Middleware for Mobile Systems

European Commission -
US National Science Foundation

Strategic Research Workshop

Middleware for Mobile Systems

Vienna, 1-2 July 2002

Workshop Report

Report on the
EU/NSF Strategic Workshop on

Middleware for Mobile Systems Workshop

July 1-2, 2002
Technical University of Vienna

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Workshop coordinators and editors

Remi Ronchaud and Randy Chow
Organisational coordinators

Foreword

The mission of the workshop, unlike a conference special session, is to present and discuss future R&D directions, challenges, and visions in the emerging area of Mobile Systems.

The goal of the workshop was to bring together researchers from the United States and Europe to deliberate on the current state and future directions for research in the area of *Middleware for Mobile Systems*. Seven researchers from Europe and nine researchers from the United States of America have participated in the workshop.

The workshop was held under the auspices of the Future and Emergent Technologies Unit of the Information Society DG of the European Commission and the National Science Foundation of the United States of America

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Workshop Organisation

The workshop was held in the Technical University of Vienna, in association with the 22nd International Conference in Distributed Computing Systems (ICDCS 2002). The coordinators of the workshop would like to thank the ICDCS general chairs A Min Tjoa and Makoto Takizawa, and the ICDCS local organization chair Maria Schweikert for hosting the workshop.

The workshop was composed of one and a half days of brief presentations and discussions. Half a day was devoted to organize and discuss the major issues raised during the workshop. The results of that discussion served as the basis for the workshop conclusions reported in this document. This report has circulated among the workshop participants and has been amended and can be considered as a view of the workshop as a whole. The coordinators of the workshop would also like to thank all the participants for their contribution.

The workshop Chairmen were Dr Luís Rodrigues and Dr Ravi Prakash.

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1. Summary of Recommendations

In preparing the workshop, the invited participants were required to provide the Chairmen with a brief overview of what they believed will be the future research fields in *Middleware for Mobile Systems* (MMS).

On receiving the participants contributions, the workshop structure was designed to address four broad areas:

- **Models**
- **Continuing Research**
- **Long-term Research**
- **Applications**

After the roundtable presentation of the participants, the workshop first focused on defining the scope of these 4 broad areas, before identifying specific research trends within each one:

- **Models:** Current research in the area of MMS has considered a variety of system appearing similar, have significant differences so that results pertaining to one model may not be easily applicable to other models. So, it is important to develop a good understanding and taxonomy of system models.

- **Continuing Research:** Significant research is underway on a variety of MMS-relevant issues like consistency models, adaptation, mechanisms and tools for composition, location-, energy- and context-awareness, peer-to-peer and pervasive computing, overlay networks, agents for mobile code, indirect communication, etc. There is need to continue exploring these areas.

- **Long-term Research:** Several important issues like security and trust management, cooperation models for mobile nodes, generic consistency models, etc. need to be investigated in depth. These are relatively new issues for MMS researchers and should be the focus of long-term research.

- **Applications:** MMS researchers have focused primarily on a small set of applications for mobile systems, namely military operations, civilian search-and-rescue missions, personal communication, etc. However, there are a large number of other applications in the areas of ambient intelligence, augmented reality, health-care, entertainment and recreation, etc. that need to be looked into. Such applications have their unique demands that can serve two purposes: *(i)* provide new MMS-related problems to investigate, and *(ii)* expand the applicability of MMS results. There is a need to think

beyond computer science and look at a variety of real-world applications where MMS results can be applied.

In addition to the research topics listed above, the workshop participants were also encouraged to discuss the issue of future European-US collaboration:

- **Future European-US Collaborations:** There is a need to increase the research collaboration between European and US researchers. On several problems, US and European researchers complement each other very well. Hence, a collaboration between such researchers will be highly productive and will have a global impact. It would be useful to consider a joint program between the NSF and EU funding agencies through which such collaborative research could be promoted.

All the above mentioned topics (Models, Continuing Research, Long-term Research, Applications and Future European-US Collaborations) have been discussed during the workshop and each of these issues is described in detail in the following sections.

2. Models

It is important to develop a good understanding of various models of operation of mobile systems, and unique research issues pertaining to each of these models. Multiple topological models of mobile systems exist. for example, cellular networks, mobile ad hoc networks (MANETs), body area networks (BANs), wireless LANs (WLANs). It is important to understand, capture and describe the representative characteristics of each of these models and to identify the most common architectures that combine these basic models in more complex architectures.

Some research has focused on such networks operating in a stand-alone fashion. For example, a MANET formed by nodes coming together in a region with no infrastructure, or when the infrastructure is destroyed due to natural or human activity. Other research has assumed that MANETs always have connectivity to the external world, namely the Internet, through gateway(s). The presence or absence of connectivity to a fixed network has a significant impact on system behavior, and consequently on the research problems that need to be addressed. For example, when the MANET is connected to the Internet through gateways, it can be assumed that naming and directory services are supported by dedicated servers. In the stand-alone mode of operation there are no dedicated servers. Therefore, these services have to be supported collectively by the member nodes, which are all relatively resource-poor.

This leads to another important model-related research issue, namely the cooperation model of nodes in a mobile network. At one extreme, it can be assumed that all nodes have similar capabilities and are fully cooperative towards the accomplishment of similar goals. At the other extreme, it can be assumed that the mobile system is composed of heterogeneous mobile nodes that may be operating in a ``selfish'' mode to accomplish potentially conflicting goals. A significant body of research exists for the former system model that represents enterprise networks. Further investigation is necessary for the latter model of operation where networks are formed by nodes
under no single administrative control.

The issue of cooperation among nodes in a network also extends to security and trust models in mobile networks. Can member nodes be trusted? If not, then what are the security issues that need to be addressed? Are the security problems identical for infrastructure-less systems operating in the stand-alone mode and those that have connectivity to the Internet? Furthermore, what research issues are posed by the internetworking of several mobile networks, each under different administrative control, and communicating with the others through gateways?

While investigating various aspects of mobile systems, it is pertinent to address the following questions:

- What characteristic of mobile systems makes them different from other networking and distributed system models?

- What impact does mobility have on the operation of solutions designed for static systems?

- What are the representative mobility and connectivity models that need to be considered for the purpose of performance evaluation?

- Is the ``random waypoint model'' representative of how nodes will move in MANETs?

- Is it possible to form a repository of mobility patterns during the course of operation of a mobile node?

- Is it practical to use knowledge of past behavior, stored in such a repository, to predict future mobility and take appropriate actions to optimize performance?

- What impact do network partitioning, and partition merging have on the performance of mobile networks?

- If the breaking of wireless communication links, due to the relative movement of nodes, is a ``way of life'' and not an instance of link-failure, is there a need to revisit the classification of failure models being used by operating systems and distributed computing research community?

It was felt that more work needs to be done to capture the important parameters that characterize a significant set of architectures and applications. Often, research results are compared using artificial mobility, connectivity, traffic and failure assumptions which differ widely and may not be representative of concrete application scenarios. To agree on a set of benchmarking parameters, would simplify the task of assessing the merits of each solution.

With respect to programming and application models for MMS, there is need to investigate location-based naming and programming models. In order to account for location-based information, such models should provide means to map between logical and physical addresses of mobile nodes, and incorporate location/network environment information to trigger specific events when a node moves between different network domains.

In many established areas there are a number of services that have been identified as fundamental building blocks of an architecture. For instance, operating systems offer services such as process management, synchronization, communication, memory management, etc; distributed systems offer services such as name services, traders, distributed file systems, transaction management etc.

Therefore, it is felt that the MMS area has not matured enough such that similar building blocks have already been identified in an indisputable manner. However, the identification of such blocks would allow to develop a common architectural framework to glue otherwise separate research efforts.

3. Continuing Research

Research in MMS has progressed in several interesting directions. However, such work is far from reaching its conclusion and needs continued support. For example, a number of consistency models have been proposed for mobile systems. The strong consistency model for wired networks, where nodes are always connected to each other, can result in reduced availability of services in mobile networks. Hence, weak consistency has been proposed to support disconnected mode of operation. However, different notions of weak consistency have been employed for different system models. Several questions are then arising:

- Does this mean that to support mobility, the middleware will have to support multiple consistency models at the same time?

- Is application-specific consistency the only solution?

- Furthermore, if different consistency models are to be used concurrently, how to ensure mutual consistency among objects using different consistency models?

Additionally, and assuming that multiple consistency protocols would need to be supported in future MMS systems, one needs to search for common services and interfaces that ease the task of developing application specific consistency protocols and that help migration from one model to other more adequate in the future. It would be interesting to derive a common set of mechanisms (logs, context repositories, access pattern profilers) and interfaces (callbacks, re-integration, synchronization) that could be used by a large amount of consistency protocols.

The middleware for mobile systems should provide adequate support to applications so that:

(i) the application can be location-aware, and
(ii) the application can be energy-efficient.

That said, the research needs to be continued in the direction of providing context-awareness to the application. As the mobile node moves from one environment/domain to another, the middleware should provide support to the application to adjust to the changed network bandwidth, energy supply, processing power, user interface, etc.

An area of research that has interesting similarities with mobile computing, especially MANETs, is peer-to-peer computing. The goal of both is to provide services through member node collaboration in the absence of dedicated servers. Hence, solutions for peer-to-peer computing may find interesting applications in MANETs provided such solutions can address the dynamism of network population in a timely and efficient manner.

Adaptation was identified as a key feature of future MMS. Therefore, further research needs to be provided on the adequate mechanisms to support adaptation, mechanisms to monitor and register changes in the environment (available physical resources, location, number and location of peers, etc), to identify the relevant feedback loops. It is likely that language mechanisms such as reflection may play an important role in supporting the level of adaptation required for MMS. At some level, adaptation can be achieved through the composition and reconfiguration of components. It is therefore important to perform more work on tools to support and validate composition. Research needs also to be performed on how to accommodate unanticipated adaptation and evolution.

Another area of research that has interesting synergies with MMS is the area of mobile code and intelligent agents. This technology seems particularly well suited to deal with disconnections that are common in MMS but raises a number of issues on its own (security, efficiency, etc). More research needs to be performed to assess the relevant trade-offs when these two areas are combined.

Finally the issue of information dissemination and data aggregation is also an important continuing research theme. The issue of how to support in an efficient manner the publish-subscribe paradigm and, in particular, content based addressing is still a research issue. Other paradigms, such as group communication may also need to be redefined in the MMS context, for instance by exploiting location information to define multicast scopes. Aggregation mechanisms and policies can also play an important role to optimize the use of networks resources during information dissemination.

4. Long-term Research

There are several areas where significant long-term research is needed in the context of middleware for mobile systems. Some of these are security and trust management, cooperation management, generic consistency models, communication via the environment, self-organization, and pervasive computing. These will be further described in the following paragraphs.

To increase the acceptance of mobile computing it is important to address issues pertaining to security and trust management. In the context of mobility, it is logical to assume that often a mobile node will be operating in a ``foreign network'' about which it does not have much information. Likewise, a network may have ``visitor nodes'' from other networks. The mobile node and the network can both expect to be under attack from the other. For cellular networks, wireless LANs and MANETs with gateways to the Internet it is possible to adapt existing solutions for authentication, encryption, etc. However, in the case of stand-alone MANETs composed of nodes originally belonging to different domains there is no trusted third-party to provide and verify certificates.

So, how would authentication or key-exchange be done in such networks? The fundamental problem is to develop trust among nodes in a network where there are no trusted third parties. This is a challenging problem that needs further research.

As discussed in Section 2, cooperation management among nodes in a mobile network needs to be addressed. It can be safely assumed that mobile nodes are relatively resource-poor, compared to their static counterparts. So, it is natural for a mobile node to try to conserve its resources by restricting its activity to the minimum needed to support its applications. However, several models of mobile computing, especially MANETs, require active participation of mobile nodes to support a variety of services. For example, it is expected that ordinary nodes in a MANET will be willing to act as routers and forward packets that neither originate there, nor are destined to them.

However, what incentive is there for a node to do work for others when such work results in a drain on its own battery? Even if this work is done with the expectation that others will provide it with the same service, what guarantees exist to back such expectations? Rather than leaving it to chance, there is need to research new ``punishment/reward'' policies, and their implementation in the middleware. With such policies in place, it will be realistic to expect cooperation among nodes, and will be possible to penalize non-cooperating nodes.

