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MOBILE COMPUTING AND COMMUNICATIONS: AN INTRODUCTION

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ABSTRACT

This paper gives an overview of mobile computing and issues related to the field. The discussion starts with definitions of various terms associated with mobile computing. The diversity of mobile applications is explored to give readers an idea of what mobile computing has to offer, followed by a discussion on the limitations of wireless networks and the issues which have to be addressed in order to support roaming users.

Keyword: ***Mobile computing, Wireless computing, Nomadic users***

1.0 INTRODUCTION

Advancing technology in wireless communication offers users anytime, anywhere access to information and network resources without restricting them to the fixed network infrastructure. Mobility introduces new challenges as several assumptions made regarding distributed networks are no longer valid. Many of the research issues regarding wireless networks and mobile computing are not new, for they have been discussed in the context of distributed systems. However, the fact that users are no longer restricted to fixed hosts, that users are free to roam the globe and can connect to a network from various locations, and that an address no longer gives the location of a machine, have made the research problems harder and more interesting.

Wireless networks are also associated with various constraints - bandwidth is scarce, the quality of connection varies, communication delays are high and users may disconnect frequently from the network. In addition, mobile devices usually have lower computing power and storage capacity compared to a host on a fixed network. Mobile devices and applications have to address these limitations in order to deliver services which are of acceptable quality to the users. As users roam, they will encounter heterogeneous network environments and computing resources may become lost or new resources may become available. Mobile applications need to be smart enough to be able to make full use of resources as they become available.

Katz [20] saw the progress in wireless communications as the next logical step in the evolution of computers, where computing resources can be used more flexibly as users are freed from being physically connected to the underlying network. He defined ***wireless information systems*** as computing systems that provide the ability to compute, communicate and collaborate anywhere at any time. In his paper, Katz gave the following definitions, though it should be noted that there is no general consensus in this matter:

- ***Wireless computing*** refers to computing systems that are connected to their environment via wireless links, such as radio frequency (RF) or infrared (IR), and usually apply to computing devices participating in a wireless LAN, with gateways to wired networks. Users are able to participate in work groups via a collection of computing devices and servers in order to share data and information, implying relatively symmetric bandwidth between the wireless node and the network, and relatively high bandwidth.

- ***Nomadic computing*** refers to the ability to compute as users relocate from one computing environment to another. In this scenario, individual organisations with their own wireless infrastructures are linked together by public wired internetworks. Nomadic computing will make it possible for a user to use his own device within a foreign organisation's wireless infrastructure. The issues of trust, security and privacy must be addressed to enable users to roam in foreign environments while protecting their privacy, and the foreign networks against malicious users.

- ***Decoupled computing*** refers to the ability to compute when disconnected from the network. If mobile devices are full-function computers such as notebook computers, decoupled computing makes operations such as file access transparent across disconnections by using techniques such as prefetching and caching.

Katz also predicted that the distinction between communications and computing will continue to blur, leading to a new field of telecomputing.

In addition to the definitions above, Weiser [30] presented the interesting idea of ***ubiquitous computing*** where computers are made *'invisible'* to users by integrating them into users' environment. He pointed out that anthropological studies of work life showed that people primarily work in a world of shared situations and unexamined technological skill. The computer technology today does not conform to this description because it remains the focus of attention instead of being a tool which disappears from users' awareness. Ubiquitous computing aims to make computers widely available throughout user environments and effortless to use. In other words, users should be able to use computing devices without having to acquire technological skills to use them.

The definitions above indicate different classes of applications and, in the following sections, the diversity of mobile applications is described, followed by a discussion on the constraints and limitations imposed by wireless networks which must be addressed in order to provide services which are of acceptable quality to the users.

2.0 MOBILE COMPUTING APPLICATIONS AND SERVICES

There is a wide range of applications (either under study or readily available) to support users on the move. The applications and services range from personal guides and electronic news services to collaborative applications for emergency services.

Mobile context-aware applications can be used as personal guides in museums and galleries which will allow users to take personalised tours [23]. Information about an exhibit is downloaded as a user moves towards it and he could then download more detailed information about it. Personal guides are different from human guides in that a user can browse and download information tailored to his own interests. Objects of interest are sensed using active beacons or identified using computer vision recognition. The hand-held devices might use position measurement systems such as indoor beacons or The Global Positioning System (GPS) to locate users, and an electronic compass or inertial navigation system to find user orientation.

