

GRID SEARCH ALGORITHM FOR FINDING TWO-HOP ROUTING POLICIES IN DELAY TOLERANT NETWORKS

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Abstract— Social-based routing protocols has shown its promising capability for improving the message delivery efficiency in Delay Tolerant Networks (DTNs). The efficiency relies mostly on the quality of the aggregated social graph that has been determined by the metrics used for measuring the strength of social connections. In this paper, we have proposed an improved metrics that leads to the high-quality social graph by taking both frequency and duration of the contacts into its consideration. Furthermore, to improve the performance of the social-based message transmission, we have systematically studied the community evolution problem that has been little bit investigated in the literature. Distributed algorithms based upon our new proposed metrics have been developed in such a manner that the overlapping communities and bridge nodes (i.e., connecting nodes between communities) can be dynamically detected in the evolutionary social network. Finally, we have taken all the results above into our social-based routing design. The extensive trace-driven simulation results have shown that our routing algorithm outperforms in the existing social-based forwarding strategies significantly.

Keywords— Delay tolerant networks, Social-aware routing, connection strength metric, social graph, community, bridge node.

1. Introduction

With the advances in wireless communication technologies and the decreasing cost of smartphones, handheld devices, and laptops, wide-area mobile ad hoc networks have been deployed spanning entire cities. Such networks involve pedestrians and vehicles on the roads, existing infrastructure on the road sides, and even people and devices inside buildings. These types of heterogeneous networks are characterized by their fast and continuously changing topologies, a diverse variety of resource-constraints such as buffer, energy, and bandwidth, and the frequent partitioning among its nodes. Because of these challenges, data is handled on

a best-effort basis, and the objective becomes the delivery of as much data as possible with the minimum resource consumption. These networks are called delay tolerant networks (DTN). Applications of DTN have been found in many challenging environments such as providing delay-tolerant Internet services in suburban and rural areas. This project has been implemented by first mile solutions with a system called DakNet. Vehicular networking is a wide and growing field of DTNs, where many applications are being explored. One of these applications is the virtual warning signs that bring the hidden or unseen warning signs to the vehicle driver to be able to take the required precautions as early as possible. Another application is to provide Internet access to vehicles, by connecting to roadside wireless base stations. Non-commercial applications include monitoring and tracking wildlife animals and whales in oceans, and environmental monitoring, such as lake water quality monitoring and road-side noise monitoring. Traditional routing protocols for wired and wireless networks fail to work in the DTN environment because they assume the existence of continuous end-to-end connections between sources and destinations. Routing protocols developed for DTN should be adapted to this challenging environment by sending multiple copies of data packets to increase the probability that one of the copies reaches the destination. Nodes receiving the packet copies store them until they meet other nodes or meet their destinations. From the analysis of current DTN routing protocols, it is found that there are several trade-offs to be considered in a protocol design:

- A trade-off between maximizing packet delivery ratio and minimizing the delivery cost. [2] Maximizing delivery ratio requires increasing the number of packet copies spread throughout the network to increase the probability of reaching the destination, while minimizing delivery cost, in terms of network overhead, requires decreasing the number of copies.
- Another trade-off is the compromise regarding the amount of information collected to guide the packets to their destinations. Collecting information from the network helps in selecting the relaying nodes to the destination, but requires time to collect the information that increases the packet delays. On the other hand, collecting little or no information leads to spreading the packet copies blindly, and decreases the probability of reaching the destination unless a large number of copies were spread.

Our objective is to develop a routing protocol that spreads a small number of packet copies to reduce network overhead, while guiding the packet copies using only local information to reach the destination. To achieve that goal, we exploit the social grouping characteristic of DTN nodes. We consider two nodes to belong to the same social group if they contact each other frequently compared to their contacts with other nodes[6]. All of the previous work focused on using inclusive social metrics, which predicts the path from source to destination by including nodes with strong social connections. The disadvantages of this approach are the need to collect network wide information to better predict the path to destination. We claim that our work is the first to propose an exclusive social metric, which sprays messages by excluding nodes that are not expected to add a significant value to the

node carrying the message. Using exclusive metrics reduces the need to collect network wide information, while improving the performance metrics. More explanation is provided in Section 4. We summarize our contributions in this paper as follows:

