The Case of Multi-hop Peer-to-Peer Implementation of Mobile Social Applications

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***Abstract*— In this paper we consider issues related to the design of mobile social software in a multi-hop peer-to-peer environment. We believe that by enabling multi-hop peer-to-peer communication could in certain cases make social mobile applications more attractive in terms of location privacy or embarassement, but also more effective in terms of the quality and quantity of the matches achieved. Such an approach could thus contribute in the construction of a critical mass which is necessary for the success of these applications and probably one of the reasons they are not yet widely deployed. On the other hand, it introduces significant implemention challenges related to the contruction and management of a dynamic ad-hoc network. We focus on the provision of the suitable incentives for packet forwarding which is a fundamental problem that needs to be addressed in this context since the ad-hoc nature of the mobile social applications constitutes pricing and reputation (or accounting) based approaches of limited applicability. In this paper we argue that suitable memory-less mechanisms should be devised sketching two such mechanisms for different types of packets exchanged in a mobile social application. Interestingly, as we explain, our proposed mechanisms enforcing contribution while consuming have a more general applicability and could also be used in other applications such as the peer-to-peer resource sharing in ubiquitous computing. We finally discuss several strategic issues that should be also taken into account but are ignored by the corresponding literature and more specifically the consideration of mobility and power transimission as part of the rational strategy of peers participaing in such a system.**

I. Introduction

Mobile Social Software (or MoSoSo) is attracting recently an increasing attention of the industry[1] and the research community[2]. The possibility for people to initiate social or other interactions assisted by mobile and information technology is very appealing and could increase significantly their quantity and quality. Notably, there are many cases where there is plenty of free time available for social interactions (e.g. at an airport or on a ship, at a beach, etc.) or even business opportunities (e.g. at a conference) but there are limited ways for the interested parties to exchange their preferences and thus find an appropriate match.

So, in a social mobile application, devices residing in the same physical region exchange user profile information in order to initiate 'spontaneous' social interactions of various types (from flirting in a public place to business meetings in a conference). Such applications have been proposed many years now (see for example [2]) and efforts for commercial deployment were actually made in Japan back in 1998 [3]. But their success to this day has been limited, to say the least, even though the large percentage of people carry mobile devices with significant capabilities several years now.

However, the facts that even more powerful mobile devices and new wireless communications technologies are being deployed and that people are getting used to profile matching through on-line communities such as friendster, flickr, etc., have renewed the interest in such applications and many efforts for large scale commercial deployment of mobile social software are becoming reality [1] [4] [5].

Until now most commercial but also research approaches assume that the inter-device communication would be initiated only when the devices are in direct communication, within the transmission range of each other (i.e. 1-hop away) [6] [2] [7] [3] [8] [9] [10]. Such communication can be in principle further supported by centralized components which decide on the possible matches based on the users' profile information stored in centralized databases as for example, in the case of Dodgeball [1] or Serendipity [4], in which mobile devices connect to a (central) server and send profile information and a Bluetooth ID. Then, when two devices come close and sense one another, their IDs are sent to the server and by profile comparison the server decides whether the two people involved should be introduced or not and if yes, sends an alert to the parties involved.

The main drawback of these centralized approaches is that they raise important privacy concerns both concerning the location of users but also concerning their personal information being stored in a central database (see [11] and references therein). The peer-to-peer approach addresses the first issue (location privacy) while the second issue (personal information privacy) could be addressed at the application by sophisticated configurable matching algorithms given that in a p2p implementation the users are themselves responsible for the degree of their private information that they disclose. This part of the design of mobile social software is out of the scope of this paper but we elaborate a little more on this in the next section.

But independently of the p2p-ness of the application (whether it is implemented in a distributed, peer-to-peer, way or not) the fact that in most existing approaches users can

[1] it is characteristic of this attention the fact that google decided to buy Dodgeball [1] at its first steps as a mobile social software company.

[2] see the CHI2006 Workshop on Mobile Social Software.

only find a match that it is one-hop away from them limits in general the value of the application due to the reduced probability to actually find a match. Moreover, it could limit the participation of users since exchanging personal information with strangers which are within visual contact could be embarrassing for some people.

Dodgeball [1] has managed to overcome this problem by requiring from users to login manually to a central server indicating their location. So, unlike serendipity, users can initiate social contacts with people that are close to them without their devices being able to directly communicate. Although this feature has probably played an important role to its success, in this paper we choose to consider applications that are not assisted by central servers to achieve this multi-hop communication for reasons already explained. Our main goal is to identify the most important implementation issues that are associated with this decision and make a first step towards addressing them. So, in the following we further motivate our multi-hop peer-to-peer approach and discuss some possible mechanisms for addressing the issue of providing incentives for packet forwarding in this context and the corresponding trade-offs that arise.

