MobySpace: Mobility Pattern Space Routing for DTNs

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1. INTRODUCTION

In one common scenario for delay tolerant networks (DTNs), nodes are mobile and have wireless networking capabilities. They are able to communicate together only when they are within transmission range. The network suffers from frequent connectivity disruptions, making the topology intermittently and partially connected. This means that there is a very low probability that an end-to-end path exists between a given pair of nodes at a given time. End-to-end paths can exist temporarily, or may sometimes never exist, with only partial paths emerging. Due to these disruptions, regular adhoc networking approaches to routing and transport do not hold, and new solutions must be proposed. The Delay Tolerant Networking Research Group (DTNRG) [1] has proposed an architecture [3] to support messaging that may be used by delay tolerant applications in such a context. Messages transferred in DTNs are called bundles.

Most of the work concerning routing in DTNs has been in the context of predicted contacts, such as the algorithm of Lindgren et al. [5], which relies on nodes having a community mobility pattern. Nodes mainly remain inside their community and sometimes visit the others. As a consequence, a node may transfer a bundle to a node that belongs to the same community as the destination. In a similar manner, Burns et al. [2] propose a routing algorithm that uses past frequencies of contacts. The case study presented in this poster relies also on contacts that can be characterized as predicted, but the underlying idea is a more generic abstraction compared to previous work, being able to capture the interesting properties of major mobility patterns for routing. The main contribution of this poster is the use, for routing in DTNs, of the formalism of a high-dimensional Euclidean space based on nodes' mobility patterns. We show the feasibility of this concept through an example in which each dimension represents the probability for a node to be found in a particular location. We conduct a simulation that produces promising initial results for this concept.

2. CONCEPT

The Euclidean mobility pattern space, or *MobySpace*, introduced here is a generalization of ideas that are already current in the DTN literature. The principle is to use a Euclidean space as a tool to help nodes to take routing decisions. These decisions rely on the notion that a node is a good candidate for taking custody of a bundle if it has a mobility pattern similar to that of the bundle's destination. Routing is done by forwarding bundles toward nodes that have mobility patterns that are more and more similar to the mobility pattern of the destination.

In the MobySpace, the mobility pattern of a node provides its coordinates. Several questions arise. What type of dimensions do we choose, how many, and what kind of range for values do we define? How do we define the notion of distance? Is straightforward Euclidean distance useful or are other similarity functions more appropriate? Is it possible to have an infinite space in terms of the number of dimensions? What might be the problems with such a scheme? The purpose of this poster is not to answer all of these questions, but to describe a formalism that lends itself to interesting and potentially fruitful elaboration.

3. A CASE STUDY

Recent studies of the mobility of students in a campus [4] equipped with PDAs or laptops able to be connected to wireless access networks, show that they follow common mobility patterns. They show that significant aspects of the behavior can be characterized by power-law distributions. Specifically, the session durations and the frequencies of the places visited by users follow power laws. This means that users typically visit a few access points frequently while visiting the others rarely, and that users may stay at few locations for long periods while visiting the others for very short periods. If we take these wireless access network studies to be representative of a class of mobile node behavior, we can consider that these observations are applicable to at least certain DTN scenarios.

From such observations, we propose the following simple mobility model. Let us consider a set of nodes that move among a set of N locations. Two nodes can communicate only if they are at the same location. Node movements are based on power-laws, and each node has a mobility pattern defined by the distribution of P. $P(i)$ is the probability for the node to be at location i and $P(i) = K\left(\frac{1}{d}\right)^{n_i}$ with n_i the preference index of the location i, d the exponent of the power-law based mobility pattern and K a constant. $n_j = 0$ means that the location j is the preferred one. Because $\sum_i P(i) = 1$, we have: $K = (1 - \frac{1}{d})/(1 - \frac{1}{d^N})$

Under this model, d is the fundamental parameter governing node behavior. When d is high, nodes tend to move among a very small subset of locations, having one that they strongly prefer to the others. As d approaches 1, the range of locations that nodes visit regularly becomes wider, while still presenting a hierarchy of preferences. When $d = 1$, we have equiprobability.

Each time a node moves, it choses a destination randomly according to its power-law based mobility pattern and decides to stay there for a time t uniformly distributed between $[t_{\min}, t_{\max}]$. This process is repeated infinitly.

