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Supporting User Mobility

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Abstract

The availability of wireless network connections to laptop computers and PDA's has created interest in the issues surrounding mobile computing. However, enabling users to be genuinely mobile in their work requires more than a wireless connection. Distributed system services are needed to support the locating of people, equipment and software objects, and, especially for mobile multimedia applications, network transport protocols which can adapt to a wide range of networking conditions must be developed. This paper reviews some important mobility issues, looks at some of the systems requirements raised by user mobility, and describes some practical experiences with mobile applications at Olivetti Research Ltd. (ORL).

Keywords

Mobility, mobile multimedia, personalisation

1 INTRODUCTION

User mobility is a more general concept than wireless terminal mobility or mobility enabled by portable computers. Instead of requiring the user to carry around a laptop or PDA it is in many instances more convenient to simply use any networked computer or information appliance which is to hand, including those which may have a wireless connection to the network.

Current computing systems have the idea of user ownership deeply ingrained in them, even diskless workstations become private property once someone has logged into them. This runs counter to trends in the workplace where, increasingly, people's working patterns are more mobile, and rooms, desks and equipment may be used only temporarily - they are not "owned" by anyone in particular.

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Desktop and portable computers are usually highly personalised, both in their hardware and software configuration and because they contain unique copies of files. It is not easy to borrow another computer. These problems would be avoided if, instead of private, personalised hardware, we had public, *depersonalised hardware* which would be equally accessible to everyone. To achieve this kind of mobility the hardware on which user interaction occurs must be stateless, or perhaps only have state during the course of a user interaction. The computing environment would still be personalised, of course, but now that would be taken care of elsewhere in the network. In this view the only "private" property is in persistent software objects and associated files residing on networked servers. By removing the close binding between individuals and their personal computers we give ourselves the freedom to allow computer interactions to persist and *follow* us as we move between tethered, or untethered computers, both in our work and leisure.

Recently several companies, including Oracle Corporation and Sun Microsystems, have announced the intention to market products, known as *network computers* which contain elements of these ideas. Only a limited amount of software need be stored locally and applications would be downloaded from network servers, freeing users of systems administration issues, and all user status would be stored at networked locations. These developments are linked to widespread interest in highly portable architecture-independent languages such as Java* and, if successful, may lead to the widespread adoption of computers which are well suited to support user mobility.

It is natural to also expect multimedia applications to be always available to us by following our movements. What is required is an architecture providing an infrastructure which makes user mobility transparent, in the sense that adaptation to varying resources is automatic, and which includes integrated support for the special problems of multimedia data transport.

Section 2 reviews the benefits that mobile multimedia could bring. Section 3 looks at some important systems which are required to support user mobility and reports on some practical experience at ORL with various aspects of mobility.

2 THE PROMISE OF MOBILE MULTIMEDIA

User mobility will make possible many new and exciting applications, as well as making life much easier for people who are mobile in their work. It should be possible to bring a personal computing environment to not only alternative work locations, and to the home, but also to endpoints sited in public places, such as restaurants, banks and airports. See Weiser (1993) for generalisations of these concepts.

The development of mobile multimedia applications will create demand for activities such as the browsing of archives of audio, video and images; mobile video-conferencing; mobile video-on-demand; and persistent multimedia connections for monitoring remote activity. Monitoring applications could include site security and industrial safety. Monitoring officers could carry a portfolio of audio-visual inspections with them during the course of their work,

* Java is a trademark of Sun Microsystems

and could also continue the activity off-site. Some of these potential mobile multimedia applications, in the context of wireless networking, have been discussed by Lee (1995).

There is strong evidence of an increasing commercial interest in networked multimedia applications involving mobility. For example, in the UK, BBC Television has embarked on a long-term plan to create a "newsroom of the future" which must take into account the work habits of roving journalists and programme makers who wish to access multimedia information. They would like journalists remote from the studios to not only be able to easily contribute new multimedia material, but also to take part in editorial decisions and browse multimedia library material. Other commercial applications include live feeds from news agencies; the rapid dissemination of graphics and video to mobile workers in public services; and the transport of images to organisations like insurance companies. On a more personal level, some people may like to have live family photos on their desk, or answer their front door remotely.

