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NETWORKING SUPPORT FOR MOBILE COMPUTING

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TUTORIAL

NETWORKING SUPPORT FOR MOBILE COMPUTING

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ABSTRACT

With increasing use of small portable computers, wireless networks and satellites, a trend to support "computing on the move" has emerged. This trend is known as mobile computing or “anytime” and “anywhere” computing. Some people refer it as “Nomadic” computing. No matter which name is applied, all these terms really imply that a user may not maintain a fixed position in the network. The user is free to roam from one place to another. However the mobile user still expects uninterrupted network access and the ability to run some networked applications. To support such mobility, the user is typically provided a wireless interface to communicate with other fixed and mobile users.

The mobile computing environment can be described by the following attributes (a) mobile users, (b) mobile support stations or base stations serving an area, (c) wireless interface, (d) wireless medium with varying channel characteristics (due to fading, noise, interference, etc.) and (e) various applications requiring specific support. A mobile computing environment raises such issues as how to route packets as the mobile user (hosts) moves from one place to the other and how to overcome limitations including limited bandwidth and storage.

This tutorial presents an introduction to mobile computing, to the challenges introduced, and to emerging networking infrastructures for mobile computing.

Keywords: Mobile Computing, Networking, Mobile Internet Protocol (IP), Wireless, Wireless Asynchronous Transfer Mode (ATM), and Wireless Local Area Networks

I. INTRODUCTION

With increasing use of small portable computers, wireless networks and satellites, a trend to support "computing on the move" has emerged. This trend is known as mobile computing or “anytime” and “anywhere” computing. Some people refer to it as “Nomadic” computing. No matter which name is applied, all these terms really imply that a user may not maintain a fixed position in the network. The user is free to roam from one place to another. However the mobile user still expects uninterrupted network access and the ability to run some networked applications. To support such mobility, the user is typically provided a wireless interface to communicate with other fixed and mobile users. A typical scenario for mobile computing system is shown in Figure 1.

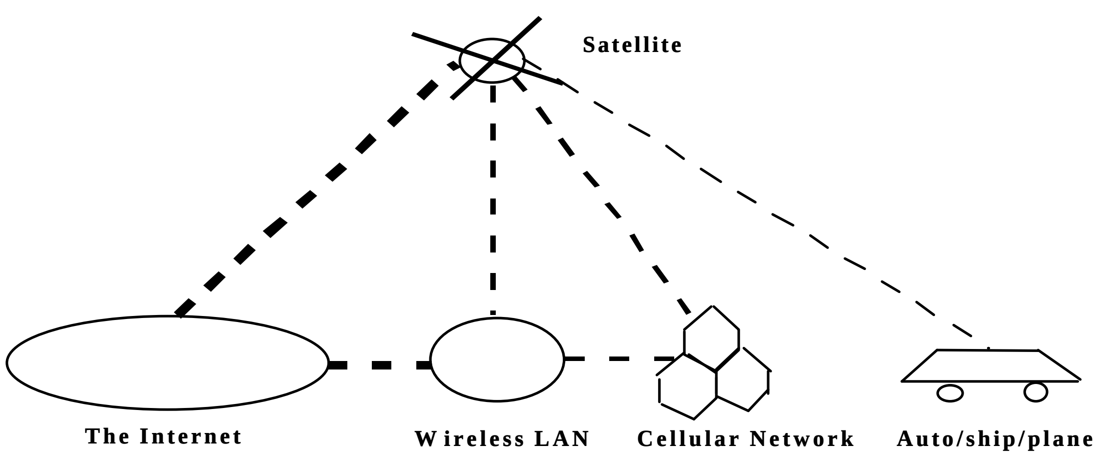


Figure 1. Mobile Computing Systems

A wireless environment provides limited and variable amount of bandwidth and, as a result, mobile users may be disconnected while moving from one coverage area to another. In addition, hand-held devices suffer from the lack of storage and memory and small screen size. Due to these limitations, applications that were designed to run on fully networked and stationary workstations do not run well on mobile computers today. However, serious attempts are being made to overcome these obstacles by using techniques to utilize wireless bandwidth effectively, by improving hardware and software support for mobile devices, by modifying applications to fit mobile devices, and by modifying existing operating systems to suit mobile devices (e.g. Windows CE 2.0).