Section 3 raises the possibility of the middleware having to support multiple consistency models to deal with the requirements of different applications. While each application has its unique availability versus weak consistency tradeoffs, there is no conclusive proof that it is impossible to have a generic consistency model that would be configurable for specific applications. So, is there a possibility to develop a common weak-consistency model that will be applicable to a variety of mobile applications? An impossibility result will yield

insights into the difficulty of ensuring consistency in mobile applications. However, if such a common weak-consistency model is indeed developed, it will be a major breakthrough in the area of middleware for mobile systems.

In mobile networks there is a distinct possibility that nodes may join and leave the network at will. Each time a node departs the network, or gets disconnected from it, the information stored in that node becomes unavailable to the rest of the network. Due to the memory-constraints of mobile nodes it is not possible to replicate all the information at all the nodes. Hence, an interesting research challenge would be to have mobile nodes communicate with each other via the environment, without having to maintain all the information locally. Related research question is where and how should the information be stored? Some possibilities that come to mind are ``location-based'' tuple spaces, or using the physical environment as ants use *pheromones* to communicate with each other.

In addition to the mobility of the devices, future MMS will have to cope with the mobility of users among devices. Given the myriad of devices and their ubiquity, users will be likely to terminate a task in a device different from the one the task was initiated. This means that one needs to study mechanisms to migrate applications and state from one device to another in an environment where heterogeneity is the rule.

Another research issue that has received considerable attention from the industry is that of self-organization. The ability of mobile nodes to self-monitor, self-tune and self-administer will enable them to monitor the system and automatically change policies as needed. This ability to self-organize will enable nodes to predict user behavior, and also detect intrusions. Hence, research in this direction also has positive security implications.

5. Applications

As mentioned in Section 1, there is need to identify new applications for mobile systems. In addition to personal communications, search-and-rescue missions, and defense applications, mobile systems can be used in a variety of social settings.

Another important application is health-care. Mobile devices enable medical information to be available to medical professionals any time, and anywhere. This enables fast decisions making and can be life-saving.

Augmented reality, through mobile devices, also has several industrial and recreational applications. A user, wearing special equipment, can receive environment-specific visual and tactile information through a wireless link. This can be used to superimpose blueprints and maps on the objects being viewed by the user. In an industrial setting this can increase the pace of assembly of parts and reduce the possibility of errors. Similarly, tourists can use such a service to get more information about landmarks. Augmented reality not only provides an interesting mobile application, but also creates new opportunities for research in the area of human-computer interaction.

Ambient intelligence is another interesting application of mobile systems. The goal is to create an environment that creates a safer operating environment for users and enriches their experience. Mobile devices carried by users can communicate with the environment as the user moves. Such communication can enable the device to transmit the user's interests to the environment and pre-fetch information that the user may be interested in. This can enrich the user's experience. Similarly, communication between mobile users can be used for traffic management and collision avoidance. Automobiles moving close to each other can exchange information to maintain safe distances between each other. Also, they can exchange information with sensors on and around the roads to maintain course and prevent themselves from veering off the road.

Workshop participants feel that a number of interesting applications for mobile systems are waiting to be discovered. To identify such applications there is need to communicate with professionals beyond computer science. Perhaps, a workshop could be organised with participants drawn from the user community to identify such applications.

6. Future European-US Collaborations

Participants in this workshop felt the need for a common European Union and US program to promote collaborative research. Such a program would enable EU and US collaborators to submit joint proposals. It is felt that US and European researchers can complement each other's strengths.

Currently, in the absence of a common program, the only support US researchers get, from the National Science Foundation, to collaborate with their European counterparts is through travel grants. However, this is not sufficient to foster long-term collaboration or to support other research personnel.

Appendix A: Workshop Agenda

Monday, July 1

- 2:30 pm - 4:00 pm:

  Session I: System Model for Mobile Systems and Middleware (Cellular, Mobile Ad Hoc, Resource discovery, Adaptibility to diverse operating environments)

  Speakers: Gregori, McKinley, Baldoni, Druschel, Blair

- 4:30 pm - 6:00 pm:

  Session II: Role of location information in MMS

  Speakers: Valerie, Cahill, Ramachandran,

Tuesday, July 2

- 8:00 am - 9:30 am:

  Session III: Consistency Models for MMS

  Speakers: Druschel, van Steen, Tripathi, Cahill

- 10:00 am - 11:30 am:

  Session IV: Programming Languages for MMS

  Speakers: Amir, Ramachandran, McKinley, Liviu

- 11:30 am - 1:00 pm:

  Lunch Break

- 1:00 pm - 2:30 pm:

  Session V: Security in MMS

  Speakers: Gregori, van Steen, Amir

- 3:00 pm - 4:30 pm:

  Session VI: Applications for MMS

  Speakers: Baldoni, Issarny, Liviu, Tripathi, Blair

- 5:00 pm - 6:00 pm:

  Session VII: Wrap-Up

  Speakers: Prakash, Rodrigues

Appendix B: **Participants**

Participation in the workshop was by invitation only. The participants were:

- **Europe**
  - Roberto Baldoni , *U. di Roma "La Sapienza", Italy.*
    http://www.dis.uniroma1.it/~baldoni/
  - Gordon Blair, *Lancaster University, U.K.*
    http://www.comp.lancs.ac.uk/computing/staff/gordon.html
  - Vinny Cahill, *Trinity College Dublin, Ireland.*
    http://www.dsg.cs.tcd.ie/~vjcahill/
  - Enrico Gregori, *CNUCE, Italy.*
    http://www.cnuce.pi.cnr.it/people/E.Gregori/
  - Valerie Issarny, *INRIA, France.*
    http://www-rocq.inria.fr/arles/members/issarny.html
  - Luís Rodrigues, *U. Lisboa, Portugal.*
    http://www.di.fc.ul.pt/~ler/
  - Maarten van Steen, *Vrije Universiteit, The Netherlands*
    http://www.cs.vu.nl/~steen/
  - Remi Ronchaud, *ERCIM, France*
    http://www.ercim.org/contacts/ercim_office/ercim_office.html

- **USA**
  - Yair Amir, *The Johns Hopkins University, Baltimore, USA.*
    http://www.cs.jhu.edu/~yairamir/
  - Roy Campbell, *University of Illinois at Urbana-Champaign, USA.*
    http://choices.cs.uiuc.edu/rhc/
  - Randy Chow, *NSF representative, USA.*
    http://www.cise.ufl.edu/~chow/
  - Peter Druschel, *Rice University, Houston, Texas, USA*
    http://www.cs.rice.edu/~druschel/
  - Liviu Iftode , *University of Maryland, USA.*
    http://www.cs.rutgers.edu/~iftode/
  - Philip McKinley, *Michigan State University, USA.*
    http://www.cse.msu.edu/~mckinley/
  - Ravi Prakash, *U. Texas at Dallas, USA.*
    http://www.utdallas.edu/~ravip/

- Kishore Ramachandran, *Georgia Tech, Atlanta, USA.*
http://www.cc.gatech.edu/fac/Kishore.Ramachandran/

- Anand Tripathi, *University of Minnesota, Minneapolis, USA*
http://www-users.cs.umn.edu/~tripathi/

Appendix C: CV of Participants

Roberto Baldoni

Roberto Baldoni was born in Rome (Italy) on february 1st, 1965. He received the laurea in Electronic Engineering in 1990 and the Ph.D degree in Computer Science in 1994 from the University of Rome "La Sapienza". Advisor: Giacomo Cioffi, Jury: Keith Marzullo, Ozalp Babaoglu and Daniel Pierre Bovet.

From 1994 to 1995 he was chercheur en informatique at IRISA/INRIA (France) in the ADP group headed by Michel Raynal, and working with Jean-Michel Helary and Achour Mostefaoui. In 1996 he was visiting assistant professor at the Department of Computer Science of Cornell University in the Ken Birman's group working with Roy Friedman and Robbert van Renesse. He has also worked with Mukesh Singhal (Ohio State University), Ravi Prakash (University of Texas at Dallas), Yoshifumi Manabe (NTT Japan) and Jerzy Brezinsky (Poznan University), Luis Rodrigues (Univ. of Lisboa).

He published more than eighty scientific papers in the fields of fault-tolerant distributed computing, middleware platforms, and communication protocols. He regularly serves as a referee for many international conferences and journals (Among others IEEE TPDS, IEEE ToC, Distributed Computing, ACM Computing Surveys). He was in the organizing and program committee of many international conferences and workshops such as ICDCS, SRDS, EUROPAR, ISORC, DOA and CoopIS. He was invited to chair the program committee of the "distributed algorithms" track of the 19th IEEE International Conference on Distributed Computing Systems (ICDCS-99) and the 6th IEEE International Workshop on Object Oriented Real-time Dependable Systems (WORDS). He has been also tutorial chair of 3rd International Symposium on Distributed Objects and Applications (DOA'01). Roberto Baldoni is member of the ESPRIT Basic Research Network of Excellence in Distributed Computing Systems Architectures (CaberNet) and of the DOA Scientific Board.

In 2002, he will be the PC Co-chair of the ACM International Workshop on Principles of Mobile Computing (POMC) and member of the following Program Committees: ICDCS, DOA and DISC.

Currently he is an associate professor at the school of engineering of the University of Rome "La Sapienza" where he leads MIDLAB a laboratory on middleware infrastructures. He is recipient of grants from the European Community (MIDAS and EU-PUBLI.com), from the Minister of the Italian Research (MIUR) and from IBM semea and Alenia MS.

Gordon Blair

Professor
Computing Department
Faculty of Applied Sciences
Lancaster University

The Computing Department at Lancaster University is a leading British computer science department with research interests that include distributed multimedia systems, mobile computing, software systems engineering, interactive systems and natural language processing. Our research was rated 5 (excellent) in the 1996 Research Assessment Exercise. We offer fully accredited BSc degree schemes in Computer Science, Computer Science with Software Engineering and Computer Science with Multimedia Systems, as well as a number of joint degrees that combine Computer Science with other disciplines. At postgraduate level we offer an advanced MSc in Distributed Interactive Systems, an MRes in Design and Evaluation of Advanced Interactive Systems and a PhD programme.

Research:

Distributed Multimedia Systems

The Distributed Multimedia Systems research group has been working for over ten years in the area of communications protocols, distributed systems architectures and operating systems. The group has close research links with British Telecom Labs, the IBM European Networking Centre, Olivetti Research Ltd, Alcatel Austria Research, Columbia University Centre for Telecommunications Research, the University of California at Berkely, the University of Paris and other internationally renowned research institutions.

The group's current research is based on an ATM network with high-quality audio and video codecs and a real-time MPEG encoding facility. The research may be classified under the following headings: Quality of Service Management; Multimedia Communications Services and Protocols; Multimedia Information Storage and Modelling; Open Distributed Systems Support; Mobile Multimedia Computing; and Formal Methods for Distributed Multimedia Systems.

Vinny Cahill

Lecturer in Computer Science,
Trinity College Dublin
Course Director, M.Sc. in Computer Science

Research:

Distributed computing, distributed object systems, language and system support for distributed programming, object-oriented techniques for building adaptable system software, mobile computing, distributed multi-media systems.

Current projects:

- Coyote: The Coyote project is concerned with the use of object-oriented reflection for the construction of dynamically adaptable system software. Within Coyote we are developing a new reflective programming model and language, called Iguana, and applying it to the construction of dynamically adaptable object support systems. The Coyote project is supported by Forbairt under a basic research award.

- Quartz: Quartz is developing a new Quality of Service architecture suitable for heterogeneous open distributed systems where different application-specific notions of QoS must be supported. The Quartz project is supported by Iona Technologies PLC.

- Mobile CORBA: The Mobile CORBA project is concerned with providing support for mobility and disconnected operation in CORBA-based systems. The Mobile CORBA project is supported by Iona Technologies PLC.

- ACE: The ACE project is concerned with the design of a customisable distributed shared memory system. The ACE project is supported by Forbairt under a basic research award.