For each of the nodes in this model, there is therefore a well defined probability of finding that node at each of the N locations. This set of probabilities is a node's mobility pattern, and is described by a point, its *MobyPoint*, in an N dimensional Euclidean space, the MobySpace. We propose to route bundles in this MobySpace by sending them to nodes having mobility patterns that are successively closer to the mobility pattern of the destination. In simple words, we prefer to give custody of a bundle to a node that has mobility habits similar to those of the bundle's destination. We used the Euclidean distance to measure this similarity. Thus, the distance dij between the points i and j is : $\sqrt{\sum_{k=1}^{n} (x_{ik} - x_{jk})^2}$.

In the routing scheme presented here, the only information that must be flooded by nodes is their mobility patterns. These mobility patterns can be spread in an epidemic fashion.

4. EVALUATION

We have implemented a stand alone simulator to perform the evaluation. We compared these routing algorithms against the following:

- *Epidemic*: This is based on epidemic routing, as described by Vahdat and Becker [6]: Each time two nodes meet, they exchange their bundles. This algorithm provides the optimum path and thus the minimum bundle delay but suffers from high buffer occupancy and high bandwidth utilization.
- *Opportunistic*: A node waits to meet the destination in order to transfer its bundle. The main advantage of this method is that it involves only one transmission per bundle.
- *Random*: When a node is at a location and the bundle's destination in not there, the node transfers the bundle to a neighbor chosen at random. We have added a rule to avoid local loops: a node can only handle a bundle one time per location visit. This scheme is used in this paper as another basis of comparison. A novel algorithm should perform better than this one in order to be valuable.

We considered a set of 25 locations. The virtual space used for routing thus has 25 dimensions. There are 50 mobile nodes. Every node generates bundles destined toward each of the others every 30s with the first bundle being sent at a time randomly chosen from a uniform distribution over the interval [0,30s]. Simulations last 4000s. We generate traffic in the first 500s of the simulations in order to give enough time for all the bundles to reach their destination. The simulator used a time step of 10ms.

We evaluate routing algorithms on their transport layer performance in the simulation. We consider a good algorithm to be one that yields a low average bundle delay and a low average route length.

We performed 5 runs for each set of parameters. Figures reported in the tables here are mean results with confidence intervals at the 90% confidence level, obtained using the Student t distribution.

d	1.1	1.5	2
Epidemic	10.9 ±7.3	13.2 ±0.4	16.2 ±0.5
Opportunistic	123.3 ±7.7	287.4 ±8.4	550.2 ±15.2
Random	117.8 ±8.0	160.0 ±1.9	203.3 ±17.3
MobySpace	103.0 ±7.7	59.1 ±2.7	54.6 ±2.0

Table 1: Average bundle delay.

Table 1 presents the mean bundle delay obtained for each routing algorithm, and for various exponents d. The notable feature of these results is that MobySpace shows improved performance with an increase in d, whereas performance declines for all other routing algorithms as d increases. Moreover, MobySpace leads to lower delays that Opportunistic and Random, specially when d increases. Opportunistic performs worst, followed closely by Random. In Random, bundles will jump to other nodes without any preference ordering. This makes for highly mobile bundles, as is borne out by their extraordinarily high average route lengths, shown in Table 2. One might not necessarily want to pay the price of such processing overhead in order to obtain modest gains in delay. Here, MobySpace shows again an interesting behavior by leading to route lengths lower than Epidemic.

d	1.1	1.5	2
Epidemic	3,7 ±0.0	3.7 ±0.0	3.8 ±0.1
Opportunistic	1 ±0.0	1 ±0.0	1 ±0.0
Random	44.5 ±0.7	55.9 ±1.0	69.8 ±2.2
MobySpace	3.3 ±0.0	3.2 ±0.0	3.2 ±0.0

Table 2: Average route lengths.

5. CONCLUSION

The main contribution of this poster is the definition of the concept of MobySpace, a generic routing scheme using the formalism of a high-dimensional Euclidean space constructed upon mobility patterns. We have shown through a scenario inspired from reality that it can applied to DTNs and that it can bring benefits in terms of bundle delay and communication costs. The idea was to apply a well know and powerful artifact for routing in DTNs. We claim through this study to have opened new perspectives for routing. However, much work remains to be done.

6. REFERENCES

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