In this tutorial we do not attempt to address all possible issues dealing with mobile computing. Our intent is to provide an introduction to mobile computing and related issues and to the emerging networking infrastructures for supporting mobile computing. The organization of this paper is as follows. We present some applications of mobile computing in Section II, and then we discuss challenges of mobile computing in Section III. An introduction to wireless networking is presented in Section IV and the emerging infrastructures for mobile computing are presented in Section V. We make some concluding remarks in Section VI.

To allow the reader to dig deeper into the many topics discussed in the tutorial, a bibliography of papers and books is included in a bibliography that follows the references. In addition, because this field uses a large number of acronyms that may be unfamiliar to the reader, a list of the acronyms used in this tutorial is presented at the end of the paper.

II. SOME APPLICATIONS OF MOBILE COMPUTING

Important applications of mobile computing are in the areas of national defense (e.g. troop movement and tracking), personal communications, emergency and disaster management, real-time control systems, remote operation of appliances and in accessing the Internet. To give a flavor of mobile applications we discuss two important applications: navigational support and claim adjustments.

NAVIGATIONAL SUPPORT

One application of mobile computing is help in navigation. We are already seeing the use of GPS (Global Positioning Systems) Satellites for help in navigation in luxury cars. A mobile computing system with satellites can also help in locating ships, goods and even cattle. One exciting development in commercial flights is the concept of “free flying”. Currently airplanes are flown along airways with directional guidance from air traffic controllers using a complex process. The concept of free flying is based on the idea that a pilot can fly an airplane by taking the most efficient route determined with the help of satellites. Satellites can inform the pilot if there are any other planes in the next few miles. By using location tracking of other planes by satellites, a pilot can find the most efficient route for his/her plane. Before this free flying concept can be put into practice, several issues including failure or even malfunction of satellites must also be considered.

CLAIM ADJUSTMENT

Many business situations involve going to a customer’s premises, taking notes of the situation, going back to the office, and then taking suitable actions. One such application is insurance claim adjustment. In a mobile computing environment, the claim adjuster can go to the customer’s premise, take photos, and save them in his/her mobile computer. Then the adjuster can download necessary information (customer’s profile and coverage information) from the insurance company’s computer. Using a small printer attached to the mobile computer, he/she can print a check to cover the claim. In this way, claim adjustment is performed in minutes rather than days. This speed of service can significantly add to a company's competitive advantage.

III. CHALLENGES OF MOBILE COMPUTING

In this section we look into challenges presented by mobile computing including networking, bandwidth issues, location tracking, limitations of mobile computers, security issues, and failure or malfunctioning.

NETWORKING

Most networks were designed for stationary users. In a network of stationary users, each user has a fixed address that is used to transfer information to them. Information is transferred by a process called routing, where a route is found to the user for information transfer. Many network protocols are optimized for a wired medium rather than a wireless medium. Thus, the mobility introduced by the movement of users affects various layers of existing network protocols. For example, the network layer is responsible for the addressing and routing functions. But with user movement, addressing becomes a problem. If the network allows a mobile user to keep the same network address, then the network has to know the current location of the mobile user every time someone wants to send a message to this user. If the network provides a mobile user with a new network address every time he/she moves, then routing becomes complex. Both these approaches (keeping the address the same in different locations for a user or giving a new address for every change of location) are being considered in different networks. For example, cellular networks and wireless Local Area Networks (LAN's) keep the same address for mobile users while the mobile Internet Protocol (IP) proposes to give a mobile user a new (care of) address for every change of location. More details on emerging networks for mobile users are presented in Section V.

The other networking challenge is the transport layer protocol which monitors loss of (or delayed) information to estimate the level of network congestion. In wireless networks, since there is a possible loss of information due to interference and user movement, the transport protocol must differentiate between losses due to network congestion and due to interference and user movement.

BANDWIDTH CONSIDERATIONS

The mobile computing environment also presents challenges in terms of the amount of bandwidth available to the mobile users. Mobile users (as compared to fixed network users) typically have to work with a limited and variable amount of bandwidth due to the nature of wireless environment. The amount of bandwidth available to a user is also location dependent in many ways. For example, if a mobile user moves to a location with many active users, then the user may receive little or no bandwidth at all. If the mobile user moves to a location where the amount of interference is high, then effective bandwidth to the user may also reduce substantially.

LOCATION TRACKING

The location management issue deals with how to keep track of a mobile user's location. Many different schemes have been proposed including pure broadcasting (paging) by the network, location updating by mobile user after every move and a combination of paging and updating. Each one of these schemes has its own overhead. Network designers have to consider the type of network resources available in choosing a location management scheme.

