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On the integration of interest and power awareness in social-aware opportunistic forwarding algorithms

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ABSTRACT

Social-aware Opportunistic forwarding algorithms are much needed in environments which lack network infrastructure or in those that are susceptible to frequent disruptions. However, most of these algorithms are oblivious to both the user's interest in the forwarded content and the limited power resources of the available mobile nodes. This paper proposes PI-SOFA, a framework for integrating the awareness of both interest and power capability of a candidate node within the forwarding decision process. Furthermore, the framework adapts its forwarding decisions to the expected contact duration between message carriers and candidate nodes. The proposed framework is applied to three state-of-the-art social-aware opportunistic forwarding algorithms that target mobile opportunistic message delivery. A simulation-based performance evaluation demonstrates the improved effectiveness, efficiency, reduction of power consumption, and fair utilization of the proposed versions in comparison to those of the original algorithms. The results show more than 500% extra f-measure, mainly by disregarding uninterested nodes while focusing on the potentially interested ones. Moreover, power awareness preserves up to 8% power with 41% less cost to attain higher utilization fairness by focusing on power-capable interested nodes. Finally, this paper analyzes the proposed algorithms' performance across various environments. These findings can benefit message delivery in opportunistic mobile networks.

1. Introduction

Exponential advancements in mobile technologies – in terms of advanced sensors and various wireless network capabilities – have enriched mobile devices with intelligent features, making them the ideal candidates for pervasive systems. In parallel, social networks with their seamless accessibility from mobile devices have given rise to a gold mine of contextual information [1,2]. The resulting ecosystem that merges the social world with the mobile world, all supported by associated technologies, enables a set of smart services and applications. However, with the current 0.9 Exabytes mobile data volume that is expected to reach 11.2 Exabytes in 2017 [3], network infrastructure becomes overloaded, and users experience occasional network service contention or unavailability. Despite the ubiquitous network advantages that have reached LTE and 4G, some connectivity problems pop up such as: users suffer from rising cost of service delivery [4]; not all devices are connected with predefined routes; and not all places are reachable. These obstacles have motivated ad-hoc communications [5], delay tolerant networks [6], and opportunistic networks [7] to act as a complementary infrastructure that enables communication in environments with disruptive connections. Therefore, reliance on ad-hoc connections among mobile nodes to forward content in a local area offers partial relief from network infrastructure overload.

Given the evolving ecosystem, merging mobile technologies and social networking, social-aware opportunistic forwarding algorithms [8–10] represent one of the most promising approaches for ad-hoc communications. These algorithms take advantage of social relationships among mobile holders in a given place to forward messages accordingly. Surveying state-of-the-art work, available forwarding algorithms can be classified into three main categories: (1) the power-oblivious social-aware opportunistic forwarding algorithms which rely on social awareness and interest, but do not pay attention to power awareness when making forwarding decisions [8–11]; (2) the social-oblivious power-aware and energy-efficient routing algorithms [12–14] which seek efficient energy routes, but do not capitalize on other contextual information such as contact frequency, mobility patterns, and usage profile of the devices; (3) the social-oblivious power and context-aware opportunistic forwarding

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algorithms which consider power and context information, but do not exploit social information [15,16]. The forwarding algorithms target either a single destination or a group of nodes. The group-oriented forwarding algorithms identify destination nodes based on either their node IDs or a common profile. Our research domain targets the profile-based forwarding algorithms developed for mobile opportunistic message delivery. In order to forward content among mobile nodes, these algorithms currently compute a rank per node to select the optimum forwarder nodes [17]. Social forwarding algorithms include the node's social rank in making the forwarding decision. However, most of these algorithms encounter a set of challenges in maintaining effectiveness and efficiency in performance. In previous work conducted, we reviewed the challenges facing these algorithms and focused on four main challenges [18]: the incentive-oblivious forwarder selection process; the overlooking of the power capabilities of the nodes in place; the limited contact durations among nodes; and, the forwarding algorithms' unfair utilization of the nodes' resources.

This research proposes PI-SOFA, a framework for integrating interest awareness and power awareness in profile-based social opportunistic forwarding algorithms. This framework integrates three main factors in making forwarding decisions: user interest in the forwarded content, user's social rank, and power capability of the candidate node. The expected contact duration between the message carrier and the candidate forwarder may also be included when making forwarding decisions.

