10.Mobile Computing

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Link to the SOTA Chapter

Ongoing Research / Future Directions

Mobile computing is becoming more and more relevant due to the enormous technological advances in the area of wireless communication (like GPRS, IEEE 802.11, Bluetooth and UMTS) and in the capabilities of mobile devices. With the increasing number of users that have access to sophisticated personal assistants, mobile phones, and devices that mix both functionalities, industry is pushing research to leverage on this infrastructure to create the higher level constructs to support the development of a myriad of new application.

While in the past a significant research effort has been invested in relatively lower-level protocols and services, such as for instance, network access, routing-protocols, QoS preservation, or power consumption. In the future, it is expected that the emphasis will shift to the upper layers, covering issues such as middleware, security, human-interfaces, applications, etc.

Wireless Networks Classification

[Prakash 1998] proposes the division of wireless networks in three categories, depending of the supporting infrastructure:

- **cellular networks** are those where each mobile host connects to some fixed base station. The base stations are connected using a wired infrastructure.

  Cellular networks were widely deployed over cities by the GSM mobile phone operators.

- **virtual cellular networks** differ from the previous ones by the mobility of the base stations, also connected using wireless links.

  Utilization of virtual cellular networks is envisioned for example in military actions, where armored vehicles can carry the base station equipment and soldiers use the mobile hosts.

  Cellular networks (either virtual or not) benefit from the existence of base stations, that are able to accept registration of new devices and can route messages between base stations to reach hosts that are not directly accessible. State of the art is shifting to the third category:

- **ad hoc networks** are autonomous systems, composed only by the communicating hosts. This kind of networks does not use base stations. The members of the network must handle every network maintenance procedure. It is expected that hosts within an acceptable range spontaneously generate ad hoc networks.

  The first applications envisioned for ad hoc networks were search-and-rescue, law-enforcement and military operations. However, ad hoc networks are also of interest for civilian applications, by allowing different hosts to share their resources towards a common goal. For example, devices within the same room can establish an ad hoc network for file sharing between the participants of a meeting. Ad hoc networks are also expected to impact on the development of Personal Area Networks (PANs), those composed of the several devices carried or near a user.

Networking and Routing Protocols

Routing protocols for mobile and ad hoc networks have been extensively studied [Johnson 1996, Perkins 1999]. However, research still evolves around the subject [Hu 2001, Spohn 2001, Santivanez 2001], some within the standardization effort performed at the MANET Working Group of the IETF [MANETWG]. One particular case of routing that may be useful for SOTA middleware is based on the geographic coordinates of the last known position of the destination [Ko 1998, Basagnin 1998]. These protocols then forward messages to hosts known to be closer to the destination than the current host holding the message.

Mobility support for IP version 6 (IPv6) is yet SOTA since the protocol may still be polished [Johnson 2002] . The Lancaster University, together with Microsoft Research, Cisco and Orange have established a research laboratory that will convert the city of Lancaster in a large-scale laboratory for Mobile IPv6 and other technologies [Mobileipv6].

Middleware

Middleware is a critical component that is mandatory to leverage the development of a wide range of applications. A fundamental challenge of middleware for mobile and ad hoc infrastructures is that the abstraction 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 [Saha 2001]. The definition of these abstractions requires the interaction of researchers with different expertise, including knowledge on ad hoc network protocols (the abstractions depend on a good characterization 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).

However, these abstractions by themselves do not have the breath 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 [Veiga 2001].

Power Management

Power and computation are scarce resources in mobile devices and should be handled carefully through the several layers. Devices must apply strategies both for power saving, and to modify their behavior under low power conditions. Some MAC protocols have already achieved good results by turning off their receivers while a transmission between two other nodes is taking place [Singh 1998, IEEE 802.11]. At the network layer, power-aware routing protocols [Singh 1998a] have also provided some contribution for the rational use of energy. The contribution from upper layers is to be defined [Jones 2001, Geihs 2001a] .

