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Leveraging Social Networks for P2P Content-Based File Sharing in Disconnected MANETs

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Abstract—Current peer-to-peer (P2P) file sharing methods in mobile ad hoc networks (MANETs) can be classified into three groups: flooding-based, advertisement-based, and social contact-based. The first two groups of methods can easily have high overhead and low scalability. They are mainly developed for connected MANETs, in which end-to-end connectivity among nodes is ensured. The third group of methods adapts to the opportunistic nature of disconnected MANETs but fails to consider the social interests (i.e., contents) of mobile nodes, which can be exploited to improve the file searching efficiency. In this paper, we propose a P2P content based file sharing system, namely SPOON, for disconnected MANETs. The system uses an interest extraction algorithm to derive a node's interests from its files for content-based file searching. For efficient file searching, SPOON groups common-interest nodes that frequently meet with each other as communities. It takes advantage of node mobility by designating stable nodes, which have the most frequent contact with community members, as community coordinators for intracommunity searching, and highly mobile nodes that visit other communities frequently as community ambassadors for intercommunity searching. An interest-oriented file searching scheme is proposed for high file searching efficiency. Additional strategies for file prefetching, querying-completion, and loop prevention, and node churn consideration are discussed to further enhance the file searching efficiency. We first tested our system on the GENI Orbit testbed with a real trace and then conducted event-driven experiment with two real traces and NS2 simulation with simulated disconnected and connected MANET scenarios. The test results show that our system significantly lowers transmission cost and improves file searching success rate compared to current methods.

Index Terms—MANETs, content-based file sharing, social networks

1. Introduction

In the past few years, personal mobile devices such as laptops, PDAs, and smartphones have been more and more popular. Indeed, the number of smartphone users increased by 118 million across the world in 2007 [1], and is expected to reach around 300 million by 2013 [2]. The incredibly rapid growth of mobile users is leading to a promising future, in which they can freely share files between each other whenever and wherever. The number of mobile searching users (through smartphones, feature phones, tablets, etc.) is estimated to reach 901.1 million in 2013 [3]. Currently, mobile users interact with each other and share files via an infrastructure formed by geographically distributed base stations. However, users may find themselves in an area without wireless service (e.g., mountain areas and rural areas). Moreover, users may hope to reduce the cost on the expensive infrastructure network data. The P2P file sharing model makes large-scale networks a blessing instead of a curse, in which nodes share files directly with each other without a centralized server. Wired P2P file sharing systems (e.g., BitTorrent [4] and Kazaa [5]) have already become a popular and successful paradigm for file sharing among millions of users. The successful deployment of P2P file sharing systems and the aforementioned impediments to file sharing in MANETs make the P2P file sharing over MANETs (P2P MANETs in short) a promising complement to current infrastructure model to realize pervasive file sharing for mobile users. As the mobile digital devices are carried by people that usually belong to certain social relationships, in this paper, we focus on the P2P file sharing in a disconnected MANET community consisting of mobile users with social network properties. In such a file sharing system, nodes meet and exchange requests and files in the format of text, short videos, and voice clips in different interest categories. A typical scenario is a course material (e.g., course slides, review sheets, assignments) sharing system in a school campus. Such a scenario ensures for the most that nodes sharing the same interests (i.e., math), carry corresponding files (i.e., math files), and meet regularly (i.e., attending math classes). In MANETs consisting of digital devices, nodes are constantly moving, forming disconnected MANETs with opportunistic node encountering. Such transient network connections have posed a challenge for the development of P2P MANETs. Traditional methods supporting P2P MANETs are flooding-based [6], [7], [8], [9] or advertisement-based [10], [11], [12]. The former methods rely on flooding for file searching. However, they lead to

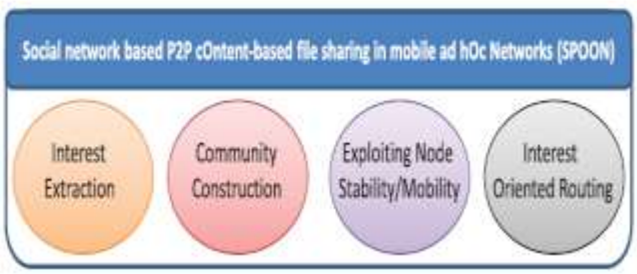

Fig. 1. Components of SPOON.