Enrico Gregori

He received the "Laurea" in electronic engineering from the University of Pisa in 1980. He joined CNUCE, an institute of the Italian National Research Council (CNR) in 1981. He is currently a CNR research director. In 1986 he held a visiting position in the IBM research center in Zurich working on network software engineering and on heterogeneous networking. He has contributed to several national and international projects on computer networking. He was the Italian delegate in the OSI standardization committees initially working on the standardization of the transport layer and later in OSI management committees. He is has lectured on computer network architecture, protocols and their performance evaluation in the Faculty of Engineering of the University of Siena, Italy. He has authored a large number of papers in the area of computer networks and has published in international journals and conference proceedings. He is co-author of the book "Metropolitan Area Networks" (Springer 1997). His current research interests include: Wireless access to Internet, Wireless Lans, Quality of service in packet-switching networks, Energy saving protocols, Evolution of TCP/IP protocols. He is on the editorial board of the Cluster Computing Journal. He is member of the IEEE.

Last five years publications (1996-2000)

In the period 1996-2000, Enrico Gregori has written over 35 research papers published (under peer-review) in international journals and in the proceedings of international conferences. These publications are related to multimedia systems, Internet architecture and protocols, wireless networks, and QoS in packet switching networks.

List of Selected publications

[1] M. Conti, E. Gregori, L. Lenzini, Metropolitan Area Networks (MANs): Architectures, Protocols and Performance Evaluation, Springer-Verlag TICS series, London, 1997
[2] M. Conti, E. Gregori, A. Larsson "Study of the Impact of MPEG-1 Correlations on Video-Sources Statistical Multiplexing". IEEE Journal on Selected Areas in Communications, special issue on Distributed Multimedia Systems and Technology, Vol. 14, N.7, September 1996, pp. 1445-1471.
[3] E. Gregori, R. Marcantonio, F. Potortì "GSn: a new service type for integrated services on the Internet", to appear on the European Transactions on Telecommunications.
[4] A. Chimienti, M. Conti, E. Gregori, M. Lucenteforte, R. Picco, "MPEG 2 Sources: Efficient Bandwidth Allocation Based on the Characteristics of the Sheltering Sky MPEG2 Traces", ACM/Springer Multimedia Systems (to appear).
[5] M. Conti, E. Gregori, I. Stavrakakis, "Impact of Temporal/Spatial Correlations on per Sessions Performance Measures: Multiple Node Case", Performance Evaluation (to appear).

Valérie Issarny

Valérie Issarny obtained her PhD in computer science from the Université de Rennes 1, in November 1991, where she proposed an exception handling model for concurrent programming. During her PhD, she was working in the LSP (Langages et systèmes parallèles) research team at INRIA-IRISA in Rennes, and she participated to the design and implementation of a distributed object-based programming system, called Gothic.

After my PhD, she spent a one year postdoc at the University of Washington where she worked in the Opal research activity, which addressed the design and implementation of a single address space operating system.

From 1993 until 2001, she has been an INRIA researcher within the Solidor research team, examining solutions to the construction of robust and efficient distributed systems. In Octobre 1997, she obtained her "Habilitation à diriger des recherches" in computer science from the Université de Rennes 1. From 1993 until mid-1999, she has been working at INRIA-IRISA, and is now working at INRIA-Rocquencourt.

Since 2002, she is leading the ARLES research team, which investigates solutions to architecture-based development of ambient intelligence systems.

Current Research Activities

Her research activities are aimed at providing solutions to the robust construction of distributed systems. Towards that goal, she is investigating solutions to the construction of distributed systems, based on software architecture description. her current research work is more specifically centered around the development of distributed systems enabling ambient intelligence applications. Further information about the research activities to which she participates may be found from the ARLES Research Page

Professional Activities

- Vice-chair of ACM SIGOPS, the Special Interest Group on Operating Systems.
- Chair of the Executive Committee of the AIR&D Joint Virtual Laboratory on Ambient Intelligence.
- Chair of the Research&Training Committee of the IST NoE CaberNet

Luís Rodrigues

Luís Rodrigues graduated (1986), has a Master (1991) and a PhD (1996) in Electrotechnic and Computers Engineering, by the Instituto Superior Técnico de Lisboa (IST).

He is Associate Professor at Department of Informatics, Faculty of Sciences, University of Lisbon. Previously he was at the Electrotechnic and Computers Engineering Department of Instituto Superior Técnico de Lisboa (IST) (he joined IST in 1989). From 1986 to 1996 he was a member of the Distributed Systems and Industrial Automation Group at INESC. Since 1997, he is a (founding) member of the LASIGE laboratory at University of Lisbon where he was a member of the Navigators group and now it leads the Distributed Algorithms and Network Protocols. group. He participated and contributes to several national and international projects.

His current interests include fault-tolerant and real-time distributed systems, group membership and communication, replicated data management, publish-subscribe systems, peer-to-peer computing and mobile computing. He has more than 60 publications in these areas. He is co-author of a book on distributed computing. He is a member of the Ordem dos Engenheiros, ACM, and IEEE.

Research Group: DIALNP: DIstributed ALgorithms and Network Protocols group

Current Projects: StrongRep, IndiQoS, Rumor, SEMP2P, GlobData, SHIFT, Moosco, Appia

Past Projects: TOPCOM, DEAR-COTS, Micra

Maarten van Steen

Professor of Computer Science
Large-Scale Distributed Systems

Dept. of Math. and Computer Science
Vrije Universiteit, Faculty of Science, Amsterdam, The Netherlands.

Courses:

Distributed systems
Operating systems
Computer networks

Projects:

A worldwide scalable location service
A system for distributing free software
Globe Web documents
Apache-based Globe for Web content
Large-scale electronic messaging
Adaptive replication for Web content
Peer-to-peer networks

Publications:

Computer and Network Organization
Distributed Systems: Principles and Paradigms

Professional activities:

PC member WIAPP 2003
Deputy vice chair Applications track WWW 2003
PC Member EDOC 2002 Workshop on Software Infrastructures for Component-Based Applications on Consumer Devices
PC Member DOA 2002
PC Member SRDS 2002 Workshop on Reliable P2P Distributed Systems
PC Member Middleware track ICDCS 2002
PC Member Performance track WWW 2002
Member organization committee Middleware 2001 (WiP)
PC Member Middleware track ICDCS 2001
PC Member SAINT-2001
PC Member Middleware 2000
Former member editorial board IEEE Concurrency
Former member editorial board IEEE DS Online

Yair Amir

Associate Professor, The Johns Hopkins University

Education

1995 Ph.D. The Hebrew University Computer Science
1990 M.Sc. The Technion Computer Science
1985 B.Sc. The Technion Information Systems Engineering

Current Interests

His work evolves around the Center for Networking and Distributed Systems (CNDS) at the Department of Computer Science at Hopkins and at Spread Concepts LLC. Highlights include:

Distributed Systems: Wide area message bus, group communication and multicast protocols, security for such systems. The initiator and original architect of the Spread Toolkit.

Internet: Database and web replication over local and wide area networks, the Backhand clustering project.

Distributed Algorithms: Distributed resource management, Metacomputing, replication, distributed agreement.

Courses:

Distributed Systems (600.437)
Operating Systems (600.418)
Advanced Distributed Systems and Communication (600.667)
Introduction to Computer Science (600.103)

Roy H. Campbell

Professor,
Department of Computer Science,
University of Illinois

Research Activities

Software Systems Research Group
Object-Oriented Operating Systems. (NSF, HP Funded)
Web Video Browsers
ATM Toolkit
Blanca Gigabit Testbed (CNRI and AT&T Funded)

Education Activities

Schools & Community Networking (NSF NIE Projec)
Operating Systems Class
Multimedia Class
The Design of Multimedia Systems (Application of Learning Technologies in Higher Education, Office of the
Vice President for Academic Affairs, University of Illinois)

Publications

-Operating Systems
S. M. Tan, W. S. Liao and R. H. Campbell, Multimedia Network Subsystem Architecture. Submitted to Network and Operating System Support for Digital Audio and Video, Zushi, Japan, March 1996.

-Multimedia
Z. Chen, S. M. Tan, R. H. Campbell and Y. Li, Real Time Video and Audio in the World Wide Web. In World Wide Web Journal, Volume 1, January 1996. Also Best Paper in Fourth International World Wide Web Conference, Boston, Massachussetts, Dec 11-14, 1995.

-Networking
S. M. Tan and R. H. Campbell, Efficient Signaling Algorithms for ATM Networks. In IFIP Third Workshop on Performance Modelling and Analysis of ATM Networks, Bradford, UK, July 1995. International Federation for Information Processing.

-Digital Libraries
A Dynamic Priority-based Scheduling Method in Distributed Systems Yongcheng Li and Roy Campbell Proc. Of International Conference on Parallel and Distributed Processing Techniques and Applications (PDPTA'95), Georgia, Nov. 1995.

Peter Druschel

Professor of Computer Science
Rice University

Peter Druschel received the Dipl.-Ing. (FH) degree from Fachhochschule Muenchen, Germany, in 1986, and the Ph.D. degree from the University of Arizona in 1994, under the direction of Larry L. Peterson. He received an NSF CAREER Award in 1995 and a Alfred P. Sloan Fellowship in 2000. He is a member of the Computer Systems Laboratory.

During the 2000-2001 academic year, Peter was on sabbatical leave, which he spent with the SRC group at Laboratoire d'Informatique de Paris 6 (LIP6) (May-June 2000), the Cambridge Distributed Systems group at Microsoft Research Cambridge, UK (August-December 2000), and the PDOS group at the MIT Laboratory for Computer Science (January-June 2001).

Research:

Peter's research interests are in operating systems, networking, and distributed systems. Current projects include the following:

Pastry/PAST: Peer-to-peer systems
FreePastry 1.1 is available!
IRIS: Infrastructure for Resilient Internet Systems
ScalaServer: System support for scalable network servers

Current professional activities :

Associate Editor, ACM Transactions on Computer Systems (TOCS)
Program co-chair, 1st International Workshop on Peer-to-Peer Systems (IPTPS'02)
Program co-chair, 5th Symposium on Operating System Design and Implementation (OSDI 2002)
Program vice-chair, 2001 Symposium on Applications and the Internet (SAINT-2001)
General chair, 7th Workshop on Hot Topics in Operating Systems (HotOS-VII)

Liviu Iftode

Assistant Professor of Computer Science,
Department of Computer Science,
Rutgers University

Academic Degrees:
Ph.D. in Computer Science, Princeton University

Research interests:
Operating Systems.
Parallel and Distributed Systems.
Embedded and Pervasive Computing Systems.
Mobile Computing and Networking.

Current projects:
Distributed Computing Laboratory
The Smart Message NSF ITR-2 award in the News (1, 2)
About the Network-Centric Systems seminar in IEEE Pervasive Computing.

Publications:
- Service Continuations: An Operating System Mechanism for Dynamic Migration of Internet Service Sessions . F.Sultan, A. Bohra and L.
- Iftode. October 2002. Submitted for publication.
- Byzantine Fault Tolerant Authentication V. Pathak and L. Iftode. Rutgers University Technical Report, DCS-TR-492, June 2002.
- Submitted for publication.
- Spatial Views: Iterative Spatial Programming for Networks of Embedded Systems U. Kremer, L. Iftode, J. Horn and Y. Ni. Submitted
- for publication. Rutgers University Technical Report, DCS-TR-493, June 2002. Submitted for publication.
- Programming Computers Embedded in the Physical World. L. Iftode, C. Borcea, A. Kochut, C. Intanagonwiwat and U. Kremer. Rutgers
- University Technical Report, DCS-TR-503, September 2003. Submitted for publication.
- Spatial Programming using Smart Messages: Design, Implementation and Evaluation. C. Borcea, C. Intanagonwiwat, D. Iyer, P. Kang,
- Saxena, U. Kremer and L. Iftode October 2002. Rutgers University Technical Report, DCS-TR-490. Submitted for publication.
- MemNet: Efficient Offloading of TCP/IP Processing Using Memory-Mapped Communication M. Rangarajan, K. Banerjee, J. Yeo and
- L. Iftode. Rutgers University Technical Report, DCS-TR-485, May 2002. Submitted for publication.

