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On the fly learning of mobility profiles for routing in pocket switched networks

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ABSTRACT

In this paper, we propose a novel routing protocol, PRO, for profile-based routing in pocket switched networks. Differing from previous routing protocols, PRO treats node encounters as periodic patterns and uses them to predict the times of future encounters. Exploiting the regularity of human mobility profiles, PRO achieves fast (low-delivery-latency) and efficient (low-message-overhead) routing in intermittently connected pocket switched networks. PRO is self-learning, completely decentralized, and local to the nodes. Despite being simple, PRO forms a general framework, that can be easily instantiated to solve searching and querying problems in adhoc smartphone networks. We validate the performance of PRO on real world traces and compare its performance with that of previous approaches.

1. Introduction

Cellphone technology has seen an adoption rate faster than any other technology in human history [10]: as of 2012, the number of cellphone subscribers has exceeded 6 billion users. The rate of innovation in this field has also been head-spinning. Nokia, Google, Microsoft, and Apple have all introduced cellphone operating systems (Symbian, Android, Windows Mobile, iPhoneOS) and provided APIs for enabling open application development on the cellphones. These modern cellphones, which are dubbed as *smartphones*, enable location-aware services as well as empowering the users to generate and access multimedia content. As such, smartphones open new opportunities for searching and information retrieval applications. Consider the following scenario:

Scenario: Mike is about to go to lunch with a colleague. He is trying to decide between an on-campus or off-campus lunch location. He finds the Student Union cafes much more convenient than off-campus locations unless there is a student event in the Union that makes conversation impossible. So he uses his smartphone to query the noise level of the Student Union. His query is forwarded hop-by-hop over the smartphones of students, and reaches a smartphone in the Student Union, which answers the query by taking audio-level samples and re-routes the reply back to Mike's phone.

Delay Tolerant Networks (DTNs), which are also known as intermittently connected networks, or opportunistic, store-and-forward networks [1,22,30,39] investigate routing techniques that would be of use in the above scenario. In DTNs, nodes are free to move and no centralized network infrastructure exists to provide communication among these mobile nodes. So, DTN routing protocols exploit the capability of nodes to perform a peer-to-peer data exchange with other nodes they encounter and strive to achieve data transfer even when the connectivity in the network is intermittent. However, the above described smartphone networks also introduce new challenge for DTN routing protocols. *The nature of human mobility and the structure of social networks* emerge as important factors in smartphone networks, while DTN routing algorithms have been oblivious to them.

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Recently Pocket Switched Networks (PSNs) [5,32,19,13] have been formulated as a subfield of DTNs where each node represents a person with a communication device. Several PSN routing protocols have been proposed [15,4,27,37]. These work assume different models on human mobility and community-structure, and use them for making routing decisions. Compared to DTN protocols, PSN protocols make use of more information about the network (context awareness), and in return aim to find faster paths to the destination with low message overhead (by involving a small number of selected nodes for message forwarding).

In this work, we are motivated by the observation that using smartphones it is possible to maintain more detailed contextual information about the nodes in the network, and hence design faster and more lightweight routing protocols than the existing work on PSNs. More specifically, we propose to employ smartphones to learn the regularity of human mobility profiles.

Previous works on human mobility [36,35] supports the regularity of mobility patterns in a way that some places are visited more frequently [36] and each node has its own set of important places [35]. Cho et al. [6] also showed that human mobility has structural patterns that is impacted by geographic and social constraints.

Our previous analysis [2] of MIT's Reality Mining dataset, which is one of the biggest publicly available cellphone connectivity data with 350 K hours of celltower connectivity logs [11], shows that significant amount of human mobility (85%) exhibits spatial and temporal regularity where users move between their top-k locations.

Here, we propose a fast (low-delivery-latency) and efficient (low-message-overhead) routing protocol for PSNs, based on the regularity of human mobility profiles and of intercontact events. Our protocol, namely PRO (profile-based routing protocol), is simple yet general enough to be easily instantiated to solve the smartphone search application scenario we introduced above. In particular the contributions of our paper are as follows:

- In a break from previous routing protocols, our protocol treats node encounters as periodic patterns and exploit them to predict the times of future intercontacts. Our profile-based estimation of intercontacts yields an accurate ranking of the potential forwarding nodes as to their ability to deliver the message earlier to the destination. Our PRO routing protocol uses self-learning nodes, and does not require pre-tuning.
- We provide an analysis on the effect of forwarding quota under random mobility model in Section 3 and show that forwarding the message to 2 other nodes is an efficient strategy in terms of communication overhead and delay trade-off. Selecting 2 as the quota improves the latency asymptotically compared to using 1 as the forwarding quota, whereas increasing the quota to more than 2 has less improvement compared to first jump. We also support our theoretical analysis with experiments on real traces in Section 5.
- We give a simple algorithm for making routing decisions. A node selects the highest ranked 2 nodes in its communication range and forwards the message to these nodes. Nodes that predict an intercontact with the destination node in the near future (*observed nodes*) have priority over nodes that are unlikely to see the destination node (*non-observed nodes*). Among the observed nodes, nodes that are likely to meet the destination node sooner have more priority. If the current node is unable to fill its forwarding quota with eligible observed nodes, it uses the available quota on non-observed nodes. Among the non-observed nodes, nodes whose profiles differ most from the profile of the current node have more priority. The rationale for this selection is to spread the message to as diverse communities as possible to improve the probability of encountering observed nodes in those communities.
- Unlike the synthetic test sets generated by simulators, we validate the performance of our routing protocol on real world datasets. We use the "Reality Mining' [11] and UCSD Wi-Fi [43] datasets for experimental purposes. Our results show that PRO achieves similar success rate and latency (10% less success and 10% more delay time) as the epidemic routing [48] with less than half the communication cost of the epidemic routing. PRO also outperforms the Prophet [39] and Bubble-rap [27] routing protocols (at least 20% less delay time and 25% more success) with less communication cost (at least 25% less communication than these two protocols).
- PRO routing protocol is completely decentralized and local to the nodes. PRO runs in an adhoc manner and does not depend on any central infrastructure or third party like Telephone Service Providers.
- Finally, we measure the performance of PRO on smartphone queries described above and show that PRO achieves similar query performance with Epidemic routing (in terms of delay and success) while using significantly less communication cost.

Outline of the paper: In Section 2 we discuss related work on PSNs. In Section 3, we present analytical results for finding the optimum number of forwarding quota. In Section 4, we present our PRO algorithm for profile-based forwarding of messages. Using the real traces, we evaluate the performance of PRO and compare it with previous work on routing in PSNs in Section 5. Finally, we conclude with Section 6.

2. Related work

In this section, we categorize and present PSN routing protocols in three broad categories. In each category, we pick a representative popular protocol and discuss it in more detail. Later, in Section 5 we use those three representative protocols to compare and contrast with our protocol.

Flooding-based protocols. In DTNs, replication of the original message is an effective way to increase the probability of successful delivery to the destination. *Epidemic routing* [48] is a representative example of these type of flooding-based routing protocols. In epidemic routing, the messages in the network diffuse like viruses by pairwise