- A new heuristic multiple-copy routing protocol, social groups-based routing (SGBR), is proposed. The protocol exploits social grouping among network nodes to increase the packet delivery probability, without flooding the network with many redundant copies.
- A mathematical model of single-copy optimal routing, OPT, is formulated, assuming the availability of present and future node contacts and buffer information. The results are used as a performance benchmark to compare with the heuristic protocols.
- Using simulations, we compare the proposed protocol SGBR, with a full flooding protocol (epidemic routing), a limited flooding protocol (binary spray-and-wait (SnW)) two guided routing protocols PROPHET and MAXPROP, and the results of the optimal routing formulation OPT in terms of their delivery ratio, packet delivery cost, and average packet delay. The comparison is conducted as a function of the buffer capacities, and the time-to-live (TTL) values of data packets.
- Results show that the proposed protocol SGBR achieves higher delivery ratio than the other protocols (around 10 percent higher than the closest heuristic protocol and more than 20 percent of the worst one) and approaching the optimal results. In addition, it reduces network overhead to less than half that of the other protocols. In terms of delay, results show that SGBR provides same or slightly lower average delay than the other protocols.

2. Related Work

2.1 Social-Aware Stateless Routing in Pocket Switched Networks

Existing social-aware routing protocols for pocket switched networks make use of the information about the social structure of the network deduced by state information of nodes (e.g., history of past encounters) to optimize routing. Although these approaches are shown to have superior performance to social-oblivious, stateless routing protocols (Binary SW, Epidemic), the improvement comes at the cost of considerable storage overhead required on the nodes. In this paper we present SANE, the first routing mechanism that combines the advantages of both social-aware and stateless approaches.

SANE is based on the observation—that we validate on a real-world trace—that individuals with similar interests tend to meet more often. In SANE, individuals (network members) are characterized by their interest profile, a compact representation of their interests [4]. By implementing a simple routing rule based on interest profile similarity, SANE is free of network state information, thus overcoming

the storage capacity problem with existing social-aware approaches. Through thorough experiments, we show the superiority of SANE over existing approaches, both state full, social-aware and stateless, social-oblivious. We discuss the statelessness of our approach in the Supplementary File of this manuscript. Our interest-based approach easily enables innovative networking services, such as interest-casting. An interest-casting protocol is also introduced in this paper, and evaluated through experiments based on both real-world and synthetic mobility traces.

2.2 On Social Delay Tolerant Networking: Aggregation, Tie Detection, and Routing

Social-based routing protocols have shown their promising capability to improve the message delivery efficiency in Delay Tolerant Networks (DTNs). The efficiency greatly relies on the quality of the aggregated social graph that is determined by the metrics used to measure the strength of social connections. In this paper, we propose an improved metrics that leads to high-quality social graph by taking both frequency and duration of contacts into consideration. Furthermore, to improve the performance of social-based message transmission, we systematically study the community evolution problem that has been little investigated in the literature. Distributed algorithms based on our new proposed metrics are developed such that the overlapping communities and bridge nodes (i.e., connecting nodes between communities) can be dynamically detected in an evolutionary social network. Finally, we take all the results above into our social-based routing design. Extensive trace-driven simulation results show that our routing algorithm outperforms existing social-based forwarding strategies significantly.

2.3 A Novel Message Scheduling Framework for Delay Tolerant Networks Routing

Multi-copy routing strategies have been considered the most applicable approaches to achieve message delivery in Delay Tolerant Networks (DTNs). [5] Epidemic routing and two-hop forwarding routing are two well reported approaches for delay tolerant networks routing which allow multiple message replicas to be launched in order to increase message delivery ratio and/or reduce message delivery delay. This advantage, nonetheless, is at the expense of additional buffer space and bandwidth overhead. Thus, to achieve efficient utilization of network resources, it is important to come up with an effective message scheduling strategy to determine which messages should be forwarded and which should be dropped in case of buffer is full. This paper investigates a new message scheduling framework for epidemic and two-hop forwarding routing in DTNs, such that the forwarding/dropping decision can be made at a node during each contact for either optimal message delivery ratio or message delivery delay. Extensive simulation results show that the proposed message scheduling framework can achieve better performance than its counterparts.

