Self-Organization in Mobile Ad hoc Networks based on the Dynamics of Interaction

Klaus Herrmann, Kurt Geihs
Berlin University of Technology
Institute for Telecommunication Systems - iVS
EN6, Einsteinufer 17, D-10587 Berlin, Germany
Email: {kh,geihs}@ivs.tu-berlin.de

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Abstract

Mobile ad hoc networks provide a communication environment that is characterized by dynamic changes in the topology and in the availability of resources. The limited transmission range of mobile devices and the mobility of the users make it difficult to transfer well-known mechanisms for the organization of distributed systems to the ad hoc networking domain. Therefore, there is a need for self-organization mechanisms that help applications in coping with these effects. So far, the research on self-organization in ad hoc networks has not resulted in generally applicable mechanisms. In this paper we present our vision of *socio-awareness* that exploits recent advances in the research on complex social networks. We propose a system that is able to capture the patterns of interactions between mobile ad hoc users and uses them to organize, for example, spontaneous information exchange and service deployment in mobile ad hoc networks.

1 Introduction

A mobile ad hoc network (MANET) [6] consists of mobile devices that are equipped with a short-range radio interface like, for example, Bluetooth [7]. Two devices can only connect to each other if they are within each other's transmission range (usually between 10 and 100 meters). Since these devices are carried by mobile users, the communication network among them potentially exhibits high dynamics. Connections are setup and torn down frequently. There is no pre-existing infrastructure through which one device may connect to some other device reliably. MANETs tend to partition and re-assemble constantly depending on the dynamics caused by user movements. Therefore, it is non-trivial to assign fixed roles to the participating devices. The traditional view on a computer network as a set of fixed well-known servers and clients does not apply in an ad hoc scenario. For these reasons, ad hoc networks are often called *infrastructureless networks* or *peer networks*.

Due to the dynamics and decentralization, it is hard to transfer well-known mechanisms of designing, structuring and organizing distributed applications to the MANET domain. So far, the bulk of research on MANETs has concentrated on the problem of routing data packets to enable conventional Internet-like applications in a spontaneously forming ad hoc network. Application areas like disaster relief, battlefield communication, and inter-vehicle communications can profit from such routing infrastructures. These applications allow direct communication links between devices and enable participants to interact while they are in the same vicinity. Another domain is location-based computing. Here, devices interact with their geographical environment and this environment creates a context that is used to gather and filter information. A example for this would be an information system in a museum that provides appropriate information on the exhibits to the visitor based on his position in the museum.

Supplementary to these approaches, we propose to make applications in mobile ad hoc networks *socio-aware* to achieve a better integration of the technology into our every-day live. Mobile ad hoc information systems should be able to capture and exploit the social structures around them to adapt themselves and optimize their delivery of information and services to mobile users. This adaptation process requires a high degree of self-organization in applications. Especially the need for ubiquitous information and service infrastructures that disappear and work in the background without explicit human intervention necessitates new approaches for adaptation and self-organization.

In this paper we propose a way to structure socio-aware applications. We introduce our MESH project that aims at building a self-organization platform. MESH stands for *MESH Enables Self-Organizing Hosts*. It employs self-organization principles from the areas of biology and complex network research to support loosely coupled information and service infrastructures in mobile ad hoc networks.

The rest on the paper is structured as follows: In section 2, we introduce the notion of socio-awareness. We give two example applications and explain the foundations and practical implications of socio-awareness. Section 3 discusses the current state of our work and section 4 sketches our future research agenda. Finally, section 5 concludes the paper.

2 Socio-aware Applications

Context-awareness covers a very broad spectrum of possible situational contexts a mobile user may be in. A context may be the time of day, sensory data like the temperature, a geographical location, or any combination of such data. Location has turned out to be the most important context in mobile computing as a mobile devices enables the user to move freely and change his location. Thus, location-awareness and location-based services have become fashionable. However, there has been no attempt yet to capture and use information about the *social context* of a mobile user. We add the notion of *socio-awareness* to the terminology of context-aware systems.

