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Greedyflow: Distributed greedy packet routing between landmarks in DTNs

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ABSTRACT

Delay Tolerant Networks (DTNs) have attracted much research interest recently due to its adaptability in areas without infrastructures. In such scenarios, moving data from one place (landmark) to another place (landmark) is essential for data communication between different areas. However, current DTN routing algorithms either fail to fully utilize node mobility or have additional requirements that cannot be satisfied easily in DTNs. Therefore, in this paper, we propose a distributed greedy routing algorithm, namely GreedyFlow, for efficient packet routing between landmarks in DTNs. GreedyFlow builds a local traffic map and a global landmark map on each node. The local traffic map indicates the node's knowledge about the amount of traffic (node transition) between landmarks in the area where it primarily visits. The global landmark map shows the distribution of landmarks in the system and is built offline. In packet routing, the global landmark map shows the general packet forwarding direction, while the local traffic map helps determine the next-hop landmark on the fastest path in the forwarding direction. As a result, packets are greedily forwarded toward their destination landmarks. We also propose advanced components to enhance the consistency of local traffic maps and exploit node-based forwarding, both of which help improve the packet routing efficiency. Extensive real trace driven experiments demonstrate the high efficiency of GreedyFlow.

1. Introduction

In delay tolerant networks (DTNs) [1], mobile nodes communicate with each other directly without the need of infrastructures during the encountering. Therefore, DTNs are suitable for areas where infrastructures are either unavailable or too costly. In these scenarios, it is desirable to be able to forward packets from one place (landmark) to another place (landmark), i.e., packet routing between landmarks, to support many practical applications.

For example, people living in mountainous villages may wish to communicate with each other through their computers. However, it is costly to build needed infrastructures or enable satellite connection in each village. In this case, DTN can be exploited to transfer data between these villages using mobile devices carried by people or vehicles moving in the area [2]. We can also enable the satellite connection in one village and rely on the DTN based packet routing to support delay tolerant applications such as email. Similarly, such a communication structure can be used to collect data from sensors attached to animals in mountain areas without infrastructures [3]. Even in areas with infrastructures, it can be an effective backup scheme to support the dissemination of important messages in extreme scenarios such as disaster and outage [4].

Packet routing between landmarks in DTNs can be implemented by always forwarding a packet to the node that is more likely to move to its destination landmark [5–9]. This indicates that nodes that can frequently visit a packet's destination landmark to deliver the packet. As a result, the mobility of nodes that rarely visit a packet's destination landmark often is not used to forward the packet. Thus, when the number of nodes that frequently visit the destination landmarks is limited, the packet routing efficiency is also limited.

To solve this problem, some researchers have proposed to forward a packet along a sequence of landmarks (called landmark path) to better utilize node mobility for packet routing between landmarks [10–13]. In each hop, the packet is carried by a node to move from current landmark to the next landmark in the path. With such a design, all nodes moving between two consecutive landmarks on the landmark path can help forward the packet, even for nodes that rarely or never visit the packet's destination landmark. This means that node mobility is better utilized to forward packets.

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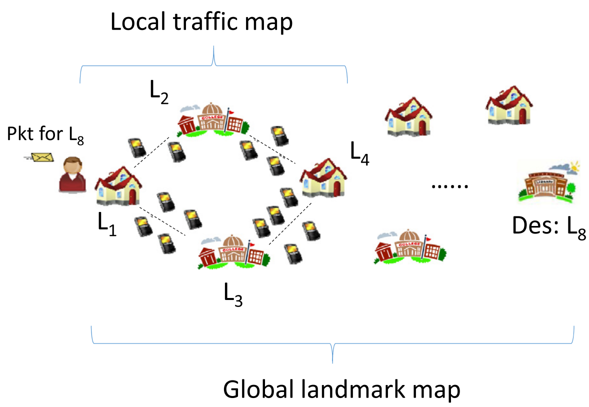

Fig. 1. Illustration of the design rationale.

However, the major drawback of these methods is that they require either base stations [10,11] or the global traffic distribution [12] to calculate the optimal landmark path for each packet. Such requirements cannot be satisfied easily in real DTNs. First, due to the long delay in DTN routing, the global traffic information cannot be updated timely on each node. Second, in some DTN scenarios, such as battlefields and mountain areas, it is hard to build base stations. Such a limitation poses a significant challenge on realizing efficient packet routing between landmarks in DTNs.

