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Mobile crowdsourcing in peer-to-peer opportunistic networks: Energy usage and response analysis

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ABSTRACT

With the popularity of mobile social networking and the emergence of ideas such as participatory sensing, mobile crowdsourcing has the potential to help tackle new problems in relation to real-time data collection and coordination among a large number of participants. Due to the unreliability and dynamic behavior of mobile opportunistic networks, there are several key issues concerning the development of crowdsourcing-related mobile applications that need to be considered. In this paper, we investigate task propagation models devised to support mobile crowdsourcing in intermittently connected opportunistic networks. The propagation strategy is used to disseminate tasks among a crowd of peers. We investigate response models (i.e., to estimate the number of responses to expect in the network) and energy consumption models (for estimating the energy used by both a task-originator and workers) and study their behavior under different conditions in comprehensive simulations. The findings will show the interplay and relationships between mobile crowdsourcing factors and the number of peers responding and energy consumption.

1. Introduction

Recently, crowdsourcing has emerged as a novel and transformative platform that engages individuals, groups, and communities in the act of collecting, analyzing, and disseminating environmental, social and other information for which spatio-temporal features are relevant (To et al., 2014). Moreover, mobile computing and wireless networks have become an important part of our modern life. For example, in emergency situations such as finding a missing child or pet, the most effective action is to inform people nearby where the child or pet was lost and ask for nearby help for the search. In this case, real time ad hoc connections among nearby smartphone users is exploited for task distribution and a trajectory map may be generated for locating or predicting the child or pet location, or to map seen areas by volunteers. In another scenario, suppose Mary wants to meet up with her friends in a nice not-too-crowded restaurant. She can search for such a restaurant by deploying mobile peer-to-peer networks to ask people who are nearby cafes or restaurants. With the popularity of mobile social networking and participatory sensing, mobile crowdsourcing has the potential to help tackle new problems in relation to real-time data collection and analysis, and coordination among a large number of participants.

Mobile devices are connected only intermittently when they opportunistically contact each other, yielding a concept known as Delay Tolerant Networks (DTNs) (Fall, 2003). DTNs use a store-carry-forward paradigm to allow communication when a path through the network is not reliable due to frequent disconnections. A node receiving a packet from one of its contacts can buffer the message, carry it while moving, and then forward it to the encountered nodes in terms of delivery. A network that routes packets using the store-carry-forward approach is also called an opportunistic network, because the nodes forward messages when an opportunity arises during an encounter or contact. With the unreliability and dynamism of mobile ad hoc or opportunistic networks, there are key issues in the development of crowdsourcing-related mobile applications that need to be considered. Due to the dynamic nature of moving hosts which may join or leave the platform at any time, the network topology is likely to change very often, and network partitioning can occur frequently. Moreover, communication range might be limited when a mobile user goes outside of a given location, causing unavailability of data (tasks or feedback from crowd) from that device at that location. A routing protocol is needed when the data needs to be transmitted between the two nodes.

Furthermore, traditional methods of data management in crowdsourcing generally considered only centralized or client–server communication while mobile ad-hoc network

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communication involves multi-hop transfers and decentralized processing. The issue related to resource constraints (e.g., energy) in mobile devices is also important. A node disseminates tasks among crowd workers through mobile peers in its range, obtains responses from such mobile devices, and integrates the responses to obtain real-time answers. The effectiveness of such processes could be limited by the lack of energy resources on mobile devices: there is a question of whether such peer-to-peer querying is feasible from the energy usage perspective. Moreover, it is not easy to estimate the response rates from peers using such an approach. To our knowledge, earlier work had not adequately studied or tackled peer-to-peer crowdsourcing in mobile environments with intermittently connected opportunistic networks, from the energy and response rate viewpoints.

Indeed, the energy consumption of mobile devices, such as smartphones, has increasingly become a concern from various sectors, ranging from smartphone manufacturers, mobile developers, to end users. Although battery capacity has been increasing in the past few years, the battery life of mobile devices is not catching up proportionally for a large spectrum of current applications. Mobile crowdsourcing applications utilize the many mobile sensors such as an accelerometer, digital compass, gyroscope, GPS, microphone, and camera to form participatory sensors networks in order to enable public and professional users to gather, analyze and share local knowledge. However, participation in these systems can easily expose mobile users to a significant drain on already limited mobile battery resources. Particularly in opportunistic communication, mobile users/nodes with high social connectivity may quickly deplete their energy resources. Hence, the energy characteristics of mobile crowdsourcing in opportunistic networks is an important issue to be addressed.