Socio-awareness can be defined as the ability of an application to capture and exploit the characteristics of the interactions among a group of mobile users. Such a group evolves over long periods of time and consists of loosely coupled individuals that access information and services via the ad hoc network they are embedded in. A socio-aware application is aware of the interactions and the social relations among the users and tailors its structure to this social network. If an application may sense its current social context, it may reach better decisions when it comes to information exchange or service provision. Before we continue our discussion on socio-awareness, we give two sample scenarios.

2.1 Scenario 1: Information Dissemination

One example for a socio-aware system would be an application that organizes the collective knowledge of a community of mobile users without a central controller. A *mobile community* is a loosely coupled group of mobile users that share one or more common interests. For example, the members of a soccer club have a common interest in soccer-related information while the members of a rock band are interested in information on music. Soccer-playing rock musicians belong to both communities at the same time. A user typically has a number of different interests which implicitly makes him a member of different communities. It is not implied that all community members know each other directly. Two members may have a mutual friend or there may be a longer chain of acquaintances that connects them. The only thing that makes them belong to the same community, is their common interest. Users may create pieces of information (info units) on specific topics using their mobile devices, or they may receive such info units from external sources. The goal of the system is to disseminate these info units among the users of a community so that the following requirements are met:

- A user should get as many info units as possible that meet his interests.
- When a user is in a certain social context (spending time with people that share special interests with him) he should be able to access the set of info units present on their devices. This set should represent a mix of topics that are interesting to the user and the whole group.
- The collective memory of all mobile devices that is used to store the over-all set of info units should be used as efficiently as possible.
- A garbage collection mechanism should remove info units (the set of their replicas) as their relevance to the community decreases.
- A new and highly requested info unit should be disseminated quickly and preserved.

Such an information system is a technological complement to the naturally existing flow of information among groups of users. It exploits face-to-face meetings to disseminate info units in the immediate environment of a user. Moreover, it enables information flows between groups that would otherwise remain unconnected.

To realize these ideas, we are currently developing SIDCO *(System for Information Dissemination in Mobile Communities)*. Based on simulations we study different socio-aware dissemination mechanisms that meet the requirements above.

2.2 Scenario 2: Service Placement

Another hard problem is the appropriate placement of services in ad hoc networks [12]. In an ad hoc network, certain services should be accessible by as many users as possible. But at the same time services should be applied as efficiently as possible. Thus, the number of services distributed in the network should be minimal. How can the appropriate nodes for service placement be found? In [12] the authors apply special algorithms to predict partitions in the network. Their fundamental assumption is that node movement is correlated and groups of nodes move together.

We argue that service placement is a problem of socio-awareness, too. If we are able to find the nodes in an ad hoc network that have had the highest number of interactions with other nodes, then these nodes would be good candidates for running services. Especially if a service is tailored to a specific community, detecting users (their devices) that are very active in this community is valuable. Services may be placed on these devices to be accessible by as many community members as possible.

2.3 Socio-Awareness and the Structure of Social Networks

The store-and-forward architecture of SIDCO exploits *social routes* (chains of acquaintances among the mobile users) to forward information. These routes form independently of any computerized infrastructure solely from our social interactions. A network of such acquaintances is called a *social network*. In the late 60s it has been shown that such networks have a remarkable ability to support effective and efficient communication between humans [9]. A hypothesis was formed that suggested that on average, two people on this planet are connected by a chain of six intermediary acquaintances. This *small world effect* was studied empirically and scientists were unable to disprove it. Later, it became famous under the term *six degrees of separation*. In the late 90s the secrets of this *small world* phenomenon were revealed. It was shown that social networks are among the vast bulk of naturally appearing networks that exhibit the small world property [3]. Small world networks have a small average path length and their nodes tend to form clusters (islands of highly inter-connected nodes). Moreover, complex social networks are *scale-free*. Scale-free networks have a small number of nodes that are connected to many other nodes while the majority of nodes have only a few connections. The highly connected nodes are called *hubs*, and they are very important for any communication process in such a network. Figure 1a depicts a small social network with 12 nodes. Nodes 3 and 9 are hub nodes.