Philip K. McKinley

Education:
1989 Ph.D., Computer Science, University of Illinois at Urbana-Champaign, Illinois.
Dissertation: Group Communication in Bus-Based Computer Networks
Doctoral Advisor: Prof. Jane W. S. Liu
1983 M.S., Computer Science, Purdue University, West Lafayette, Indiana.
1982 B.S., Mathematics and Computer Science, Iowa State University, Ames, Iowa.

Research Interests:
Distributed systems, computer networks, parallel processing. Specific emphasis on group communication protocols and routing algorithms, multicast communication, adaptive middleware, communications libraries and interfaces, multi-party applications, wireless networking, networks of workstations, wormhole-routed massively parallel computers, parallel numerical algorithms.

Professional Experience:
Professor (2002 - present)
Department of Computer Science, Michigan State University, East Lansing, Michigan.

Associate Professor (1996 - 2002)
Department of Computer Science, Michigan State University, East Lansing, Michigan.

Assistant Professor (1990 - 1996)
Department of Computer Science, Michigan State University, East Lansing, Michigan.

Member of Technical Staff (1982 - 1990) AT&T Bell Laboratories, Naperville, Illinois.

Publications:
- Monographs
Fault Covering Problems in Reconfigurable VLSI Systems, (with R. Libeskind-Hadas, N. Hasan, J. Cong, and C. L. Liu), Kluwer Academic Publishers, Norwell, Massachusetts, 1992.
- Refereed Journal Articles
"A Study of Adaptive Forward Error Correction for Wireless Collaborative Computing," (with C. Tang, and A. Mani), IEEE Transactions on Parallel and Distributed Systems, accepted to appear.
"Tree-Based Link-State Routing in the Presence of Routing Information Corruption," (with Y. Huang), Computer Communications, accepted to appear.
"Group Leader Election under Link-State Routing," (with Y. Huang), Computer Communications, vol. 23, pp. 653-666, 2000.
"On the Performance and Feasibility of Multicast Core Selection Heuristics," (with E. Fleury and Y. Huang), Networks, vol. 35, no. 2, pp. 145-156, 2000.

Ravi Prakash

Associate Professor
Department of Computer Science,
Erik Jonsson School of Engineering and Computer Science
University of Texas at Dallas

Education:
Ph.D. (1996):Computer and Information Science, The Ohio State University, Columbus, Ohio 43210, USA.

Research Interests:
Mobile Computing
Location management
Mobile-TCP
Cell Planning
Channel allocation
Checkpointing and Recovery
Causally and Totally Ordered Message Delivery
Clocks and Dependency Tracking

Research publications:
- S. Nesargi and R. Prakash. Distributed Wireless Channel Allocation in Networks with Mobile Base Stations. (This is an enhanced version of the INFOCOM'99 paper). Accepted for publication in IEEE Transactions on Vehicular Technology.
- R. Prakash. A Routing Algorithm for Wireless Ad Hoc Networks with Unidirectional Links. ACM/Baltzer Wireless Networks Journal, Volume 7, Number 6, Pages 617-626, November 2001.
- R. Prakash, Z. Haas, and M. Singhal. Load-Balanced Location Management for Mobile Systems using Quorums and Dynamic Hashing. ACM/Baltzer Wireless Networks (WINET) Journal, Volume 7, Number 5, Pages 497-512, September 2001.
- K. Chandran, S. Raghunathan, S. Venkatesan, and R. Prakash. A Feedback Based Scheme for Improving TCP Performance in Ad Hoc Networks. IEEE Personal Communication Systems (PCS) Magazine: special issue on Ad Hoc Networks, Volume 8, Number 1, Pages 34--39, February 2001.
- R. Prakash and R. Baldoni. Causality and Spatial-Temporal Ordering of Events in Mobile Systems. To appear in ACM/Baltzer Journal on Mobile Networks and Applications (MONET).

Courses
Advanced Operating Systems: CS 6378 (Spring 2002)
Mobile Computing Systems: CS 6392 (Fall 2001)
Advanced Computer Networks: CS 6390 (Fall 2001)
Telecommunications Software Design: CS 6386 (Summer 2000)
Algorithm Analysis and Data Structures: CS 3345 (Fall 2000)
Distributed Computing: CS 638

Umakishore Ramachandran

Professor
Center for Experimental Research in Computer Systems
College of Computing
Georgia Institute of Technology

He received his Ph. D. in Computer Science from the University of Wisconsin, Madison in 1986 under the direction of Marvin Solomon. Since then he has been with Georgia Tech (home of the yellow jackets), where he is currently a Professor in the College of Computing. His research interests are in the area of architectural design, programming, and analysis of parallel and distributed systems. At Georgia Tech, he has been involved in the design and evaluation of several large experimental systems including Clouds, Beehive, and Stampede (joint with Compaq Cambridge Research Lab), and studying their scalability from an applications perspective. Currently, in the ubiquitous presence project, he is investigating software and hardware mechanisms for ubiquitous distributed computing for an environment comprised of distributed sensors, embedded data concentrators, and backend clusters. He received a Presidential Young Investigator (PYI) Award from the National Science Foundation (NSF) in 1990, the Georgia Tech Doctoral Thesis Advisor award in 1993, and the College of Computing Outstanding Senior Research Faculty award in 1996.

Current Research:

NSF Research Infrastructure Project
White paper on Ubiquitous Presence
The Stampede System
The Beehive Cluster System
TASS: A Top-down Approach to Scalability Study

Recent Publications

- N. Harel, H. Mandviwala, K. Knobe, and U. Ramachandran. Dead Timestamp Identification in Stampede. The 2002 International Conference on Parallel Processing (ICPP-02), August 2002.
- H. Mandviwala, N. Harel, K. Knobe, and U. Ramachandran. A Comparative Study of Stampede Garbage Collection Algorithms . 15th Workshop on Languages and Compilers for Parallel Computing, July 2002.
- Sameer Adhikari, Arnab Paul, and Umakishore Ramachandran. D-Stampede: Distributed Programming System for Ubiquitous Computing . 22nd ICDCS, July 2002.
- R. S. Nikhil, and U. Ramachandran. Garbage Collection of Timestamped Data in Stampede. Nineteenth ACM Symposium on Principles of Distributed Computing (PODC 2000), July 2000 .
- K. Knobe, J. M. Rehg, A. Chauhan, R. S. Nikhil, U. Ramachandran, Scheduling Constrained Dynamic Applications on Clusters. Supercomputing '99, December 1999.

Anand Tripathi

Professor
Department of Computer Science & Engineering
University of Minnesota

Program Chair for IEEE 20th Symposium on Reliable Distributed Systems (SRDS 2001) October 2001

Education:

Ph.D. (Electrical Engineering)	1980	University of Texas at Austin
M.S. (Electrical Engineering)	1978	University of Texas at Austin
B. Tech (Electrical Engineering)	1972	Indian Institute of Technology, Bombay

Professional Experience:

- Program Director, Computer Systems Software Program, National Science Foundation , July 1996-97.
- Program Director, Operating Systems and Systems Software Program, National Science Foundation , July 1995-96.
- Senior Principal Research Scientist, Corporate Computer Science Center, Honywell Inc., 1983-84.
- Principal Research Scientist, Corporate Computer Science Center, Honeywell Inc., 1981-83.
- Scientific Officer, Bhabha Atomic Research Center, Bombay, India, 1972-75.

Research Interests:

Ajanta - A System for Research in Mobile Internet Agents. An experimental version of this system is due to to be released for public-use by May 1, 1999 .

Distributed systems and programming paradigms, operating systems, object-oriented programming languages and systems, fault-tolerant computing

Other topics of interests:

NSF Sponsored Workshop on New Challenges and Directions for Systems Research

Appendix D. Workshop Presentations

All workshop presentations are available for download at:
http://www.di.fc.ul.pt/~ler/ercimnsf/slides/slides.html

Middleware for Mobile “ad-hoc” networks

Roberto Baldoni

Dipartimento di Informatica e Sistemistica
Universita’ di Roma
“La Sapienza”

Models

- Partitionable vs non-partitionable
- Reliable Communication vs best effort
- Location stamping (gps, galileo)
- Common clock value (gps, galileo)

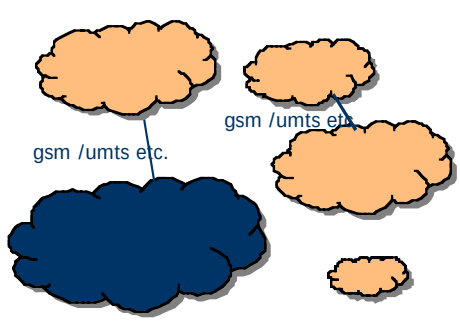
Sources of non-determinism

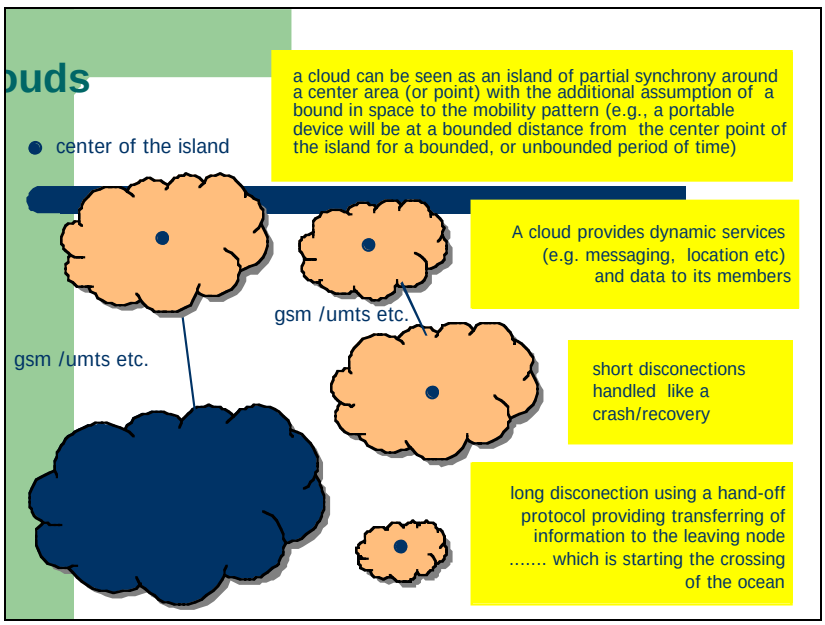
- concurrent execution of processes
- failures
- unpredictable communication delay

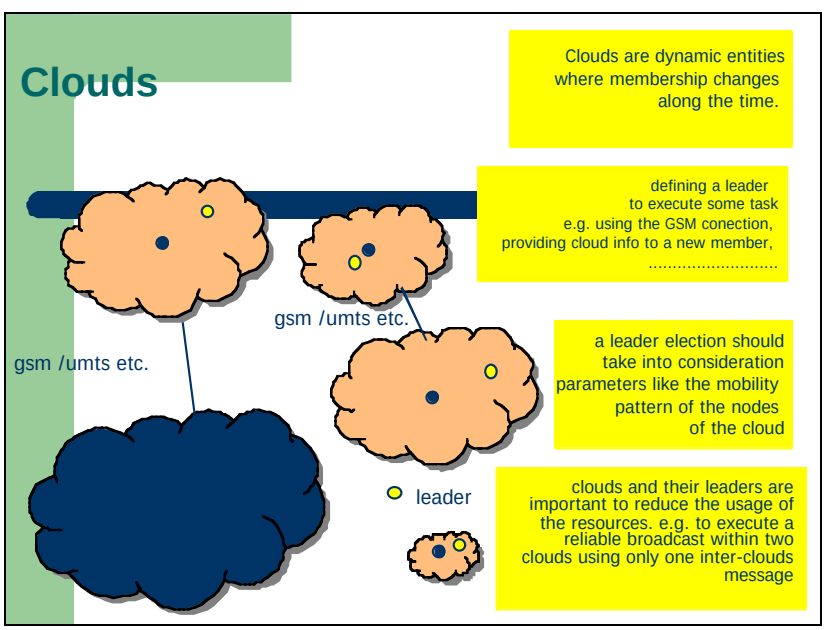
- Partitioning as a matter of life
- mobility pattern

NEW

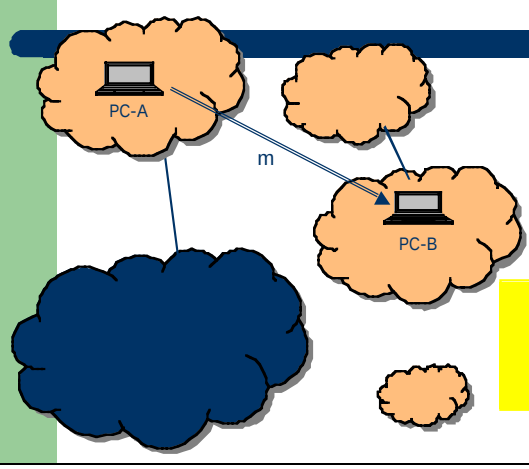
A model for “ad-hoc” networks..... Clouds




ouds
center of the island
a cloud can be seen as an island of partial synchrony around a center area (or point) with the additional assumption of a bound in space to the mobility pattern (e.g., a portable device will be at a bounded distance from the center point of the island for a bounded, or unbounded period of time)
A cloud provides dynamic services (e.g. messaging, location etc) and data to its members
gsm /umts etc.
gsm /umts etc.
short disconections handled like a crash/recovery
long disconection using a hand-off protocol providing transferring of information to the leaving node ..... which is starting the crossing of the ocean


Clouds
Clouds are dynamic entities where membership changes along the time.
defining a leader to execute some task e.g. using the GSM conection, providing cloud info to a new member, ...
gsm /umts etc.
gsm /umts etc.
a leader election should take into consideration parameters like the mobility pattern of the nodes of the cloud
leader
clouds and their leaders are important to reduce the usage of the resources. e.g. to execute a reliable broadcast within two clouds using only one inter-clouds message

Clouds



How PC-A can communicate with PC-B?