high overhead in broadcast. In the latter methods, nodes advertise their available files, build content tables, and forward files according to these tables. But they have low search efficiency because of expired routes in the content tables caused by transient network connections. Also, advertising can lead to high overhead. Some researchers [13], [14], [15], [16], [17] further proposed to utilize cache/replication to enhance data dissemination/access efficiency in disconnected MANETs. However, nodes in these methods passively wait for contents that they are interested in rather than actively search files, which may lead to a high search delay. Recently, social networks are exploited to facilitate content dissemination/publishing in disconnected MANETs [18], [19], [20], [21]. These methods exploit below property to improve the efficiency of message forwarding:

- (P1) nodes (i.e., people) usually exhibit certain movement patterns (e.g., local gathering, diverse centralities, and skewed visiting preferences).

However, these methods are only for the dissemination of information to subscribers. They are not specifically designed for file searching. Also, they fail to take into account other properties of social networks revealed by recent studies to facilitate content sharing:

- (P2) Users usually have a few file interests that they visit frequently [22] and a user's file visit pattern follows a power-law distribution [23].
- (P3) Users with common interests tend to meet with each other more often than with others [24].

By leveraging these properties of social networks, we propose social network-based P2P content-based file sharing in disconnected mobile ad hoc Networks (SPOON) with four components as shown in Fig. 1:

1. Based on P2, we propose an interest extraction algorithm to derive a node's interests from its files. The interest facilitates queries in content-based file sharing and other components of SPOON.

2. We refer to a collective of nodes that share common interests and meet frequently as a community. According to P3, a node has high probability to find interested files in its community. If this fails, based on P1, the node can rely on nodes that frequently travel to other communities for file searching. Thus, we propose the community construction algorithm to build communities to enable efficient file retrieval.

3. According to P1, we propose a node role assignment algorithm that takes advantage of node mobility for efficient file searching. The algorithm designates a stable node that has the tightest connections with others in its community as the community coordinator to guide intra community searching. For each known foreign community, a node that frequently travels to it is designated as the community ambassador for intercommunity searching.
4. 4.We propose an interest-oriented file searching and retrieval scheme that utilizes an interest-oriented routing algorithm (IRA) and above three components. Based on P3, IRA selects forwarding node by considering the probability of meeting interest keywords rather than nodes. The file searching scheme has two phases: Intra- and intercommunity searching. In the former, a node first queries nearby nodes, then relies on coordinator to search the entire home community. If it fails, the intercommunity searching uses an ambassador to send the query to a matched foreign community. A discovered file is sent back through the search path or the IRA if the path breaks.

SPOON is novel in that it leverages social network properties of both node interest and movement pattern. First, it classifies common-interest and frequently encountered nodes into social communities. Second, it considers the frequency at which a node meets different interests rather than different nodes in file searching. Third, it chooses stable nodes in a community as coordinators and highly mobile nodes that travel frequently to foreign communities as ambassadors. Such a structure ensures that a query can be forwarded to the community of the queried file quickly. SPOON also incorporates additional strategies for file prefetching, querying-completion and loop-prevention, and node churn consideration to further enhance file searching efficiency. The rest of the paper is arranged as follows: Section 2 provides an overview of related works. Section 3 presents the design of the components of SPOON. In Section 4, the performance of SPOON is evaluated in comparison with other systems. The last section presents concluding remarks and future work.

2. Related Work

2.1. P2P File Sharing in MANETs

We first introduce the P2P file sharing algorithms designed in MANETs.

2.1.1. Flooding-Based Methods: In flooding-based methods, 7DS [6] is one of the first approaches to port P2P technology to mobile environments. It exploits the mobility of nodes within a geographic area to disseminate web content among neighbors. Passive distributed indexing (PDI) [8] is a general-purpose distributed file searching algorithm. It uses local broadcasting for content searching and sets up content indexes on nodes along the reply path to guide subsequent searching. Klemm et al. [7] proposed a special-purpose on-demand file searching and transferring algorithm based on an application layer overlay network. The algorithm transparently aggregates query results from other peers to eliminate redundant routing paths. Hayes [9] extended the Gnutella system to mobile environments and proposed the use of a set of keywords to represent user interests. However, these flooding-based methods produce high overhead due to broadcasting.

2.1.2. Advertisement-Based Methods: Tchakarov and Vaidya [10] proposed GCLP for efficient content discovery in location-aware ad hoc networks. It disseminates contents and requests in crossed directions to ensure their encountering. P2PSI [11] combines both advertisement (push) and discovery (pull) processes. It adopts the idea of swarm intelligence by regarding shared files as food sources and routing tables as pheromone.