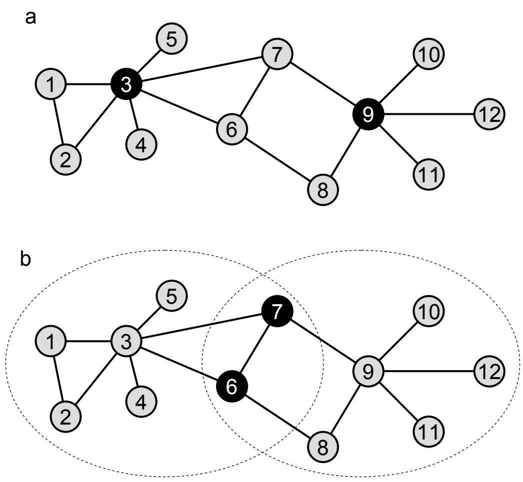

Figure 1: A sample of a small social network. Nodes represent users and edges are acquaintance relations between them. (a) The hub nodes are cloroed black. (b) Two communities are indicated by the dashed ellipses. The bridge nodes are colored black.

Socio-awareness in ad hoc networks builds on the assumption that we can use mobile devices as *social detectors*. The social network we are embedded in, shapes the patterns of our mobility and our habits to meet with other people. When a mobile user's device monitors these interactions, it can build its own local model of the user's social network. On a personal level, this model can, for example, reveal with whom the user frequently meets and how much time he spends with specific people. In SIDCO, this can be done at the topic level:

When two users meet, each device records the topics that the other user is interested in and builds its local model based on this topic-related information. When a device has to decide to whom it disseminates a specific info unit, it can inspect the local models of the neighboring devices and pick the one with the most fitting local model. By inspecting another device's local model, a system like SIDCO can recognize, whether the device's user is a hub node in the social network (has a broad range of interests and meets many people). Depending on their resources, hub nodes may then be used to disseminate information quickly and in many directions. A system may also discover specialists with very few interests that can forward an info unit in a very directed manner.

In Figure 1 the diverse roles of different nodes are depicted. In Figure 1a, the two hub nodes are colored black. These nodes have 5 and 6 edges while the rest of the nodes have between 1 and 3 edges. The majority of nodes has only 1 edge to another node. Obviously users 3 and 9 are intermediaries to many other users and thus are important for any communication in the network. In Figure 1b, the same network is depicted with the nodes partitioned into two communities (indicated by the ellipses). Nodes 6 and 7 seem to play an important role here. They are the only nodes that belong to both communities. Although they do not function as hubs, they are important as bridges between the two groups of users. Any information exchange between the two communities must pass through either user 6 or user 7.

It becomes apparent that a decentralized electronic information system can benefit vastly from detecting and exploiting these roles. It is important to note that the relations depicted in Figure 1 are long-term relations that result in repeated personal interaction. Thus, we can create information systems that function on larger scales in time and space. This goes beyond the possibilities of systems that rely on the existence on a direct multi-hop communication link between two nodes. As depicted in Figure 2, we argue that the communication between mobile users can be enriched by socio-awareness to reach a more global scale in space and a more long-term scale in time.

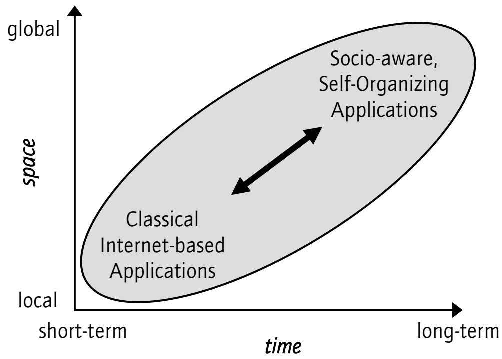

Figure 2: Classification of socio-aware applications in time and space.

2.4 Possible Problems and Pitfalls

Since hub users play a central role in social networks and, thus, also in socio-aware systems, there is a danger of overloading the devices of these few highly interactive users. Instead of accelerating information flows and improving service coverage, they could become bottlenecks. Therefore, strategies have to be found to prevent hub overload.

Another problem that is well-known in any peer-based infrastructure is caused by missing incentives for cooperation. Participants might take a passive role and try to benefit from the system without providing access to their own resources (memory, battery energy). There are proposals which may solve this general problem in ad hoc networks [5].