LIMITATIONS OF HANDHELD DEVICES

Since most mobile users will be carrying small and smaller computing/ communications devices (laptops, palmtops etc.), the problems associated with such devices, such as the limited amounts of battery power and memory, must also be considered. These factors should also be kept in mind when designing mobile applications and the network protocols that will reside on these small computing devices. The applications should also be able to deal with frequent disconnects of mobile users from the network while moving.

SECURITY CONSIDERATIONS

Unlike fixed networks, where closed offices and covered cables/wires provide some inherent network security, the openness and movement of users in mobile computing environment is vulnerable to eavesdropping and other security problems. Attempts (including the use of encryption algorithms) are being made to provide security to mobile users.

FAILURE OR MALFUNCTIONING

Mobile computing systems can fail or malfunction. In May 1998, a Geosynchronous satellite (36,000 km from earth) called Galaxy IV failed and went out of its orbit without warning. This failure disabled more than 90% (or 45 million) of US pagers, several data networks, and many credit-card verification systems that were using the satellite. Since launching another satellite (costing $250m) takes several weeks, service was interrupted for days until Galaxy IV users were moved to another existing satellite on another frequency (not a fun job for satellite antenna movers!).

IV. INTRODUCTION TO WIRELESS NETWORKING

Wireless is a general term that refers to any communications not involving actual physical wire. Wireless includes satellite communication, microwave communication, and cellular communication. Often, the words wireless and cellular communications are used interchangeably. In cellular communication, which is probably the most common form of wireless communication, the entire service area is divided into hexagonal cells (Figure 2). Each cell is served by a transmitter and receiver, termed the base station. When a mobile user moves from one cell to another, the base station serving the new cell takes over the call, and so on. This process is termed handoff. Part of the information may be lost during the handoff process, a phenomenon experienced by cellular phone users. Cell phone users at times may experience different audio quality because, physically close to a base station, the quality is good, but towards the boundary of a cell, the audio quality drops down. Some cell phone users may even experience complete disconnection from the network after crossing a cell boundary if no free channels are available in the new cell they entered. More information on the basics of wireless communications can be found in Rappaport [1996].

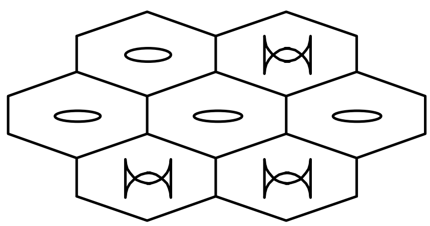
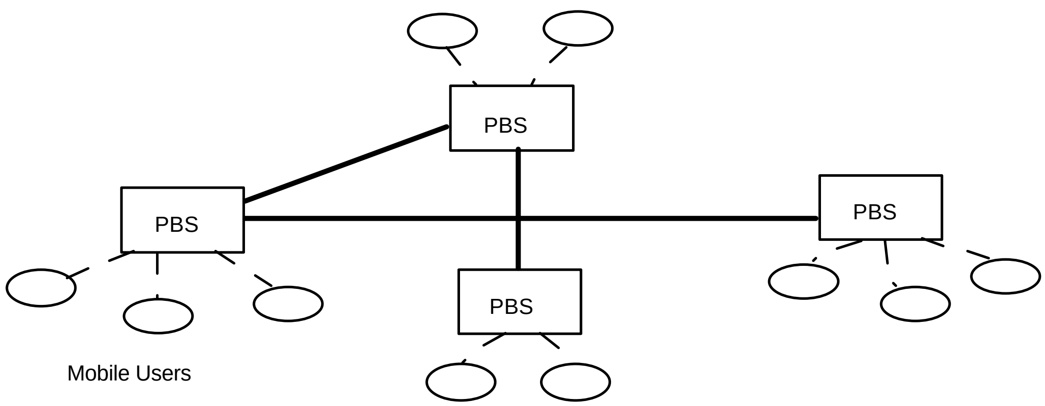


Figure 2. A Cellular Or Infrastructure Based Mobile Network

MOBILE NETWORKS

Two configurations have been proposed for mobile networks: “Ad-Hoc Configuration” and “Infrastructure-based Configuration.” In the Ad-Hoc Configuration, the topology of the wireless network is not fixed because base stations are portable and can be moved around as needed. Communication is possible between mobile users by the cooperation of these portable base stations (Figure 3). In Infrastructure-based Configuration, the topology of the network is fixed and so are the base stations (Figure 2). Both these configuration have their pros and cons. Ad-Hoc configuration provides greater flexibility for some applications (say, troop movement) at the expense of greater overhead. This overhead stems from the use of broadcasting (or paging) that is typically employed to locate mobile users. It also limits the scalability of pure Ad-Hoc networks. Infrastructure-based configurations have been employed in cellular and Personal Communications Systems (PCS) networks and may use a centralized switch (or mobile switching center) for interconnecting fixed base stations, reducing the overhead involved in location management and updating.