Context-aware devices can also be used as a measurement tool and to assist field studies. Simple hand-held sonar devices can be adapted to videotape and map a room along with user's comments. An ecological field study may be assisted by a device that automatically records the context of a particular species, assists the user in recognising plants, and also notes the surrounding objects. Another application is as an enhanced reality tool where a head-up display provides "*x-ray vision*" for a user surveying a building for renovation, to indicate the location of hidden plumbing or electrical conduits to the user based on information from sensors and/or building plans.

Another class of application is electronic news services discussed by Imielinski and Badrinath [17]. The electronic news services deliver and filter information according to individual user profiles. For example, traffic information or weather reports are filtered based on users' locality, while stock information is filtered according to users' portfolios. This class of application is further illustrated by Shekar and Lin [28] who described an application known as Advanced Traveller Information System (ATIS), which provides up-to-date information on weather and road conditions. It also provides travel information such as diversions, construction zones, bus schedules and parking, etc.

Imielinski et al [18] predicted that the massive market for mobile computing which will emerge by the end of the decade will be based on mail-enabled and information services oriented applications. These applications differ from traditional applications in that they are not computationally intensive applications and will not need to run on powerful computing devices.

Duchamp [12] predicted that mobile applications will metamorphosis low-skill and/or labour-intensive jobs into more information-based tasks which will affect people whose job involves movement over a wide area in order to deliver things or to visit immovable people or things, e.g. repair personnel, nurses and inspectors. Katz [20] gave examples of how the metamorphosis envisioned by Duchamp will change the way people in various fields work. Wireless information systems will make possible collaborative applications that require untethered real-time access to multimedia information sources to provide support for personnel in the field, emergency services, law enforcement, mapping and location finding, etc.

Katz illustrated the diversity of wireless communications in a crisis management application using a multimedia terminal for fire-fighters. The application can be used to provide maps and architectural blueprints to assist in planning fire-fighting strategy. A locator system may be incorporated to track team members as they move through the building. It should also provide voice and data communications among the team and other emergency and civil defence teams. The dynamic nature of this combined data makes it impossible to pre-store all information on the mobile device; instead, communication with a wide range of data rates must be supported, some of it unidirectional, some bi-directional and interactive. For example, symmetric communication is required to communicate with other members of the team, while downloading maps and location and tracking systems can be supported by asymmetric communication.

Mobile computing technology can also be used to support field work and increase collaboration among field workers by providing on-line access to information and interactive communication facilities. The MOST project (Mobile Open Systems Technologies for the Utilities Industries) was established to examine the impact of mobility on working practices and on the repercussions for computer systems support [6, 4, 14]. It focused on the IT requirements of field engineers within the power distribution industry.

Engineers working in the field were traditionally co-ordinated by a single control centre which approved all switching in the power distribution network and maintained an overall picture of the current state. The centralised approach ensured that conflicting requirements were resolved safely, but the centre became a bottleneck. The main disadvantages of this approach were the global network state was not available to engineers in the field and efficiency was reduced due to the bottleneck. The second point was particularly crucial when faults occurred requiring multiple unscheduled items of work to be carried out.

In order to help field engineers work more efficiently, they were given access to information previously held only at the control centre and were allowed to collaborate by exploiting the GSM network. Information which rarely changed was provided on a CD-ROM or stored on hard disk, while dynamic information was provided via a communication link to the centre. The new system also allowed them to update the current state to reflect the operations they carried out. Engineers not physically located together were able to view and manipulate shared diagrams and information. They were also provided facilities so that they could communicate with each other to ensure that conflicting switching requirements were resolved safely. The application had real-time aspects and was based on a peer-to-peer architecture instead of a client-server architecture.

Another example of collaborative application in the field is Wireless Coyote [15], which is an experiment conducted by Apple Classrooms of Tomorrow (ACOT) in co-operation with Orange Grove Middle School of Tucson, Arizona. An experiment was conducted to investigate how teachers and students could use technology in education. Mobile computers were connected by a wireless local area network (WLAN) and a wide area network (WAN) and a spreadsheet program was designed to provide real-time data sharing, immediate data display and real-time graph plotting. Students were provided with voice-activated walkie-talkies to support collaboration so that they could discuss their findings.

