CRAS QUIDEM

Tomorrow indeed

Communication, Routing And Scheduling
under QUasI DEterministic Mobility

1 Summary

Intermittently Connected Networks (ICNs), also known as Delay Tolerant Networks (DTNs), are mobile wireless networks where most of the time there is no complete path from a source to a destination (because the network is sparse or because of nodes mobility and vagaries of the wireless channel). In such a scenario information delivery is then based on the store-carry-forward paradigm: a mobile node first stores the routing message from the source, carries it from a physical location to another and then forwards it to another intermediate node or to the destination.

Most of the research on routing in ICNs has focused on two extreme cases: 1) when contacts among nodes are deterministic and known in advance or 2) when they cannot be predicted and are supposed to obey to some generic random mobility model. Many interesting scenarios do not fall in any of these two cases, because the underlying node mobility is known in advance, but it can be modified by random effects. We refer to such networks as "quasi-deterministic" ICNs.

This project aims to address the problem of message routing and scheduling in quasi-deterministic ICNs, bringing together two research teams

- INRIA Maestro Project-Team
- Telecommunication Networks Group of Politecnico di Torino

with complementary competences on routing for ICNs respectively under classical random mobility models and known deterministic contact times.

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Proposer: Giovanni Neglia, Maestro project-team.

2 Scientific Description

2.1 Background

Some of the recent applications using wireless communications (wildlife monitoring, inter-vehicles communication, battlefield communication,...) are characterized by challenging network scenarios. Most of the time there is not a complete path from a source to a destination (because the network is sparse), or such a path is highly unstable and may change or break while being discovered (because of nodes mobility and time-variations of the wireless channel). Networks under these conditions are usually referred to as Intermittently Connected Networks (ICNs) or Delay Tolerant Networks (DTNs). The existence of a path at a given moment is a fundamental assumption of all traditional routing protocols and also of those designed for ad hoc networks (like OLSR [1] or AODV [2]). Such protocols are therefore not suited for these new scenarios. Information delivery is then based on the store-carry-forward paradigm: a mobile node first stores the routing message from the source, carries it from a physical location to another and then forwards it to an intermediate node or to the destination. It is important to notice that the performance of ICNs are directly dictated by the inter-contact times between the nodes (which, in turn, are the result of nodes mobility pattern in the network). In particular, packet delivery delays become comparable with these inter-contact times, implying that application running on such networks should be tolerant to delays of order of minutes/hours (from which the name of delay tolerant networks originates). Typical examples of ICNs are those where nodes are intrinsically mobile (independently from data transfer purpose): vehicular networks [3] (in which data is carried over cars and buses), "pocket area networks" [3] (in which data is carried by people carrying small devices like PDAs), mixed ground/satellite networks and networks of sensors attached to animals [4]. Also some scenarios in which some nodes are mobile and some nodes are fixed (e.g, mobile devices with fixed gateways) present the same challenges.

The wide range of applications, promising performance results and concise modeling have led to an extensive research on ICNs during the last few years (e.g, [5–8]). At the core of this research line are *routing and scheduling algorithms*: at any given time, each node should find when and where to forward the data stored in its buffer so that it reaches the destination in a timely manner. Moreover routing for ICNs is not only limited to *forwarding schemes*, where a single copy of each packet is present in the network [9], but it also include *replication schemes*, which send many copies of the same data packet across the network. A prime example of replication schemes are *epidemic* routing algorithms (a.k.a *flooding algorithms*) in which each node sends each packet to *all* its neighbors. Replication improves performance in terms of delivery probability and delivery delay when contacts cannot be predicted or when transmissions are unreliable, but at the same time it implies higher costs in terms of required bandwidth, transmission energy and buffer requirements (see [10]).

2.2 Project Target

Most of the research on routing in ICNs has focused on two extreme cases: 1) when contacts among nodes are deterministic and known in advance (e.g. in the case of space communications among satellites, probes and earth or space stations [11]) or 2) when they cannot be predicted (e.g. for human and animal mobility [3, 4]) and are supposed to obey to some generic random mobility model, like random way-point, random direction or brownian models. Many interesting scenarios do not fall in any of these two cases: even complex mobility patterns often exhibit some form of periodicity or in other cases the underlying node mobility is known in advance, but it can be modified by random effects. A clear example is that of a vehicular network carrying data over public transportation (e.g., buses): the predictions of the contact times are derived from the schedule and routes of the buses; on the other hand, delays in bus operations clearly change the contact times or even prevent contact to occur, implying the predictions are not necessarily accurate.