Our framework consists of three modules:

The *first module* elicits interest awareness when making forwarding decisions to facilitate content dissemination to groups of interested nodes. Being aware of users' relative interest in the forwarded content, the forwarding algorithms are able to mainly approach interested users and avoid overwhelming uninterested ones, thus significantly reducing the cost wasted in massive information dissemination to uninterested recipients. This module mainly improves the effectiveness of the forwarding algorithm. Besides, it is necessary to bring in an incentive to motivate nodes in the forwarding process participation. Our framework proposes users' relative interest in the forwarded content as an effective incentive to participate in forwarding, since users will also benefit by receiving this same content which is of partial interest to them. The proposed paradigm is an interest-aware version of any social forwarding algorithm that rewards or penalizes the node's social rank based on its relative interest in the forwarded content.

The *second module*, on the other hand, integrates the awareness of the candidate node's power capabilities when making forwarding decisions. This integration directs the forwarding algorithm to rely on power-capable nodes as content forwarders through rewarding or penalizing the node's social rank based on both its power capability and its relative interest. This module reduces the overall power consumption and improves the utilization fairness of the forwarding algorithm. This approach incorporates interest and power awareness in both the ranking and the forward decision making of the social-aware forwarding algorithms to overcome four main challenges facing these algorithms: (1) the forwarder selection process is incentive-oblivious; (2) power-oblivion of the social forwarding approaches in the forwarder selection process may lead to the nodes' inability to sustain the forwarding process accomplishment; (3) power-fairness-oblivious forwarding algorithms over-utilize some forwarder nodes while lightly utilizing others; (4) overlooking the contact duration sufficiency between the encountered nodes for complete message transfer leads to a waste of non-trivial resources.

Finally, the *third module* integrates a threshold-based opportunistic forwarding to the two above integrations. This module improves the effectiveness and the efficiency of the forwarding algorithm. This extra option opens the door for guided opportunistic forwarder selection; the relatively interested users who own power capable nodes are given higher priority in the next content forwarders selection, even if they do not satisfy the other selection criteria. Being interested in the content and being power capable, these forwarders have a higher probability of meeting destination nodes and of sustaining forwarding within the content time-to-live.

The proposed framework is applied to three social-aware forwarding algorithms developed for mobile opportunistic message delivery, namely, PeopleRank [11], SocialCast [10] and SCAR [15]. First, the integration of interest awareness in the 'power-and-interest-insensitive' algorithms is proposed via the power-oblivious interest-aware versions: IPeR [19], ISCast and ISCAR. Next, the integration of power awareness is applied via the power and interest-aware PIPeR [20], PISCast and PISCAR algorithms. Finally, the inclusion of the threshold-based opportunistic forwarding is illustrated via the PIPeROp [20], PISCastOp and PISCAROp versions.

PI-SOFA framework is then evaluated via realistic simulations using our developed simulator. These simulations utilize datasets that include both realistic [21,22] and synthesized mobility traces [23], social profiles [21], social relationships [24], power consumption models [25,26], and data that are generated by our simulator. Moreover, evaluation metrics are devised for performance comparison to measure the algorithms' effectiveness, efficiency, power consumption, and utilization fairness. The results of the simulation-based evaluation are as follows: (1) integrating interest awareness into the social aware forwarding achieves up to 560% extra f-measure by precluding uninterested nodes and focusing on potentially interested ones; (2) introducing power awareness consumes 8% less power and 41% less cost to attain higher fairness in power utilization. This is achievable via focusing on power-capable interested nodes; (3) having accurate contact-duration expectations reduces 8% of the consumed power and time wasted in incomplete message transfers between nodes. After that, a set of normalized performance indices is proposed to help evaluate the performance of the presented algorithms across various environment setups. The proposed performance indices can guide advertisement/announcement senders in choosing the optimum algorithm depending on the environment in which the ad will be forwarded. Overall, the proposed versions promote a trade-off between delivery ratio and delay on one hand, and power preservation and fair utilization on the other.

The rest of this paper is organized as follows: Section 2 details the related work in this domain; Section 3 presents the proposed framework; Section 4 presents case studies of interest and power awareness; Sections 5 and 6 present the simulation-based evaluation and results; Section 7 concludes the discussion.

2. Related work

After surveying research work in the field of power and social awareness, we have found a shortage in the forwarding approaches work that combines both social awareness and power awareness. We therefore classify the current research into three categories:

2.1. Power-oblivious, social-aware opportunistic forwarding algorithms

Many social aware forwarding algorithms do not take into account power awareness in forwarding. These algorithms rank nodes upon any or combination of the following social metrics: the nodes' social popularity [11]; common interests [19,27,28]; common mobility behavior [9]; community-based metrics [29,30]; and, activeness in connectivity with other nodes [10]. In all these ranking metrics, the highly ranked nodes are the ones forming better candidates to deliver messages to destinations, given that there is a higher probability that such nodes will encounter destination nodes more rapidly. This category of algorithms favors the highly ranked nodes. However, some of these algorithms balance between social awareness and opportunistic selection of forwarder nodes, such as PeopleRank [11] and IPeR