploited in order to improve capacity, while here it is used to overcome the lack of end-to-end connectivity.

Despite a large number of existing proposals, there is no routing scheme that both achieves low delivery delays and is energy-efficient. With this in mind, in this paper we introduce a novel routing scheme called Spray and Wait. Spray and Wait bounds the total number of copies and transmissions per message without compromising performance. Using theory and simulations we show that:

1. Under low load, Spray and Wait results in much fewer transmissions and comparable or smaller delays than flooding-based schemes.

2. Under high load, it yields significantly better delays and fewer transmissions than flooding-based schemes.

3.It is highly scalable, exhibiting good and predictable performance for a large range of network sizes, node densities and connectivity levels; what is more, as the size of the network and the number of nodes increase, the number of transmissions per node that Spray and Wait requires in order to achieve the same performance decreases, and

4. It can be easily tuned online to achieve given QoS requirements, even in unknown networks. We also show that Spray and Wait, using only a handful of copies per message, can achieve comparable delays to an oracle-based optimal scheme that minimizes delay while using the lowest possible number of transmissions.

RELATED WORK:

Although a significant amount of work and consensus exists on the general DTN architecture [1], there hasn’t been a similar focus and agreement on DTN routing algorithms, especially when it comes to networks with “opportunistic” Connectivity. This might be due to the large variety of applications and network characteristics falling under the DTN umbrella.

A large number of routing protocols for wireless ad-hoc networks have been proposed in the past [6, 20]. However, traditional ad-hoc routing protocols are not appropriate for the types of networks we’re interested in here. The performance of such protocols would be poor even if the network was only slightly disconnected. To see this, note that the expected throughput of reactive protocols is connected with the average path duration PD and the time to repair

a broken path trepair with the following relationship: Throughput= min {0,rate (1−trepair/PD)}.

When the network is not dense enough (as in the ICMN case), even moderate

node mobility would lead to frequent disconnections. This reduces the average path duration significantly. Additionally, trepair is at least 2 times the delay of the optimal algorithm. Consequently, in most cases trepair is expected to be larger than the path duration, this way reducing the expected throughput to almost zero. Proactive protocols, on the other hand, would simply declare lack of a path to the destination under intermittent connectivity, or result into deluge of topology updates that would dominate the available bandwidth under high mobility.

Another approach to deal with disconnections or “disruptions” [2] is to reinforce connectivity on demand, by bringing for example additional communication resources into the network when necessary. Similarly, one could force a number of specialized nodes to follow a given trajectory between disconnected parts of the network in order to bridge the gap. Nevertheless, such approaches are orthogonal to our work; our aim is to study what can be done in the absence of such enforced mobility and connectivity.

A study of routing for DTN networks with predictable connectivity was performed. There, a number of algorithms with increasing knowledge about network characteristics like upcoming “contacts”, queue sizes, etc are compared with an optimal centralized solution of the problem, formulated as a linear program. Although it is shown that even limited knowledge might be adequate to efficiently solve this problem, the algorithms proposed apply to the types of

DTNs were connectivity is intermittent, but can be predicted. In our case, connectivity is rather opportunistic and subject to the statistics of the mobility model followed by nodes. A number of routing proposals exist that are specifically targeted towards this new context of intermittently connected mobile networks with opportunistic connectivity. Many of them try to deal with application-specific problems, especially in the field of sensor networks. In [23], a number of mobile nodes performing independent random walks serve as Data Mules that collect data from static sensors and deliver them to base stations. Each Data Mule performs Direct Transmission, that is, will not forward data to other Data- Mules, but only deliver it to its destination. The statistics of random walks are used to analyze the expected performance of the system. The idea of carrying data through disconnected parts using a virtual mobile backbone has also been used in [5, 13].In a number of other works, all nodes are assumed to be mobile and algorithms to transfer messages from any node to any other node are sought for [3, 8, 11, 14, 17, 18, 19, 27]. Epidemic routing extends the concept of flooding in intermittently connected mobile networks [27]. It is one of the first schemes proposed to enable message delivery in such networks. Each node maintains a list of all messages it carries, whose delivery is pending. Whenever it encounters another node, the two nodes exchange all messages that they don't have in common. This way, all messages are eventually "spread" to all nodes, including their destination (in an "epidemic" manner). Although epidemic routing finds the same path as the optimal scheme under no contention [25], it is very wasteful of network resources. Furthermore, it creates a lot of contention for the limited buffer space and network capacity of typical wireless networks, resulting in many message drops and retransmissions. This can have a detrimental effect on performance, as has been noted earlier in [19, 26], and will also be shown in our simulation results. One simple approach to reduce the overhead of flooding and improve its performance is to only forward a copy with some probability $p < 1$ [26]. A different, more sophisticated approach is that of History-based or Utility-based Routing [8, 17, 19]. Here, each node maintains a utility value for every other node in the network, based on a timer indicating the time elapsed since the two nodes last encountered each other. These utility values essentially carry indirect information about relative node locations, which get diffused through nodes' mobility. Therefore, a scheme can be designed, where nodes forward message copies only to nodes with a higher utility by at least some pre-specified threshold value U^{th} for the message's destination. Such a scheme results in superior performance than flooding [17, 19], and makes better forwarding decisions than randomized routing [25]. This method has also been found to be quite efficient in the context of regular, connected, wireless networks [11]. Nevertheless, utility-based schemes are still flooding-based in nature. What is worse, they are faced with an important dilemma when choosing the utility threshold. Too small a threshold and the scheme behave like pure flooding. Too high a threshold and the delay increase significantly, as we shall see.

