Social-tie based Content Retrieval for Delay-Tolerant Mobile Ad-hoc Networks

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ABSTRACT

Previous studies have shown that social networking can assist delay-tolerant routing design in many respects. In this paper, we specifically address content retrieval in delay-tolerant mobile ad-hoc networks. We propose a social-tie based content retrieval scheme to support the delay-tolerant MANET. The social hierarchy is structured using balanced connectivity criteria and a K-mean clustering algorithm. The proposed scheme has been evaluated and validated on a real social network dataset.

Categories and Subject Descriptors

C.2.2 [**Computer-Communication Networks**]: Network Protocols

Keywords

Social Network; Information-centric Network; Delay-Tolerant Mobile Ad-hoc Network

1. INTRODUCTION

One major design challenge of content retrieval in delay-tolerant Mobile Ad-hoc Networks (MANETs) is mobility. In sparse MANETs, network connectivity is highly dynamic and can vary rapidly. A common approach to deliver messages in a delay-tolerant network is social network routing. Disconnection gaps between nodes are overcome using a carry-and-forward principle. However, social network assisted delay-tolerant routing cannot be deployed directly in mobile Information-Centric Network (ICN), since the content provider is not exposed during the content search phase, and a naïve-flooding query method will produce a high transmission cost. Moreover, content search and content delivery phase are sequential and, as we shall see, cannot use the same social network for routing.

In this paper, we propose a Social-Tie based Content Retrieval (STCR) scheme in delay-tolerant MANETs, which address the scalable content retrieval in large-scale sparse MANETs. We build a hierarchical architecture using K-mean clustering algorithm based on the social-tie between nodes to improve forwarding efficiency. We also propose novel methods to compute the social-tie relationship considering both frequency and recency, and to compute centrality sequence considering both average social-tie and its balanced distribution. We show that STCR scheme is effective in providing efficient content retrieval in delay-tolerant MANETs.

2. RELATED WORK

PeopleRank [1] is inspired by the PageRank algorithm [2] to identify the most popular nodes to forward the message to, given that a higher PeopleRank value means more "central" in the social graph. SimBetTS [3] uses egocentric centrality and its social similarity to forward messages toward the node with highest centrality to increase the possibility of finding the potential carrier to the final destination. BubbleRap [4] combines the observed hierarchy of centrality and observed community structure with explicit labels, to decide on the best forwarding nodes. Our work differs from all studies above in several aspects. First, we build the social hierarchy by centrality using both frequency and freshness criteria and employing a novel social metric computation. Second, we use centrality to direct the content query process to avoid naïve flooding method. After the content provider is exposed, we use social-tie routing to forward messages to the relay node that has the best probability to reach the content provider than other nodes. We don't use the concept of centrality in this phase since higher centrality only reflects the higher average probability to meet all other node, not the target destination. Third, we use the K-mean clustering algorithm to identify which forwarding direction offers the best performance in terms of message retransmission costs.

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3. PROTOCOL DESIGN

3.1 Preliminaries

To support the content retrieval in sparse MANETs, STCR performs the following main operations.

1) Advertise *Hello* message

Each node periodically advertises Hello messages for discovery of encounters in its transmission range. Hello message contains sender's node-id. Hello transmission interval is 100ms.

2) Record encounter event

A data structure called encounter-vector which includes encountered node-id and timestamp of this encounter event, as shown in (1), will be created after each encounter event:

<node-id, timestamp> (1)

Every node maintains an encounter-table which stores encounter-vectors created by the node at the encounter time.

3) Compute social relationship

Combining the concepts of frequency and freshness, we define the social-tie concept that will be used to evaluate two nodes' social relationship. The encounter event's contribution to this value is determined by a weighing function $F(x)$, where x is the time span from the encounter event to the current time. Assume that the system time is represented by an integer and based on n encounter events of node i, the social-tie value of node i relationship with node j at time t_{base}, denote by $R_i(j)$, is defined as (2).

$$R_i(j) = \sum_{k=1}^{n} F(t_{base} - t_{j_k}) \qquad (2)$$

where $F(x)$ is a weighing function and $\{ t_{j_1}, t_{j_2}, \cdots, t_{j_n} \}$ are the encounter time when node i met node j and $t_{j_1} < t_{j_2} < \cdots < t_{j_n} \leq t_{base}$. We take $F(x) = (\frac{1}{2})^{\lambda x}$ where $\lambda = 1e^{-4}$. The social-tie value at the time of nth encounter event can be computed from the time of the $(n-1)th$ encounter event and the social-tie value at that time. The computational and storage overhead can be reduced drastically due to this feature and each node is not required to maintain the record of all the past encounter events.

4) Exchange social-tie table

Each node maintains a social-tie table that contains the social distances from the current node to all other encountered nodes, and each social-tie comes with a timestamp t_{base} when computed, and exchanges with each other.