2.2. P2P File Sharing in Disconnected MANETs

The disconnected MANETs are featured by sparse node density and intermittent node connection, which makes previously introduced methods infeasible in such networks. We then further introduce two categories of P2P file sharing methods for disconnected MANETs.

2.2.1. Cache/Replication-Based Methods: Huang et al. [13] proposed a method that considers multiple factors (e.g., node mobility, file popularity, and file server topology) in creating file replicas in file servers to realize optimal file availability in content distribution community. Gao et al. [14] proposed cooperative caching in disruption tolerant networks. It replicas each file to network central locations, which are frequently visited by nodes in the system, to ensure efficient data access. QCR [15] uses file caching to realize effective multimedia content dissemination in opportunistic networks.

2.2.2 Social Network-Based Methods: Recently, social networks have been utilized in content publishing/dissemination algorithms [18], [19], [20], [21] in opportunistic networks. MOPS [18] provides content-based sub/pub service by utilizing the long-term neighboring relationship between nodes. It groups nodes with frequent contacts and selects nodes that connect different groups as brokers, which are responsible for intercommunity communication. Then, contents and subscriptions are relayed through brokers to reach different communities. MOPS only considers node mobility, while SPOON is more advantageous by considering both node interest and mobility as described previously.

3 The Design of Spoon

In this section, we first present trace data analysis to verify the social network properties in a real MANET. A P2P MANET file sharing system usually consists of 1) a method to represent contents, 2) a node management structure, and 3) a file searching method based on steps 1 and 2. Accordingly, SPOON has three main components: 1) interest extraction, 2) structure construction including community structure and node role assignment, and 3) interest-oriented file searching and retrieval based on components 1 and 2. We then present each component of SPOON.

3.1. Trace Data Analysis

To validate the correlation between node interests and their contact frequencies, we analyzed the trace from the Haggle project [26], which contains the encountering records among 98 mobile devices carried by scholars attending the Infocom'06 conference. Some participants completed questionnaires, indicating the conference tracks that they are interested in. We use Tt to denote the time length of the trace, and define the total meeting time of two nodes as the sum of the time length of each encountering. By regarding a community as a group of nodes in which each node has total meeting time larger than Tt=4 with at least half of all nodes in the community, we detected eight communities from the trace.

3.2. Interest Extraction

Without loss of generality, we assume that node contents can be classified to different interest categories. It was found that users usually have a few file categories that they query for files frequently in a file sharing system. Specifically, for the majority of users, 80 percent of their shared files fall into only 20 percent of total file categories [22]. Like other file sharing systems [27], [28], we consider that a node's stored files can reflect its file interests. Thus, SPOON derives the interests of a node from its files.

3.3 Community Construction

Social network theory reveals that people with the same interest tend to meet frequently [24]. By exploiting this property, SPOON classifies nodes with common interests and frequent contacts into a community to facilitate interest-based file searching, as introduced latter in Section 3.5. Nodes with multiple interests belong to multiple communities. The community construction can easily be conducted in a centralized manner by collecting node interests and contact frequencies from all nodes to a central node. However, considering that the proposed system is for distributed disconnected MANETs, in which timely information collection and distribution is nontrivial, we further propose a decentralized method to ensure the adaptivity of SPOON in real environment.

3.4 Node Role Assignment

A previous study has shown that in a social network consisting of mobile users, only a part of nodes have high degrees [20]. We can often find an important or popular person who coordinates members in a community in our daily life. For example, the college dean coordinates different departments in the college, and the department head connects to faculty members in the department. Thus, we take advantage of different types of node mobility for file sharing.

3.5 Interest-Oriented File Searching and Retrieval

In social networks, people usually have a few file interests [22] and their file visit pattern generally follows a certain distribution [23]. Also, people with the same interest tend to contact each other frequently [24]. Thus, interests can be a good guidance for file searching. Considering the relation among node movement pattern [33], individuals' common interests, and their contact frequencies, we can route file requests to file holders based on nodes' frequencies of meeting different interests. Then, the interest-oriented file searching scheme has two steps: intra community and intercommunity searching. A node first searches files in its home community. If the coordinator finds that the home community cannot satisfy a request, it launches the intercommunity searching and forwards the request to an ambassador that will travel to the foreign community that matches the request's interest. A request is deleted when its time-to-live (TTL) expires. During the search, a node sends a message to another node using the interest-oriented routing algorithm, in which a message is always forwarded to the node that is likely to hold or to meet the queried keywords. The retrieved file is routed along the search path or through IRA if the route expires.