To solve the above challenge, we propose a distributed packet routing algorithm in DTNs, denoted GreedyFlow. We assume that the network is split into sub-areas represented by landmarks. GreedyFlow follows the idea of landmark-by-landmark forwarding to better utilize node mobility. It builds a global landmark map and a local traffic map on each node (Fig. 1). The global landmark map indicates the distribution of landmarks in the network and is built offline. The local traffic map reflects a node's knowledge about how frequently nodes transit between landmarks where it primarily visits. When a node meets another node, it collects the other node's transit frequencies between landmarks covered by its local traffic map to update the traffic map.

The global landmark map and local traffic map are used to guide packet routing. The basic idea is to greedily forward a packet to a landmark closest to the destination landmark within current packet holder's local traffic map (called temporary destination landmark). When a node (say N_i) receives a packet, it first determines the temporary destination landmark for the packet. Then, the node determines the fastest landmark path to the temporary destination landmark on its local traffic map and selects the next landmark on the path as the next-hop landmark. Next, N_i forwards the packet to the node that is predicted to move to the next-hop landmark.

For example, as shown in Fig. 1, suppose a node in L_1 receives a packet that is destined to far-away landmark L_8. The node uses its global landmark map to identify the landmark that is closest to L_8, which is L_4. It further uses the local traffic map to find the fastest path to L_4, which is $L_1 \rightarrow L_3 \rightarrow L_4$. Then, the packet is expected to be forwarded along this path to L_4. This process repeats when the packet arrives at a new node. With such a design, the packet is always forwarded towards the landmark closest to the destination landmark through the fastest path based on local information.

The above routing paradigm is further improved from two aspects. First, we allow nodes to exchange not only their own transit frequencies but also those they have learned from others, thus improving the consistency of the distributively collected local traffic maps. Second, instead of purely relying on the landmark-by-landmark forwarding, we allow packets to be carried by nodes to reach their destination landmarks directly when the expected delay is reduced. Both the two features are designed as optional components for GreedyFlow.

GreedyFlow makes packet forwarding decisions locally without the requirement of base stations or global traffic distribution. This is the major contribution of this work over current works [10–12] that also adopt landmark-based forwarding. In summary, the contributions of this paper include

- We propose a distributed traffic map generation method that enables each node to learn the node transition frequencies between landmarks in the area where it primarily visits. We also design a feature to enhance the consistency of those traffic maps.
- We propose a fully distributed greedy algorithm that routes packets in a landmark-by-landmark manner with the local traffic map and the global landmark map, thus better taking advantage of node mobility to realize efficient packet routing between landmarks in DTNs. In addition, an advanced component is proposed to exploit node-based forwarding appropriately to further improve the routing efficiency.
- Extensive real trace based experiments demonstrate the efficiency of the proposed algorithm.

The remaining of this paper is arranged as follows. Section 2 introduces related work. Section 3 presents the detailed system design. Section 4 conducts performance evaluation through real trace driven experiments. Finally, Section 5 concludes the paper with remarks on future work.

2. Related work

2.1. Packet routing between landmarks in DTNs

Packet routing between landmarks in DTNs [5–14] has been extensively studied recently. The authors in [5] observe the long term mobility pattern of each node and use such information to forward packets to nodes that frequently move to their destinations. GeoOpps [6] routes packets to geographical locations through vehicle networks. It always forwards packets to vehicles on the route with the smallest minimal estimated time of delivery (METD). In the work of [7], a packet is always forwarded to the node that has closer distance to its destination landmark. Both the works of [8] and [9] exploit multi-copy relay to efficient forward packets to areas that may cover destination nodes. The next-hop carrier of a packet is selected according to nodes' movement range estimated from historical location records [8] and homogeneous/heterogeneous mobility parameters [9], respectively. These methods mainly rely on nodes that are likely to visit the destination landmarks/areas. When the number of such nodes is limited, the routing efficiency is also limited.

In order to improve the efficiency of routing between landmarks, researchers have proposed to better utilize node mobility by forwarding packets in a landmark-by-landmark manner [10–14]. In LOUVER [10], base stations are built on road intersections for packet relay. Vehicle mobility is exploited to forward packets from one base station to another to reach the destination area. DTNFLOW [11] expands to general DTNs. It splits the whole network into sub-areas represented by landmarks. Then, predicted node mobility is used to carry packets from one landmark to another landmark. Geomob [12] utilizes the global traffic distribution to forward packets to different areas through the landmark based relay. AAR [13] decides the weights of road segments based on the traffic distribution and uses such information to find the fastest path to reach sub-areas in vehicular delay tolerant networks. MobiT [14] takes advantage of the trajectories of different types of vehicles to forward packets to landmarks that can deliver packets to destination vehicles.