Single-copy schemes have also been extensively explored in [23, 25]. Such schemes generate and route only one copy per message, in order to significantly reduce the number of transmissions. Although they might be useful in some situations, single-copy schemes do not present desirable solutions for applications that require high probabilities of delivery and low delays.

Finally, an optimal “oracle-based” algorithm has been described in [25]. This algorithm is aware of all future movement, and computes the optimal set of forwarding decisions, which delivers a message to its destination in the minimum amount of time. This algorithm is of course not implementable, but is quite useful to compare against proposed practical schemes.

Our scheme, Spray and Wait, manages to significantly reduce the transmission overhead of flooding-based schemes and have better performance with respect to delivery delay in most scenarios, which is particularly pronounced when contention for the wireless channel is high. Further, it does not require the use of any network information, not even that of past encounters. We also provide analytical methods to compute the number of copies per message that Spray and Wait requires achieving a target average message delivery delay. Finally, we demonstrate that Spray and Wait, unlike other schemes, is remarkably robust and scalable, retaining its performance advantage over a large range of scenarios.

SPRAY AND WAIT ROUTING:

Based on the previous exposition, we can identify a number of desirable design goals for a routing protocol in intermittently connected mobile networks. Specifically, an efficient routing protocol in this context should:

Perform significantly fewer transmissions than epidemic and other flooding-based routing schemes, under all conditions. Generate low contention, especially under high traffic loads.

Achieve a delivery delay that is better than existing single and multi-copy schemes, and close to the optimal. Be highly scalable, that is, maintain the above performance behaviour despite changes in network size or node density. To this end, we propose a novel routing scheme, called Spray and Wait that is simple yet efficient, and meets the above goals, as we will demonstrate in the next sections. 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.

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, it stops and lets each node carrying a copy perform direct transmission. In other words, Spray and Wait could be viewed as a trade off between single and multi-copy schemes. Surprisingly, as we shall shortly see, its performance is better with respect to both number of transmissions and delay than all other practical single and multi-copy schemes, in most scenarios considered.

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.

Definition: The source of a message initially starts with L copies; any node A that has n > 1 message, and encounters another node B, hands over to B (n/2) and keeps n/2 for itself; when it is left with only one copy, it switches to direct transmission.

As L grows larger, the sophistication of the spraying heuristic has an increasing impact on the delivery delay of the spray and wait scheme. Figure.1 compares the expected delay of

Binary Spray and Wait and Source Spray and Wait as a function of the number of copies L used, in a 100×100 network with 100 nodes. This figure also shows the delay of the optimal scheme.

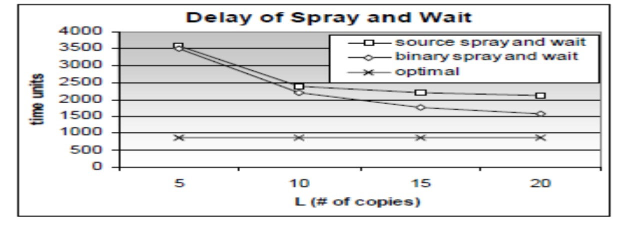


Fig 1: Comparison of Source Spray and Wait, Binary Spray and Wait, and Optimal schemes (100× 100 network with 100 nodes).

OPTIMIZING SPRAY AND WAIT:

By definition, most ICMN networks are expected to operate in stressed environments and by nature be delay tolerant. Nevertheless, in many situations the network designer or the application itself might still impose performance requirements on the protocols. For example, a message sent over an ICMN of handhelds in a campus environment, notifying a number of peers about an upcoming meeting, would obviously be of no use if it arrives after the meeting time. It is of special interest therefore to examine how Spray and Wait can be tuned to achieve the desired performance in a specific scenario.