Incentives for packet forwarding in ad-hoc networks is a generic, very challenging, research problem which has received significant attention over the last years [12] [13] [14] [15] [16] [17]. Our work is differentiated from this literature in that it explores the use of 'memory-less' mechanisms (ones that do not require accounting of a user's past behaviour nor pricing schemes to be implemented) studied in the light of a specific mobile ad-hoc application in which participating users are independent entities and thus would in general act towards maximizing their own benefit.

II. Motivating a p2p multi-hop approach

We believe that p2p multi-hop communication could provide the means to address two of the important challenges for the successful deployment of social mobile applications. Namely,

- the creation of a critical mass: unless no user intervention is required, a significant probability for a successful match should exist in order for the users to get interested in such applications and invest their time in participating.
- addressing privacy concerns: most people would like to have control over their profile and location information while participating in mobile social application.

Clearly, if we allow profiles to travel over multiple hops (instead of one) the possibility for finding a match substantially increases since we can reach distant parts of the ad-hoc network. In the single-hop case one would be confined to meet only with people he would encounter "face-to-face" (especially if a short range of transmission is employed). On such a case if the degree of mobility is low and the network is not dense enough, the number of walker-bys would not be significant and hence profile-matching would be very rare. In the contrary in a multihop environment physical proximity is much less of an issue and even mobility and density (assuming that an acceptable degree of connectivity is provided) doesn't play a significant role in finding a match. This way the profile may travel to more distant places and reach far away locations much faster than a user would do just by moving.

Additionally, from the energy consumption point of view, nodes can save significant amounts of energy in the case of multihop profile dissemination. In wireless networks energy consumption is closely related to transmission range. The higher the transmission range the more power is needed for an antenna to broadcast a signal and hence more energy must be expended. In the single hop case a user would normally try to denote its presence setting its transmission range to the maximum, trying to reach as many users as possible. However, in the multi hop case a user can rely on the fact that his profile can travel over multiple hops and reach distant users, and hence choose a much smaller transmission range.

However, the introduction of multi-hop p2p matches brings into the picture incentive and routing issues whose cost could be in some cases disproportionally big compared to the corresponding benefits. The main reason is that unlike most p2p systems whose main principle is the exploitation of untapped resources at the edges of the network, sharing of resources in an ad-hoc network (mainly packet forwarding) is a costly action since it involves the consumption of a rivalrous and consumable resource: battery power. So, a very important obstacle for the implementation of the required functionality is the need for users to contribute their resources for the common good. And more specifically, they should agree to forward packets belonging to communications in which they are not personally interested.

As already mentioned, the use of a centralized server to implement the matching algorithm based on the profiles sent by nodes entering into a specific area described above is very attractive in terms of communication costs and power consumption and could be easily extended to include the multi-hop case. However, many people don't feel comfortable having their personal data stored in central databases of companies and having them responsible for finding matches for them [3]. We believe that a p2p implementation is more attractive because

- information is exchanged directly between users through the ad-hoc network formed (one or more hops away) and no information is passed or stored on a third party's server.
- users are responsible themselves (through the suitable configuration capabilities offered by the software) to calculate the matches of interest and possibly decide the level of their commitment (whether the will be *active* controlling themselves the application or *passive* configuring an autonomic behaviour). So, they don't just fill some profile information, but also configure the algorithm that will decide whether a candidate match is what the user is seeking for the specific moment.

Thus they can implement more sophisticated and individualized matching algorithms tuning more effectively the

[3] even from a psychological point of view, it is often better for people to feel that they are responsible for a match rather than being introduced through a third party.

quality of the matches since a p2p implementation allows them to incrementally disclose their personal data. Ideally, the appropriate tools should be provided for such sophisticated matching to be possible (see also [18]). For example, one could design a handshake protocol where a user's personal information will be revealed step by step and a candidate match would be 'challenged' to provide additional information in order for the initiator to verify the similarity of interests. Otherwise, attackers could always 'agree' in all fields of a match request. Note that since all messages should travel over an ad-hoc network, there is a trade-off between the amount of information transmited and the number of transactions required per match. Another approach is to disclose private information partially, in the form of a "fill-the-blanks" game. In this case, some parts of the secret are revealed, and a possible match can occur only in the event of someone guessing what the missing values are. This could happen in an autonomic way or with active user participation. In the latter case, an even more demanding version could require asking and answering of specific questions in order for a match to take place, making the application a distributed multi-player social ad-hoc game. Such a social game of questions and answers being exchanged in the form of instant messages seems a more attractive option in a lounge setting, where people are frequently in search of an activity to spend their free time and the percentage of active users is expected to be higher.

