Delay tolerant networks and spatially detailed human mobility

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***Abstract*—We propose a prototype for a real-world, human network proximity experiment with detailed recordings of the position of individuals. Our aim is to provide a comprehensive dataset to investigate the internal correlations between mobility and network properties, as well as to compare our results with different datasets, involving different social groups or mobile agents. As a further result, we expect the capability to formulate a model able to evaluate the relative importance of location and network centrality for efficient delay tolerant networks, with the added benefit of being able to synthesise realistic trace data for simulation.**

I. Introduction

Delay Tolerant Networks (DTN) have been attracting attention in the past few years as a very challenging research area, which could shape future technological applications. An important example of DTNs are the Pocket Switched Networks (PSN), networks constituted by mobile devices carried around by human beings. In a future scenario, people will be carrying around more and more complex mobile devices, giving more and more scope for networking applications. However, range and limits of such applications are still a matter of discussion and several efforts have been made to give insights into the problem [1], [2]. It has also been envisioned that knowledge of human movement patterns and proximity networks can be used to design an enviromental sensing system for cities, which puts sensing in the pockets of its human occupants.

A priviledged way to investigate PSN is to study real case scenarios. One typically equips a set of people with a smart phone with short ranged coverage and records the sightings of other devices within the available range. A few experiments have been made in this direction and each of them has helped improve our understanding of human mobility, social and working behaviours. Among the different efforts, the MIT Reality Mining dataset is an accurate collection of real life traces, based on the Bluetooth sightings of smart phones carried by approximately one hundred people working or studying in the same place (the MIT campus), for a period of 9 months [3], [4]. There are several similar experiments in the literature, involving a smaller number of individuals, shorter time, or even different types of mobile agents (rollerbladers, taxi cabs, animals, etc.) [5], [6], [7]. However, given the hetereogeneity of such datasets, it can be difficult to infer general properties from a particular experiment. Also, the Reality Mining data, for example, does not take into account the actual position of individuals, and thus information about the relationship between mobility patterns and network topology. Indeed, there also exist large scale experiments, based on the record of mobile phone calls, which are more focused on human mobility and uncover universal patterns and typical behaviours. Gonzalez et al studied the movements of 6.2 million individuals over a period of six months [8]. They found that the data shows a high degree of temporal and spatial regularity, i.e. individuals have a significant probability to visit the same locations. In a later paper [9], they studied the propagation of mobile phone viruses using not only local interactions (Bluetooth) but also non-spatial interaction (MMS). The data the authors used for this study were based on phone records which included the location of the cell tower in which calls were placed, the average service area of each tower was approximately between $1km^2$ and $3km^2$ and location information is therefore, quite coarse grained.

II. Our Idea/Approach

In this paper we propose to prototype a new experiment, based on PSN, which aims to investigate both the detailed movement patterns of people, and the corresponding dynamic network generated by such movements. This initial experiment will help us to refine our approach before planning a larger full-scale experiment. We are not only interested in the proximity network at Bluetooth distance, but also in the network of phone calls. In fact, we believe that efficient DTN should exploit all the internal correlations and reproducible properties of such dynamic networks at their best, in order to maximize efficiency and timing. We acknowledge that a full-scale experiment would need multi-disciplinary industry and academic support, and will need a large number of participants to be effective. In this experiment we will concentrate on exploring properties of these networks that we may be able to exploit, rather than the technical complexities of implementing communications using heterogeneous devices and protocols.

Several DTN algorithms already follow this approach, for example implementing routing based on some characteristic metrics [10], [11]. However, we believe that insights into the spatial location of nodes will be very useful in determining, for example, whether location should be considered as a further metric to improve information dissemination.

DTN researchers use simulators to create conditions that enable them to test their algorithms before deploying them to real-world applications. There is a number of factors within simulations that affect how life-like the simulators operate, namely the models used to simulate movement, transmission range, sensing range (in the case of WSN) and communications models.

Existing movement/interaction models for the simulation of PSN fall into three categories; those that are generated from a mathematical mobility model; those that are based on real traces, such as the Reality Mining dataset[4]; and those that are synthesised based on real data traces, such as the ZNetSim, from the ZebraNet [7] project.

We recognise that if one wants to send a message around in a human proximity network there can be a competition between two policies: routing based on some intrinsic network metric or a dissemination based on some fixed, highly frequented locations. We propose routing based on a mixture of local metrics. Messages are forwarded to nodes with higher values of the quantity μ, defined as:

$$\mu = max\{(c(d) - \bar{c}), (l(r) - \bar{l})\}, \quad (1)$$

where $c(d)$ is a notion of centrality based on a local connectivity information such as the node degree (d) [10], [12], and $l(r)$ is a location popularity based on the position r, and the history of the node itself. Both sub-metrics are measured with respect to a threshold parameter ($\bar{c}$ and $\bar{l}$), which depends on the particular type of network.

III. Goals

This study will help us to discover the inherent properties of human networks that can be exploited for communication. It will also generate a dataset with which we hope to synthesise new trace data, allowing us to test new communication mechanisms over realistic but simulated, human networks.

Our vision is to create a platform for PSN that can be adapted to a wide range of applications. Communication across a human proximity network will require a number of different mechanisms for delay tolerant communications depending upon the type of message to be transmitted: one-to-one, one-to-many, many-to-one and many-to-many. Our envisaged platform will have the following capabilities: smart routing based on patterns of co-location with other nodes and trajectories of movement which govern the likelihood of visiting some common place, and the ability for local phenomenon to affect global behaviour.

IV. Experimental Setup

We suggest an experiment using mobile phones, equipped with GPS, Bluetooth, GSM and WiFi antennas, which record the movements of participants, along with data about phone calls and SMS communications. Proximity will be based on Bluetooth devices spotted nearby. This is similar to the data collected in the Reality Mining project[3], however the observance of GPS readings for each device, combined with a recording of GSM cell-towers and WiFi access points with known locations, allows for extrapolation into accurate spatial location information [13].

Each device will be programmed communicate using one or more DTN routing methods (e.g. Flooding, Epidemic or CAR). Devices are instructed to communicate messages about basic environmental sensor data, such as temperature, humidity and light level, along with data about the path taken to deliver the message. In this way, we hope to be able to corroborate actual communications experiences with the recorded locational information.

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