During the last decade it has been possible to observe impressive scientific, technological and experimental advances in the area of ad hoc *networks. Although this technology is considered one of the main infrastructures for future applications, there is today the lack of appropriate middleware abstractions that adequately address the requirement of such a challenging environment.*

Middleware for Network Eccentric and Mobile Applications (MINEMA)

An ESF scientific programme

The purpose of the MINEMA programme is to bring together the main groups from different communities, working on middleware for mobile environments, and to foster the definition and implementation of widely recognised middleware abstractions for new and emerging mobile applications. The challenges of such a task are considerable, because the diversity of infrastructures and application requirements promotes the development of ad hoc*, specialised middleware solutions that are hard to re-use in different contexts. The interest of this programme is that it gathers together research groups whose interests are close enough to promote the emergence of concrete solutions, while at the same time combining complementary expertise in the area of distributed systems, networks, algorithms, programming languages, software engineering, and application development.*

MINEMA

The European Science Foundation acts as a catalyst for the development of science by bringing together leading scientists and funding agencies to debate, plan and implement pan-European initiatives.

Objectives

Middleware is the critical component needed to leverage the development of a wide range of applications for the *ad hoc* infrastructure. The MINEMA programme intends to foster the definition and implementation of middleware abstractions for new and emerging applications on top of *ad hoc* networks. These range from so-called mobile and ubiquitous applications to peer-to-peer applications.

Despite their usefulness, only a limited number of applications have been designed for *ad hoc* networks. One of the reasons for the current scenario is that most research performed so far in the area has concentrated on communication and system level issues such as network access, routing protocols, QoS preservation, or power consumption. While these issues are extremely important, it is of paramount importance for the design and implementation of meaningful applications to start by encapsulating low level and networking issues using a high-level middleware layer.

A fundamental challenge of middleware for *ad hoc* infrastructures is that the abstractions provided to the programmer must be implementable in an environment that is radically different from the fixed environment but, simultaneously, should be as close as possible to abstractions that are known, accepted and understood by most programmers. The definition of these abstractions requires the interaction of researchers with different expertises, including knowledge on ad hoc network protocols (the abstractions depend on a good characterisation of the environment), distributed algorithms (to specify the relevant distributed protocols that support the abstractions), software engineering (the abstractions should be expressed using the appropriate language constructs), and applications (the abstractions must satisfy the applications requirements).

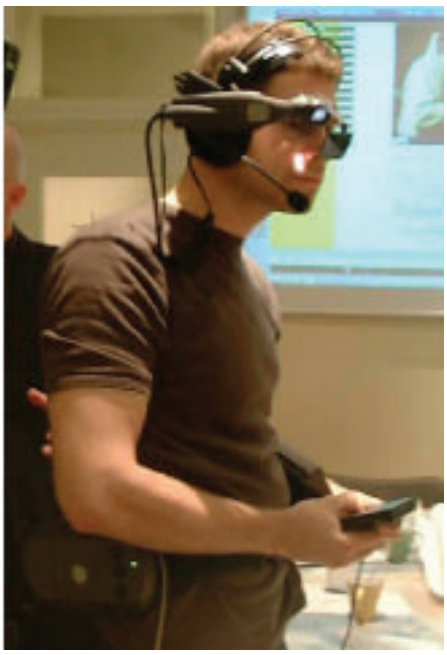
A number of paradigms, as described later, are emerging as candidates to play a significant role in *ad hoc* networks. The publish-subscribe paradigm is one example of a model of interaction that extends the more conventional remote procedure call (RPC) paradigm to address new types of applications. However, these abstractions by themselves do not have the breadth needed to ease the development of applications. The middleware for fixed networks complements the basic remote invocation paradigm with a number of services (name services, transaction services, storage services, replication services, etc) that, in their current form, cannot be directly applied to the mobile environment. Therefore, a goal of the current programme is also to define the auxiliary services that should become first class citizens of the middleware environment for *ad hoc* networks.

