Network Structure Discovery for Vehicular Ad-Hoc Networks

Ian Downes Leonidas Guibas

1 Introduction

We are in an era of ubiquitous computing. No longer are we required to move to the computer, we are now able to take the computer with us, roaming freely. But with this freedom comes challenges; where there was once a static communication infrastructure there are now independently mobile agents, all demanding access to a communication network. Different approaches exist to form the communication network but all share a reliance on understanding the movement patterns of those mobile agents to guide the design and functioning of the network.

In this paper we raise the question of how the movement patterns of mobile agents affect the establishment of an ad hoc communication network between the agents. We seek answers to questions such as the following:

1. In what ways do the movement patterns affect the design of the communication network and its protocols?
2. What types of communication networks are feasible given the agent mobility?
3. How can the communication protocols take advantage of the movement patterns?
4. How much information about the movement patterns is needed for the communication protocols?
5. How can the movement patterns be compactly represented?

In the last part of the paper we make a few comments about a large simulated vehicular traffic dataset from the traffic engineering community.

2 Mobile Ad Hoc Networks

The general setting is of agents moving in some physical space and equipped with short range radios. It is assumed that the range is sufficiently short such that agents cannot directly communicate with each other but that as the agents move they may come within communication range for some timespan. Every agent has a communication schedule of destination nodes, amount of data and time of initiation and desires to use the communication network to meet that schedule.

One (successful) approach is to build an infrastructure based network. Source to destination communication is achieved by utilizing a static infrastructure of wireless basestations, all of which are linked by some backbone network. Although movement pattern analysis does play a role in determining placement of the basestations it is of lesser importance once the network is established and so we explicitly do not consider such a network. Instead, we focus on an ad hoc network where no infrastructure is present and the movement patterns dictate the communication opportunities in the network.

In the ad hoc network communication is achieved by using the mobile agents themselves as the relay nodes. This is a more challenging task as the connectivity is highly dynamic and is driven by the movement patterns. There are two mechanisms by which data can be transported in the network, each with different characteristics:

multi-hop relaying Agents send data to another agent in range who in turn relays the data to another agent, repeating until the data reaches the destination. Transport speed is fast and is only limited by the processing time at each hop. The wireless medium is shared so transmissions will interfere with others nearby, limiting simultaneous data transport capacity. Some concept of routing is necessary to decide who the next hop relay is at each step.

data muling Data is physically carried by the agents as they move. Transport speed is the velocity of the mobile agent. No interference means that the transport capacity is limited only by the buffer capacity of the agent. No routing per-se is necessary as the data travels with the agent.

In practice, communication is achieved by a combination of the two mechanisms depending on the movement patterns.

2.1 Movement Patterns

To illustrate the effect movement patterns can have we consider a few illustrative patterns as given in Figure 1 and described in detail below.

Unstructure Movement

A common approach in the MANET community is to assume no pattern in the agents' movement. Each agent moves independently within a bounded region according to the Random WayPoint (RWP) model where repeatedly a random waypoint is selected and travelled to at a random speed. The resulting movement, although clearly not representative of many real-word examples, allows tractable probabilistic analysis of the properties relating to communication and permits simple communication protocols.

The primary result of the RWP model is that there is (in expectation) a finite intercontact time for any pair of nodes. Simply put, an agent doesn't have to wait too long before it will come in contact with a desired agent by virtue of their movements alone. At the contact point it can directly transmit its data to the destination agent. In this scenario, only the data muling transport mechanism is exploited, no multi-hop relaying is necessary (or feasible).

Highly Structured Movement

As a second example we can consider the highly structured movement as shown in Figure 1. In this scenario every agent follows the same trajecory but with a delay, separating the agent's positions. Assuming that the agent separation is less than the maximum communication range then a static network is formed. There are no useful opportunities for data muling and all data transport must occur by using multi-hop relaying. Standard protocols can be used to discover the network connectivity and build routing tables.

Mixed Movement

The final example of figure 1 is intermediate between the first two examples. Two highly structured components are linked by a randomly moving agent. Communication within a component is by multi-hop relaying but communication between components can only be achieved by data muling. Since the location of the randomly moving agent cannot be predicted there cannot be any simple routing that between the components. Instead the data should be disseminated to all of the agents in a component to ensure that whenever the agent returns the data can be collected.

3 Zurich traffic dataset

In the MANET community the analysis of movement patterns appears to be restricted to investigating the inter-contact and contact time distributions. These distributions are primarily useful in determining the feasibility of simple opportunistic forwarding protocols such as that described in the RWP example above. The datasets used in the cases did not log actual agent positions but only the instances of contact and length of contact between agents.

We have had considerable difficulty searching for a suitable dataset that was either from the real-world or accurately simulated real-word movement patterns. To date the most suitable that we have found is the trace of simulated vehicular traffic in and around the Zurich Canton over a 24 hour period [1].

The Zurich dataset exhibits a variety of movement patterns. At the most fundamental level all of the vehicles are constrained to move about the road network, rather than freely moving. Many vehicles move in highly structured form, for example, vehicles moving towards a populous destination may all travel on the same motorway and at approximately the same speed. This coherent motion can support both multi-hop relaying and also data muling. In Figure 3 the inter-contact and contact time cummulative density functions are shown. Over 95% of the randomly selected source-destination pairs never make contact over the 24 hour period of the dataset.

References

[1] Bryan Raney, Andreas Voellmy, Nurhan Cetin, Milenko Vrtic, and Kai Nagel. Towards a microscopic traffic simulation of all of Switzerland. In *International Conference on Computational Science (1)*, pages 371–380, 2002.