In this paper, we extensively investigate a task/query propagation strategy expressly devised to support mobile crowdsourcing in intermittently connected peer-to-peer opportunistic networks. We attempt to address for end-users who want to issue tasks/queries the following queries: How long should I wait given my resource constraints? While crowdsourcing platforms can use the Web or centralised approaches, this paper focuses on only peer-to-peer propagation and collection of tasks/queries and their responses. The propagation strategy is used to disseminate crowd tasks among peers. More specifically, we study the number of responses in the network using such a strategy, and propose an energy consumption model for estimating the energy used by both an owner (source node) and workers (mediator or terminal node).

The next section starts by introducing our basic network model and assumptions. In Section 3, the crowdsourcing task/query propagation strategy is detailed. Section 4 gives analytical results on peer responses and energy consumption, but for limited idealised well-structured networks. This is then compared to extensive simulation and evaluation results given in Section 5 to study response rates and energy usage behaviors in other types of randomly generated networks. Related work is given in Section 6. Finally, Section 7 concludes with future work.

Our studies are carried out based on assumptions about a system for mobile crowd computations called *LogicCrowd* (Phuttharak and Loke, 2003, 2014) that can run on mobile devices, and where a script is executed on the mobile device to send tasks/queries to the surrounding crowd and then to wait for and aggregate results. However, we believe that similar insights are generally applicable to other similar systems.

2. Basic network model

The fundamental dynamic network topologies investigated in our framework are based on spatial random node distributions

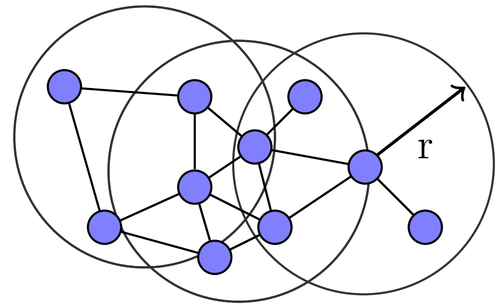

Fig. 1. Modeling the topology of an ad-hoc network.

and presumed short-range wireless connectivity between the nodes. We assume a network composed of N nodes. Nodes are assumed to be randomly placed in an area A, interconnected by wireless links and have the same capabilities to store messages in a buffer of maximum size α. We can define a constant node density $\rho = N/A$, i.e., the expected number of nodes per unit area.

In mobile crowdsourcing in our case, a requestor/originator propagates tasks/queries to peers/workers whom it discovers. When receiving the queries, a worker answers the queries and replies to the requestor. Moreover, the peer is able to forward tasks to others. This process might continue with subsequent peers. We assume that a user, and therefore a node, may act as both a requestor and a worker in this network model. During the peer-to-peer propagation process, we define time-to-live and power-to-live values to limit the lifetime of tasks so that the action of forwarding tasks to other peers can been stopped. Responses are returned along the path tasks/queries are propagated. To model the wireless transmission between the nodes, a radio link model is assumed in which each node has a certain transmission range r and uses omnidirectional antennas. As illustrated in Fig. 1, two nodes are able to communicate directly via a wireless link, if they are within range of each other. Only bidirectional links are considered. This link model corresponds to a propagation model with certain signal attenuation.

We provide some basic definitions from graph theory and define the nomenclature used in this paper. With the above network model, we represent an ad hoc network at each time instant as an undirected graph G. A simple graph G is a pair $G=(V, E)$ where V is a set of n nodes, called the vertices, and a set of m node pairs called the edges of G. The set of nodes, denoted by $V = \{1, \ldots, n\}$, represents the network enabled ad hoc devices; and the set of edges, denoted by E, represents the bi-directional wireless communication links (note that the link needs to be maintained for transfer of a task/query and a response). Hence, the size of a graph is the number of vertices of that graph. In graph theory, the degree of a node of a graph is the number of edges connected to the node. The degree of a node v, denoted as $d(v)$, is the number of neighbors of node v, i.e., its number of links. A node of degree $d=0$ is isolated. The number $d_{min}(G) = \min\{d(v)| \ v \in V\}$ is the minimum degree of G, the number $d_{max}(G) = \max\{d(v)| \ v \in V\}$ is the maximum degree. The average node degree of G is denoted as $d_{avg}(G) = \frac{1}{n}\sum_{v=1}^{n} d(v)$.

3. Task propagation strategy in mobile crowdsourcing

In this section, we describe the main characteristics of our propagation strategy. Mobile crowdsourcing refers to a distributed problem-solving model in which problems/tasks are propagated beyond the local database through public networks, especially mobile ad-hoc or opportunistic networks. Mobile users can easily interact with each other in a mobile network fashion which can be regarded as an ad-hoc network supporting multi-hop routing,