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Social Networks: The Killer App for Wireless Ad Hoc Networks?

Karim Seada and Charles Perkins
Nokia Research Center Palo Alto
http://research.nokia.com
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Abstract:
We discuss whether social network applications could be the killer app for ad hoc network technology and become a driver for its proliferation. We argue why we believe this is a valid standpoint based on observations from web-based social networks and the required technology. Then we present a proposal for realizing *proximity* social networks using existing device base and wireless interfaces. Finally, we discuss some of the research challenges to be resolved.

Index Terms:
ad hoc networks
social networks
proximity networks
local search

1. INTRODUCTION AND MOTIVATION

The past decade has witnessed a large interest in wireless ad hoc networks research as observed in the influx of papers, dissertations, and conferences dedicated solely to this area of research. On the contrast, there have not been many noticeable commercial real-world deployments of this promising technology (the related technologies of mesh networks and sensor networks have picked up in providing real-world applications in contrast to infrastructure-less networks of personal mobile devices).

In this paper we consider whether social network applications could be the killer app for this technology and become a driver for ad hoc networks proliferation. We argue why we believe this is a valid standpoint based on observations from web-based social networks and the required technology. Then we present a proposal for realizing *proximity* social networks using existing device base and wireless interfaces. Finally, we discuss some of the research challenges to be resolved.

There has been a surge recently in the number of web-based social networking sites. These sites attract a large number of users and some of these sites are among the most accessed sites in the web with millions of registered users (e.g. MySpace [1] is the second busiest site in the US[1] and has about 100 million registered users[2]). These sites also attracted a lot media attention recently due to commercial success (News Corporation acquired MySpace for $580 million in 2005, and in 2006 Google pays $900 million to become the search provider on MySpace) or security and privacy concerns. Some of these sites are more focused on specific communities or categories of users (e.g. students [2], professionals [3], video sharing [4], …), but they all share similar functions (registering, creating a profile with interests, building or joining a network).

It has been pointed out that users of these sites are interested in two factors: on the one hand, building their online digital communities of peers that share similar interests and on the other hand enhancing their real offline life. For certain applications that do not depend on the peers' actual physical location (e.g. online gaming or trading music files) the locality or proximity factor is not important, but for other applications where users are interested in peers nearby (e.g. looking for activity partners or trading physical items) the proximity factor becomes important. In general, users will have more friends and tend to connect to peers in the same locality [22]. Some sites recognize this fact and focus on locality issues more than others (e.g. Frappr [5]). The location information is normally presented by a logical identifier such as city or zip code, or other information such as attending the same school and the classes taken, but this is as far as current applications usually go. There is no way for current web-based applications to detect in real-time the actual proximity of two peers based on their claimed locations. In this way, ad hoc networks could be of special value, adding the proximity factor to social networking applications in a very natural and distributed way. In addition, interest in social networking will inspire new applications targeted towards on-the-fly ad hoc networks that find and connect nearby users for new experiences.

We summarize the following factors leading to the emergence of proximity social networks based on ad hoc networks:

- Cell phones and mobile devices are proliferating at a much faster pace than PCs. These devices are becoming smarter and will offer a great deal of memory and computing power. Many of these devices are now equipped (more expected in the future) with common wireless interfaces as WiFi and Bluetooth that allow peer-to-peer connection without going through a base station.
- Users are interested in accessing the social networking applications using their mobile devices while on the go and some of the sites started to provide mobile services adapted to cell phones [6], but the content the user gets is still the same. The availability of social networking on mobile devices will increase user demand for proximity and other innovative applications that cannot be provided by current infrastructure.
- New services that use proximity between cell phones started to appear recently. An example of such service is Nokia Sensor [7] which uses Bluetooth for detecting other users in range, sending messages, and exchanging files with them. Current services are limited only to a single hop and do not take advantage of the extended network. Multi-hop ad hoc networks allow new applications and services that extend beyond the first hop to cover larger areas.

We believe that ad hoc network technology is the best way to provide the proximity factor for the following reasons:

[1] according to market researcher comScore Media Metrix
[2] as of August 2006

- Users can connect directly to peers in their range, without the need of any other infrastructure or cell phone coverage, which also provides a cost-effective way for connectivity and reduces the load on the base stations.
- Users can detect and verify the proximity of their peers and they can actually know where they actually are within certain accuracy and not only where they *claim* to be.
- In certain scenarios, such as large events with high density or spontaneously crowded locations (e.g. the beach on a hot summer weekend), centralized base stations may not be able to handle the load and a distributed approach (by forming instantaneous networks on the fly) is likely to offer a viable alternative.