So, in general one should cope for the forwarding of two different types of messages: matching queries that include some top level profile information, topics of interest and a public key for private communication and encrypted messages exchanged between peers which they have identified one another as a possible match.

III. Incentives for packet forwarding

Researchers have proposed specific mechanisms to provide incentives for peers to cooperate in terms of packet forwarding and thus contribute part of their resources for the common good (see for example [12] [13] [14] [15] [16] [17] among many others) It is trivial to see that without such mechanisms in place, the nash equilibrium will be the system failure since the rational strategy of each peer is to refuse to forward any packet, free riding on the efforts of those that agree to do so.

The major challenge for all these schemes is the ability of the users to account for contribution and discover 'type' (e.g. altruistic or egotistic) of the participating nodes. Existing approaches propose either the use of token based currencies [14] or the use of reputation [13]. These suffer from the highly dynamic nature of ad-hoc networks (both in terms of participation and node capabilities) and the untrusted environment in which accounting should be implemented (see also arguments in [19]).

Two are in our view the most challenging issues for accounting for the contribution of a node in terms of packet forwarding in an ad-hoc network:

- in many cases nodes cannot monitor the actions of their neighbors (cannot overhear their transmissions) and identify the exact point of failure (e.g. hidden action).
- the highly dynamic aspects of the network and the variable capabilities of the nodes over time[4]

Moreover, all of these approaches assume there is a known destination for a packet, but as argued [20] this is rarely the case in ad-hoc networks, at least for applications such as the ones discussed here (where discovering the right destination is an important part or most of the problem). Instead of addressing the generic problem of packet forwarding using sophisticated accounting mechanisms that are difficult to be implemented in practice (especially when the destination of the packets is not known in advance and, thus, it is not easy to deduce the effort put by agents based on the outcome of the transactions), we wish to explore the use of simple memory-less mechanisms in the context of a specific and realistic application, namely the mobile social ad-hoc communities.

Additionally, existing work ignores important issues concerning the behaviour of users in this setting and more specifically the fact their mobility pattern could be part of their strategy either for technical reasons (reduce their load) or for social ones (move close to attractive people in order to increase the probabilities that they will manage to exchange information with them). We believe that social incentives cannot be totally decoupled from technology since it is not the technology itself but the way people use it that affects the efficiency of a community. For example, the technological pattern of normal use and "attack" could sometimes be identical (e.g. in Friendster, people accept everybody as their friendster in order to have a global view of the network and broaden their choices [21]). In general, the tendency to see technology as independent from the social environment of which it is a part, has contributed to the impressive failure rate of projects in other contexts (e.g. [22] [23]).

Finally, in many cases users could have the alternative to increase their transmission range in order to reach a maximum number of users with one-hop communication sacrificing battery power for the transmission of their packets but avoiding the extra contribution cost required by participating in a peer-to-peer community according to the corresponding incentive mechanism. In SectionVI we sketch an abstract model to evaluate the cost incurred by an incentive mechanism in a multi-hop ad-hoc mechanism (and the corresponding efficiency in terms of successful packet transmissions) compared to the cost (and efficiency) by increasing the transmission range.

IV. Memory-less incentive mechanisms

Bittorrent has introduced a nice example of a memory-less mechanism in the context of p2p file sharing. That is, the direct exchange of resources (namely upload bandwidth for downloading popular content items). Such a mechanism is very easily enforced, but requires mutual interest between two peers. In Bittorrent this is not an issue since peers are synchronized around the provision of very popular content items by

[4] For example, the fact that battery power is consumable means that nodes that cooperate have a decreasing probability to be able to do so as time passes and this informaton is hidden.

central servers. In [24] a less strict memory-less mechanism is proposed focusing on content availability ensuring that peers contribute to the common good while consuming resources (i.e. downloading files).

We believe that memory-less mechanisms of this sort is a very promising class of incentives mechanisms which is particularly suitable for the case mobile social application because the timescales in the ad-hoc networks formed are in general very short and relying on history to reward contribution and punish free riding is in many cases misleading or inappropriate. Moreover, as we will see, memory-less mechanisms don't rely on the ability of users to overhear the messages sent by their neighbours as do approaches like [15]. Finally, they are optimistic in principle, which is important for encouraging participation.

We distinguish between matching queries and private communication. Note that this distinction is fairly general and in most ad-hoc networks destinations are not already known and users should first exchange some sort of queries in order to identify those with which they wish to communicate before initiating private communication.