Non-determinism due to partitioning

similar to asynchronous persistent communication in wired-networks..... much more difficult to implement

who stores m? options: leader of PC-A's cloud, borderline PCs of PC-A cloud, within the big internet , ...

Problems

- QoS messaging for ad-hoc networks
  - reliable messaging -> (persistent storage)
  - weak reliability (e.g. a message is available only for a given amount of time)
  - stability tracking algorithm to reduce storage
- consistency condition on replicated data

Related Work

- Bayou
- The notion of domain by Luca Cardelli
- Fuzzy group membership by Roy Friedman
- IBM Tivoli architecture
- peer-to-peer architectures
- extended virtual synchrony
- .....

Middleware Impact

- Dyamic and adaptable components
- Location aware services
- Persistent Messaging
- Garbage collection mechanisms
- Location services

Applications for “ad-hoc” networks

Roberto Baldoni

Dipartimento di Informatica e Sistemistica
Universita’ di Roma
“La Sapienza”

Context

- Air-Traffic Control
- European Sky Fragmented
  - no interoperability among the ATCs
  - routing flight decisions taken on a local base
- Single sky for Europe by 2020

Problem

- Landing slot assigned at take-off time
- due to local routing decisions flights do a zigzag over Europe
- flights miss their landing slots
  - those slots cannot be re-assigned
  - these flights need another slot to land

Solution

- flights and the control tower have to cooperate to
  - re-schedule slots as quick as possible
  - to reduce the time of the slot (expected result 1/3 of the current slot time which is 3 minutes)
- Flights around an airport form a dynamic group
- communication done through intelligent trasponders or VHF band

Mobility Patterns

- reducing non-determinsm due to mobility
  - proximity protocols
  - repository of mobility information
  - mobility data processors

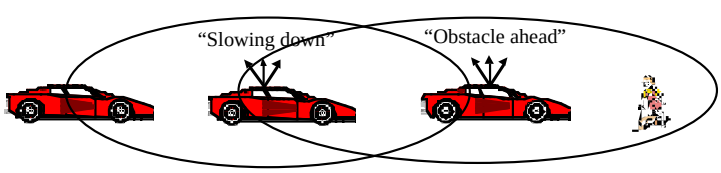
Proximity-based Group Communication

Vinny Cahill
vinny.cahill@cs.tcd.ie

Distributed Systems Group
Trinity College Dublin

Sentient Traffic Management

- Group membership determined by proximity constraints
- e.g. obstalce warning system



Issues

- Group membership often depends on location
  - Very dynamic groups
- Difficult to differentiate between the failure of a host and its movement out of network coverage
  - Network partitions are expected!
- Network topology changes frequently due to mobility
- Variable round-trip times make predictable behaviour difficult

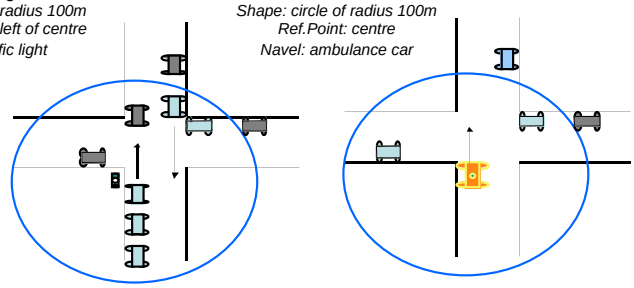
Proximity-based Group Communication

A Proximity group G is defined by its name reference point, shape, and navel

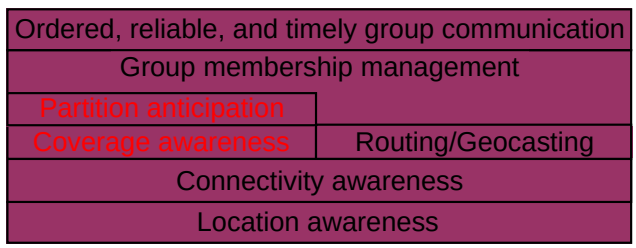
G = {Name, Reference Point, Shape, Navel}

Traffic light
Shape: circle of radius 100m
Ref. Point: 10m left of centre
Navel: traffic light

Ambulance
Shape: circle of radius 100m
Ref.Point: centre
Navel: ambulance car



Proximity-based Group Communication

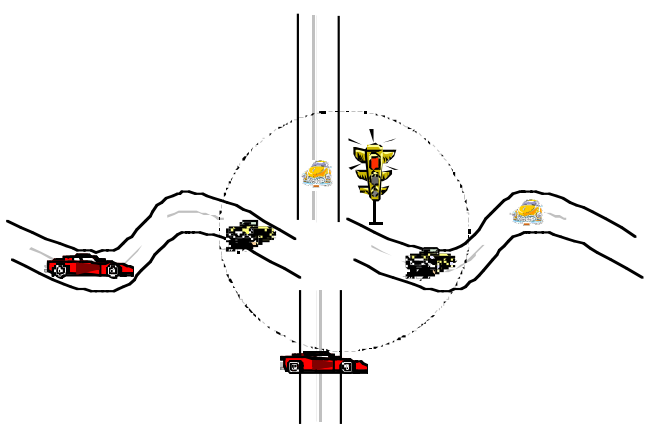


Consistency in Mobile Applications

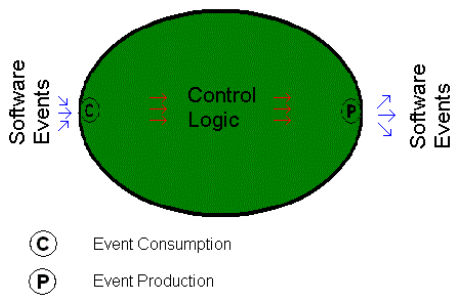
Vinny Cahill
vinny.cahill@cs.tcd.ie

Distributed Systems Group
Trinity College Dublin

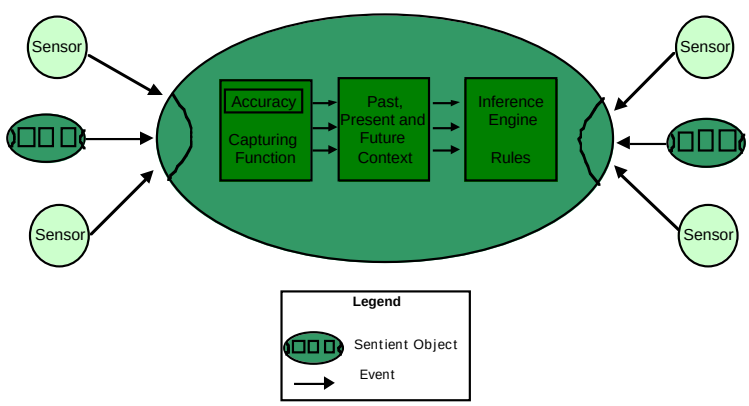
Sentient Traffic Management



Sentient Objects



Context Awareness



Issues

- Are context models of individual sentient objects mutually consistent?
  - Difficulty of distributed consensus
- Is context model consistent with the real world?
  - Inherent inaccuracy of sensor data

Stigmergy

- Communication via the environment
- Biological systems
  - E.g. pheromones

Trafeoff: consensus vs. accuracy

MS&M for Consumer-oriented Ambient Intelligence

Valérie Issarny, Arles Research Team, INRIA

Ongoing work as part of the OZONE IST Project

Ambient Intelligence

- Enhancing the quality of life by offering relevant information and services to the individual, anywhere and at anytime
- Putting the user in the foreground and the system in the background
- **Combining**
  - Intelligent aware interfaces
  - Ubiquitous networking
  - Ubiquitous computing

Intelligent Aware Interfaces

- People perceive the system as intelligent
  - Automatic adaptation to their personal preferences
  - Natural way of interaction through, e.g., speech
- The system reacts to the presence of people, their location and their activities instead of waiting for the next anonymous keystroke or mouse click

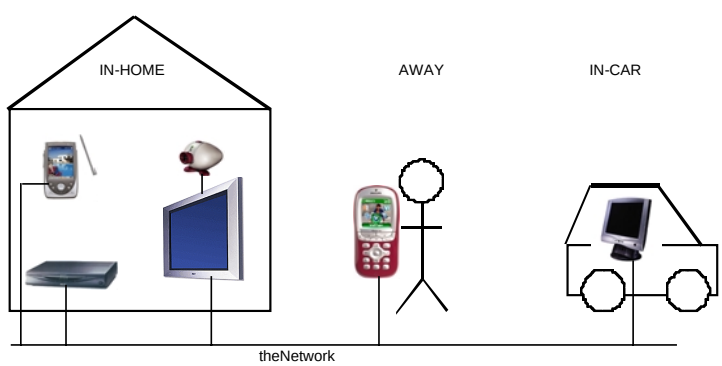
Ubiquitous Networking & Computing

- Useful, pleasant and unobtrusive presence *everywhere* – at home, en route, in public spaces, in the car, at work and wherever else the electronic support of our environment extends
- The network and computing facilities are distributed and accessible in wide varieties as needed

The OZONE Ambient Intelligence Scenarios

- **OZONE IST Project:**
  - **Offering a generic framework to enable consumer-oriented ambient intelligence applications**
  - 32 months project, started November 01
  - 7 partners:
    - PHILIPS (coord.), INRIA, TMM, EPICTOID, IMEC, PRF, TU/E
    - 9 INRIA research teams
- **Focus on consumer-oriented ambient intelligence**
  - Accessing naturally, freely, anytime, anywhere, the multimedia content that is available at home and on the Internet
  - *"Feeling at home everywhere"*

Feeling at Home Everywhere



Requirements

- Supporting access to services from light-weight, low-power to high-performance terminals
- Exploiting the various network protocols and infrastructures that are available
- Support for user interactions allowing:
  - Speech recognition and synthesis
  - Multi-modality
  - Managing user profiles
- Enforcing security & privacy

Requirements (Cont'd)

- Managing multimedia content to allow:
  - Access to and delivery of video, audio, text, image, and graphics
  - Situation-sensitive delivery of multimedia content
  - Negotiating quality of service
- Managing services and content to allow:
  - Access to services & content delivery on any (mobile) networked device, including from one to another
  - Situation-sensitive discovery, composition and delivery of services that are available in the local- and wide-area
  - Replication of content over devices, while ensuring coherency

➢ **Need for a supporting middleware infrastructure**

Middleware for Ambient Intelligence

- Development support towards assisting the design and implementation of robust ambient intelligence systems
  - Configuration-based development
  - Mobile agent technology
- Core middleware infrastructure enabling the implementation of distributed applications and services that may be requested by users in various situations, and involve services from various locations.