2. ARCHITECTURE

In this section we present an ad hoc network architecture that can support various social networking applications. Ad hoc social networks could be extensions to web-based social networking services or independent social networks formed for specific occasions. A scenario for the first case is locating friends that might be close by while walking in town. A scenario for the second case is forming a social network between attendees of a conference, who might not have met before, based on their interests.

There are several components with various options required to build this architecture starting from bootstrapping or joining a social network, sending and receiving messages for locating friends or people with similar interests, localization aspects, security and privacy, and connectivity to the Internet or gateways to online site databases.

2.1 Wireless Interface

The fundamental requirement is for devices to be equipped with wireless interfaces that support peer-to-peer mode. The most commonly deployed such interfaces today are WiFi and Bluetooth that allow nodes to connect directly to their neighbors within a certain range.
- *WiFi peer-to-peer mode*: Allows two nodes with the same SSID (Service Set Identifier) to communicate directly without an access point. The first node establishes an IBSS (Independent Basic Service Set) and starts sending beacons periodically. Other nodes interested in joining the network, receive these beacons and use it for synchronization and parameter setting. Typical WiFi ranges are up to 100m indoors and 300m outdoors, but can be much higher with line-of-sight.
- *Bluetooth*: A radio standard for low-power low-bandwidth direct communication between personal devices. It has much lower range than WiFi, typically around 10m in current devices and power levels. A Bluetooth *Piconet* consists of a master and up to 7 active slaves and 256 inactive slaves; the master can bring nodes into active status and determines when a slave can send. Any node can be a master or a slave and nodes can switch master/slave roles anytime. Several Piconets can connect to form a *Scatternet*, within which some nodes can be members of multiple Piconets with different master/slave roles and act as bridges. Bluetooth uses FHSS (Frequency Hopping Spread Spectrum) at the physical layer, allowing more devices to share the radio spectrum and transmit on the same frequency at the same time.

2.2 Forming and Joining:

Devices interested in joining a social network will need to detect their physical neighbors that are part of the same social network service (or other neighbors that may not be using the same service but can act as ad hoc relays). Once a neighbor is detected, the new device can establish a connection with this neighbor and become part of this network. If none of the neighbors is part of the desired social network service, the device will become an isolated node of the network, waiting for new nodes to join. This checking can be performed periodically to detect if other members came into range.

In order to recognize that a node is a member of the same social network service, a common identifier representing this network is required. This common identifier could be obtained from the web-based social networking site in cases where the node is joining its ad hoc extension, or it could be provided by other means such as providing it in the event or conference where this network is formed.

2.3 Search

The next step after joining the network is to locate friends or people with similar interests. Each member of the network has a unique member identifier that could be its member ID in a corresponding social networking site or an ID for that specific network. To locate friends in proximity, a node will send a message containing its ID within certain range. This could be done using controlled flooding or extended ring search up to a number of hops (similar to RREQs in the AODV [8] routing protocol). If a localization mechanism exists for nodes to identify their locations [9], the search can also be done within a more specific geographic region [10]. Nodes receiving this message who are members of the network should be able to detect if the sender is in their friends list.

This is one of the challenging problems facing our proposal due to its distributed nature. If the friends list is a small list for instantaneous social networks formed for a specific occasion, then this should not be a problem, since the whole list can be kept in memory and the received member ID can be searched in the list. If the ad hoc social network is an extension to a web-based social networking service, then recognizing friends will be challenging, since the list could be large and needs to be obtained or checked from the social networking site. We will discuss this in more detail later.

For locating people with similar interests, the same mechanism could be used by including the interests in the messages sent. The interests could be as simple as a set of keywords to be matched, or a more structured semantic could be used [11][12]. More logic is required in this case based on the application to decide which messages to reply to or deliver to the user.

2.4 Localization

Localization is not required for social networking to function, but its existence will make several basic tasks easier and allow additional utilities and applications that make use of the location information. As mentioned, during the search if the location is not known, a flooding mechanism could be used within a certain range, and the proximity could be decided based on the number of hops. If the locations of nodes are available, searching can be performed within specific regions depending on the granularity of the location information using geocasting mechanisms [10]. In addition, delivering packets to specific nodes or locations can use geographic routing mechanisms. This approach takes advantage of several recent advances for such routing mechanisms [13][14][15].