Thus the dissemination of matching queries is of great importance for the success of any ad-hoc p2p application. The fact that in our case this service is delay-tolerant, best-effort, and symmetric (all participating users are inherently interested in all others' queries) motivates us to use a direct exchange mechanism as described below.

A. A direct exchange mechanism for matching queries

A direct exchange strategy, 'Give me queries I don't have to give you queries you don't have', is a potential candidate for providing the suitable incentives for forwarding matching queries. But note that it is not necessary that all peers receive all the queries of the group. From the point of view of a specific pair of peers, it suffices that one of them receives the query of the other. If they match she can then make the first move.

An important behavioral pattern appearing in the described communitites has to do with the degree of selectivity of a user in choosing a match. *Eager* users are more willing to make a match, regardless of a peer's characteristics, while *selective* users are less tolerant and accept a match only if their requirements are highly fulfilled. Another important feature as to which users can be distinguished is their degree of participation/commitment in the community. Normally, some people may be better-disposed towards taking part in the social game (*active* users), while others are not as enthusiastic or they are just busy, though still interested in being a member of it (*passive* users).

User selectivity has a major impact in building one's profile but could affect other aspects of a user's behaviour as well. For example, the eager ones would in general like to have the maximum possible amount of information in order to maximize their chances to find one or more matches, while selective and passive ones could prefer that their queries travel around just in case an interesting match is found.

The proposed mechanism gives the ability to nodes to tune their benefit and cost by placing themselves appropriately in the network. Nodes at the edges not having queries to offer for an exchange will settle for just transmiting their own with the hope that they will reach a large percentage of the network (being used by intermediate nodes for exchanges) and thus avoiding to offer their resources for forwarding packets of others. On the other hand, eager nodes could move towards the center of the network in order to be able to acquire a large amount of queries paying the cost of contributing significantly in terms of forwarding and acting as gateways for the queries travelling around the network.

It is very important for such a system to provide a good trade-off between quality of service (the probability that a query will reach the majority of the nodes) and cost (how much resources should be contributed to achieve this probability) in order for nodes to decide to participate. Our on-going work includes the development of a simulation that will help us compute the efficiency achieved (the ratio of matches discovered to the total number of existing ones) and personal net benefit acquired as a function of the position in the network and contribution under different assumptions on density, node capabilities, range used, etc.

Of course, one should also provide the means to actually enforce this direct exchange of resources in an ad-hoc network which is a non-trivial task. Many attacks such as overhearing could be addressed through cryptography but others such as the exchange of fake information requires more sophisticated policing mechanisms. It is out of the scope of this paper to provide complete solutions to all these very challenging research questions. Our goal is just to motivate the need to address them.

B. A 'contribute while consuming' mechanism for encrypted bilateral communication

The next step is to provide the suitable incentives to nodes to forward encrypted packets belonging to bilateral communications between candidate matches. The fact that only two parties are interested in each packet makes the incentive issues involved more critical.

Nodes are required to forward packets indifferent for them and without any direct benefit[5]. Instead of implementing trading (token-based) or indirect reciprocity (reputation-based) schemes we wish to enforce a node to contribute her resources to *any* other node in the system *while consuming*.

If a majority of peers agree to play by these rules and pay the corresponding enforcement cost (a requirement for the distributed enforcement of any incentive mechanism) then in order for a peer to be able to acquire service, she should first contribute her resources to some other peers (increasing this way the overall utility).

So, a memory-less mechanism should exploit the fact that participating nodes would be in general interested themselves

[5]Note that sacrificing privacy in favour of less required communication one could include more information in matching queries and perform the next steps of communication through another channel.

to forward their own packets and require from peers to forward a certain number of additional packets piggybacked with their own. In addition to acting as a 'proof' for contribution, piggybacking will have a positive effect on the overall cost for packet forwarding. The case where each node simply forwards every other node's packets would lead to a much faster energy drainage of the network as a whole as shown in [25] and [26] (note that "the number of packets has greater impact on energy consumption than packet size does").

But the requirement to first receive a number of requests for forwarding before sending your own packets could be very restrictive in general. However, the fact that users are delay-tolerant and that they keep participating only while they have personal interest (which means that all nodes will have packets to send and thus the probability to receive requests is high) reduces its significance.

In any case, there could be nodes (e.g. those at the edges of the network) that don't have enough packets to piggyback. Similarly with the case of matching queries, such nodes could rely on the need of others to piggyback packets and thus have their packets —with much smaller probability— reach their destination.

