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A sociality-aware approach to computing backbone in mobile opportunistic networks

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ABSTRACT

There are increasing interests on mobile opportunistic networks which have promising applications. Constructing a mobile backbone can effectively improve the packet delivery performance of a mobile opportunistic network by excluding poor relay nodes and reducing packet collisions. However, it is highly challenging to construct an effective mobile backbone because of the absence of the quantitative relationship between the network performance and the selection of backbone nodes, and expositive search space. We theoretically prove that the backbone construction problem is NP-Complete (NPC). By analyzing the real traces collected from around 100 users, we reveal that the nodes exhibit clear *sociality*. Motivated by this observation, we explicitly take such node sociality into account when computing the backbone for mobile opportunistic networks and we incrementally propose three algorithms for computing the mobile backbone. One of the algorithms is proved to achieve near-optimal solution under a specific model. Trace-driven simulations have been conducted and simulation results demonstrate that the sociality-aware algorithms can achieve low delivery delay and high delivery ratio.

1. Introduction

Because of the proliferation of wireless communications and fast progress of wireless networking techniques, there are increasing interests on mobile opportunistic networks, in which the communication between mobile nodes is opportunistic. Two nodes in mobile opportunistic networks can communicate with each other as they are within the communication range. Thus, there is usually not a connected path between a pair of nodes in the network. There are many examples of mobile opportunistic networks [18], such as vehicular ad hoc networks [21], and pocket switched networks [12]. A wide range of existing applications have been envisioned, e.g., driving safety for vehicular ad hoc networks and file sharing for pocket switched networks.

Inter-node packet delivery is a routine operation in mobile opportunistic networks, which is crucial to high-level applications. The performance of inter-node packet delivery in terms of delivery delay and success ratio is highly dependent on *relay selection*. Many forwarding algorithms [5,22,32,7] have been proposed for relay selection in mobile opportunistic networks. However, there remains a serious problem. Most of them assume that any node in the network can serve as a relay node, which is impractical and not wise. On the one hand, many nodes in the network can be limited in mobility, encountering few other nodes. If such poor nodes were selected as relays, the performance of packet delivery would suffer. On the other hand, if too many nodes act as relay nodes, there would be inevitable

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radio interferences among nodes, which degrade the network throughput.

Constructing a mobile backbone [24,14] can effectively solve the problem mentioned above. As illustrated in Fig. 1, a mobile backbone is a subset of network nodes, which serve as relay nodes. Nodes outside of the backbone do not relay packets. To deliver a data packet to the destination node, a source node can deliver it to the destination node either directly by itself or through multihop transmissions over nodes of the mobile backbone. By constructing the mobile backbone, the performance of inter-node packet delivery can potentially be improved by excluding poor relay nodes and reducing packet collisions.

However, it is highly challenging to construct an effective mobile backbone for mobile opportunistic networks. The main difficulties are as follows. *First*, the quantitative relationship between the network performance of packet delivery and the selection of backbone nodes is still unclear. *Second*, the search space for backbone nodes selection is explosively huge, which prevents expositive search.

A number of algorithms have been proposed for constructing a mobile backbone for mobile ad hoc networks (MANETs), which can be sorted into two categories. One category of algorithms [19,24] deploy heterogenous backbone nodes into the original network, which usually have more powerful communication capabilities. The algorithms of this category are unsuitable for constructing the backbone in a mobile opportunistic network. First, such heterogenous nodes are usually unavailable in mobile opportunistic networks. Second, constructed backbones by these algorithms cannot support a network with high mobility. The second category of algorithms select nodes from the network to form the backbone. The main idea is to construct a minimum connected dominating set (MCDS). However, all these algorithm require that the node density is high so that the network of nodes is well connected. As is well known, mobile opportunistic networks feature network disruptions and a very sparse node density. Thus, the algorithms of the second category are inappropriate for selection of backbone nodes in mobile opportunistic networks.

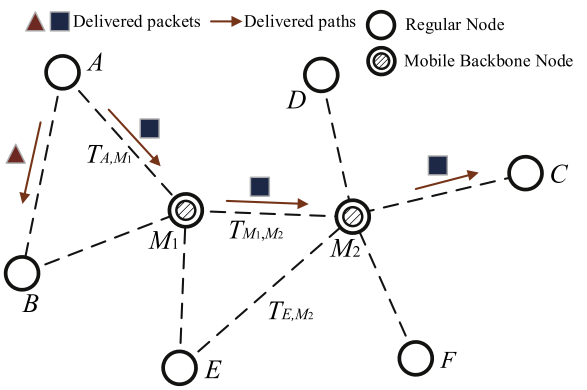

Fig. 1. An illustration of the backbone in a mobile opportunistic network. Two nodes have an edge which characterizes the encounter frequency between the two nodes. The two nodes $\{M_1, M_2\}$ together form a backbone. A packet delivered from node A to node C can be relayed by backbone nodes, as shown in the path.

By analyzing the real traces collected from around 100 users attending an international conference, we reveal that the inter-contact time of the mobile opportunistic network follows the *power law*, and thus the nodes in such a network have a strong feature of sociality. More specifically, some nodes encounter other nodes much more frequently than the rest of nodes. This suggests such sociality characteristics should be taken into account when constructing the mobile backbone.

Motivated by this observation, we explicitly take the network sociality into account when computing the backbone for mobile opportunistic networks. First, we characterize the quantitative relationship between the network performance of packet delivery and the selection of backbone nodes. Specially, we subdivides an opportunistic network into single-hop model and multi-hop model, according to the number of relays on a routing path. The construction of the backbone is then formulated as an optimization problem with the objective of minimizing the delivery delay between nodes. We theoretically prove that this problem is NP Complete (NPC). Next, we incrementally propose three algorithms for computing the mobile backbone. The first algorithm greedily selects backbone nodes according to the maximum decrement of delivery delay. Moreover, we prove it is an approximated algorithm in the single-hop model. Leveraging the sociality feature, the rest two algorithms consider node betweeness which characterizes the centrality of a node in the whole network. The second algorithm greedily selects backbone nodes according to node betweeness. Improving the second algorithm, the third algorithm further refines the computation of node betweeness by incorporating the inter-contact time of each node pair.

The main technical contributions of this paper are summarized as follows.

- We formulate the problem of computing the mobile backbone of a mobile opportunistic network as an optimization problem and formally prove that this problem is NPC.
- We propose three efficient algorithms for computing the mobile backbone. Two of the algorithms exploit the sociality feature of mobile opportunistic networks by computing node betweeness.
- We have performed extensive simulations based on real traces. Experimental results show that the sociality-aware algorithms achieve better packet delivery performance than other competing algorithms.

The rest of this paper is organized as follows. In Section 2 we review the related work. In Section 3 we describe the network model and formulate the problem of backbone construction. Section 4 presents the design details of the three algorithms for selecting mobile backbone nodes. In Section 5 we evaluate the algorithms via trace-driven simulations. We conclude in Section 6.