Research issues and overview of economic models in Mobile-P2P networks

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Abstract

The mobile-P2P paradigm is becoming increasingly popular. Existing mobile-P2P solutions largely do not consider economic incentive models for enticing peer participation without eliminating free-riders and for effectively handling mobile resource constraints such as energy. This paper presents an executive summary of the existing solutions and an overview of some of the important issues for handling problems in mobile-P2P networks using economic models. We also present our perspectives on building 'real' mobile-P2P applications using economic models.

1. Introduction

Proliferation of mobile devices (e.g., laptops, PDAs, mobile phones) coupled with the ever-increasing popularity of the P2P paradigm (e.g., Kazaa) has sparked considerable interest in Mobile ad-hoc Peer-to-Peer (M-P2P) networks. M-P2P networks facilitate mobile users in sharing information with each other *on-the-fly* in a P2P fashion. In this paper, we shall use the term *'M-P2P network'* to imply both mobile-P2P networks and mobile ad-hoc networks (MANETs).

M-P2P applications include customers in a shopping mall sharing information about the cheapest available 'Levis' jeans, and swapping shopping catalogues. Car users can share information concerning available parking slots and traffic conditions a few miles ahead [28, 29]. Tourists in different sight-seeing buses could share touristic information (e.g., images of castles) with each other. Museum visitors could request images/video-clips of different rooms of the museum to decide which room they will visit first. Mobile users could exchange popular songs or video-clips (as in a future mobile eBay market). Conference visitors could find people, who share similar interests.

Such P2P interactions among mobile users are generally not freely supported by existing mobile communication infrastructures. To realize these applications, several challenges need to be addressed. Notably, most of the peers are typically free-riders [6, 8, 10, 14, 15, 23] i.e., they do not provide any data. Moreover, mobile devices have generally limited resources (e.g., energy, memory, bandwidth), which are taxed by sharing data and relaying messages. Frequent network partitioning due to peers joining/leaving the network arbitrarily coupled with peer trust issues in an inherently untrustworthy environment pose further challenges. Thus, *economic incentive models*, which entice participation of non-cooperative mobile users (as opposed to eliminating them) become a necessity for effective information sharing in M-P2P networks. Timeliness requirements for data delivery (due to M-P2P ephemerality) and data quality issues further motivate the need for economic models.

Existing mobile-P2P solutions largely do not consider economic incentive models for enticing peer participation without eliminating free-riders and for effectively handling mobile resource constraints such as energy. This paper presents an executive summary of the existing solutions and an overview of some of the important issues for handling problems in M-P2P networks using economic models. In particular, we examine replication issues, incentive schemes and present our perspectives on building 'real' mobile-P2P applications using economic models.

2. Economic Replication in M-P2P networks

Replication has been traditionally used for improving data availability and system reliability of distributed systems. However, traditional replication strategies [12] are not adequate for P2P environments as they do not address free-riding, incentives for node participation, lack of global knowledge and nodes arbitrarily joining/leaving the system. For improving data availability in static P2P and M-P2P environments, replication has been addressed in [4, 9, 24]. The work in [4] examines updates in decentralized and self-organizing P2P systems. The update strategy is based on a hybrid push/pull Rumor [7] spreading algorithm, the aim being to provide probabilistic guarantees as opposed to strict consistency. The MANET replication schemes in [9] create groups of mobile hosts that are biconnected components in a network. It allocates replicas based on read-write ratios of data items in larger groups of mobile hosts for providing high stability.

The work in [24] deals with adaptive searching and replication of images in a hierarchical M-P2P network. It discusses the replication of fragments of images (having possibly different resolutions) such that a peer may either download the whole image or re-construct the image from the fragments depending upon cost-effectiveness in terms of resource constraints. Notably, the replication approaches in [4, 9, 24] assume that peers are willing to store replicas, hence they do not consider economic incentive models to entice peer participation for combating free-riding.