For devices equipped with GPS, accurate locations could be obtained (but with restrictions within buildings). There are also other algorithms for localization in ad hoc Networks based on triangulation with a set of reference points or based on base stations coverage [16][17]. Location information would help to obtain other forms of physical addresses directly, such as mapping the GPS locations on a street map. It is part of our purpose to investigate ways to use these bits of positional information when setting up the social networking contexts.

2.5 Security and Privacy

This is as important topic for such architectures as it is for infrastructure-based social networking sites – in fact, it may be even more important. Adding here the factors of proximity and location revealing makes it important to provide reliable authentication mechanisms. For online social networking sites, authentication will require access to the site servers or obtaining certificates to be kept in the mobile devices. Privacy can be controlled by the user, starting from the decision to join the network and what kind of information users want to reveal about their locations and to whom.

For social applications based on ad hoc networks, there are other concerns that need to be considered, such as the trust of intermediate nodes to relay packets and the protection of the packet contents. Simple encryption mechanisms can be used when transmitting packets between two friends once they are identified, but more sophisticated mechanisms may be required during the detection and locating phases.

2.6 Internet Connectivity

In general, our proposal allows nodes to form a social network independently without the need for Internet access. But if the network is an extension to a web-based site, then access to the site may be required on several occasions in order to have full functionality. In addition, caching some data from the servers may significantly improve user experience. Nodes could have data channels (e.g. through a WiFi base station or GPRS) for accessing the Internet which are separate from the peer-to-peer ad hoc network. In fact, gateways within the ad hoc network could provide Internet access to the rest of the nodes, and earn credits within the social structure for doing so.

3. RESEARCH CHALLENGES

The application of building social networks on ad hoc networks provides extra research challenges that have not been addressed before in traditional ad hoc networks research. We will discuss some of these challenges in the following sections.

3.1 High Density Scenarios

In many scenarios such as large events, concerts, or crowded spots, the number of nodes within radio range could become quite large reaching hundreds or even thousands of nodes. This high density poses various challenges for ad hoc networks that have not been considered very often in previous research, which often assumes densities of around 20 neighbors or less. The high density will mean that nodes need to maintain a large neighbors list, which uses more memory in the mobile device and requires extra processing power and delay in updating the neighbor list. The high network connectivity will cause large contention between neighbors in accessing the channel and many collisions in contention–based MAC protocols. Situations where several nodes are searching simultaneously using flood-based requests are common in such application and can cause significant overhead on the high dense network and on the nodes receiving the broadcasts. In addition power consumption is a serious issue for mobile devices and our experiments have shown that even simple single-hop discovery applications running continually can consume lot of power and shorten the battery life significantly. For these reasons, smarter mechanisms for connectivity, topology management and power management are required.

There are many ideas here that deserve serious attention. One direction is to reduce the number of floods generated using smart flooding mechanisms [19] in addition to the aggregation of requests by encapsulating several friend or interest searches within the same packet. The other direction is to use power control to limit the number of neighbors and reduce the interference on other parts of the network. Standards like Bluetooth with its shorter radio range and FHSS radio transmission could be a good candidate. We also envision that future cognitive radios [20][21] will exist that can deal in a smart way with many of these problems. Cognitive radios should enable wireless devices to locate unused radio spectrum and adapt their communication functions to the network and user demands.

3.2 Storage and Management of Friends List

Some users of web-based social networking sites have hundreds or even thousands of connections in their friends list. These lists are stored and maintained in the site servers and when a user logs in, the site centrally identify all the friends that are online (many of the sites actually do not provide interactive connections and use only offline message exchange). Small lists can be stored in the mobile device, but for larger lists this will become more challenging (for future devices that might not be a problem; currently some advanced cell phones can have up to 2GB of memory and the hard drive technology is improving in this direction). In proximity social networks, locating friends in the proximity is a main operation that cannot usually be solved in centralized traditional ways. There are several levels on the complexity of this problem which depends on whether location information is available or not and whether access to the site Internet servers is available or not.

Following are the four possible classifications:

- Location available / Internet access: This is the easiest to solve, since every node can register its location by the servers and the servers can identify friends that are within its proximity and provide this information for the ad hoc nodes to connect directly.
- No Location available / Internet access: Users can get information from the servers about their friends that are online, so that the search and access of the list can be restricted to the online friends only. More information such as the current city, zip code, last encounter, or other context information can be used to restrict the list further.
- Location available / No Internet access: Without access to the servers, the nodes will need to have a friends list locally in the mobile device. The list stored does not have to be the complete list and could be a partial list of preferred friends (in general, we would expect that most people may not want to locate everyone in their web-based list in real-life and they will have some kind of preferential list that could also be formed automatically based on various metrics such as the frequency of communication) or friends within a certain category that the node may want to locate during this no-Internet-access period. The availability of location information may allow advanced locating mechanisms to be used such as geographic rendezvous mechanisms [18], but in general this case could resolve to the next general case.