5) Compute centrality

Centrality measures the average social distance from the given node to all other encountered nodes in (3), where N is the number of nodes observed from social-tie table, and R is the social-tie from the given node to each of other nodes.

$$\frac{\sum_{k=1}^{N} R_i(k)}{N} \tag{3}$$

We adopt Jain's Fairness Index mechanism [5] to evaluate the balance distribution of social-tie values in (4).

$$Jain's\ Fairness\ Index\colon balance = \frac{(\sum x_i)^2}{n \times \sum {x_i}^2} \tag{4}$$

The centrality metric is defined in (5), where N is the encountered node count in the encounter table, α is set to 0.5.

$$C_i = \alpha \frac{\sum_{k=1}^{N} R_i(k)}{N} + (1-\alpha) \frac{\left(\sum_{k=1}^{N} R_i(k)\right)^2}{N \times \sum_{k=1}^{N} (R_i(k))^2} \tag{5}$$

3.2 Content Name Digest and Convergence

In the content query phase, in order to avoid pure flooding, we design this digest convergence process. Each node uses a 128-bit Bloom Filter to digest its contents' name, and actively announces its content name digest with timestamp to higher centrality nodes. In this way, each node collects content name digests from lower centrality nodes, and reports the collected digests to higher centrality nodes. The higher centrality node has the larger knowledge of the content name digests, and knows which content provider contains which content.

3.3 Content Request

An Interest packet which contains requester's node-id and content name will be generated and forwarded to a higher centrality node to avoid naïve flooding. If the relay node has a similar centrality with the current node, they may have a similar knowledge on the content name digests, thus we may not get much benefit from this forwarding. We divide nodes into clusters according to their centrality distribution, and forward the Interest packet to a newly encountered node which belongs to a higher centrality cluster to further reduce the transmission cost. We use K-mean clustering algorithm to build a social hierarchy, and nodes in social-tie table are assigned into different levels. After each forwarding, the nodes (both content requester and relay node) keep a copy of Interest packet and forwards to the next encountered node that has an even higher social level than last relay node. Following this strategy, the Interest packet is forwarded upward level by level or jumps to a higher level towards the most popular node in the centrality hierarchy, and will be solved eventually when the Interest name matches one content name in the digest table for a certain node at some level of the hierarchy.

3.4 Social-tie Routing

The content provider's node-id has been disclosed and attached in the Interest packet. Using the local social-tie table and K-mean clustering, we can generate a content provider's social-tie sequence and build a social-tie hierarchy, then forward Interest to higher social-tie hierarchy toward content provider. Content provider will send the content back to the requester using the social-tie routing again.

4. PERFORMANCE EVALUATION

We implemented the proposed STCR scheme in NS-3.17 network simulator and evaluate its performance via INFOCOM'06 contact traces comparing with BubbleRap and PeopleRank.

Hit rate: the percentage of Interests that are successfully delivered to the content providers and the content data are successfully delivered to the requesters. This metric reflects the capability of a method to discover the requested content.

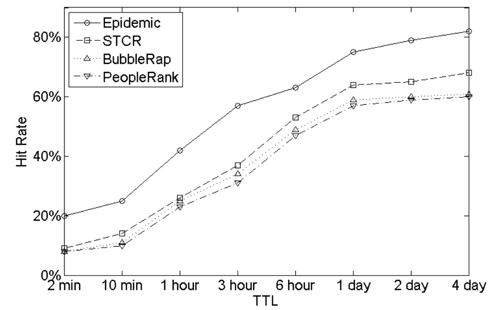

Fig. 1. Hit Rate

Total cost: the total number of messages replicas in the network. To normalize this, we divide it by the total number of unique messages created.

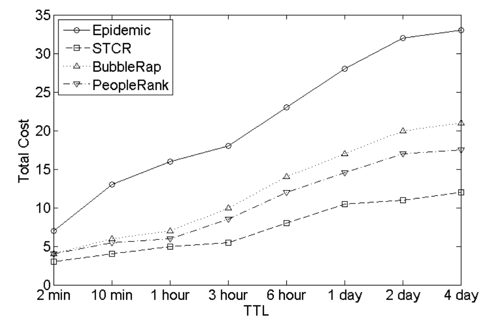

Fig. 2. Total Cost

5. CONCLUSION

We proposed a social-tie based content retrieval protocol to address the content retrieval in delay-tolerant MANETs. The social-tie routing scheme uses K-mean clustering to improve efficiency, considering both the frequency and freshness of encounters, and balanced connectivity with all other nodes.

6. REFERENCES

[1] A. Mtibaa, M. May, C. Diot, and M. Ammar, "PeopleRank: Social Opportunistic Forwarding," in INFOCOM 2010 Proceedings pp. 1-5, 2010.

[2] S. Brin and L. Page, "The anatomy of a large-scale hypertextual Web search engine," Computer Networks and ISDN Systems, vol. 30, pp. 107-117, 4, 1998.

[3] E. M. Daly and M. Haahr, "Social Network Analysis for Information Flow in Disconnected Delay-Tolerant MANETs," Mobile Computing, IEEE Transactions on, vol. 8, pp. 606-621, 2009.

[4] H. Pan, J. Crowcroft, and E. Yoneki, "BUBBLE Rap: Social-Based Forwarding in Delay-Tolerant Networks," Mobile Computing, IEEE Transactions on, vol. 10, pp. 1576-1589, 2011.

[5] R.Jain, D.M.Chiu, and W.Hawe, "A Quantitative Measure of Fairness and Discrimination for Resource Allocation in Shared Systems," DEC Research Report TR-301, 1984.