Key Middleware Functions

- Core message broker
- Naming, discovery & lookup
  - Retrieving the optimal service & content according to the user's situation
- Local caching
  - Improving performance and managing coherency
- Dynamic networking
  - Managing service configuration, service composition & groups of peers
- Resource monitoring
  - Monitoring local resource availability for reserving, negotiating, and adapting resource usage
- QoS management
  - Managing adaptive QoS delivery of streams

Some of the Challenges

- Core middleware infrastructure
  - From Web Services to situation-sensitive service composition in mobile environments
- Naming, discovery & lookup
  - Situation-sensitive discovery of services based on declarative specification
- Local caching
  - Situation-sensitive replication & coherency management
- Dynamic networking
  - Creating and managing secure, dynamic networks of services
- Handling continuous media
  - Dedicated middleware support, based on proprietary solutions, for the delivery of streams

For More Information

- OZONE:
  - http://www.extra.research.philips.com/euprojects/ozone
- ARLES:
  - http://www-rocq.inria.fr/arles/work/work.html

Locating Services in MS: Combining WLAN Infrastucture-based and Ad Hoc Modes

Valérie Issarny, Arles Research Team, INRIA

Thanks to Francoise Sailhan

INRIA

Supporting Seamless Access to Services

- **Supporting access to services&content anywhere, anytime from mobile terminals**
  - E-mail, personal data, Internet, ...
- **Two types of supporting wireless networks**
  - Infrastructure-based networks (GSM, GPRS, UMTS)
  - Ad hoc networks
- **Issues in mobile access**
  - Connectivity: expected or unexpected disconnections
  - Energy consumption: communication & computation
  - Base Station bottleneck in the infrastructure-based mode
  - Network congestion in the ad hoc mode

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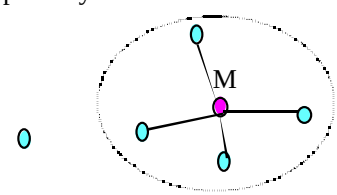
Existing Solutions to Mobile Access (Cont'd)

- **Service location protocol in the local area**
  - Exploits available services in the WLAN communication range
  - Centralized or distributed repository



- **Still,**
  - **Issue of network congestion and connectivity**
  - **Issue of trust and service availability**

Our Approach

- **Combining the WLAN infrastructure-based and ad hoc modes**
  - Available base station:
    - Conventional access in the infrastructure mode
  - No base station:
    - Adaptive collaboration among mobile nodes
    - Exploits ad hoc routing protocols

Ad Hoc Networking

- Dynamic configuration
- Peer to peer communication
- Radio communication properties with IEEE 802.11 (propagation)
- Ad hoc routing protocols for multi-hop communication
  - Routing table management
    - Shortest path computation

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Multi-hop Routing Protocols

- Proactive protocol (OLSR)
  - Routing table periodically updated
  - No delay before transmission
  - ➢ Network flood even if no transmission requested
- Reactive protocol (AODV, DSR)
  - Check the validity if path exists
  - Path computation if unavailable
  - ➢ Significant delay before transmission
- Hybrid protocol (ZRP)
  - Defines the intra-zone and the inter-zone
    - Proactive approach in the intra-zone
    - Reactive approach in the inter-zone
  - ♣ ⇒Limitation of the flood to the intra-zone
  - ♣ ⇒Only the nodes in the intra-zone are frequently requested to handle messages

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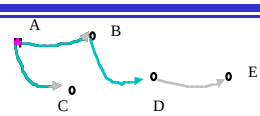
ZRP Routing Protocol



- Inter/Intra-zone (= 2 hops)
- Routing table periodically updated for intra-zone:
  - B,C,D information in A Table
- Intra-zone Communication (e.g., A with B)
  - No delay before transmission
- Inter-zone Communication (e.g., A with E)
  - Path computation
    - ⇒ significant delay before transmission

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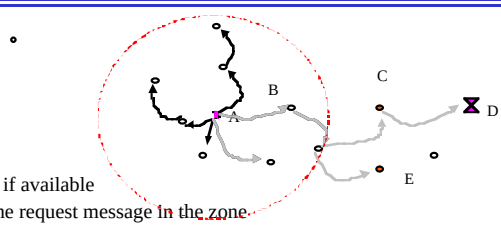
Collaboration in Ad Hoc Networks



- In-Zone communication:
  - Request to Base Station if available
  - Otherwise, broadcasts the request message in the zone
    - ⇒ Limited network congestion
- Out-Zone Peer to Peer communication
  - With mobile terminals
    - Closer than a base station
    - Most likely to collaborate (trust, shared interests, available resources, …)

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Open Issues

- **Middleware support for:**
  - Service location
    - Combining local- and wide-area service discovery
  - Caching
    - Content & services
  - Collaborative data sharing
    - Private & public data
  - Security
    - Adequate support for symetric/asymetric cryptography

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For More Information

- http://www-rocq.inria.fr/arles/work/work.html

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Massive Distributed Programming

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www.amonline.net.au/invertebrates/mal/gallery/octopus.htm

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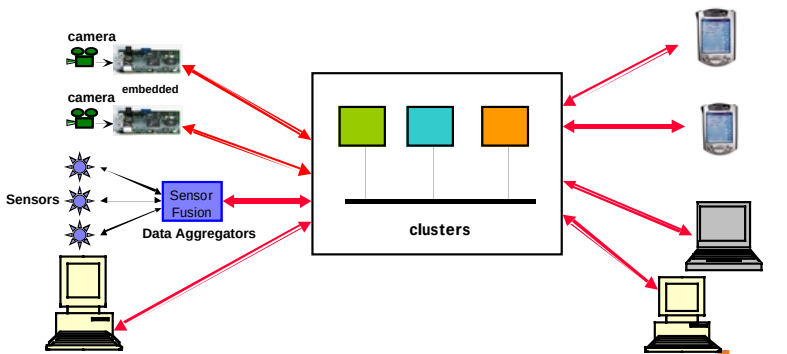
Future Complex Systems

- Computing, Communication, Interaction (CCI) continuum
- Near term "Octopus" Hardware model



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Future Complex Systems (Contd.)

- Far out
  - more implicit
    - wristwatches, lamp-posts, telephone poles, ceiling panels, floor tiles, my belt buckle, …
    - telepathy? :-)
    - neurological?
  - hardware continuum
    - single chip to distributed walls of connected computational bricks (integrated CCI)
      - mobile sensors
      - embedded/real-time devices
      - in the limit smart dust
    - ambient mostly invisible computing infrastructure
- What they will not be
  - standalone entities for number-crunching, problem solving, information transfer

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What will they be used for?

- "Follow me" systems
  - nomadic meetings
  - mobile offices
  - telepresence
- Real-life emergencies
  - natural and man-made disaster response
    - earthquakes, twisters, fire, terrorist situations
- Environmental monitoring
  - viruses, pollution, …
  - animals and birds in natural habitats

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What will they be used for (Contd.)?

- Healthcare
  - caring for the elderly, childcare
- Home applications
  - augmenting and enhancing everyday activities such as cooking
- Augmented reality applications
  - training for hazardous situations
  - battlefield management

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Application Characteristics

- Physically distributed heterogeneous devices
- Distributed mobile sensing and actuation
- Interfacing and integrating with the physical environment
- Information acquisition, processing, synthesis, and correlation
  - streaming high BW data such as audio and video
  - low BW data such as from a haptic sensor
  - on-line and off-line analyses => archiving
- Computation continuum from low end device-level filtering to high end inference

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Challenges

- Programming abstractions
  - uniform transcending the hardware continuum?
  - temporal guarantees, stream handling
  - distributed synchronization?
  - varying computation/communication capabilities?

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Challenges (Contd.)

- Naming and resource discovery
  - location tracking in a large scale mobile environment?
    - global static IDs are no good especially when entities are mobile
  - integrate location tracking with distributed programming?
    - translating naming at the programming level to location information for the physical artifacts

Challenges (Contd.)

- Adaptive distributed plumbing
  - orchestrate the dynamic connectivity of mobile components?
  - deal with changing end points?
  - component-based programming in a highly mobile environment?

Challenges (Contd.)

- Adaptive data fusion
  - aggregation and low-level filtering under resource constraints?
  - aggregation over space and time of multi-modal sensor data?
  - application level data fusion with error-prone and insufficient data?
  - confidence and risk analysis?
  - integrating with information databases?
  - organization methods and data mining?

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Challenges (Contd.)

- Security and Privacy
  - integrity and authenticity of data?
  - privacy of individuals and related data?

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Challenges (Contd.)

- Failures
  - computational model?
  - self-monitoring computational abstractions?
  - self-tuning computational abstractions?
  - self-healing computational abstractions?
  - algebraic reasoning in the presence of failures?

Challenges (Contd.)

- Runtime mechanisms
  - adaptive naming of communication end points?
  - migration of communication end points?
  - state saving and reconstruction (data and meta data)?
  - data transformations?
  - computation elision, merging?

Challenges (Contd.)

- System evaluation
  - application level QoS?
  - availability?
  - performance and scalability?

Consistency in Middleware for Mobile Systems

Maarten van Steen
Vrije Universiteit Amsterdam

Why consistency is important (1/2)

- **Observations:**
  - Worldwide systems introduce scalability problems that demand caching, replication, and distribution of data (and possibly also computations)
  - Having multiple copies introduces a synchronization problem when it comes to updates
  - Synchronization in a wide-area system is inherently expensive
  - Distribution of data may introduce a geographical scalability problem: data and its users may be far apart if no special measures are taken (lack of locality).

Why consistency is important (2/2)

- **Solutions**
  - No general ones; just make sure that your copies are consistent enough for the application you are dealing with.
    - Consistency models from DSM systems (Munin, Treadmarks)
    - Client-centric consistency models (Bayou)
- **Consistency and mobility:**
  - Matters get worse because it may be difficult to find out where data is needed next:
    - A mobile user may pop up everywhere after having been offline for some time (or disconnected mode)
    - Ad hoc groups of users

Support for consistency models

- **Many consistency models have been developed. I'm not quite sure how many more we need or will show up; probably more than we can now think of**
- **Since CDNs, some more attention is being paid to the placement of copies across large networks taking usage patterns into account**
- **Less attention has been paid to the range of possibilities for implementing models**

Separate mechanisms from policies

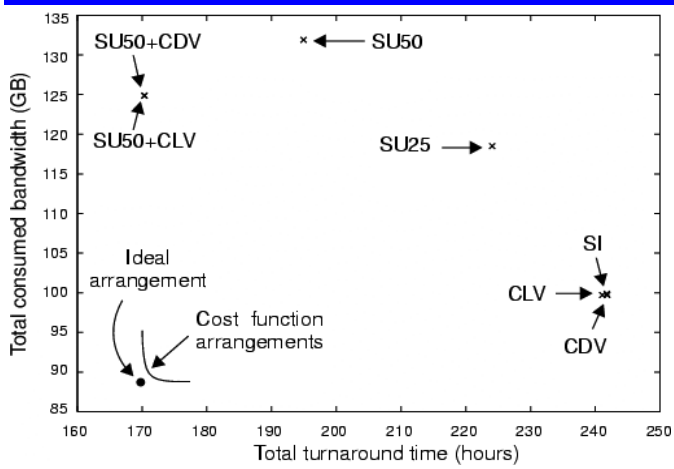
Trade-offs for implementing consistency protocols

- **How are changes distributed:**
  - notification
  - full state
  - state differences
  - operation
- **How quickly does a copy react to inconsistency**
  - immediate
  - lazy
  - passive
- **What does a nonpassive copy do with updates**
  - push to others
  - pull from others
- **How many concurrent updates are to be supported**
  - single
  - multiple

Does differentiation make a difference?

- **Experiment:**
  - Monitored accesses and updates for our VU CS Website
  - For each request:
    - from which autonomous system did it come from?
    - what was the latency to the client's AS?
    - what was the bandwidth to the client's AS?
  - Did what if analysis experiments:
    - what if document D had been replicated to AS X?
    - what if AS Y had installed a proxy server for document D?
    - what if document D was always kept at its home server?
    - ….