3.6 Information Exchange among Nodes

We summarize the information exchanged among nodes in SPOON. In the community construction phase, two encountered nodes exchange their interest vectors and community vectors, if any, for community construction. In the role assignment phase, nodes broadcast their degree centrality within their communities for coordinator selection. When the coordinator is selected, the coordinator ID is also broadcasted to all nodes in the community. Then, each node reports its contact frequencies with foreign communities to the coordinator for ambassador selection. Besides, when a node meets a coordinator of its community, the node also sends its updated node vector to the coordinator to update the community vector and retrieves the updated community vector from the coordinator. When an ambassador meets the coordinator of its community, it reports the community vectors of foreign communities to the coordinator. After above information exchange, two encountered nodes exchange their node vectors and history vectors for packet routing. Each node checks packets in it sequentially to decide which packets should be forwarded to the other node based on the file searching algorithm introduced in Section 3.5. Further, when network turns to be stable, the frequency of information exchange for community construction and node role assignment can be reduced to save costs.

3.7 Intelligent File Perfetchng

Ambassadors in SPOON can meet nodes holding different files because they usually travel between different communities frequently. Taking advantage of this feature, an ambassador can intelligently prefetch popular files outside of its home community. Recall that a query in a local community for a file residing in a remote community is forwarded through the coordinator of the local community. Thus, each coordinator keeps track of the frequency of local queries for remote files and provides the information of popular remote files to each ambassador in its community upon encountering it. When a community ambassador finds that its foreign community neighbors have popular remote files that are frequently requested by its home community members, it stores the files on its memory. The prefetched files can directly serve potential requests in the ambassador's home community, thus reducing the file searching delay.

3.8 Querying-Completion and Loop-Prevention

Given a file query, there may exist a number of matching files in the system. A node can associate a parameter Smax with its query to specify the number of files that it wishes to find. A challenge we need to handle is to ensure that the querying process stops when Smax matching files are discovered when multicopy forwarding is used. To solve this problem, we let a query carry Smax when it is generated. When a query finds a file that matches the query and is not discovered before, it decreases its Smax by one. Also, if this query is replicated to another node, Smax is evenly split to the two nodes. A query stops searching files when its Smax equals 0. When a query needs to find more than one file, it is likely that IRA would forward a query to the same node repeatedly. To avoid this phenomenon, SPOON incorporates two strategies. First, the query holder inserts its ID to the query before forwarding the query to the next node. Second, a node records the queries it has received within a certain period of time. The former method avoids sending a packet to nodes it has visited before, while the latter method prevents sending different replicas of the same query to the same node. Specifically, when a node, say Ni, needs to forward a query to a newly met node Nj based on IRA, Ni checks whether the query's record of traversed nodes contains Nj. If yes, Ni does not forward the query to Nj. Also, when a node receives a query, if the query exists in its record of received queries, the node sends the query back to the sender. These two strategies effectively avoid searching loops by simply preventing a node from forwarding the same query to nodes that have received the query before.

3.9 Node Churn Consideration

In SPOON, when a node joins in the system, it first finds the communities it belongs to and learns the IDs of community coordinators, and then reports its files and utility values to the community coordinator when encountering it. This enables the coordinator to maintain updated information of the community members. A node may leave the system voluntarily when users manually stop the SPOON application on their devices. In this case, a leaving node informs its community coordinator about its departure through IRA. If the leaving node is an ambassador, the coordinator then chooses a new ambassador. If the leaving node is a coordinator, it uses broadcast to notify other community members to select a new coordinator. A node may also leave the system abruptly due to various reasons. Simply relying on the periodical beacon message, a node cannot tell whether a neighbor is left or is just isolated from itself, which is a usual case in MANETs. To handle this problem, each node records the time stamps when it meets other nodes, and sends it to the coordinator through IRA. The coordinator receives this information and updates the most recent time stamp of each node seen by other nodes. If the coordinator finds that a node's time stamp is more than Tx seconds ago, it considers this node as a departed node. Similarly, normal nodes in a community also maintain and update the time stamp of the coordinator to determine whether it is still alive. A node piggybacks the coordinator departure information on the beacon messages. Then, its nearby nodes can know whether the coordinator has left. Note that a node can know the number of community members from the coordinator. When a node finds that more than half of community members have found that the coordinator has left, it broadcasts a coordinator reelection message to select a new coordinator using the same method explained in Section 3.4.1.