This experiment involved 5 groups of students, four teachers, a naturalist and personnel from Apple Computer. The students made a field trip to learn about Sabino Canyon in Tuscon. Four of the five groups were placed at different locations in the canyon, where three groups in the canyon used traditional scientific methods to measure soil and water temperature, wind speed and soil pH in their assigned locations, and the fourth group served as a base station and provided co-ordination among the other three groups by walkie-talkie, delivered additional supplies and co-ordinated requests for two digital cameras among the three groups. The base station was not involved in data collection, but was responsible for monitoring data collection activities of the field groups and transferred those data by cellular modem to the fifth group, located at the school which was 15 miles away. The school group built a database about the canyon based on the data collected by the field groups and used print and video resources at the school to add images and other content to their database. The naturalist provided them with expert opinion to help them to understand their findings.

The LAN made each group's data instantly available to all; consequently, they were analysing environmental data of the whole canyon. The walkie-talkie helped students and teachers to discuss their findings and to decide on the next step to take. The interactive nature of the application made the learning process more interesting and fun for the students.

Other collaborative applications proposed are Bayou [9] and WebExpress [16]. Bayou is an architecture which provides users with facilities to share appointment calendars, documents, bibliographic databases, etc. in spite of intermittent network connectivity. WebExpress was designed for repetitive commercial applications and targeted for visiting medical personnel, salespersons, service workers who carry out repair at remote locations, etc. It was designed to reduce data volume and latency of wireless communication.

The discussion above illustrates the diversity of mobile applications and how the applications might change the way people work. Naturally, prediction of future trends is highly speculative and often subject to over-optimism by those in the field. However, it is undoubtedly the case that mobility has brought and will continue to bring forward new opportunities. Further, there are now large commercial concerns whose existence derives from mobile telephony who have a vested interest in seeing (and selling) the expansion of the sort of services they offer. Consequently, the claims made for wireless computing are probably not far wide off the mark, although timescales may differ and commercial pressures are likely to play the major role in determining how far and how fast we can go. In the next section, the limitations of wireless networks and the challenges which must be met in order to deliver mobile applications at a quality of service which is acceptable to the users is discussed.

3.0 LIMITATIONS AND CHALLENGES OF WIRELESS NETWORKS

Several issues must be addressed in order to deliver the sort of applications and services described in the previous section. The problems encountered are not only due to the inherent limitations of wireless communications, but also due to the fact that the locations of mobile users/devices are constantly changing as users move. The configuration of a wireless network changes dynamically because users are no longer attached to a fixed point during the duration of a connection. The problem is further compounded by heterogeneous environments encountered by users as they move between various points of attachment.

The amount of bandwidth available to users as they move between networks varies greatly. While connected to a wireless LAN, a user may have available bandwidth of up to 2 Mbps, or 10 Mbps in the near future while when venturing outdoors, the available bandwidth may drop to only 9.6 kbps. Considering the amount of bandwidth currently available on fixed networks and the bandwidth-consuming applications available in the market, the low bandwidth, high latency communication medium offered by wireless networks must be considered primitive.

Satellite-based systems which provide wide area coverage are also used to provide the wireless communication infrastructure, albeit at a very high cost. Among well known satellite services are Odyssey, Globalstar and Iridium. There are three types of satellite services:

1. **Geostationary/Geosynchronous Orbit System** (**GEO**), which is positioned 36,000 km above the earth, requires expensive satellites and large antennas, but with only three are required to cover the earth. GEO may provide hundreds of high bit-rate data links using multiplexing, but involves a transmission delay of 0.5 second due to its high altitude. Its large regional coverage makes it difficult to provide the small-cell coverage necessary for frequency reuse to provide higher overall system capacity.

2. **Low Earth Orbit System** (**LEO**), which is positioned 1000 km above the earth is the least expensive of the three types of satellite systems, but more is required to cover the earth. The coverage area is small compared to GEO, thus allowing a higher capacity within a given spectrum allocation. The transmission delay is also significantly less than GEO.

3. **Medium Height Earth Systems** (**MEO**) is between the two extremes.