Security

Because new hosts can be added to the network without connecting cables, wireless networks are more vulnerable to attacks than their wired counterparts. Therefore, one needs to be concerned with the mechanisms required to ensure the integrity and confidentiality of messages. Additionally, mobile and ad hoc networks make the establishing of relations of trust more difficult because a centralized trusted key server may not be available. Solving the problem of key distribution in a mobile setting is an on-going task. Some approaches try to adopt paradigms from the animal world to define trust policies in the mobile setting: for instance, [Stajano 2002] proposes to mimic ducklings behavior by making mobile nodes trust the sender of the first heard message (ducklings acknowledge the first movement that they see with their mother) .

Ad hoc networks composed of nodes managed by independent authorities, for example the network composed by the laptops of attendants to a conference, will present strong similarities with

human societies. The scarce available resources, namely battery power, may stimulate some of the participants to become selfish, attempting to make use of the resources provided by the community while avoiding to provide their contribution. Nodes may, for example, refuse to forward messages from other hosts but expect theirs to be forwarded. To mitigate this behavior, mechanisms such as a virtual currency named nuglets [Buttyan 2000], a tamper-proof hardware module [Buttyan 2001] and a protocol based on the reputation of the nodes [Buchegger 2002] have been proposed. Future work on this topic should also address the problem of denial-of- service attacks in wireless networks, for instance by preventing attacks to deplete the battery power of one host by repeatedly requesting him to forward messages to other hosts.

Fairness

The implementations of middleware protocols, such as replicated distributed objects, publisher/subscriber, group membership, order protocols and timely communication for wireless networks, should not rely exclusively on distributed algorithms with centralized control. In these algorithms, coordinators usually have a higher load and deplete their batteries at a much faster pace than the remaining participants in the computation. The same problem can exist with message forwarding in mobile and ad hoc networks if a high number of participants share known routes. Power-aware routing protocols mitigate the problem by using metrics based on the battery power available at each node [Singh 1998a, Jones 2001].

Peer-to-Peer, Publish-Subscribe and Group Communication

The peer-to-peer and publish-subscribe are examples of new models of interaction that try to extend the more conventional remote procedure call (RPC) paradigm to address new types of applications [Cugola 2001, Jacobsen 2001]. An example of a system that relies on these paradigms for mobile systems is the CORTEX [Verissimo 2002] } project, that is defining a framework for sentient objects: autonomous objects that sense the environment and act accordingly.

Most existing implementations of the publish-subscribe paradigm are resource hungry and too complex to be directly supported on low performance devices. Only recently, the issue of building publisher-subscriber schemes for devices with low capacity, such as smart sensors, industrial networks and robots started to be addressed [Kaiser 1999].

Peer-to-peer systems are a promising technologies for mobile networks but many open issues still remain. Locating peers with common interests for example, is a problem with no fully satisfactory solution in peer-to-peer networks [Renesse 2002, Kan 2001] that is also present at the ad hoc networks. Defining peer-to-peer frameworks for ad hoc networks is also a new research topic [Kortuem 2001].

Group communication is also a useful paradigm for many applications in wireless networks for which reliability, consensus and timeliness are fundamental requirements. However, most research on group communication has been performed in the context of wired networks. Existing solutions for group communication in mobile systems relate membership with the distance between the group members [Prakash 1998, Roman 2000, Meier 2001].

Context and Location Awareness

The goal of context-aware applications is to reduce the amount of needed human attention, by inferring some of the information from the surrounding environment. For example, a query for restaurants should automatically consider the location, the food preferences of the user and the current wait time of the candidate restaurants. Infrastructure support for general context-aware applications is state of the art [Tseng 2001]. The work presented in [Ebling 2001] describes a middleware framework allowing context-aware applications to work in anticipation, extending the context information from the present current location, to encompass also the user preferences and habits (retrieved from the information learned in the past).

The previous examples are concrete cases of the more general problem of identification of resources. In practice, it is not intuitive to refer to physical entities (such as a printer or a door lock) by a full URL. If proximity, context and ownership is taken into account resources can be identified in a more intuitive and practical manner.