Security and privacy naturally interfere with the idea of an openly accessible information and service infrastructure like the one proposed here. Therefore, there is a limitation to the type of content that is offered via this system. Typically, this content is not subject to privacy concerns as the system is explicitly used to share information in much the same way as common Peer-to-Peer platforms in the Internet are used.

3 Current State of Work

We are currently in the process of developing the foundations for socio-aware systems in the MESH project. In this section we will briefly sketch the current state of our work.

3.1 MESH*Mdl* – Middleware Support for Socio-Awareness

MESH*Mdl* [8] is a middleware for ad hoc networks that represents a fundamental building block in the MESH project. It is based on mobile agents [11] as application components and tuple spaces [2] for asynchronous and anonymous communication. MESH*Mdl* achieves mobility-awareness by introducing a neighborhood abstraction. Applications may discover neighboring devices and interact explicitly with them via the local tuple space. This is an important pre-condition for socio-awareness. Many middleware systems aim at providing transparency rather than awareness [10] which would hamper the attempt to capture the patterns of interaction in an ad hoc network. Furthermore, MESH*Mdl* puts a high emphasis on decoupling applications in order to deal with the dynamics. Socio-aware systems strongly rely on an event-based programming style, as interactions between users are best implemented as events which applications can react to. Thus, the reactive, event-driven nature of communication that is enabled by using the concept of tuple spaces, provides an ideal basis for implementing socio-aware software. We have developed a prototype of MESH*Mdl* that is currently used in our research and by students in our courses.

3.2 MESH*Sim* – An Ad hoc Network Simulator

In order to test applications developed for MESH*Mdl*, we implemented the simulator MESH*Sim*. MESH*Sim* provides a server and a graphical interface for creating, moving and animating artificial mobile ad hoc nodes. Simulation clients may attach to the server and get mobility-specific events as nodes become neighbors (meet each other) and separate again. Each simulation client gets these events and emulates a Bluetooth API to a running application. Via this API, applications may discover new devices in their simulated vicinity and establish connections to the applications running on these devices. The applications are provided with the standard *javax.microedition.io* functionality to open connections and communicate.

3.3 Multi-Agent Simulations

MESH*Sim* provides a realistic testbed for real applications. However, although it enables distributed simulations, its capacity is limited to only a few dozen simulated nodes. However, self-organization, and in particular socio-awareness, is a group phenomenon that, in some cases, may only be observed in simulations with a few hundred actors. Therefore, we have also built a simulation framework based on the publicly available RePast multi-agent simulator [1]. This simulator was explicitly designed to conduct simulations of social networks. The SIDCO simulation is based on this framework. It allows us to experiment with hundreds of artificial users who have interest profiles and exchange info units. We are currently developing distributed algorithms for the organization of information in mobile communities.

3.4 A Social Mobility Model

To create realistic simulation of mobile users who move according to their social network, we had to create a new mobility model. This model builds on the findings of Barabási et al. [4] about complex networks. In the mobility model, a social network is created according to the scale-free network model. This network is then used to create mobility schedules for the individual users. In the running simulation, two users who are connected in the social network, meet frequently at a specific location. We have been able to show that the network resulting from these meetings closely matches the original social network. A publication on this mobility model is forthcoming.

4 Future Research

So far, we have concentrated on information organization in mobile networks. We hope to finish this work soon and transfer it to real applications based our MESH*Mdl* and MESH*Sim*. The next step will be to investigate the socio-aware self-organization of service infrastructures in ad hoc networks. We will try to develop a system that enables service coverage in public places without the need for a costly fixed-wired infrastructure.

5 Conclusions

In this paper we introduced our notion of socio-awareness. We discussed possible application domains and briefly explained the foundations of social networks. Finally, we gave an overview on the state of our work and our future research agenda in the MESH project.

We conclude that socio-awareness is a new and promising approach to capture and exploit the inherent dynamics of interaction in mobile ad hoc networks. This can lead to new mechanisms for self-organizing applications. Social networks exhibit a natural form of self-organization, that manifests itself in their internal structure. We should try to unleash this potential and use it to our advantage by building long-term and global information and service infrastructures on top of it. In the MESH project we set out to lay the foundations for these infrastructures.

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