But what if all nodes rely on this fact and never piggyback others' packets? In certain cases (with low traffic) this could work but it is the nodes at the center who will discourage this behaviour since they will receive more packets than required for their needs and as a result would give probability to piggybacked ones. Thus moving to the center of the network only such packets will manage to get through.

In general, there is an abstract function that relates the position of a peer in an ad-hoc network and the number of piggybacked packets required for each packet transmission with the probability of a successful transmission minus power consumption given network topology, diameter, number of nodes, transmission range,etc. We elaborate more on this in Section VI.

Again, a major threat the proposed system may face is the fact that a node can produce fake packets to deceive the proposed incentive mechanism avoiding the cost of receiving packets from the network. In general, however, users are willing to receive packets in case they are the destination and thus the cost for performing such an attack wouldn't justify the corresponding gains. However, in cases where such an attack is beneficial a system designer should devise ways for peers to detect such fake packets. This is actually the major challenge one should address when implementing any memory-less 'contribute while consuming' mechanism. But we believe that its attractive properties constitute the research of practical ways to verify contribution to the system as a whole while consuming, for this and other types of p2p applications, an interesting avenue for future work.

V. The case of ubiquitous computing

Extending the notion of an ad-hoc network to include the numerous intelligent devices that people will carry with them in the future, a vision termed *ubiquitous computing* [27], one could imagine the cooperation of these devices in order to perform complicated computations sharing their unused capacity over time.

In this context, besides the actual sharing of computational resources (as this is envisioned to happen in the case of grid computing [28] [29]) additional suitable incentives should be in place for the creation of a p2p ad-hoc network over which the devices will be able to communicate their needs and find the peer devices that have the necessary resources and perhaps required software (their matches). Additionally, when two or more such devices are identified this network will be also responsible to carry the necessary data between the client machine to the server machine (for a specific computation) in order for the computations to be performed.

Towards this end, our proposed mechanisms above could form the basis for providing the necessary incentives for cooperation in this setting without the need for complicated accounting and enforcement mechanisms to be in place.

VI. Strategic Issues

In this section we discuss two additional strategies available to nodes participating in an ad-hoc network: mobility and tranmission range tuning. The decisions of a peer concerning his position in the network and the transmission range used are considered as predefined in existing work on incentive mechanisms for packet forwarding in ad-hoc networks. However, depending on the incentive mechanism and on the commitment of the user, moving around and selecting appropriately her transmission range could be part of her strategy (both at the routing and at the application level) and should not be disregarded.

In our case for example, as already explained, active nodes could move close to people that they find attractive or place themselves at the edges so as to avoid been asked to forward packets, etc. We would like to model such strategies and compute the corresponding equilibria using tools from game theory. For example, we could model the position of a node using the euclidean distance from the "gravity center" of the network graph. For strategic (active) nodes, this would be part of their strategy while for passive peers this would be randomly selected (according to an underlying mobility model assumed).

As far as transmission range is concerned, nodes have always the possibility to increase it (within the limits of technology) in order to reach as many one-hop destinations as possible and thus avoid the costs incurred by the incentive mechanism when participating in a multi-hop network. These would be the fixed costs for running the underlying protocol and the usage based ones according to the degree of reciprocity enforced (in our mechanism the extra power required for transmiting the required piggybacked packets).

So, nodes have have also the strategy of whether to participate in the p2p community using the smallest possible transmission range and if not, select the exact (larger) range that they will use. Note that transmitting with maximum range could create significant congestion in many settings and thus reduce the perfance of all nodes. Thus the cost incurred by a node in order to transmit a single packet in both cases depends also on the strategies of all the other peers.

According to the net benefit acquired which is a function of the full strategy space and the incentive mechanism applied, each node will decide whether she would get involved in the multi-hop scheme and how she will behave in each case (in terms of position and range used).

This is a very complex game. We hope to study some interesting cases. For example solve the problem without considering mobility or simplify it by assuming that mobile users could choose between a small predefined set of positions.

Such models could provide useful insights to system designers to assess the efficiency of certain incentive mechanisms and tune appropriately their parameters. For example, one could estimate the optimal number of packets that should be piggybacked under various contexts, in terms of network performance or economic efficiency.

VII. Conclusion

More questions are raised than answered in this paper. Our overall objective was to motivate the design of multi-hop and peer-to-peer mobile social applications. Then a very important problem that needs to be addressed in this context is the provision of incentives for packet forwarding. Towards this end, we initiated an application-specific approach for tackling this very challening research problem mobile ad-hoc networks based on realistic assumptions about the ability of nodes to account for other's contribution and their strategy space. We have made a first attempt to provide certain insights and proposed some mechanisms towards this end.

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