Additionally, both the middleware and the application may adapt their behavior according to the proximity and other network factors when accessing resources form the mobile hosts. Wireless, mobile devices are constantly subject to variations of the executing environment (the context), for example, bandwidth, battery power and location. One of the biggest challenges to be faced by middleware for mobile networks is how to express these changes in order to make them meaningful to the application, allowing it to adapt its behavior. Reflection and metadata may perform an interesting role on this subject, by allowing the applications to express to the middleware how the execution environment should react to the execution context changes [Capra 2001].

Human Interfaces and QoS

The final goal of the communications, network protocols, and middleware infrastructure is to provide support for the development of application. However, the success of these application will be extremely dependent of their user-interfaces. Therefore, the issue of human interfaces is a fundamental block of the mobile systems architecture. The vision of a ubiquitous computing world is now attempting to be materialized by some research projects like Oxygen [Oxygen], lead by the MIT (USA). One of the fields of investigation is the human interaction with the devices, in particular, voice driven interfaces.

To be attractive to the public, the new devices must also support multimedia content. To be able to present multimedia content with acceptable quality, the infrastructure must be able to negotiate and maintain Quality of Service (QoS) parameters [Nahrstedt 2001, Corson 1999]. The content and the applications must also be dynamically adapted to the available bandwidth [Sow 2001, Noble 1999, Yarvis 1999]. These two topics are presently state-of-the-art, mostly due to the narrow bandwidth available for wireless networks.

CaberNet Related Activities

- **2WEAR (A Runtime for Adaptive and Extensible Wireless Wearables)**
    - FORTH, Greece

  The goal of the 2WEAR project is to explore this vision by developing a distributed personal computing system that will be inherently extensible and adapt itself to its changing configuration. The system will be able to detect and seamlessly connect to various devices, also exploiting the available surrounding computing infrastructure. It will also dynamically adapt its functional and interactive elements, based on the availability of components and the context of use, without having to reset or shutdown running applications.

- **ALICE (Architecture for Location Independent Computing Environments)**
    - Trinity College Dublin, Ireland

  A number of problems are posed by the operation of applications on mobile computing devices, including addressing problems, intermittent connectivity and physical resource constraints on the mobile device itself. ALICE is a framework designed to offer general support for distributed object-oriented applications operating in wireless mobile environments. ALICE solves the problems posed by the characteristics of such environments in a layered manner with a session level approach coupled with application support.

- **Aware Goods**
    - Universität Karlsruhe, Germany

  In order to supervise goods during transport from the supplier to the consumer we are trying to introduce a small digital device with a CPU, memory and sensors on it. This device has to control the goods and the resulting measuring values are stored in the device's memory. Once arrived at the product's final destination the device will be automatically read out via infrared or any other possibly wireless communication and the data will be transferred into the consumer's backend system (quality management system/ERP system). The backend system can then check the recorded data and determine the state of the goods. If certain limits are exceeded, an alarm can be invoked and the damaged goods can instantly be returned to the supplier. This system shall offer a continuous control over the goods and a seamless integration into the existing backend systems of the suppliers as well as the consumers, following the concepts of electronic commerce. The advantage is that the error rate is much lower as no manual transferring of data is needed any more. The goods supervise themselves, which results in the term "aware goods". The measurements of digital devices are also much more accurate than those of analogous ones. This offers better control and accuracy of values to present in insurance matters. The transferring of the values is accelerated and thus costs can be reduced.

- **CASCO (Investigating Context Aware Support for Cooperative Applications in Ubiquitous Computing Environments)**
    - Lancaster University, UK

  This project is exploring how the sharing of context in ubiquitous environments can support cooperation and what issues this raises, e.g. privacy.

- **CAMS (Context Aware Mobile Services)**
    - Trinity College Dublin, Ireland

  A smart space will only be truly smart when it reacts to the task a user is actually pursuing, rather than simply reacting directly to their actions. In order to achieve this, task and space level information must be integrated into an application model receiving inputs from a variety of sensors.