A much less expensive alternative to satellite systems is offered by the Stratospheric Telecommunications Services, which uses air platforms that remain geo-stationary above metropolitan cities to provide T1/E1 access to users in the service area[1]. The air platforms, which are positioned 22 km above the earth, incur very low communication delays and low infrastructure costs.

Apart from the variability of available bandwidth, users may also experience rapid and massive fluctuation in the quality of service provided by the wireless infrastructure [8]. Bagrodia et al [3] stated a fundamental way in which mobile computing differs from conventional operation is the huge variability in connectivity to users' computing environments. Even though there will be improvements as these limitations are addressed in future technologies, the discrepancy between wired and wireless networks are likely to remain [29]. Badrinath and Welling [2] claimed that although the constraints of mobile computing will become less noticeable, the mobility of devices will always induce constraints compared to non-mobile devices. Ebling et al [13] stated that even as global wireless connectivity becomes available in the near future, much of it will be intermittent with low bandwidth and high latency and will be limited to a few oases in a vast desert of poor connectivity. Watson [29] argued that the limitation imposed calls for a software architecture which reduces the demands placed on the wireless link and supports disconnected operation.

It is very unwise to make any assumptions about the underlying support provided by the network infrastructure because, as users encounter heterogeneous environments while moving, resources and services not previously available may now be offered by the new network, or a critical service needed to run an application may be lost [7, 8]. Mobile applications must deal with this heterogeneity and try to deal with failure gracefully while minimising inconvenience to users. Davies et al [8] termed the class of service which is designed to operate in a dynamic environment, and is able to adapt itself to the heterogeneity of the network as ***adaptive service***, while Katz [20] termed this type of communication ***adaptive communication***. Katz regarded making applications aware of their limited and dynamically changing bandwidth as a critical challenge. Applications designed for mobile users must take into consideration the resource constraints they may face and be able to make the best possible use of available resources [2], and they may need to present different views of functionality and quality depending on the location of the mobile device.

Duchamp et al [11, 12] listed the challenges in designing system software to insulate applications from hardware and networking changes imposed by mobility:

1. *Support for mobile operation*: most current software for distributed computing assumes that computing devices do not move and packets are routed based on network number. This is especially true for routing protocols like the Internet Protocol (IP). This shortcoming, however, has been addressed by protocols such as Mobile IP [19, 25, 26].

2. *User interface design for very small computers*: the user interface has to be modified to accommodate the shrinking size of portable computer's display.

[1] The information is obtained from the Sky Station International Inc. home page at http://www.skystation.com.

3. *Adjustments to new hardware trade-off*: the hardware employed by portable devices will inevitably be different from hardware devices on fixed networks. For example, since portable devices might have reduced disk storage, new storage management algorithms will have to be designed.

4. *Emerging new technologies:* applications should be able to adjust and take advantage of any unique characteristics of new technologies that might be used in future portable workstations.

5. *Security*: providing authentication, accounting and management over a wide area and across organisations is not a new problem, but is aggravated and made more urgent by the advent of mobile computers.

6. *Compatibility*: the requirements above should be provided while retaining a reasonable level of compatibility, i.e. applications should provide interfaces and performance so that a user's desktop computing environment is available in his/her hand without the need to rewrite applications.

Davies et al [6] classified the challenges of mobile computing technology as being either communications, distributed systems or cooperative working, which are explained below:

1. *Communication issues*: most existing wireless protocols are tailored for voice whereas mobile computing technology needs media access protocols for the radio channel which exploit the characteristics of the media and are suitable for transmitting a wide range of data types, e.g. voice and image.

2. *Distributed system issues*: the low bandwidth and error-prone wireless communication medium calls for object replication and message batching techniques to overcome the problems associated with poor communication channels.

3. *Implications for collaborative working*: collaborative applications in high-bandwidth networks often use multimedia to enhance interaction among users. The wireless communication medium restricts the range of services which can be offered by collaborative applications and the impact of this restriction on users' ability to collaborate has to be studied.

Davies et al's study of available technology and the user requirements of mobile computing systems led them to conclude that there is a significant mismatch between the two.

Katz [20] stressed that in spite of the discrepancies between wired and wireless networks, mobile users should have access to the services they see in wired networks, albeit at potentially lower resolutions and possibly longer latencies. A crucial challenge is to make applications aware of their limited and dynamic environment so that they can adapt to what is available as appropriate.