4. Performance Evaluation

We evaluated the performance of SPOON in comparison with MOPS [18],Cache DTN [14], PodNet [16], and Epidemic [34]. MOPS is a social network-based content service system. It forms nodes with frequent contacts into a community and selects nodes with frequent contacts with other communities as brokers for intercommunity communication. PDI+DIS is a combination of PDI [8] and an advertisement-based DIS semination method (DIS) [12]. PDI provides distributed search service through local broadcasting (three hops), and builds content tables in nodes along the response paths, while DIS let each node disseminate its contents to its neighbors to create content tables. CacheDTN replicate files to network centers in decreasing order of their overall popularity. In PodNet, nodes cache files interested by them and nodes they have met. We adopted the "Most Solicited" file solicitation strategy in PodNet. We doubled the memory on each node in CacheDTN and PodNet for replicas. In Epidemic, when two nodes meet each other, they exchange the messages the other has not seen. We have conducted the following experiments:

1. Evaluation of community construction. We first evaluated the proposed community construction algorithm introduced in Section 3.3.
2. GENI experiments. We deployed the systems on the real-world GENI ORBIT testbed [35], [36] and tested the performance using the MIT Reality trace. The GENI ORBIT testbed contains 400 nodes with 802.11 wireless cards. Nodes can communicate with each other through the wireless interface. We used real trace to simulate node mobility in ORBIT: two nodes can communicate with each other only during the period of time when they meet in the real trace.
3. Event-driven experiments with real trace. We also conducted event-driven experiments with two real traces.
4. Evaluation of enhancement strategies. We evaluated the effect of the enhancement strategies introduced in Sections 3.7, 3.8, and 3.9 through event-driven experiments.
5. NS2 experiments with synthetic mobility. We conducted experiments on NS-2 [37] using a community-based mobility model [38] to evaluate the applicability of SPOON in different types of networks. Due to page limit, the results are shown in Appendix, which can be found on the Computer Society Digital Library a thttp://doi.ieeecomputersociety.org/10.1109/TMC.2012.239.

Besides the Haggle trace, we further tested with the MIT Reality trace [39], in which 94 smartphones were deployed among students and staffs at MIT to record their encountering. The two traces last 0.34 million seconds (Ms) and 2.56 Ms, respectively. As in MOPS, we used 40 percent of the two traces to detect groups in which nodes share frequent contacts. Here, we use "group" to represent a group of nodes with frequent contacts, and use "community"to represent a group of nodes with common interests and frequent contacts. We got seven and eight groups for the MIT Reality trace and the Haggle trace, respectively. Then, because there is no real trace for P2P over MANETs, we collected articles from different news categories (e.g., sports, entertainment, and technology) from CNN.com and mapped them to the identified communities. Each node contains 50 articles from the news category for its community. Each node extracts its interests from its stored files. The similarity threshold was set to 70 percent in AGNES for file classification. In experiments with the Haggle trace and the MIT Reality trace, we set the initialization period to 0.09 Ms and 0.3 Ms, the query generation period to 0.1 Ms and 1 Ms, and the TTL of a query to 0.15 Ms and 1.2 Ms, respectively.

5. Conclusion

In this paper, we propose a social network-based P2P content file sharing system in disconnected mobile ad hoc Networks. SPOON considers both node interest and contact frequency for efficient file sharing. We introduce four main components of SPOON: Interest extraction identifies nodes' interests; Community construction builds common-interest nodes with frequent contacts into communities. The node role assignment component exploits nodes with tight connection with community members for intracommunity file searching and highly mobile nodes that visit external communities frequently for intercommunity file searching; The interest-oriented file searching scheme selects forwarding nodes for queries based on interest similarities. SPOON also incorporates additional strategies for file prefetching, querying-completion, and loop-prevention, and node churn consideration to further enhance file searching efficiency. The system deployment on the real-world GENI Orbit platform and the trace-driven experiments prove the efficiency of SPOON. In future, we will explore how to determine appropriate thresholds in SPOON, how they affect the file sharing efficiency, and how to adapt SPOON to larger and more disconnected networks.

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