  CAMS is exploring these issues from two sides: the creation of novel smart artefacts to directly support particular tasks, and ways of relating the progress of tasks to the low-level cues obtained from these devices.

- **CORTEX (Co-operating Real-time Sentient Objects: Architecture and Experimental Evaluation)**
    - Trinity College Dublin, Ireland

  The CORTEX project deals with the emergence of a new class of application based upon mobile intelligent software components that interact with each other in ways that demand predictable and sometimes guaranteed quality of service. The application scenarios envisaged for CORTEX are large scale, mobile, safety critical distributed systems such as air traffic control, traffic systems and teleoperation of mobile robotics. The project deals with event-based communication models, group communication, context-awareness and the provision of timeliness guarantees all within a heterogeneous network environment (including wireless networks).

The CORTEX project will develop a programming model for mobile intelligent software components, which will take into account the provision of incremental real-time and reliability guarantees and will design a scalable system architecture that reflects the heterogeneous structure and performance of underlying networks.

- **Emergency Multimedia**
  - Lancaster University, UK

  Emergency Multimedia (EMM) explores the use of mobile computer systems to assist the Langdale and Ambleside Mountain Rescue team (LAMRT). The system is based around a set of devices (medical ECG, pulse and blood oxymetry monitor, GPS compass, digital camera carried in a single rescuer's rucksack whose data can be combined a transmitted in real-time back to the mountain rescue base. The rucksack also contains a small embedded PC (based around a PC104 stack) with a 'DiskOnChip' solid state disk containing Linux and our driver software.

- **EYES**
  - Universiteit Twente, The Netherlands

  The EYES project is a three year European research project (IST-2001-34734), on self-organizing and collaborative energy-efficient sensor networks. It address the convergence of distributed information processing, wireless communications, and mobile computing.

- **GLOSS (Global Smart Spaces)**
  - Trinity College Dublin, Ireland

  We are currently experiencing the emergence of high-quality, low-cost mobile computational and networking devices, which will result in a global computational and information network. The GLOSS project addresses the scenario where only devices at the human interface are visible and is seeking to develop a precise understanding of how services (both physical and information-based) are used and interleaved into people's daily lives.

- **GUIDE II (Context-Sensitive Mobile Services for Residents in a Networked City)**
  - Lancaster University, UK

  Our experiences within the GUIDE project have led us to hypothesise that the combination of mobile context-sensitive information and, critically, context-sensitive services may together prove a major catalyst in the development of the mobile data market. The EPSRC funded GUIDE II project will design and develop such a prototype system that will enable us to test this hypothesis.

- **Fault-tolerance in Audio / Video Communications via Best Effort Networks**
  - University of Hamburg, Germany

  Best effort networks typically are not able to satisfy any quality of service (QoS) guarantees regarding (minimum) packet throughput, (maximum) packet delay or delay jitter. Therefore, these networks have to be modified in order to be able to support real-time communications. In this project we elaborate new techniques for fault-tolerance which allow one to accept some deficiencies in network quality (e.g. packet losses). The

techniques we investigated and analyzed are either part of some dedicated middleware or they are directly supported by the distributed applications. In case of audio / video communications, which has been the focus of our studies up to now, we are analyzing, in detail, techniques such as FEC, adaptive video encoding, information dispersal, traffic smoothing as well as combinations of these techniques [Richter 2001], [Wolfinger 2001]. Both, quantitative and qualitative assessments of the improvement in video quality are focal points of our research [Heidtmann 2001].

- **LinkMe: Distributed Link Services for Mobile Environments**

  - Imperial College, UK

  The overall objective of this project is to provide a distributed link service for mobile users of distributed hypermedia (Web) information systems.