PBS: Portable Base Stations

Figure 3. An Ad-Hoc Topology Based Mobile Network

LIMITATIONS OF WIRELESS COMMUNICATIONS

Wireless channels have limited bandwidth and are subject to interference from other sources, noise, and fading. The resulting error rate experienced by mobile users can be as high as 20-30%. These errors can be overcome by selective retransmission of information and powerful error control techniques such as Forward Error Correction schemes involving the transmission of “extra information” to allow receivers to correct any transmission errors.

CELL SIZE AND OTHER FACTORS

Typically a cell can use all available frequencies which are not used by its neighboring cells. Frequencies may be divided in such a way that neighboring cells do not share the same frequencies. As the number of mobile users increases, more channels are required. Since the frequency band allocated to a vendor is fixed, cell size can be reduced so that frequencies can be reused more frequently in the same area. The reduced cell size implies an increase in the number of total cells (and corresponding increase in base stations and cost) covering the same area as before, but supporting more users. The three different cell sizes in use are macro cells (2 Km or larger), micro cells (0.5 to less than 2 Km), and pico cells (few meters to less than 500 meters). Several major airports currently employ pico cells to support a large number of customers.

PERSONAL COMMUNICATIONS SYSTEMS (PCS)

PCS are second generation wireless networks. They differ in three ways from first generation wireless (or analog cellular) systems.

1. PCS are digital whereas cellular networks are analog.
2. PCS are designed to provide a family of services (including data services), not just mobile phone service as are cellular systems.
3. The frequencies used in PCS are higher than those used in cellular systems. PCS allocations include 1850-1890, 1930-1970, 2130-2150, 2180-2200 MHz. The unlicensed PCS band includes frequencies of 1890-1930 MHz.

CELLULAR DIGITAL PACKET DATA (CDPD)

The basic idea behind CDPD is to use cellular frequencies to transfer digital data. A CDPD modem is required. When cellular frequencies are not in use, the CPPD modem can modulate digital data and transmit over the cellular frequencies. CDPD modems are becoming a popular choice for accessing an ISP (Internet Service Provider), corporate wireless intranets, e-mail, and other wireless services.

PERSONAL DIGITAL ASSISTANTS (PDA)

PDAs are small portable devices that manage personal information. In terms of size and capabilities, they fall between electronic organizer and small notebook computers. A major shortcoming of PDAs since their introduction in 1993 is their lack of network connectivity. However this situation is beginning to change as many vendors are developing and selling communications-enabled PDAs. One example is the Nokia-9000 Communicator that combines a wireless phone, modem, and basic PDA functionalities into one device.

V. EMERGING WIRELESS NETWORKING INFRASTRUCTURES

Due to the expected demand for networking infrastructures to support mobile computing applications, a lot of progress has occurred in designing and building mobile networks and protocols. These networks include wireless Local Area Networks (WLANs), satellite-based networks, mobile Internet Protocol (IP) for the Internet, and wireless Asynchronous Transfer Mode (ATM) networks [Varshney, 1998a]. Satellites can provide support for mobile users over a larger area than WLANs. Mobile IP extends the usage of the Internet to mobile users. Wireless ATM can add mobility support to users interested in certain high-end applications (e.g. multimedia) in both local and wide area environments. We now discuss these networks, starting with wireless LANs, followed by satellites, mobile IP, and wireless ATM.

WIRELESS LOCAL AREA NETWORKS

Wireless Local Area Networks are designed to provide support for mobile computing in a small area, such as a building, hallway, park, or office complex. They can extend or replace wired LANs (such as Ethernet) and can be designed for both Infrastructure or Ad-hoc configurations (Figures 2 and 3). The main issues in WLANs are channel allocation, frequency of operation, and interference and security. We briefly discuss these issues and then examine two emerging standards for WLANs.