Before we do so though, we summarize in the following lemma a few of our own results from [25] regarding the expected delay of the Direct Transmission and Optimal schemes:

Lemma 4.1. Let M nodes with transmission range K perform independent random walks on a √N× √N torus. Then:

1. The delay of Direct Transmission is exponentially distributed with average

$\mathrm{ED}_{\mathrm{dt}} = 0.5\mathrm{N}(0.34\log\mathrm{N} - \frac{2^{\mathrm{k}+1}-\mathrm{k}-2}{2^{\mathrm{k}}-1})$ 2. The expected delay of the Optimal algorithm is EDopt $=\frac{\mathrm{H}^{\mathrm{M}-1}}{\mathrm{M}-1}$EDdt,

Where Hn is the nth Harmonic Number, i.e. Hn= $\sum_{i=1}^{n} \frac{1}{i} = \Theta(\log n).$

Lemma 4.2. The expected delay of Spray and Wait, when L message copies are used, is upper-bounded by

$$ED_{SW} \leq (H_{M-1} - H_{M-L})ED_{dt} + \frac{M-L}{M-1}\frac{ED_{dt}}{L}$$

(1).

This bound is tight when L<< M.

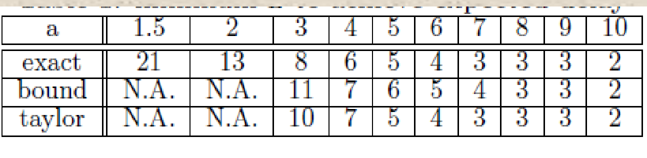
Choosing L to Achieve A Required Expected Delay:

In this section we analyze how to choose L in order for Spray and Wait to achieve a specific expected delay. Note that the issue of energy dissipation is also directly tied to the number of copies L used by Spray and Wait, since Spray and Wait performs exactly L transmissions. Lemma 4.1.1 The minimum number of copies Lmin needed for Spray and Wait to achieve an expected delay at most aEDopt is independent of the size of the network N and transmission range K, and only depends on a and the number of nodes M. The above lemma states that the required number of copies only depends on the number of nodes, and is straightforward to prove from Eq.(1). Furthermore, since the upper bound of Eq.(1) is tight for small L/M values, if the delay constraint a is not too stringent, we can use one of the following methods to quickly get a good estimate for Lmin: (i) solve the upper

bound equation Eq.(1) for L, by letting EDsw = aEDopt, and taking _L_, or (ii) approximate the harmonic numberHM−L in Eq.(1) with its Taylor Series terms up to second order, and solve the resulting third degree polynomial: where $(H_M^3 - 1.2)L^3 + (H_M^2 - \frac{\pi^2}{6})L^2 + \left(a + \frac{2M-1}{M(M-1)}\right) L = \frac{M}{M-1}$,

$H_n^r = \sum_{i=1}^{n} \frac{1}{i^r}$ nth Harmonic number of order r.

Table 1: minimum L to achieve expected delay.



a	1.5	2	3	4	5	6	7	8	9	10
exact	21	13	8	6	5	4	3	3	3	2
bound	N.A.	N.A.	11	7	6	5	4	3	3	2
taylor	N.A.	N.A.	10	7	5	4	3	3	3	2

One could also iteratively calculate the exact number of copies needed, using the system of recursive equations from [24]. However this method is quite more cumbersome. In Table 1 we compare exact results for Lmin to the ones calculated with the two approximate methods for different values of a. We assume the number of nodes M equals 100. ‘N.A’ stand for ‘Non Available’ and means that such a low delay value is never achievable by the bound. As can be seen in this table the L found through the approximation is quite accurate when the delay constraint is not too stringent.

In this method converges eventually, its speed depends on network size and could take a very long time in large disconnected networks. However, if we assume that nodes perform independent random walks, we can produce an estimate of M by taking advantage of inter-meeting time statistics. Specifically, let us define T1 as the time until a node (starting from the stationary distribution) encounters any other node. It is easy to see from Lemma 2. That T1 is exponentially distributed with average

T1 = EDdt/(M − 1). Furthermore, if we similarly define T2 as the time until two different nodes are encountered, then the expected value of T2 equals EDdt ($\frac{1}{M-1}+\frac{1}{M-2}$). Cancelling EDdt from these two equations we get the following estimate for M:

$$M=\frac{2T_2-3T_1}{T_2-2T_1}$$

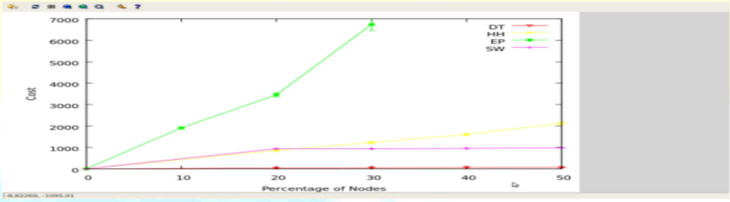
Scalability of Spray & Wait:

We depict the behaviour of Lmin/M as a function of M for different values of a. It is important to note here that, as the number of nodes in the network increases, the percentage of nodes that need to become relays in Spray and Wait to achieve the same performance relative to the optimal is actually decreasing. In other words, although the performance of the optimal scheme also improves with M, the performance of Spray and Wait seems to improve faster. The intuition behinds this interesting result is the following: when L _ M the delay of Spray and Wait is dominated by the delay of the wait phase; in that case, if L/M is kept constant, the delay of Spray and Wait decreases roughly as 1/M. On the other hand, the delay of the optimal scheme decreases more slowly as log (M)/M, as can be seen by Equation 1.