3 SYSTEMS REQUIREMENTS FOR TRANSPARENT MOBILITY

There are some key technologies and indispensable system services needed to support user mobility. Designing the required infrastructure involves an interesting combination of computer science issues. I will focus on some areas of interest at ORL: distributed software support for multimedia; location; intelligent adaptation to changing network and endpoint characteristics; and wireless mobility appropriate for multimedia. The security issues related to mobility will not be considered here.

3.1 Distributed Multimedia Applications

The ability to distribute applications across networked computers in order to take advantage of intelligence elsewhere on the network is an important ingredient of a mobile architecture. The standardisation of interfaces and protocols for handling distributed software objects achieved by the Object Management Group (OMG)* has been an important milestone in software engineering. Use of the OMG Interface Definition Language (IDL) enforces modularity and facilitates code re-use. CORBA (OMG, 1995) is a language-independent standard to which multiple vendors conform, allowing interoperability between software objects on different computer architectures. The standard provides a "software bus" for monitoring and controlling software objects which are distributed across networks. Microsoft's Active X♣ architecture will offer an alternative and widespread option for creating distributed systems.

However, support for multimedia in conventional distributed systems is inadequate. The methods available to move data between software objects do not match the special transport requirements of multimedia. Live multimedia streams must have a minimal end-to-end latency and low jitter, and some stream types may require a different quality of service from others.

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* OMG , OMG IDL and CORBA are trademarks of the Object Management Group Inc.

♣ Active X is a trademark of the Microsoft Corporation

Standard remote method invocations can be used to control the software objects through which multimedia streams flow. But for movement of data a transport protocol specialised to support multimedia is necessary. Until these ideas are absorbed into the distributed system standards a "back door" for live multimedia data transport will still be needed.

The Streams project at ORL and Cambridge University Computer Laboratory is using CORBA both to distribute multimedia sources, sinks and pipeline elements across networked computing devices and to access the distributed system services required to support mobility. Of particular interest is the ability to monitor and control directly networked sources and sinks of multimedia data such as video cameras, display devices, audio input/output devices and multimedia file stores.

3.2 Intelligent Adaptation

Users may interact with a wide variety of stationary and mobile systems in the course of their day so it will be necessary for mobile applications to intelligently adapt to different environments and to different users.

Network Adaptability

Moving between a tethered workstation and a computer with a wireless network connection may cause a change in the characteristics of the network connection, such as a change in the bandwidth, and a change in latency and error rate. A different change in connectivity will happen when moving to the home or to a remote site which may not have high-speed network connections. If information on network characteristics were stored in a network resource database then some high level adaptation decisions could be made by the application. But to handle dynamic changes in the network characteristics the transport protocol must be aware of the way conditions are varying so that it can notify the application of changes in the quality of service.

Endpoint Adaptability

Applications will also have to adapt to the capabilities of different endpoints. Kantarjiev (1993) and Richardson (1994) have noted the problems of migrating X Window* displays between workstations with different display characteristics. Displays can differ both in their resolution and colour-handling, and unless applications are written with user mobility in mind ad hoc solutions must be adopted. The user-interface may also differ from the standard keyboard and mouse, PDA's often only have a pen interface, and in the future may have a speech interface. It is unusual to design user interfaces which can dynamically adapt to alternative input and output devices. The Model-View-Controller architecture for applications may offer some solutions (Gray, 1990 and Stajano, 1995). Here, the Model is the core of the application, moving between different application states. It presents an interface to which multiple Controllers (input devices) and Views (output devices) can be attached.

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* The X Window System is a trademark of The X Consortium.