CHANNEL ALLOCATION

Unlike cellular networks where either a frequency is allocated or the call is rejected by the base station, WLANs are typically based on sharing frequencies by many active users. Because many simultaneous users may cause packet collisions (and hence waste channel bandwidth), it is important that packet collisions be avoided. It is difficult to detect collisions in WLANs because:

- the power levels of two signals coming to a mobile user may be different
- the hidden station problem (a station not being able to detect a potential competitor for the medium)
- the exposed station problem (a station hears a signal from one side and decides not to transmit on the other side).

Protocols are being designed to support efficient channel allocation without collisions.

FREQUENCY OF OPERATION

The choice of frequency depends on whether microwave, spread spectrum, or infrared type communication will be used. Since infrared cannot penetrate walls, it does not require licensing from Federal Communications Commission (FCC). Microwave or spread spectrum does require FCC license.

However, some exceptions do exist, including the Industrial, Scientific and Medical (ISM) bands that consists of 902-928 MHz, 2400-2483.5 MHz, and 5725-5850 MHz, respectively. The ISM bands are designated for unlicensed commercial use and are widely used by ambulances, police cars, taxicabs, and Citizen Band (CB) radios.

INTERFERENCE AND SECURITY

Interference and security depend on the type of communications method used in the WLAN. Because infrared cannot penetrate walls, it encounters very little interference from external sources but is limited in its coverage. For security, some form of encryption may be used. If the ISM band is used, some interference is likely to occur because the band is open to other users/agencies.

WLAN STANDARDS

There are two WLAN standards:

1. The IEEE (Institute of Electrical and Electronics Engineers, the major standard body in the US) standard, known as IEEE 802.11, uses ISM Band at 2.4 GHz and allows both infrastructure and ad-hoc configuration based topologies. For physical layer, the choice could be Spread Spectrum or infrared light. Two different data rates are proposed: 1 Mbps (required) and 2 Mbps (optional) [LeMaire et. al. 1996].
2. The European standard is HIPERLAN (HIgh PErformance Radio LAN), operating at 23.5 Mbps and uses frequencies of 5.15-5.30 GHz. A priority scheme is used to allow fast transfer of important information.

SATELLITES

Satellites provide broadcasting services, long distance and international phone services (to stationary users), paging services (to mobile/stationary users), and data networking services. However, with advances in technology, it is becoming possible to provide mobile phone, data, and video services using satellites. The first such satellites are part of Project Iridium, from Motorola. Around 1990, Motorola started the plan to provide mobile communications at every point on this planet. In theory, three Geosynchronous satellites (satellites that are 36,000 Km from earth and complete one rotation of earth in 24 hours, thus remaining stationary with respect to the earth), cover every single point on the earth (Figure 4). However, Geosynchronous satellites were ruled out due to interference and the amount of battery power needed for every mobile phone/terminal to transmit a signal to 36,000 Km without intermediate amplification. The second factor could lead to requiring everyone to carry a very large mobile phone to use a Geosynchronous system. The R&D team decided that they would use Low Earth Orbit (LEO) satellites (usually 200-600 miles from the earth). Since a LEO satellite completes a rotation of earth in approximately two hours, several LEOs are needed to provide service at every point. They therefore proposed that 11 LEO satellites be placed in each of seven polar orbits. Since this configuration requires 77 satellites, they chose the name Iridium because it represents chemical element with 77 electrons rotating around the nucleus. However, after some discussion with management, the number was reduced to 66, but no one wanted to call it Dysprosium (the name of element 66). Furthermore, the name Iridium was derived from the Greek Goddess of the rainbow [Varshney, 1998a]. Iridium satellites in polar orbits are shown in Figure 5.