Other constraints faced by mobile devices are that they have significantly lower memory capacity and computing power compared to a fixed host. For this reason, Badrinath et al [1] proposed that the computation and communication load should be borne by the static network as much as possible. Doing so will reduce the burden of computation on mobile hosts and also helps conserve battery power.

The limited battery power on mobile devices is an issue which has to be addressed as users on the move will want their battery to last for as long as possible. Cox [5] pointed out that the possibility of a ten-fold improvement in battery capacity in the short to medium term is essentially nil. Cox stated that, "*Frequently, the suggestion is made that battery technology will improve so that high-power handsets will be able to provide the desired five or six hours of talk time in addition of 10 or 12 hours of standby time, and still weigh less that half of today's smallest cellular handset batteries. This 'hope' does not take into account the maturity of battery technology, and the long history (many decades) of concerted attempts to improve it. Increases in battery capacity have come in small increments, a few percent, and very slowly over many years, and the shortfall is well over a factor of 10. In contrast, integrated electronics and radio frequency devices needed for low-power low-tier PCS continue to improve and to decrease in cost by factors of greater than 2 in time spans on the order of a year or so. It also should be noted that, as the energy density of a battery is increased, the energy release rate per volume must also increase in order to supply the same amount of power. If energy storage density and release rate are increased significantly, the difference between a battery and a bomb become indistinguishable! The likelihood of a x10 improvement in battery capacity appears to be essentially zero*".

Since there is unlikely to be much improvement in battery capacity, it is important that power utilisation is managed efficiently and economically. Without this, the potential of mobile system, and the commercial realisation of projects such as described above will be difficult to realise. It is hard to overstate its importance in the future development of mobile systems. As a result, there have been several studies which attempt to address this issue, among them [10, 27, 22, 21 and 24].

We do not discuss studies which attempt to address the issues highlighted in this section for that is beyond the scope of this paper. Interested readers may refer to http://www.fsktm.um.edu.my/~mazliza/mobile/resources.html, which provides pointers to organisations working in the field of mobile computing and ongoing research. The list is by no means complete nor exhaustive, but provides a starting point.

In the next section, the development of various standards are discussed to give an idea of the direction mobile computing and communication is heading.

4.0 FUTURE SYSTEMS

Mobile devices are no longer used solely for the purpose of communications, but now are also used by roaming users to allow greater flexibility over working practices, effectively extending the office into the wider environment. In the next decade, it has been forecasted that 20% to 30% of GSM revenue might come from mobile data. If the rapidity of increase in the amount of data carried by terrestrial wired telecom networks is an indicator, this may well be a conservative estimate.

By the nature of the way that the radio medium is licensed, the future of mobile data depends largely on the development of appropriate standards. Currently, the bandwidth available over GSM for mobile data is low (typically in the range of 9.6 kbps to 14.4 kbps). However, there are a number of initiatives to develop high speed, wide area, data services. Thus trials of High Speed Circuit Switched Data (HSCSD) are currently underway, and it is projected that General Packet Radio Service (GPRS) will roll out in the near future. These services will offer data rates up to about 130 kbps. Enhanced Data for GSM Evolution (EDGE), which is a successor of GPRS, will provide data rates of up to 348 kbps.

In a wider context, Iridium is planning a second generation satellite system offering a bandwidth of up to 120 kbps, which it plans to launch in 2003. It is also targeting 64 kbps / 125 kbps throughput for handheld devices. Ericsson and Telia are testing a wireless interconnection to IP-based enterprise networks, effectively providing enterprise LANs for fixed and mobile terminals. The commitment shown by the industry to provide support for mobile data is evident from the Wireless Application Protocol (WAP) Forum, which is joined by 60 companies, with a goal of designing and establishing standards for mobile data.

Perhaps the most significant development for the future will centre around ETSI's work on the Universal Mobile Telecommunications Standard (UMTS) or the ITU's work on IMT-2000. UMTS is a third generation mobile (3G) systems. Its goal is to cater for future market demands for low cost, high quality mobile personal communications. UMTS will deliver pictures, graphics, video communications and other wide-band information as well as voice and data to mobile users. It extends the existing capabilities of mobile, cordless and satellite technologies to provide increased capacity, data capability and a wider range of services, blurring the distinction between the use of telephones for voice communications and the use of PCs for data transmissions. Since UMTS provides a wide range of services, it also provides support for a wide variety of terminals, from PDAs to palmtops to laptops.