Another interesting adaptation issue is how intelligence should be partitioned between networked servers and endpoints. Bartlett (1994) noticed that he obtained much better performance by locating the intelligence for his wireless Web browser in a powerful networked workstation, while only requiring the endpoint, a PDA, to behave as a dumb alphanumeric display. Another example of partitioning of intelligence and display at ORL is described by Wood (1996). Here a dumb ATM-networked LCD screen called a VideoTile shows an X Window display by being refreshed, when necessary, with blocks of screen pixels from a process on a networked workstation. Kantarjiev (1993) examined various points along the line from dumb X display to full X server in an effort to optimise a wireless X display. It may be that the positioning of the intelligence within a mobile application will have to be automatically reconsidered as the mobile user moves between endpoints. Some endpoints with poor network connectivity would be able to sink more data if a better compression scheme were used, but the endpoint may then not have the resources to decompress that data and deal with the resulting increased data rate.

3.3 Location

All models of mobility require a mechanism for identifying the location of both users and computing equipment. One might simply assume that the user is adjacent to the machine he is logged into, but this is open to ambiguity. It is possible to imagine cumbersome methods of indicating location information to the computer system. The user could log in to a computer and signal his or her presence, but this makes assumptions about the location of the computer and ancillary hardware which may not be valid - computer hardware and peripherals are frequently repositioned for a variety of reasons. Wireless mobile computers can be located to some volume served by their base station but the wireless cell sizes may range from several rooms within a building up to many miles in an unpredictable fashion, so this is unsuitable for reliably collocating users with other users or equipment.

Active Badges

ORL has developed a method of automatically locating users and equipment called the Active Badge* Location System (Want, 1992 and Harter, 1994). Considerable experience has convinced us that such a location system is an important enabling technology for automating features of mobile applications, allowing user interactions to become simple and transparent. Schilit (1993) has also experimented with the use of infra-red passive location systems to permit customisation of mobile applications.

The installed Active Badge system at ORL maintains a dynamically updated record of the location of both people and hardware and has made possible interesting experiments involving mobility. If one is to make progress in a field there is no substitute to building systems and gaining experience and insight by using them in day-to-day work.

Medusa The Medusa multimedia installation at ORL (Wray, 1994) makes use of an extensive switched ATM network to connect together various kinds of directly network connected

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* Active Badge is a registered trademark of Ing. C. Olivetti & C., S.p.A.

endpoints. These endpoints include video cameras, high quality audio input and output, VideoTiles (networked colour LCD displays), storage devices and workstations. Applications use badge location information on both users and equipment to make video and audio connections to people who are referred to by name, rather than network address. If you are near enough to suitable multimedia hardware then the multimedia connection will be automatically routed to you, without any login requirements.

Teleporting The ORL teleporting system (Richardson, 1994) is an example of a user-mobile application where the interface is made transparent by the use of Active Badge location information. Teleporting offers a means of redirecting the user interface of ordinary applications which run under the X Window System. Instead of being fixed to one display as part of a standard "X" session, applications can be part of a "Teleport session" which can be dynamically called to any suitable display on the network. When called up on a new display, the applications within the Teleport session appear in exactly the state the user left them on a previous display. This allows users the freedom to move around whilst retaining immediate access to their computing environment wherever there is a suitable display. This is remarkably useful, and has convinced us that user mobility is a goal worth pursuing. Apart from the obvious benefit of being able to carry one's work when moving between rooms, it is very useful to be able to show complete multi-window screens to others, whilst retaining all of one's own environment, and not even requiring the other party to log out. Because VideoTiles display the X Window world, it is also possible to teleport to any VideTile on the ATM network. It has a pen interface, and no keyboard, but this is very appropriate and comfortable for using a Web browser teleported to a VideoTile. VideoTiles are stateless networked computers and if rebooted or power cycled immediately recover their display from the remote X server.

Follow-Me Video It is of interest to extend the concept of teleporting to include other data types such as multimedia. In order to become familiar with the issues involved we have experimented with both Follow-Me audio and Follow-Me video. It is possible to take part in a multi-party audio conference using Medusa software. Each end of the conference can be called to another location using buttons on your Active Badge. The Follow-Me video prototype makes it possible to materialise live video connections on a nearby workstation or VideoTile. The video images could be views of your office, simulating a security application, or views of the car park, simulating the ability to see what commuter traffic conditions are like. This is only an experimental prototype, but experience with it will help us to develop our distributed multimedia and adaptive transport protocol work.