2.4 SGBR: A Routing Protocol for Delay Tolerant Networks Using Social Grouping

Delay tolerant networks (DTN) are characterized by a lack of continuous end-to-end connections due to node mobility, constrained power sources, and limited data storage space of some or all of its nodes. To overcome the frequent disconnections, DTN nodes are required to store data packets for long periods of time until they come near other nodes. Moreover, to increase the delivery probability, they spread multiple copies of the same packet on the network so that one of them reaches the destination. Given the limited storage and energy resources of many DTN nodes, there is a tradeoff between maximizing delivery and minimizing storage and energy consumption. In this paper, we study the routing problem in DTN with limited resources. We formulate a mathematical model for optimal routing, assuming the presence of a global observer that can collect information about all the nodes in the network. Next, we propose a new protocol based on social grouping among the nodes to maximize data delivery while minimizing network overhead by efficiently spreading the packet copies in the network. We compare the new protocol with the optimal results and the existing well known routing protocols using real life simulations. Results show that the proposed protocol achieves higher delivery ratio and less average delay compared to other protocols with significant reduction in network overhead.

2.5 Combined Optimal Control of Activation and Transmission in Delay-Tolerant Networks

Performance of a delay tolerant network has strong dependence on the nodes participating in data transportation. Such networks often face several resource constraints especially related to energy. Energy is consumed not only in data transmission but also in listening and in several signaling activities. On one hand these activities enhance the system's performance while on the other hand, they consume significant amount of energy even when they do not involve actual node transmission. Accordingly, in order to use energy efficiently, one may have to limit not only the amount of transmissions but also the amount of nodes that are active at each time. Therefore we study two coupled problems:

- i) The activation problem which determines when a mobile will turn on in order to receive packets, and
- ii) the problem of regulating the becoming. We derive optimal energy management strategies by formulating the problem as an optimal control one, which we then explicitly solve.

We also validate our findings through extensive simulations which are based on contact traces.

d formal definitions of forward-secure signature and presented

3. Proposed Method

A homogeneous DTN is modelled as a set of N nodes, all moving according to a specific mobility model in a finite area, where inter-encounter time between each pair of nodes follows an independent and identical distributed (iid). Let the number of total messages in the network be denoted as $K(t)$, and the buffer capacity of each node be denoted as B messages.[1] The messages are generated arbitrarily between source and destination nodes. Each message is destined to one of the nodes in the network with a time-to-live (denoted as T_x). A message is dropped if its T_x timer expires. For any given node a , it is assumed that $J_a(t)$ messages are stored in its buffer at time t . Each message i , $i \in [1; J_a(t)]$ is denoted by a tuple of variables denoted in Table 1. Obviously we have $s_i(t) = n_i(t)$ if all the encountered nodes of message i have available buffer space, and $n_i(t) \leq m_i(t) + 1$. Let the inter-encounter time of any two nodes a and b be denoted as $4T(a;b)$, which is defined as the time period taken by the two nodes to enter into their transmission again. The average encounter (or mixing) rate between a and b , denoted as $(a;b)$, is the inverse of the average inter-encounter time for the two nodes: $(a;b) = 1 / E[4(a;b)]$. We assume that all inter-encounter times, $4T(a;b)$; $a, b \in [1;N]$ are exponentially distributed (or referred to as with an exponential tail).

3.1 MODULE DESCRIPTION

3.1.1 General Route Based Module:

In order to evaluate the performance of an RB switching scheme, we make the following assumptions. In the case of NRB switching, there is no reservation of a route prior to data transmission. As opposed to an RB scheme, in this scenario, multi-hop routes can overlap. In particular, a node can serve as a relay for more than one route. In other words, when a node receives a message from another node (i.e., it acts as a relay), it places such message in its own queue (intermingled with its own generated messages). The messages in the queue are transmitted sequentially (i.e., the priority given to relay and new locally generated messages is the same).