- No Location available / No Internet access: This is the most general and challenging case. As in the previous case, nodes will need to have their friend list or a subset of it locally. There are several ways to look for friends. A user may send its ID, requesting friends that have its ID in their friends' list to reply back. A user can also send a list of some of its friends, it is looking for, and a node receiving this request will check if its ID is in this list. Since the ratio of friends to the rest of the nodes in the proximity network could be quite small (especially at higher densities [22]), nodes are likely to receive a lot of requests not intended for them. This could place a high burden on the nodes that may repel them from joining the network especially if the probability of getting a request from a friend is too low compared to the rest of requests. This problem could, unfortunately, reduce the incentive for nodes to cooperate particularly if they are not benefiting much from joining the network. We believe that innovative mechanisms are necessary to locate and connect friends without placing a large burden on the rest of the network and we are planning to investigate new mechanisms to find more effective solutions.

Interest-based search is simpler to deal with since there are no friend lists that need to be maintained and searched. A user can send its interests or what it is looking for in a request and receivers with similar interests can reply back. It may still be advantageous for a node to offer some directory services for the interest group. We would like to find out how to characterize the scenarios when such directory services would be beneficial; it is likely to depend on traffic patterns associated with the group.

3.3 Advanced Information Structuring

We plan to investigate advanced mechanisms for interest–based matching and topology building. One promising direction is to use ideas and tools from *Knowledge Representation* research in order to utilize user and context information for constructing and searching the network. We envision that by structuring the information in mobile devices and other context information from the user environment, we can automate the discovery and matching processes and solve some of the problems mentioned in the previous sections. For example, instead of a user entering its preferences manually, which could be a distracting and time-consuming task, the device can monitor the user behavior in its context, and use knowledge representation, inference and reasoning techniques to adjust the information in the user's profile and its relation to other users in the social network.

3.4 Security

As mentioned above, it is important that intermediate nodes cooperate in processing and forwarding requests and replies despite the overhead that may place on them. From the experience of web-based social networks and different peer-to-peer systems (e.g. sharing files and resources), users are normally willing to cooperate as long as they are receiving value as being part of the network.

Without access to the web-site servers that can authenticate users, a distributed authentication mechanism is required to verify that a node is actually the friend who it claimed to be. Certificates can be stored locally for nodes to identify themselves. A public-private key mechanism can be used for authentication that allows a node to verify that a request or reply is from a friend and can be used for encrypting messages during communication between friends.

While hiding the message content through encryption could be simple, there are other levels of privacy that are not as simple and require further investigation. For example, preventing intermediate nodes and neighbors from knowing a user's friends and communication partners is a harder problem to solve in ad hoc networks. We will look for partial solutions if a complete solution seems infeasible.

4. LOCALIZED SEARCH

Social networking in ad hoc networks is an interesting application of localized search. There are other important applications of localized search that will benefit from the same mechanisms. For example, shopping for close-by items (cars for sale within a certain distance), looking for housing in a certain area (searching for the closest houses for sale while driving in a street), or looking for physical items inside a building. The localized aspect of these applications makes it somewhat different from general service discovery, in that users are not interested in a reply about any node but about nodes that satisfies certain proximity conditions. Interpreting the location and distances is an interesting aspect here. For example, nodes can estimate how distant other nodes are, based on the number of hops and the radio range. Other mechanisms for estimating the direction can also be used if some reference points exist. Research results related to localization without additional infrastructure can be of value here and allow useful applications such as mapping the derived location to a physical address on a map and relating different nodes in a locality. Another useful application is to use the social network for obtaining up-to-date location-specific or community-specific information by sending queries to neighbors that are more likely than other sources to have answers to these queries [23].

5. CONCLUSIONS

We presented a case for social networking accelerating the deployment of wireless ad hoc networks and discussed some of the research challenges for realizing this architecture. In our future work we plan to investigate the presented issues in more detail and evaluate a detailed architecture for our proposal. We also plan on experimenting with a real-world application to assess the viability of this approach.

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