JavaTel extends some of these ideas to areas beyond the range of the Active Badge system. Web browsers present a platform-independent view of the World Wide Web which has some of the characteristics of user mobility, despite its bandwidth limitations. It is possible to automatically download and execute Java applets within some Web browsers. This programmable intelligence at the users endpoint can be used to make a Web page behave like a dumb graphics display. At ORL, Wood (1996) has written a Java applet which simulates the behaviour of an ORL VideoTile, creating a globally mobile X session. This is an interesting foretaste of what true user mobility might hold.

A Dynamic Location and Resource Database

Mobile applications will need to be able to discover the current locations of not only users, but also computers, peripheral equipment and resident software objects. It will also be necessary to know what software objects could be created, if required, on a particular platform. The characteristics of each endpoint that the user interacts with must be stored, and, for any particular user, the system will need to be able to find out what facilities are available in their immediate vicinity. A dynamically updated object naming, location and resource database is required to maintain all this information. It must contain resource descriptions of hardware and software objects allowing mobile applications to make queries and receive callbacks when hardware and software objects change position or state. A constant stream of location updates should arrive at the database from a wide variety of location and movement detection sensors. Clifford Neuman (1993) has identified some of these system support issues, and at ORL the SPIRIT (Spatially Indexed Resource Identification and Tracking) project will provide a comprehensive solution.

The availability of such a service will make possible the automation of many user interface issues and will make user mobility a transparent process. For example, information on a machine's power and the software base available to it will allow automatic resource allocation of particular tasks to processing engines specialised to carry them out. A networked speech recognition service might need to be run on a powerful machine equipped with a large amount of memory and local storage (Brown, 1995) and it could be optimised by adapting to different users by accessing speaker-dependent speech data.

The appropriate information would now be available to automatically adapt user interfaces to match the capabilities of different platforms. Qualities like screen resolution, colour capability and input/output peripherals would be known to the system. If the database contained details of network connection characteristics for different machines then automatic intelligent adaptation of multimedia streams could be done as the user moves to parts of the network which have different performance characteristics. As an example, an alternative video compression scheme might be chosen for a low bandwidth connection to a home compared to that for a high bandwidth ATM connection in the workplace. The local processing capabilities of the endpoints would also influence such a decision.

3.4 Wireless Mobility

Imielinski (1994) has presented an overview of wireless mobility, but wireless network technologies are not generally suitable for transporting good quality live multimedia. Handling live multimedia brings special problems, particularly of latency, synchronisation and continuity. For example, in a live videophone call the audio and video streams must be delivered with sufficient synchronisation to avoid obvious lack of lip-sync, the latency must not be intrusive, and there should not be any breaks in connection when the mobile does handoffs to another base station. To save bandwidth media streams over wireless connections may be compressed in some way, this places constraints on the tolerable error rate for these connections.

So there are a number of important considerations for good quality live wireless multimedia: the wireless connection needs to have sufficient bandwidth for transporting multimedia; it must offer separate qualities of service for each media stream, so that compressed streams are well handled and streams can be prioritised; and handoffs between different base stations must not interrupt the streams or add latency to them.

The ability to offer different qualities of service to different media streams is usually associated with connection-oriented networks. Wireless ATM can have the property of maintaining end-to-end quality of service, just as in wired ATM, and so is particularly interesting for mobile multimedia. ORL has been working for some time on a wireless ATM network designed with the characteristics of multimedia in mind (Porter, 1996). It provides the equivalent of a wireless ATM drop cable from the base station (which is connected to the wired ATM network) to the wireless endpoint. Since it supports standard ATM adaptation and signaling protocols it is possible to treat the wireless section like a normal connection to the wired ATM network. Wireless ATM VideoTiles behave just like wired ones, with the exception that the wireless bandwidth is limited to 10 Mbps, soon to be extended to 25 Mbps.