Our works in [19, 18] also address replication in M-P2P networks. The proposal in [19] proposes a context and location-based approach for replica allocation. It exploits user mobility patterns, avoids broadcast storm during replica allocation and considers different levels of replica consistency and load as replica allocation criteria. In [18], both collaborative replica allocation and deallocation are performed in tandem to facilitate optimal replication and to avoid 'thrashing' conditions. However, these works do not consider economic models for replication.

Existing systems incorporating P2P replication include ROAM [25], Clique [26] and Rumor [7]. ROAM [25] focusses primarily on mobility-aware replication. Clique [26] is a P2P, server-less distributed file system, which is based on optimistic replication algorithms. Clique supports epidemic replication, a no-lost updates consistency model, conflict management and replica convergence. Thus, Clique is well-suited to highly disconnected environments, network partitions, and peers joining or leaving the system. Rumor [7] is an optimistically replicated file system for mobile computers. Rumor supports opportunistic update propagation among any sites that replicate files. However, these systems do not use economic models to combat free-riding.

Given rampant free-riding, dynamically changing network topology, mobile resource constraints and incomplete global knowledge, open issues in M-P2P replication follow.

- How to entice the free-riders to host replicas?
- How to estimate the optimal number of replicas?
- How to address replication-related trust issues?
- How to keep track of peers storing the replicas so that updates can be propagated?
- Who caches frequently queried paths for efficiency?

We believe that some of these open issues can be effectively addressed by extending existing replication approaches using economic models. In [20], we propose such an economic replication model, designated as EcoRep, for dynamic replica allocation in M-P2P networks. EcoRep requires a query issuing user to pay the *price* (in virtual currency) of his requested data item to the user serving his request, thereby enticing peer participation. In EcoRep's super-peer architecture, replicas are allocated based on a data item's *price*, which depends on its access frequency, the number of its existing replicas, its (replica) consistency and the response time required for accessing it.

In economic models, the optimal number η of replicas for a given data item d would eventually be achieved based on the market forces of demand and supply. Notably, each mobile user can be expected to maximize his own profit per unit of his device's limited memory space. Hence, if the number of existing replicas for d exceeds η, the market price of d would decrease due to competition, thereby motivating the host peers to deallocate the replicas. If the number of existing replicas for d is less than η, d's price would be higher due to less competition, hence more peers would be enticed to store d's replicas. Such replica allocation and deallocation can be performed economically as in our work in [22]. In [22], incentives are provided to mobile peers to form collaborative peer groups for maximizing data availability and revenues by mutually allocating and deallocating data items using a royalty-based revenue-sharing method.

Replication-related trust issues can be addressed either by incorporating trust in the data pricing formulae or by viewing trust itself as a currency. Moreover, certain peers can act as brokers [22] to index replicas for propagating updates in lieu of a broker's commission. Brokers could also be enticed to cache frequently queried paths by offering them a commission for each query facilitated by them.

3. Incentives in M-P2P networks

Incentive schemes for combatting free-riding in static P2P networks have been discussed in [6, 23, 8, 10, 15]. The work in [6] uses a formal game-theoretic model to analyze equilibria of user strategies in P2P file-sharing systems under different kinds of payment mechanisms. The incentive scheme in [23] is based on utility functions, which measure the usefulness of peers in a P2P file-sharing system. The proposal in [8] also introduces a utility function to capture user contributions and discusses an auditing scheme to maintain the integrity of the values of the utility function to reduce cheating by malicious peers.

The incentive scheme in [10] uses a participation metric, which is designated as a peer's EigenTrust score, for rewarding participating peers. EigenTrust scores are able to accurately capture different kinds of participation criteria. The work in [15] observes that users have considerably higher download bandwidth than their available upload bandwidth. Hence, the incentive scheme in [15] is *asymmet-*

ric in that a unit of upload bandwidth is valued higher than a download unit. Furthermore, it uses a token-based accounting system to provide asymmetric incentives to peers.