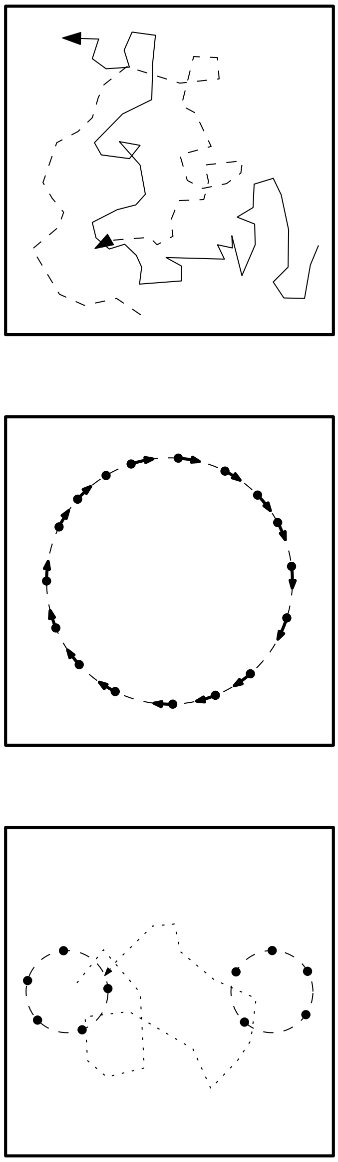
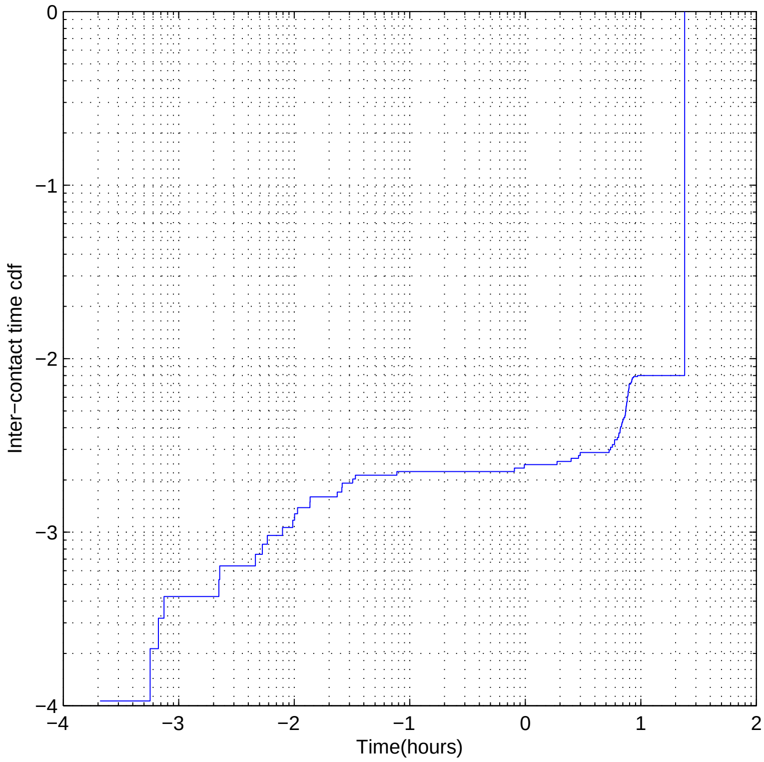
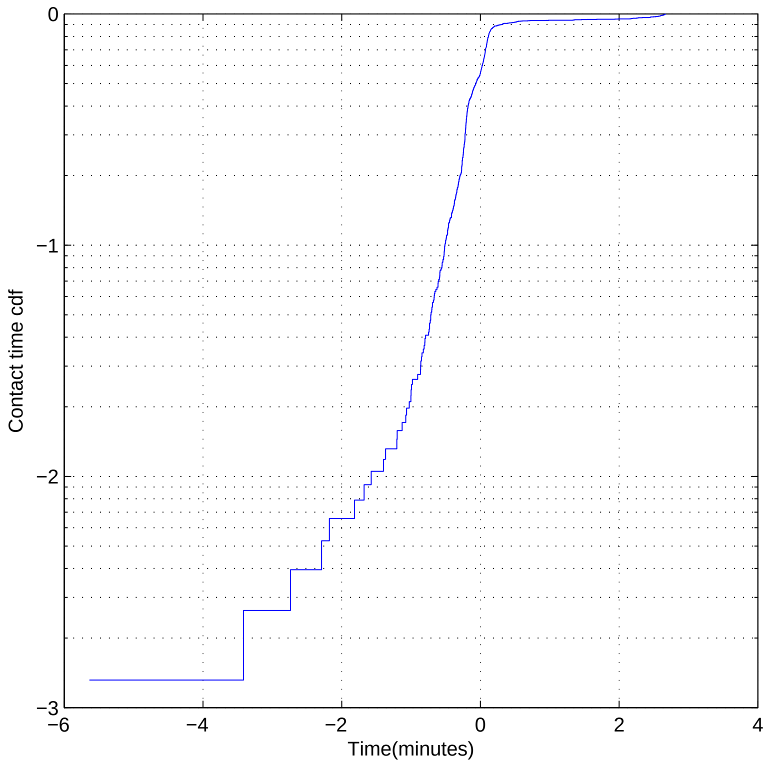


Figure 1: Examples of simple movement patterns that give rise to different communication mechanisms.



(a) Inter-contact time CDF.



(b) Contact time CDF.

Figure 2: CDFs for the inter-contact and contact time distributions for random source-destination pairs. Over 95% of the chosen pairs never make contact.