Differentiation makes a difference!



What do we need for mobility?

- **Observation:**
  - we just picked some caching and replication strategies
    - there may be many more that could be relevant
    - we had a simple, relatively boring Web site
- **Mobility:**
  - we're talking about communication between possibly moving parties; this makes matters only “worse”
  - we're also talking about communication between parties that need not be online simultaneously.

We need mechanisms to support many different message-distribution strategies

Rich set of mechanisms introduces problems

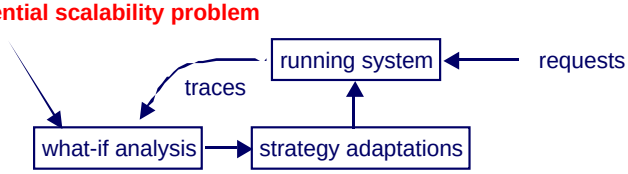
- **Observation:**
  - successful commercial applications do *not* separate mechanisms from policies: it's just too difficult for application developers and users to understand
    - Conclusion from Munin DSM: too many alternatives
    - Bayou had similar problems for selling their model
- **Conclusion:**
  - separation is OK, but you need to derive strategies/policies automagically

We need self-adapting middleware solutions to handle the variety of consistency models

Self-adaptation is a tough problem

- **Back to the example:**
  - we collected partial traces to predict changes in distribution strategies and did runtime (i.e., in-the-loop) what-if analyses
  - evaluating a total of 10 different strategies, analyzing 100 documents using a 500-request trace took 140 ms on a 600 MHz PIII.

Potential scalability problem



Some conclusions

- **Consistency models are needed to achieve acceptable performance, and there will be quite a few of them**
- **Middleware has to offer simple mechanisms for supporting a myriad of models**
- **We need efficient feedback control loops for self-adaptation of model parameters: applications and users can't handle this stuff**

Security in Middleware for Mobile Systems

Maarten van Steen
Vrije Universiteit Amsterdam

Security statements

- **I do not consider myself a security expert**
- **I do not believe that current security measures come even close to what is needed**
  - too many successful security attacks
- **I do not believe we need the same level of security in all situations**
  - analyzing risks is what counts (“how much does it hurt?”)

It’s all a matter of trust

Picture this...

- **Worldwide distributed system consisting of:**
  - many fixed servers
    - have easy-to-find addresses
      - locally easy to find: service lookup protocol
      - sometimes globally easy to find: naming and directory services
    - implement many different services
      - local services (geographically relevant)
      - global services (could be anything)

Picture this... (cnt'd)

- many fixed servers
  - ....
- many more mobile hardware devices (PDAs and the likes)
- many, many more mobile software devices (some of which reside statically on the hardware devices)
  - software agents (for performance, for asynchronous communication)
  - software data objects (performance)

Mobility issues in middleware start to show when thinking in the large

What's the problem?

- **Mobile (hardware or software) device owned/managed by Alice enters environment owned/managed by Bob**
  - requires mutual authentication
  - requires message integrity measures
  - possibly requires confidentiality

  } **Secure channel**

- **Secure channels are something we understand and can be implemented using well-known techniques**
- **Secure channels solve only part of the problem (and still have their own problems to solve: PKI)**

Picture this...

- **To make effective use of Bob's service, Alice may need to download software from Bob**
  - check preferences to make searching easier
  - maps to help go through a store, building, etc.
  - "intelligent" software to assist in decision-making process
    - looking for X but Bob's Y may offer better value for money
    - guaranteed lowest-price bargain based on prices Alice (automatically) picked up at Chuck's
    - ....

What's the real problem?

- **Can Alice trust Bob, even if she knows for sure she is talking to Bob?**
  - Can she trust Bob's software not to mess up her PDA?
  - Is she willing to pay for services offered by Bob, and how?
  - Where can she go to when things go wrong?
- **Of course, let's not forget Bob:**
  - Why would he trust Alice?
- **Important: for mobility, local/autonomous decision-making may suddenly become an issue**
  - you can't expect to set up a secure channel to a home station

What should we be doing? (1/2)

- **If trust is the issue, we should concentrate on developing trust models**
- **Note: having only Verisigns is just not going to work**
- **Scalability issues demand that we work on computational reputation systems:**
  - reputation is expressed in numerical values (ratings)
  - system can be represented as a graph:
    - nodes represents agents/users/processes/…
    - arc (a,b) with weight w: a rates b with value w
  - combining ratings leads to reputation of a node

What should we be doing? (2/2)

- **Lots of problems to solve:**
  - how to get an initial reputation?
  - how should reputation values propagate to the unknown?
  - In general: what does a rating actually mean (when does trust start and distrust end)?
- **Fortunately: some work is being done (but certainly not enough)**

Trust models require verification techniques

How can we check trust? An example (1/2)

- **Imagine a web of servers that promise to host each other's data (cf. promise to offer a service)**
- **Data is migrated/replicated on servers using a reputation-based trust model**
  - we've experimented with Dempster-Schafer models for trust propagation
  - models are robust and can even stand gang attacks
  - assumptions are simple (e.g., independent ratings)
- **Problem: how do we know that our trust in a server is not violated?**

How can we check trust? An example (2/2)

- **Nonsolutions:**
  - anonymous requests (anonymity is enough to let a malicious server return a correct answer)
  - let servers check each other (a malicious server can probably gradually learn the distinction between servers and clients, and thus treat clients badly)
- **Solution?**
  - ask arbitrary clients to pass their server responses back to data owner
  - no need to put 100% trust in selected clients

Bottom line

Forget about all-the-time guaranteed security

Start working on probabilistic security models in which trust plays the key role

- **What are appropriate trust models?**
  - scalability, local decision making
- **How do we build in trust verification techniques?**

ERCIM-NSF Workshop

Conclusions

Edited by Luis Rodrigues & Ravi Prakash

Five classes of issues

- Where we stand?
  - Are there widely accepted models?
- What is missing to glue existing results?
  - Lots of research but missing pieces...
- What are the open issues?
  - Issues that have not been addressed.
- Applications
  - Classes, important apps
- Future collaborations

Models

- Network model
  - Classification and properties (BAN, MANET, WLAN, etc)
  - Connectivity to the Internet
- Cooperation model
  - Every node with same goals, conflicting go hererogeneity

Models

- Security model
- Trust model
- Architecture
  - Models for composition of networks
  - NES, clouds, etc
- Performance model
  - What are the important metrics?

Models

- Mobility models
  - Characterize network dynamism
  - Repository of mobility patters
- Benchmarks
  - Agree on family of representative mobili connectivity/ failure/ etc patterns for eva of solutions
  - Models for heterogeneous environments

Models

- Set of services
  - In the wired world: name services, brokers, servers, etc)
  - There are specific services that should be available in most mobile middleware systems
    - Data agregation, distributed hash-tables, persist messaging, garbage collection, spacial data management

Models

- Naming and addresssing
  - Location aware names
  - Mapping from logical to physical addresses
  - Spatial programming models

Models

- Capture specific issues in mobility
  - What “really” makes mobility different from other system models
    - Voluntary disconnection
    - Awareness
    - Administration (different domains)
    - Autonomy
  - Ex: asynchronous system subject to omission failures
- Scalability models

Models

- Programming and application models
  - Location based programming
  - Mobility in space
  - Mobility in time (connect disconnect)
  - Mobility among domains
  - Location (physical, logical, context) aware
    - Location triggered events or actions (interface the real-world)
    - Parallel with real-time (the environment has a

Continuing research themes

- Consistency models
  - Need to support lots of models at the same t
  - What is the glue missing?
    - Common mechanisms: logs, context
    - Common interfaces: callbacks, re-integration, synchronization
    - Ex: (load/restore, serializable, monitorable)
  - Mutual consistency among objects using different consistency models

Continuing research themes

- Adaptation
  - Policies not part of the middleware
    - Mechanisms to support change of policies
  - To changes in the context
    - Physical, mobility, resources (energy, etc), interaction
  - Is reflection the missing link?
    - New languages are also important
  - What are the feedback loops needed?
  - Accomodate unantecipated adaptation and evolution

Continuing research themes

- Mechanisms and tools for composition
  - For mobile software components
  - For verification
  - Policy driven composition

Continuing research themes

- Location awareness
  - How to describe, store, rate and use location information
  - Common formats/interfaces?
- Energy-awareness
  - Common interfaces?
- Context-awareness
  - As a generalization of previous bullets
  - Infrastructure awareness
  - Execution evironement awarness

Continuing research themes

- Peer-to-peer vs pervasive computing
  - User-centric environement
  - Best-place, Best-time, Best-way
- Overlay networks vs mobile networks
  - Similarities and differences (topology changes)
- Agents and mobile code
  - Execution migration
  - Specific for mobile networks?
    - Ease to cope with disconections
    - New problems vs problems solved.

Continuing research themes

- Indirect communication
  - Content-based addressing (attribute)
  - Groups and contact points
  - Relation with data fusion and aggregation

Long term research

- Security and trust management
  - Privacy
- Selfishness and cooperation management
  - Punish/reward mechanims, policies
- Generic consistency model
  - Is it possible?
  - Do we need to live with many different consistency models.
  - What are the “basic” and “configurable” models that solve most problems?

Long term research

- Communication via the environment
  - What should be preserved in the environment
  - Where should the information be stored
    - Virtual: “location-based” tuple spaces, shared memory mo
    - Physical: environement
  - Relation with the context model
  - Data fusion
- Users moving from one device to the other
  - Change of domains
  - User interfaces
  - Prevasive computing

Long term research

- Self-organization
  - Hot topic in industry (IBM, ATT, Microsoft)
  - What exactly is this?
    - Self-monitoring, self-tuning, self-administration self-tuning
    - Monitors the system and automaticaly changes the policies
    - Estimate user behavior, intrusion detection
  - Relies on some basic adaptive framework

Applications

- Identify relevant applications
  - Ambient intelligence
  - Rescue
  - Augmented reality
  - Social issues
  - Health care
- Missing:
  - Identify unique requirements
- Idea:
  - Organize an workshop with users outside CS field

Collaborations

- Integrated proposals
  - Suggest a common program
  - Identify complementary issues
  - Emphasize global impact of common research
- Should we consider to extend the workshop repo to a book?
  - Report first
  - Extended version as a paper
  - Collect feedback

TO DO

- All:
  - Send CV+abstract
  - Send slides
- Luis and Ravi
  - Make a draft of the report

Challenges and Opportunities for Next-Generation Middleware Systems

Anand Tripathi

Department of Computer Science
University of Minnesota, Twin Cities

This work is supported by NSF grant ITR 0082215

1

Driving Factors

Emerging distributed applications require new classes of services from the next generation middleware architectures. These requirements are driven by six factors:

1. **Increasing importance of component integration as opposed to programming.**
2. **Mobility of users, appliances, and mobile code/component/agent technologies.**
3. **Development of context-aware smart environments.**
4. **Integration of geographic information in managing services for mobile users.**
5. **Multimedia based real-time interactions in groupware and collaboration systems demanding QoS guarantees.**
6. **Security of system operations is a growing concern.**

2

Challenges … 1

1. **Meta protocols to facilitate policy-based integration and management of application components and system services.**
   - **Techniques for specifying policies, which may be concerning with a diverse set of aspects.**
   - **Tools for policy analysis (e.g. identification of conflicting policies).**
   - **Middleware mechanisms for aspect integration and management.**

3

Why a policy-based approach?