4 CONCLUSIONS

A multimedia system supporting user mobility needs a highly distributed software system which must be extended to handle the specialised transport requirements of multimedia streams. By building and maintaining an object naming and location database which stores system resource information, it becomes possible to automate many aspects of mobility and so make user mobility transparent.

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6 REFERENCES

Bartlett, J.F. (1995) The Wireless World Wide Web, *Workshop on Mobile Computing Systems and Applications, Dec 8-9 1994, Santa Cruz, IEEE Computer Society Press*, 176-178.

Brown, M.G., Foote, J.T., Jones, G.J.F., Sparck Jones, K. and Young, S.J. (1995) Automatic Content-Based Retrieval of Broadcast News, Proceedings of ACM Multimedia '95, San Francisco CA. 35-43

Clifford Neuman, B., Augart, S.S. and Upasani, S. Using Prospero to Support Integrated Location-Independent Computing , *Proceedings of the USENIX Mobile and Location-Independent Computing Symposium*, Aug 1993, Cambridge MA. 29-34

Gray, P.D. and Mohamed, R. (1990) *Smalltalk-80: A Practical Introduction*, Pitman.

Harter, A. and Hopper, A. (1994) A Distributed Location System for the Active Office, *IEEE Network*, **8(1).**

Imielinski, T. and Badrinath, B.R. (1994) Mobile Wireless Computing, *Communications of the ACM*, **37(10),** 19-28

Lee, K. (1995) Adaptive Network Support for Mobile Multimedia, *ACM MobiCom 95, The First Annual International Conference on Mobile Computing and Networking*, Nov 1995, Berkeley, CA.

Kantarjiev, C.K., Demers, A., Frederick, R., Krivacic, R.T. and Weiser, M. (1993) Experiences with X in a Wireless Environment, *Proceedings of the USENIX Mobile and Location-Independent Computing Symposium*, Aug 1993, Cambridge MA, 117-128.

OMG (1995) *The Common Object Request Broker: Architecture and Specification*, Object Management Group.

Porter, J., Hopper, A., Gilmurray, D., Mason, O., Naylon, J. and Jones, A. (1996) The ORL Radio ATM System, Architecture and Information. ORL technical report, available through the ORL Web server at http://www.cam-orl.co.uk/

Richardson, T., Bennett, F., Mapp, G., and Hopper, A. (1994) Teleporting in an X Window System Environment, *IEEE Personal Communications Magazine*, **1(3)**, 6-12.

Schilit, B.N., Theimer, M.M. and Welch, B.B. (1993) Customizing Mobile Applications, *Proceedings of the USENIX Mobile and Location-Independent Computing Symposium*, Aug 1993, Cambridge MA, 129-138.

Stajano, F. and Walker, R. (1995) Taming the Complexity of Distributed Multimedia Applications, *Proceedings of the 1995 USENIX Tcl/Tk Workshop*, Toronto, July 1995.

Want, R., Hopper, A., Falcao, V. and Gibbons, J. (1992) The Active Badge Location System, *ACM Transactions on Information Systems,* **10(1)**, 91-102.

Weiser, M. (1993) Some computer science issues in ubiquitous computing. *CACM*, **36(7)**, 137-143.

Wray, S., Glauert, T. and Hopper, A. (1994) The Medusa Applications Environment, IEEE Multimedia, **1(4).**

7 BIOGRAPHY

Martin Brown obtained a B.Sc. in physics in 1974 and a physics Ph.D. specialising in computer simulation, both at Imperial College, London. After spending some time in the broadcast audio and videographics industry he joined Olivetti Research in 1991. Here he has worked on many aspects of the Medusa distributed multimedia system, with a particular interest in the audio. He manages a joint research project with Cambridge University Engineering Dept. called VMR which uses speech recognition and information retrieval techniques to perform keyword indexing into video mail archives.