Scientific background

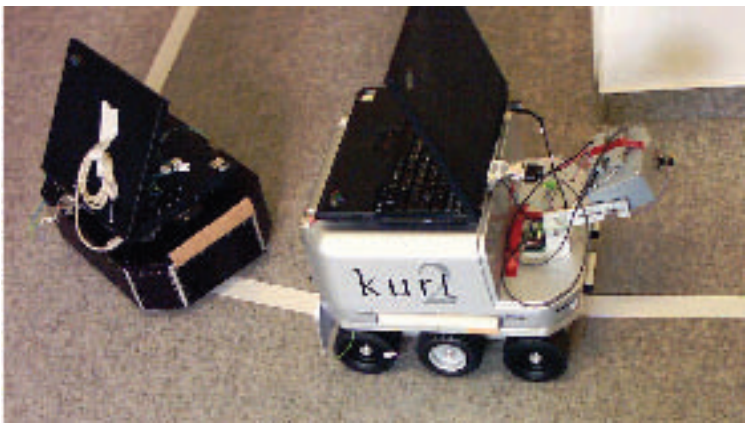
The main challenge of MINEMA is to identify new paradigms, or new specialisations and adaptations of known paradigms that are adequate for mobile and peer-to-peer systems. This requires a re-evaluation of solutions that have proved successful in the fixed and wired setting, which is typically characterised by good connectivity, high bandwidth connections and a rich availability of memory, processing and power resources. On the other hand, the environment targeted by MINEMA is characterised by a huge heterogeneity of devices, scarce resources and poor or intermittent connectivity. It is expected that, in the target environment, computers will be embedded in a wide range of appliances ranging in size from door locks to vehicle controllers, and will co-operate to perform tasks on behalf of their human users ranging from automatically opening doors to routing vehicles to their intended destinations in co-operation with other vehicles' controllers.

Consider for instance the architecture of information systems in the wired setting. The heart of an information system has traditionally been the central database server. Several client processes can store and retrieve information of interest through a database server process. Such a client-server mode of interaction is typically done in a synchronous way where clients query-update the database server and resume their activities when the query-update is over, or in an asynchronous way by subscribing to the database and receiving information of interest whenever such information is published on the database. In the latter case, we talk about an active database and a publish-subscribe interaction scheme.

In a large-scale environment, relying on a central database server hardly makes any sense. The database might easily turn out to be a single point of failure and a bottleneck performance. One might indeed consider implementing the database on a cluster of machines that provides acceptable performance and high availability, but this still poses the problem of accessing that cluster. A reasonable way to overcome the reachability problem is to replicate the database on several processes, and make sure that these processes are reachable to clients that potentially require access to the information. However, in a mobile environment, trying to ensure such a reachability is hopeless, precisely because potential clients are mobile and it is not clear how to determine the adequate processes on which the database should be replicated. Therefore, one needs to consider a system where the database is *everywhere*; that is, distributed in a way that it can be accessed despite the several impairments inherent in the mobile setting. We can identify a number of abstractions and mechanisms that need to be revisited in the context of MINEMA to materialise this vision. Namely, the following issues will be addressed by the participants of the MINEMA programme (the list is not exhaustive, as one of the aims of the



Wearable mobile platforms for augmented and virtual reality. © Distributed Computing and Systems Group, Chalmers University, Sweden



Robots spontaneously form a team triggered by physical proximity. The event-based middleware allows them to share sensors and coordinate actions dynamically.
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projects is to identify unsolved problems and attract new participants):

- ***Discovery and location services.*** Study mechanisms and algorithms that allow nodes to locate other nodes and relevant services. In the type of environments target by MINEMA nodes will be interested in finding 'near' servers. Therefore, it is fundamental to understand which are the relevant 'nearness' metrics.

- ***Resource naming and addressing.*** Definition of an adequate namespace for mobile and highly dynamic environments. Namespace management must consider security and efficiency constraints. An individual (and his/her devices) can have multiple identities or roles: employee (acting on behalf of company), student (certain privileges), parent (with regard to child's devices), and private individual. The namespace must reflect these roles (also in terms of connections) and be managed in a secure and efficient way.