Our preliminary investigation suggests that there is currently no framework to study comprehensively all the range of possible scenarios between deterministic contacts and unpredictable random contacts. For this reason, during the project, we plan to focus only on a specific class of networks characterized by *small deviations* from the deterministic contact model. We refer to such networks as "quasi-deterministic" ICNs. In particular, we consider the two following models as a starting point for our investigation. In the first one we assume that *predictions* of the contact times between nodes are known in advance, however these predictions are not necessarily accurate: contacts can occur either before or after their prediction times (e.g. the bus my arrive earlier or later to the stop). Meeting time jitters can be modeled as independent random noises. In the second model the noise affects the presence itself of the contact: contacts either occur at the expected time or do not occur at all (e.g. delays can prevent two buses with intersecting routes to have a contact), so that a meeting can be modeled as a Bernoullian process. To the best of our knowledge the first model was not considered in prior works, while [7] performs a preliminary analysis of the second model.

Given these two models, we aim to carry the following research axes:

1. Noise sensitivity of deterministic optimal routing. In [12], researchers participating to this project have determined optimal routing schemes under deterministic contacts. A preliminary stage of our work is to evaluate to which extent these schemes are robust to noise in the meeting process, i.e. to evaluate how performance decrease when routing is based on predicted contact times ignoring the presence of noise. From another point of view we want to evaluate what is the maximum amount of noise for which the stochastic nature of the process can be ignored. To this purpose we will also use real traces in order to model stochastic noise and evaluate its influence on the network performance.

2. Speed of infections. An important performance metric is the minimum time needed to spread an information to the whole network. This is strongly related to the notion of graph diameter. We want to derive a similar notion for the dynamic graphs corresponding to quasi-deterministic ICNs extending in some sense the approach of [13].

3. Offline optimal routing and scheduling. Given the contact predictions and *a priori* statistical information on the noise process, we are planning to develop a *multi-hop routing and scheduling algorithm* and evaluate its performance as a matter of throughput, delay and delivery probability. Going back to our vehicular DTN example, it is clear that, the shorter the waiting time between connections, the higher is the probability to miss the second connection. Thus, any routing algorithm should, for instance, choose between routing with long waiting times (implying high success ratio but large end-to-end delay) or routing with short waiting times (implying small end-to-end delay but low success ratio). We intend to develop an algorithm which balances these two options using a limited amount of data replication.

4. Online optimal routing and scheduling. An important extension of the study above is considering the possibility of online decisions, so that a node can choose how to route a packet at a given time on the basis of its knowledge of the noise process until that time. Clearly re-computing the routing and scheduling after each transmission may enhance the performance of the algorithm since recent network status will be taken into consideration. On the other hand, such re-computations (and information gathering) may be infeasible in real-life situations. The analytical framework to study this issue can be that of Markov Decision Processes, assuming that the evolution of the system depends only on the current state and on nodes actions.

From the methodological point of view, given the lack of a well established analytical framework to study these networks, we plan, as a first step, to evaluate the problem on simple topologies (such as lines, trees, rings or Chord-like ones) and relatively simple noise models (e.g. a Gaussian distribution). This analytical study will be complemented by simulations on many experimental traces, publicly available in [14], for different mobility scenarios (like public transportation systems, human meetings). These traces will also used to estimate realistic models for the noise process.

2.3 Potential Impact

We believe that the project may have a strong impact both from the theoretical and the practical point of view. In fact the problem is not only novel from the networking point of view, but also the considered contact processes originate a typology of dynamic graphs that has not been considered in graph theory literature. Also problems considered in transportation are essentially different, because there the focus is on node mobility planning (while in our case mobility is given), so that randomness can be addressed by imposing deterministic bounds to delay in order to guarantee specific performance with a given probability. From the practical point of view, our study could contribute to provide guidelines and algorithms to deploy operational vehicular networks with predictable mobility, like those based on public transportation or on car movements in a highway.

3 Participants

- INRIA Maestro project-team. The project-team Maestro has a large experience in stochastic models and performance evaluation of routing schemes for DTN networks under classical random mobility models (random waypoint, random direction, brownian motion, etc.).
  - Giovanni Neglia (CR2) has been working on fluid models and optimal policies for routing in ICNs [10, 15–17].
  - Leonardo Rocha (intern).
- Telecommunication Networks Group - Politecnico di Torino. The Telecommunication Networks Group has strong background in routing issues related to telecommunication networks.
  - Paolo Giaccone (Assistant Professor) has been working on capacity scaling in ad hoc networks [18], bounds to the performance of routing schemes in real DTN [19], and on optimal routing algorithms for ICNs with known deterministic contact times [12].
  - David Hay (PostDoc) is interested in algorithmic aspects of routing and has been working with Paolo Giaccone on optimal routing for deterministic ICNs [12].
  - Saed Tarapiah (PhD student).

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