UMTS offers a wide range of quality of service (QoS) by optimising the communications channel for each individual service. By tailoring the communications channel QoS (bandwidth, error rate and latency) to a range of services, traffic can be packed into the channel more efficiently, potentially reducing costs to service providers, and price for users. Although UMTS offers connectionless services, users will get the impression of being connected for the whole duration of a session. In reality, communication channels and other resources will only be occupied while data is being sent. As soon as the transmission is completed, the resources are automatically released to another user. 3G systems will provide adaptive services where if a requested QoS cannot be met, the service is adapted to provide a similar, but lower quality version, taking into account the dynamic nature of radio channel and traffic characteristics. A mechanism will be introduced to price services according to the QoS provided.

Initially, UMTS will provide transmission rates of up to 2 Mbps. Later on, UMTS will be integrated with picocellular systems based on Wireless LAN (W-LAN) and Broadband Radio Access Networks (BRANs) to provide a bandwidth of up to 155 Mbps. The UMTS networks will be comprised of terrestrial networks and Satellite UMTS (S-UMTS) networks. S-UMTS is required to serve rural and remote areas, which is essential to achieve the goal of providing a ubiquitous and universal services. In addition to multimedia services, UMTS will also provide interactive services and the Virtual Home Environment (VHE) services.

Bluetooth[2] is another project which will make ubiquitous computing a reality. Bluetooth aims to replace proprietary cables connecting devices with one universal short-range radio link to facilitate access to both LANs and WANs to provide a universal bridge to existing data networks. It will also provide a mechanism to form small private ad hoc groupings of connected devices away from network infrastructures. Any digital device can be part of the Bluetooth system: laptops, handheld computers and digital cellular phone can be used together seamlessly. For example, emails can be received on the laptop via the digital cellular phone the user is carrying, and a presentation can be downloaded from a user's laptop to a data projector without connecting cables.

The proliferation of wireless technology applications will not be limited to supporting roaming users. In the future, wireless and mobile computing technologies will also be widely deployed at home. For example, Shared Wireless Access Protocol (SWAP) aims to provide a new, common air interface which supports wireless voice and LAN data services in the home environment. The specification ensures interoperability among PCs, communication and consumer electronics devices equipped with wireless communication capabilities, and is aimed for the home

[2] Bluetooth web page is at http://www.bluetooth.com/.

market. Among the applications which will be made possible by SWAP are:

- Information delivered via the Internet to anywhere in the home, e.g. a mobile display pad connected to the Internet can access recipe information in the kitchen, or it can be taken into the garage for the latest automobile mechanical updates;

- Control of electrical systems and appliances, e.g. to turn on/off lighting in the house while users are away to give the impression that someone is at home;

- Effective utilisation of communication channels by dynamically allocating phone line for incoming and outgoing calls, fax and Internet access.

These are only a few examples of possible applications, more information can be obtained from http://www.homerf.org.

In conclusion, the ongoing work in this field suggests that a ubiquitous computing environment where users truly have anytime-anywhere-access will one day be achieved, and the services will be provided at affordable prices. The use of wireless technologies will become widespread, encompassing every aspect of people's life, and giving users access to information whenever it is required. Access to the network will no longer be limited to downloading information or exchanges of emails and short messages, but will cover all aspects of applications currently available only to users on fixed networks, as well as a range of applications yet to be developed for the consumer electronics market.

In summary, we are currently seeing the conception of systems in which computers and networks will be transparently integrated into users' everyday lives. The goal of ubiquity will be reached and the demand for the services which run over such systems will be driven by the usefulness of the services rather than lower level technical specifications.

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BIOGRAPHY

Mazliza Othman obtained her MSc in Data Communication Networks and Distributed Systems and a PhD degree from the University of London. At present, she is a lecturer at the Faculty of Computer Science and Information Technology in the University of Malaya. In addition to mobile computing, her interests include resource allocation problem and mobile agents.