Incidentally, the works in [6, 23, 8, 10, 15] are too static to be deployed in M-P2P environments since they assume peers' availability and fixed topology. Hence, they cannot handle mobility of peers and frequent network partitioning, which are characteristic of M-P2P networks.

Incentive schemes for MANETs have been proposed in [1, 27, 2, 3, 30]. For stimulating the nodes to forward messages, a simple counter-based mechanism in each node, is discussed in [1]. In [27], a distributed algorithm is utilized by the nodes in a MANET to determine whether to accept or reject a relay request. In [2], an auction-based incentive scheme, designated as iPass, has been proposed to entice nodes in MANETs to forward packets. The market price of the packet forwarding service is paid to the relay nodes. The work in [3] provides incentives to MANET users for acting as transit nodes on multi-hop paths by rewarding nodes according to their ability to send messages.

The work in [30] proposes Sprite, which is a cheat-proof, credit-based system for stimulating cooperation among selfish nodes in MANETs. Sprite provides incentives for mobile nodes to cooperate and report actions honestly. Incidentally, the proposals in [1, 27, 2, 3, 30] do not consider mobile-P2P architecture, data item prices and different prices based on data requested and queries answered. Moreover, they do not entice free-riders to become part of the network.

Incentive schemes for M-P2P networks have been discussed in [29, 28, 21, 22]. The work in [29] provides incentives for peer participation in resource dissemination in M-P2P networks. Each disseminated report contains information about a spatial-temporal resource e.g., parking slot availability at a given time and location. The work in [29] has been extended in [28], which considers economic models for resource information dissemination in transportation applications. In the opportunistic dissemination paradigm in [28], a mobile peer transmits its resources to the peers it encounters, and obtains resources from them in exchange.

Our work in [21] proposes a bid-based economic incentive model for enticing non-cooperative mobile peers to provide service in M-P2P networks. It encourages relay peers to act as brokers for performing value-added routing (i.e., pro-actively search for query results) due to bid-based incentives. It also smoothly integrates newly joined peers in the system seamlessly by sharing the loads with the neighbouring brokers. This helps the new peers to earn revenues in order to be able to obtain services. In [22], we propose a broker-based incentive model for handling constraint queries in M-P2P networks. Users may issue queries with varying constraints on query response time, data quality of results and trustworthiness of the data source.

Incentive schemes for P2P and mobile environments with trust and security aims have been proposed in [14, 13, 17]. In [14], the aim is to design a robust scheme in which cooperative peer groups can be formed in NICE, which is a platform for facilitating the implementation of cooperative applications over the Internet. The focus in [14] is on distributed trust inference and peer reputation issues since peers may be malicious. In [13], incentives are provided to mobile users for cooperating in a secure routing protocol. It facilitates in detecting and punishing selfish routing behaviour by mobile peers. It also addresses confidentiality of peer location. The work in [17] presents an incentive mechanism for reputation management, the aim being to facilitate the trustworthiness evaluation in ubiquitous computing environments. It supports reputation evolution and propagation, while stimulating honest and active recommendations from the peers for making better trust decisions.

Some open issues for M-P2P incentive schemes follow.

- How to ensure trusted accounting of virtual currency?
- How to ensure payment collection?
- How to prevent counterfeiting of virtual currency?
- To what extent would virtual currency be successful?

In the next section, we discuss possible M-P2P architectures for addressing these open issues.

4. Our Perspectives on Architectures for real Economy-based M-P2P applications

This section discusses existing system models for M-P2P networks and presents our perspectives on possible M-P2P architectures for supporting a virtual currency model.