- **Decouples the requirements of a distributed application from the implementation of its functionality.**
  - **A distributed application may span multiple administrative domains.**
  - **A distributed application may evolve with changes in administrative policies and user experience.**
  - **New devices, tools or artifacts are quite often needed to be integrated into an existing environment.**
- **A policy based middleware provides the flexibility in building and managing a distributed application, as different policies can be easily plugged in to meet the evolving nature of the requirements.**

4

Challenges … 2

2 **Mechanisms for supporting composition of mobile software components (agents) and hardware devices in an application.**

- **Security in integrating mobile components**
  - **Trust and certification**
  - **Delegation of trust by a user to its mobile agents**
- **No prior knowledge of all the components that would be integrated in an evolving system.**
- **A spectrum of resource discovery protocols:**
  - **Low level -- interface based**
  - **High level -- service descriptions and constraint based**

5

Motivations

- **An intermittently connected client could launch an agent in the backbone network to perform tasks on its behalf.**
- **Mobile agents could be used to migrate a user's current execution environment to another host.**
- **An agent could act as an active mobile artifact in a collaboration or workflow environment. (self managing, active object).**
- **Mobile agents/components could be used for composing new services.**
  - **Security policy definitions and mechanisms for their enforcement are crucial.**

6

Challenges … 3

3. **Support for context-dependent and location-aware computing:**
   - **Device/client location (network or GPS location)**
   - **User application context and its relationship to physical location**
   - **Security policies controlling access to local resources by mobile users and devices.**
   - **Confidentiality of location information.**
   - **Service availability and configuration based on the geographic location of the user.**
   - **High level service/resource description mechanisms to be used by environments and mobile components.**

7

Motivations

- **Context-aware smart environments**
- **An application is aware of its user's execution context and physical environment.**
- **An environment is aware of the presence of a mobile user and his/her computing appliances.**
- **The application/environment may be able to take some proactive actions**
  - **Moving data to a remote server if the user is most likely to move to a location closer to that server.**
  - **Security policies should be taken into consideration.**
- **Adapting to the current physical environment – limited bandwidth or switching to a different communication mode.**

8

Opportunities

To address the increasingly complex requirements in building and managing distributed applications:

- **The next generation middleware systems are being designed to support policy-driven integration of application-level components with system-level services and resources.**
- **Policies are defined by both the application developers and the system administrators.**

9

QoS Aspects of an Application

- **Traditional view of QoS is related to performance measures such as latency, throughput etc.**
- **A more general view of QoS includes requirements of:**
  - **Reliability**
  - **Availability (may be based on the location of the user)**
  - **Data consistency**
  - **Security**
  - **Real-time guarantees**
  - **Synchronization of streams in multimedia systems**
  - **Support for debugging and auditing**

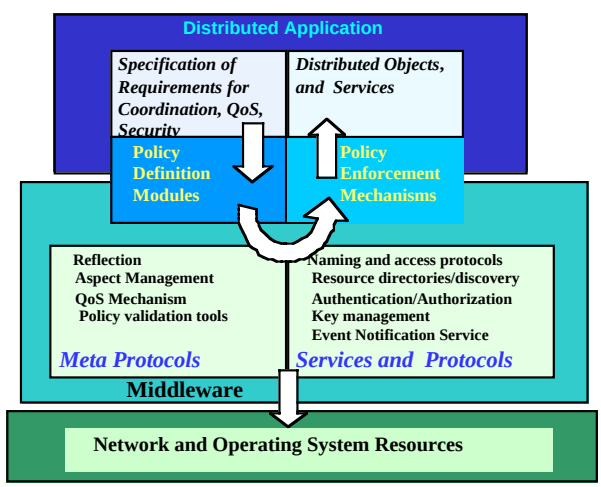
10

Policy Specification and Enforcement

- **Applications define policies for managing different aspects.**
- **Middleware provides tools to:**
  - **Validate policies for any conflicts**
- **For each aspect, policy modules are derived from the specification.**
- **Middleware integrates these policy modules with**
  1. **Application components**
  2. **Middleware services**
  3. **Network/OS mechanisms for QoS**
  - **Meta protocols and reflection.**

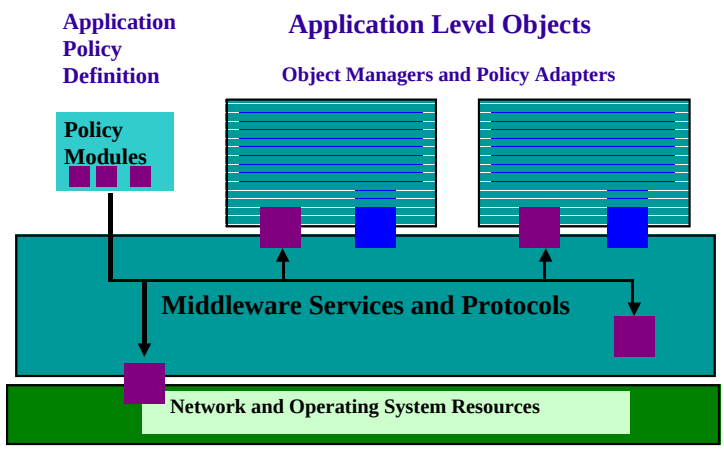
11

Framework for Policy Based Middleware



12

Policy Integration Mechanisms



System Services

- **Core Services**
  - **Naming and resource access protocols**
  - **Resource directories and resource discovery mechanisms**
  - **Authentication, access control, and authorization**
  - **Event notification service**
  - **System configuration and management**
- **Application Specific Services to support:**
  1. **Context-aware computing**
  2. **User and appliance mobility**
  3. **Integration of mobile agents/components with applications**
  4. **Services based on network location and geographic information**

14

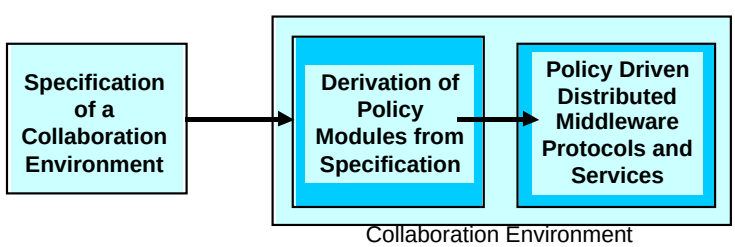
A Middleware for CSCW Systems

- **Construction of secure collaboration environments from their high level specifications.**
- **Rapid construction of a collaboration environment using a generic middleware.**
- **Analyze and reason about the coordination and security policies independent of their implementation level details.**

15

Approach for Policy Driven Collaboration

1. **A security and coordination specification model for CSCW systems.**
2. **Derivation of policy modules from the specifications.**
   - **Inter-relationships between the modules (e.g. event communication)**
   - **Management of user roles, shared objects, and activities**
3. **A policy-driven middleware for secure distributed collaboration.**



16

Middleware Support for Object Caching and Consistency Management in Distributed Systems

Anand Tripathi

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This work is supported by NSF grant ITR 0082215

1

Outline

- **Optimistic Approaches for Data Management in Mobile Computing Environments**
- **Challenges**
- **Spectrum of Consistency Models**
- **Middleware support for object caching and consistency management**
- **Current directions of our work**

2

Optimistic Approaches for Data Management

Reasons:

- **To support replication of data with weak consistency models for high availability in weakly connected environments.**
- **Disconnected operations with shared data for nomadic users.**
- **In broadcast based wireless environments, clients may not be able to execute expensive locking protocols with the servers.**
  - **Clients execute transactions optimistically and then submit to the server for validation.**

3

Replication with Weak Consistency

Replicas of an object are managed using optimistic schemes

- **"Read any / Write any"**
- **Supports continued operations under weakly connected environments, network partitions, and disconnected conditions**
- **Used for improving performance in a collaborative environment, where each user works on a local replica of a shared object.**

➔ **Detection of update conflicts**

➔ **Resolution of conflicting updates**

4

Mobile Environment Characteristics

- **Frequent disconnections between a client and its servers/peers:**
  - **Forced disconnections**
    - **Anticipated**
    - **Unanticipated**
  - **Voluntary disconnections**
    - **To reduce connection costs**
    - **Nomadic computing**
- **Clients are resource-limited**
  - **Important concerns are power and limited bandwidth.**

5

Mobile Environment Characteristics…

- **A mobile client may connect to different servers of a replicated data service as it moves through the network during a session.**
- **Asymmetry of connection bandwidth**
  - **In some wireless environments, the server-to-client bandwidth may be much higher than that available in the reverse direction.**
  - **At times, a low powered client may not be able to communicate with a server.**

  ➔"Broadcast Disk" model of computing used in some wireless environments, where the clients need to work with cached data.

6

Consistency Models

- **Eventual Consistency (Bayou, Fisher-Michael, Wuu-Bernstein)**
  - **In a quiescent state, all copies have received the same set of updates and the replicas are mutually consistent.**
- **Session Consistency (Bayou)**
  - **A client/application sees a consistent view of its actions on shared data. It provides certain guarantees**
    - **"read your writes", "monotonic reads", "writes follow reads", "monotonic writes"**
- **View Consistency (Goel-Pu)**
  - **Extends the session consistency model to a group of clients**
  - **Enforced by a client itself, without requiring expensive protocols.**

7

General Requirements

- **Causality preservation**
- **User intention preservation or suitable notifications**
- **Convergence or eventual consistency**

8

Update Resolution Techniques

- **State Based or Content Based Resolvers**
  - **Data Patch techniques developed for partitioned databases**
  - **Ficus and Coda**
- **Log Transformation**
  - **Merging update logs of concurrent updates**
  - **IceCube (static and dynamic constraints in reordering)**
- **Operation Transformation**
  - **Introduced in GROVE collaborative editor system**
  - **Update logs are merged, and**
  - **Update operations are transformed based on the preceding operations**

9

Challenges

- **How to design objects which incorporate conflict resolution methods and operational transformations?**
  - **Tools to help object developers writing such functions.**
  - **Automated generation of such transformation rules.**
  - **Exploit properties of operations: state partitioning, commutativity How to transparently support caching of objects with different consistency requirements?**
- **How to dynamically change the consistency model used for a given client by the object server?**
- **How to support coordination among a set of objects in executing resolution functions?**

10

Challenges …

- **Semantic Callbacks:**
  - **Similar to the ideas proposed by Satyanarayanan.**
  - **A client, when caching an object, may indicate to the server a precondition whose invalidation should result be communicated to the client.**

11

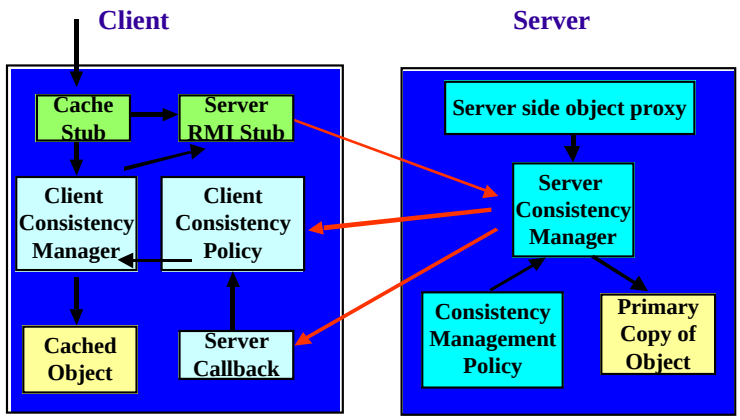
A Framework for Object Caching

- **Transparent caching of objects at client side in Java RMI applications**
  - **An existing RMI client does not know that the server has introduced support for client-side caching.**
- **Support different consistency models for different objects**
  - **The object designer should be able to choose and integrate the appropriate protocols for the desired consistency model.**
- **Support caching of only parts of an object, as needed by the client's request**
  - **Reduce false sharing**

Reference: Paper by Eberhard-Tripathi in Middleware'2001

12

Mechanisms for Object Caching



13

Client Consistency Manager

- **Directed by *Client Consistency Policy* object.**
- **For each method, the policy object returns an *Actions List*.**
  - **Examples of actions:**
    - **Invoke method locally**
    - **Invoke method on server**
    - **Contact server for synchronization operations**
    - **Update local cache copy**
    - **Update the policy state**
- **Server can change client policy using *callbacks*.**

14

Challenges

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Challenges …

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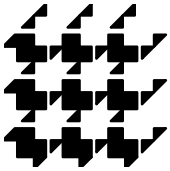
16

FET - Future and Emerging Technologies



DIMACS — Center for Discrete Mathematics & Theoretical Computer Science

This workshop is part of a series of strategic workshops to identify key research challenges and opportunities in Information Technology. These workshops are organised by ERCIM, the European Research Consortium for Informatics and Mathematics, and DIMACS the Center for Discrete Mathematics & Theoretical Computer Science. This initiative is supported jointly by the European Commission's Information Society Technologies Programme, Future and Emerging Technologies Activity, and the US National Science Foundation, Directorate for Computer and Information Science and Engineering.

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