- **Living in a Smart Environment**

  - Universität Karlsruhe, Germany
  - Universität Stuttgart, Germany

  This is a research project founded by the Gottlieb Daimler and Karl Benz Stiftung. It combines the competences of various institutes and will look into the implications of the introduction of ubiquitous computing on social life and society. TecO as participant in this overall project will develop a second generation of the Memo Clip. The Memo Clip II project is focused on improving and extending the concept of the standard PDA. PDAs provide the user with a simple context aware application: the calendar. This application is designed to interactively alert the user depending on the actual date and time to remember appointments, entered earlier. In Memo Clip II we want to extend this well established system with additional context information the user can use as a trigger for the reminder event. One major focus in this work will be on location as an additional context to connect with relevant information.

- **MICS (Mobile Information and Communication Systems)**

  - Ecole Polytechnique Fédérale de Lausanne, Switzerland

  The goal of this project is to define and implement distributed middleware building blocks and algorithms for Mobile Ad-hoc NETworks (MANETs).

- **Nexus (An Open Global Infrastructure for Spatial-Aware Applications)**

  - Universität Stuttgart, Germany

  Development of concepts and techniques for a system-level support of location-aware applications with mobile users.

- **Ozone (New Technologies and Services for Emerging Nomadic Societies)**

  - INRIA, France

  Ozone, an IST project whose goal is to investigate, define and implement/integrate a generic framework to enable consumer oriented ambient intelligence applications.

- **Relate (Assessment of a Relative Positioning Technologies for Compositional Tangible User Interfaces)**

- Lancaster University, UK

The Smart-Its project is interested in a far-reaching vision of computation embedded in the world. In this vision, mundane everyday artefacts become augmented as soft media, able to enter into dynamic digital relationships. In our project, we approach this vision with development of "Smart-Its" - small-scale embedded devices that can be attached to everyday objects to augment them with sensing, perception, computation, and communication. We think of these "Smart-Its" as enabling technology for building and testing ubiquitous computing scenarios, and we will use them to study emerging functionality and collective context-awareness of information artefacts. This is a European IST project (project IST-2001-39264).

- **R-Fieldbus**

  - Instituto Politécnico do Porto, Portugal

The R-Fieldbus project (funded by the European Commission - IST-1999-11316) aims at developing an innovative wireless communication architecture supporting industrial multimedia. Within this project the group has proposed a new hybrid wired/wireless PROFIBUS solution where most of the design options are made in order to guarantee the proper real-time behaviour of the overall network [Alves 2002]. Furthermore, the group has also participated in the development of a double stack architecture, allowing the tunnelling of TCP/IP traffic in wired/wireless PROFIBUS networks [Pacheco 2001].

- **Smart-Its**

  - Lancaster University, UK
  - Universität Karlsruhe, Germany

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- **SmartOffice**

  - Universität Karlsruhe, Germany

SmartOffice interoperates the development of different applications and hardware projects located in the field of interactive and ubiquitous office augmentation. This includes for example mechanisms for enhanced meeting room scheduling and different applications providing added value for the participants in a meeting and the employees in an office environment. One of the major contributions to this project will be the development of an interactive and interconnected doorplate for meeting rooms and offices porviding easy access to relevant data and environmental functions.

- **Smart Shelf**

  - Universität Karlsruhe, Germany

The goal of the Smart Shelf project is the devlopement of a prototype of an augmented shelf for various consumer products. Products located on the shelf will be equipped with

RF-ID tags, replacing the now used barcodes. In addition to the functionality of the familiar barcode the RF-ID tags open up new ways of stock management. One example of a field of application for the Smart Shelf is the feasibility of the implementation of an ongoing taking inventory not only in the stock but also in the shop. This we hope to achieve by the ability to detect every single product in a shop placed on a Smart Shelf.

- **VIVIAN (Opening Mobile Platforms for the Development of Component-based Applications)**

    - INRIA-Rocquencourt, France

    Mobile communication, personal computing and distributed information services are merging in a rapid pace and existing commercial platforms for mobile devices need a substantial boost in order to meet the new market needs. To help in this direction, the ITEA VIVIAN project proposes a suite of middleware services for a variety of application domains accompanied by a developer's guide which together will ease the task of third party vendors producing applications for mobile end-users.

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