- ***The use of location information to improve the operation of mobile applications.*** For instance, we can use location information to anticipate partitions and hence take preventive measures to ensure a graceful degradation of the application functionality. When disseminating information on a large scale, it is of primary importance to consider locality. Participants who are 'close' should interchange information more often than 'distant' ones.

- ***The issue of effectively supporting group communication.*** This line of activity will seek not only new protocols but also new definitions of membership, such as location-aware group membership services. We can easily imagine many cases where this would be interesting: in traffic management, for example, the area around a traffic-light could be used to define a group with cars in that vicinity becoming members of the group to receive notifications of changes to the state of the lights; in a similar way, we might want to define a group corresponding to the area around an ambulance in order to inform nearby cars to yield the right of way. This line of activity will also look for new protocols for data dissemination and message ordering.

- ***Gossip-based multicast.*** Several gossip-based protocols have been proposed for information broadcasting (that is, to the entire system), along with studies of their performance and reliability. Most of these protocols use the network intensively. New algorithms, more adequate to systems where the network is a scarce resource have to be designed.

- ***Agreement and coordination services.*** Fundamental distributed agreement problems such as consensus, atomic commitment, reliable broadcast, totally ordered communication and leader election have been widely studied in the wired environment. Given their importance in the support of higher level abstractions, one needs to find similar counterparts for mobile networks. Not only new algorithms, more adequate to the characteristics of the environment have to be sought, but the definition of these services, itself has to be revisited.

- ***Transactional services, weak consistency models and support for reconciliation.*** Serializability is the most used correctness criterion for distributed and concurrent transactions in the wired environment. Given the difficulty of enforcing this criterion in environments subject to disconnections, a myriad of weaker consistency models have been proposed during the last years. Some of these models allow participants to have divergent views of the information which can be later reconciled. It is important to identify the fundamental building blocks that will support a wide range of complementary approaches.

- ***Timeliness and QoS.*** Protocols that are able to offer predictable behaviour in the time domain, or to satisfy various qualities of service properties must be designed. Despite the challenges posed by the highly dynamic nature of the environment, protocols may exploit a diversity of routes for supporting communications with real-time delay constraints such as multimedia messaging (data, voice and, possibly video).

- ***Security.*** Security analysis of the MINEMA environment (including the robustness to malicious attacks). Solutions for providing authentication, privacy, and robustness. Data cryptography and individuals/devices authentication are essential services that need to be provided for supporting a wide set of applications, ranging from messaging services to complex multimedia applications and file sharing.

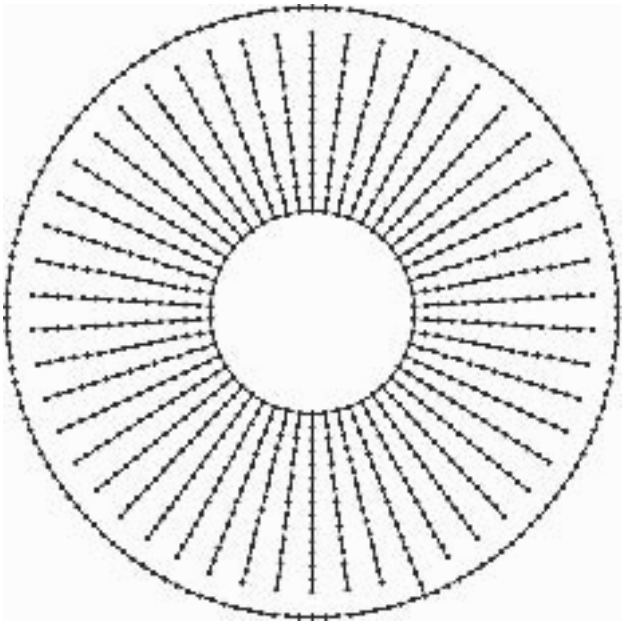
- ***The issue of providing the adequate support for implementing messaging services in mobile environments.*** Such service requires the integration of a myriad of distribution strategies for targeting messages to their destinations, while at the same time taking into account the heterogeneity of the underlying network, which may contain wired as well as wireless subnets. Additionally, the implementation of this service has to be much lighter-weight than their fixed counterparts, as it should also be able to be hosted on simple computers such as portable digital assistants.