3.1.2 Securer Route based Module:

Each node in the network generates messages according to a Poisson process with average arrival rate λ_m (dimension: [msg/s]). [2] While a node is acting as a relay, it still generates its own messages, which are buffered for future transmission. The message length L_m is exponentially distributed with average value L_m (dimension: [b/msg]). Considering a fixed transmission data rate R_b (dimension: [b/s]), the message duration is therefore exponentially distributed with mean value equal to L_m/R_b . Since intermediate nodes on a multi-hop route serve only one source node at a time, simultaneously active multi-hop routes are disjoint. In addition, given that each multi-hop route has a certain

average length, there exists a maximum average number, denoted by C_s , of simultaneously active routes.

3.1.3 Destination module:

The task of this module is to accept the packet from the Egress router and stored in a file in the Destination machine.

3.1.4 Comparison Module:

The overall behaviour of an RB scheme can therefore be characterized as bimodal: either almost constant, with respect to traffic load, or infinite. [3] It represents that the delay of an RB scheme is lower than that of an NRB scheme by more than one order of magnitude for every considered node spatial density. Based on these results, we predict that, in a realistic network, an RB scheme is still likely to outperform an NRB scheme in terms of delay. Nonetheless, the maximum traffic that an RB scheme can support is lower than that of the RB scheme. This is due to the constraint on the disjoint routes. It is important to note, however, that the difference between the maximum traffic loads that the two schemes can support decreases as the node spatial density increases. In other words, an RB switching scheme becomes preferable, delay wise, in dense ad hoc wireless networks.

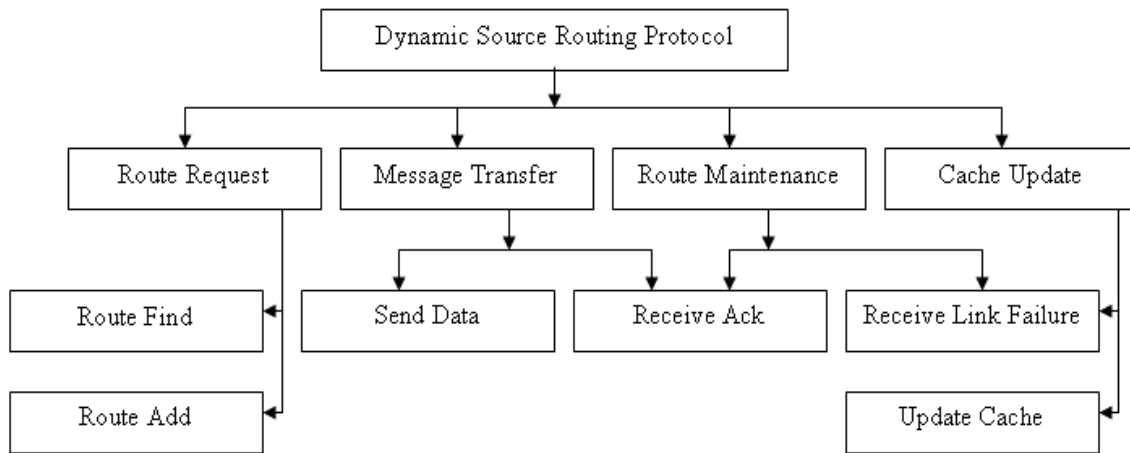


Fig. 3.1 Architecture diagram

4. Conclusion

This paper has investigated a novel message scheduling framework for epidemic and two-hop forwarding routing in homogeneous delay tolerant networks (DTNs), aiming to optimize



either the message delivery ratio or message delivery delay. The proposed framework incorporates a suite of novel mechanisms for network state estimation and utility derivation, such that a node can obtain the priority for dropping each message in case of buffer full. Using simulations based on two mobility models; a synthetic (Random Way Point) and a real trace model (Zebra Net), the simulation results show that the proposed buffer management policies, named GHP, can significantly improve the routing performance in terms of the performance metrics of interest under limited network information.

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