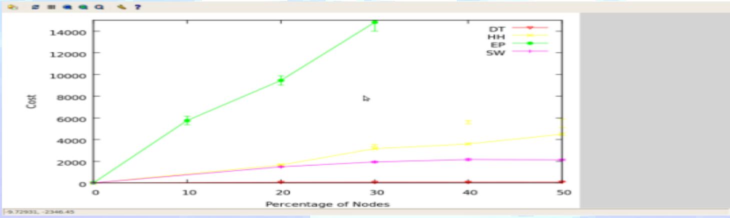
SIMULATION:

We use a custom discrete event-driven simulator to evaluate and compare the performance of different routing protocols under a variety of mobility models and under contention. A slotted, random access with collision detection MAC protocol has been implemented in order to arbitrate between nodes contenting for the shared channel. We simulate delivery ratio, cost and delay of different protocols in homogeneous and

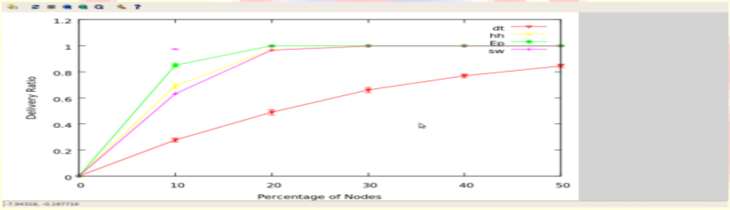
Heterogeneous environments.



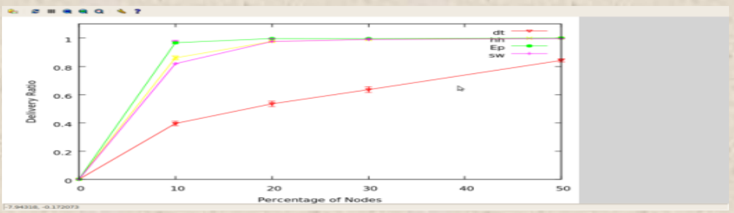
Cost in homogeneous environment



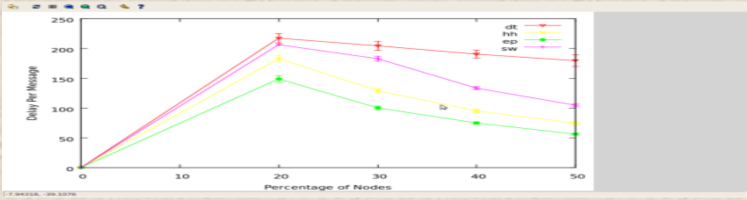
Cost in heterogeneous environment



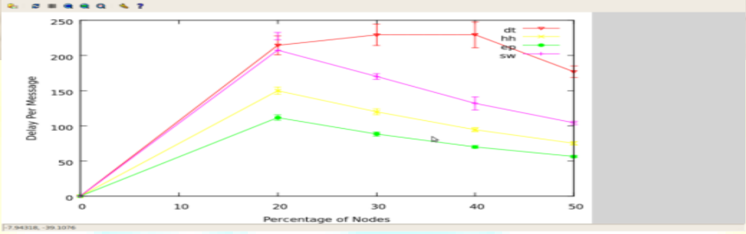
Delivery ratio in homogeneous environment



Delivery ratio in heterogeneous environment



Delay in homogeneous environment



Delay in heterogeneous environment

CONCLUSION:

In this paper, we investigated the problem of efficient routing in intermittently connected mobile networks. We proposed a simple scheme, called Spray and Wait that manages to overcome the shortcomings of epidemic routing and other flooding-based schemes, and avoids the performance dilemma inherent in utility-based schemes. Using theory and simulations we show that Spray and Wait, despite its simplicity, outperforms all existing schemes with respect to number of transmissions and delivery delays, achieves comparable delays to an optimal scheme, and is very scalable as the size of the network or connectivity level increase. In future work we intend to look in detail into schemes that spray a number of copies quickly, and then use utility based or other efficient single-copy schemes to route each copy independently. Such schemes would aim to realize the performance advantages of the generic Spray and Wait approach in cases where mobility might be restricted or correlated in space and time.

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