- ***Information retrieval.*** Mechanisms supporting efficient retrieval of the information are important middleware services for a virtual community, where each user has a set of local data that he may share with the other members of the community. Code mobility appears to be an efficient solution for supporting information retrieval in an environment in which bandwidth is a scarce resource and users' mobility makes continuous communication a very complex (if not impossible) task.

- ***Splitting knowledge.*** The interests of individual participants, as well as their identities, have to be managed in a non-centralised manner. The knowledge has to be split between participants to increase scalability, and must nevertheless be redundant to ensure a certain degree of reliability. It is important to find strategies to disseminate information in such a way that makes it highly probable for a node to obtain the information it needs even in environments where nodes are moving and may become disconnected.

Using location information.

Lower bound graph. © DIALNP, 2004



- ***To apply techniques derived from complex adaptive systems.*** These techniques should enable the construction of robust, self-organising and self-repairing information systems for deployment in *ad hoc*, peer-to-peer and grid computing systems. The work on these aspects has ramifications with work on distributed artificial intelligence.

- ***Cooperation model.*** A self-organising network must be based on an incentive to the users to collaborate. There must be a mechanism that encourages users to behave as 'good citizens' by (a) letting their device relay packets for the benefit of other users; (b) making their data available; and (c) providing support to the other computations. Our approach to stimulate such behaviour is founded on a credit-based cooperation model.

- ***Reflection and adaptation.*** Reflection offers important techniques in creating middleware that is able to dynamically reconfigure itself based on environmental changes. This area seeks to create reflective middleware that best supports mobile applications within the heterogeneous and highly dynamic mobile environment.

- ***Programming language constructs and conceptual framework.*** Development of new programming language constructs for supporting distributed, mobile, ubiquitous (pervasive) and peer-to-peer applications. Most programming languages paradigms, including procedural, functional- logic and object-oriented programming, are based on a programming model that assumes locality. During the last decades, object-oriented programming has become a dominant paradigm with languages such as Smalltalk, C++, and Java. Part of the success is that the OO paradigm is based on a conceptual framework for understanding phenomena and concepts in the real world, including conceptual means such as classification, generalisation/specialisation, composition/aggregation and association. This conceptual framework originated with the Simula languages in the 1960s, but it does not cover distributed computing. In order to successfully discover new abstractions for distributed computing, it is important to develop associated conceptual means. A conceptual framework for distributed programming should include means for understanding notions such as publish-subscribe, gossip-based multicast, time, location and mobile agents.

- ***New applications.*** In many cases, applications available for mobile and peer-to-peer systems are adaptations of applications previously developed for the fixed environment. The programme will also consider the study of new applications built from scratch having the MINEMA environment in mind.

- ***Integration of the results with industrial solutions.*** In particular, their integration into next versions of UML and CORBA. The notion of a smart component as a basic networked building block recently became popular. The characteristics emphasise the ability to cooperate in a decentralised setting. The project will take actions to intervene in standardisation activities and will invite key people in this process to the open workshops.

Activities

The programme includes the following planned activities:

- Short-term visit/exchanges among the programme participants (namely PhD students).
- Organisation of workshops for programme participants, to allow the dissemination of early research results and experiences.
- Sponsoring of conferences in the area of MINEMA.
- Organisation of schools on the subjects covered by the programme.
- Organisation of open workshops in the area of MINEMA.
- Setting up a comprehensive Internet research dissemination channel and publication activities.

More information at: www.esf.org/minema

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For the latest information on this programme consult the *MINEMA* home page: www.esf.org/minema

Cover picture:
It is a goal of Palpable Computing to support people in understanding what is going on in systems that use *ad hoc* networks. Palpable systems support control and choice by people. © PalCom

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