The work in [16] proposes a system model for service allocation in MANETs. It uses a distributed algorithmic mechanism design and a Vickrey auction mechanism for service allocation in MANETs. The approach stimulates service provisioning and shows reasonable performance for service allocation despite each agent's selfish behaviour. The work in [11] presents the requirements and design for a P2P-based service platform for mobile environments. The design incorporates P2P lookup and information distribution, reliability, controllability, bootstrapping and reputation management. To handle the challenges in mobile environments (e.g., device heterogeneity and frequent peer joins and leaves), it proposes a hierarchical P2P system as the main component for a P2P service platform. The work in [5] examines middleware solutions for MANETs used in emergency and rescue situations, the aim being to improve availability of services and information by improving resource awareness. It also predicts future connectivity between nodes by means of information about a node's vicinity, which is extracted from the routing protocol.

Now we examine ways to realize M-P2P applications, while considering the open questions posed in Section 3. In traditional cellular architectures, a mobile user can connect to another peer using the base station. In this case, however, the communication will always involve the base station. The advantage is that the base station can always account for usage, payment of virtual currency and other accounting issues. Furthermore, the base station can prevent counterfeiting of virtual currency via securely encrypted digital signatures.

Another architecture is a pure MANET, where peers can communicate with others using single or multiple hops. However, it is difficult to employ incentive models in a pure MANET since managing currency is difficult. One solution is to have a prepaid charge card for different applications, which automatically detects the payment before providing a service, and the resulting payment is added to the charge card of the service providing peer. Another option is to have some superpeers who are trusted entities like a base station, and all the peers communicate with these superpeers for the payment and the service guarantee. Here, superpeers will be responsible for implementing the incentive model and payments of virtual currency in lieu of service payments. An additional way is that a peer can connect to the Internet and pay in advance to a *trusted* third party (e.g., a mobile phone service provider or a bank), who can open an account for the peers. Upon service completion, payments are done via the third party.

Virtual currency has several advantages such as low cost of micro-economic transactions, high level of security due to effective traceability of transactions and convenience of use (i.e., cashless travel). These advantages of virtual currency are likely to be spread by word-of-mouth. We believe that virtual currency would work as larger number of users would start using it, and it would be possible to obtain more services by using the virtual currency.

Interestingly, some efforts in this direction have already been undertaken. A virtual currency, which is designated as Edy (Euro-Dollar-Yen), is already in existence in Japan. Edy can also be in-built into mobile phones, thus it can facilitate micro-economic payments for M-P2P transactions between strangers and micro-economic payments for Internet auctions for users who use mobile Internet services in Japan. Notably, smart cards such as the Suica card used for Japan's train services and the Octopus Card used for Hong Kong's mass transit system may also be viewed as forms of virtual currency. These cards are generally also useful for making micro-payments.

Mobile Internet applications also represent a significant step in the direction of real M-P2P applications. A wireless internet service, which is designated as *i-mode*, enables mobile phone users to access mobile internet sites. It was launched by NTT DoComo. Other leading mobile network operators of Japan such as KDDI/AU and Vodafone have also introduced their mobile Internet services, namely the EZWeb and the Vodafone Live respectively. Notably, i-mode also facilitates mobile gaming applications. Mobile phone casino games and gambling provided by the OnGame developer also highlight the possibilities for pure M-P2P applications. Additionally, mobile phone-centred dating services are already in existence and enjoy high popularity in Japan and in other countries. These services allow users to find persons of interest by text messaging and mobile chatting. Observe that these services allow absolute strangers to interact with each other, thereby indicating that pure M-P2P applications could potentially use the existing infrastructures used by these services. Since these services are able to connect users, the possibilities of information sharing among mobile users are practically endless. For example, users can potentially share a range of diverse information with each other such as the best restaurants in town, tips for a healthy diet, the recommended books and software for learning any given language, and so on. In essence, the connectivity provided by mobile devices has revolutionized information sharing even among complete strangers.

5. Conclusion

We have presented an executive summary of the existing solutions and an overview of some of the important issues for handling problems in mobile-P2P environments using economic models. We believe that economic incentive models would be useful for extending the existing solutions to entice peer participation and for handling mobile resource constraints such as energy. We also present our perspectives on building 'real' mobile-P2P applications using economic models. We hope researchers from both academia and industry will work towards making M-P2P applications a reality in the near future.

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