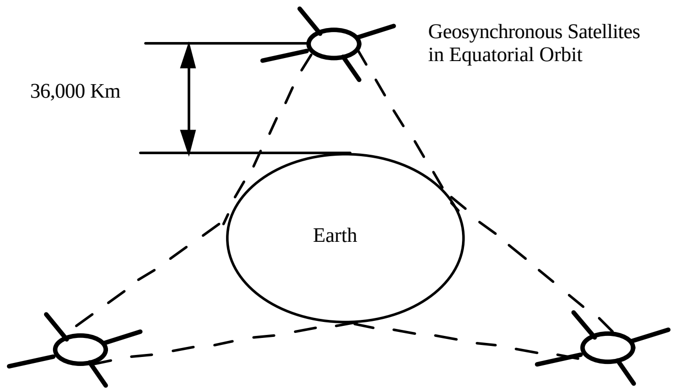


Figure 4. Geosynchronous Satellites

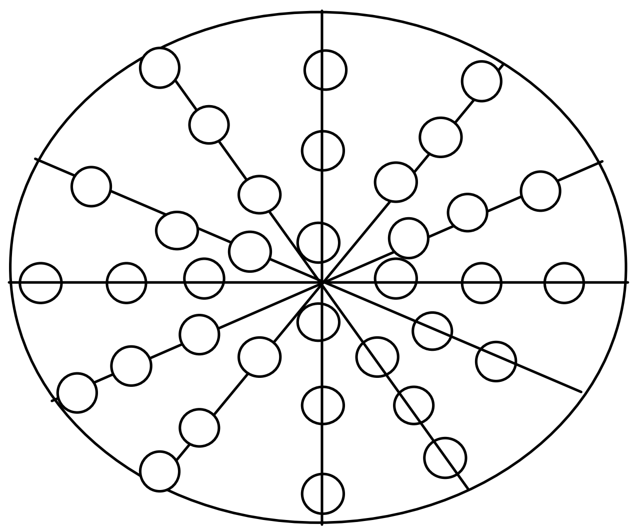


Figure 5. Iridium Satellites In Polar Orbits

Iridium has attracted much attention worldwide, and many developing countries have bought channels on this system. In a typical developing country, there are villages and other remote areas where no telecommunications infrastructure is in place. Rather than placing copper wire to provide basic telephone service, it is possible to use Iridium.

Most Iridium satellites have already been launched and are expected to provide service from September 1998. It will be interesting to see the pricing structure of Iridium as the initial costs of such projects are very high. The total cost includes the cost of satellites, launch costs, insurance premiums, and, of course, sales and marketing costs. One other factor is that satellites have a limited lifetime of five to seven years and, in case of failure, repairs are not possible using current technologies. Iridium and similar systems can be used to provide mobile phone service to people walking or driving, to people lost in strange places, ship and airplane navigation, tracking of goods/inventory, and emergencies.

Many other similar satellite based projects have been started. The most notable is Teledesic funded by Microsoft and McCaw communications. The project originally planned to launch 840 LEO satellites to provide worldwide coverage at much faster bit rates than Iridium or any other systems. Then it was scaled down to 288 satellites to be manufactured by Boeing. Each satellite will handle up to 155.52 Mbps to and from the ground and 622.08 Mbps to and from other satellites. These bit rates are enough to support voice, data and video services. Teledesic is planned to be operational in 2001-2002.

MOBILE IP

To support mobile computing over the Internet, the Internet Engineering Task Force (IETF) created a mobile IP (Internet Protocol) [Johnson, 1995, Perkins and Johnson 1996]. An extension to the current Internet Protocol, mobile IP does not require changes in the basic functioning of the Internet. Mobile IP is only concerned with the routing of data packets to the current location of the mobile host. This routing supports only connectionless-type Internet applications running on fixed/mobile hosts. In other words, using mobile IP, a mobile user can access the Internet in the same way as a fixed host connected to the Internet. However, the Internet access by a mobile user is limited by other factors, such as limited bandwidth, frequent disconnection, and location. Mobile IP does not deal with these factors.

INTERNET PROTOCOL

Before discussing the operation of Mobile IP, we briefly summarize the operation of the current version of IP (IP version 4). IP is the most popular network layer protocol used on the Internet. IP accepts variable size packets from the upper layer protocol and prepares its packets with addressing information. It uses datagram-style packet routing, where no connection is set up before the data transfer is started and each packet is routed independently. The routing is performed by specialized computers, called routers, which use routing tables containing network addresses. Since packets are routed independently, they may arrive out of order at the receiver, and may be duplicated or lost due to router and communication errors. The receiving computer must be able to figure out if any of these problems has occurred and must be able to take some corrective action.

Since an IP address corresponds to an interface and not to a host, if the host moves (causing a change in its interface point), addressing and routing (how to continue routing to it) problems are created. To support mobility, IP must provide for routing of datagrams to and from mobile hosts. This routing must also be transparent to the upper layers. Mobile IP is based on the idea of encapsulation and forwarding of packets (datagrams) by a designated agent of the mobile host (the home agent).

BASIC OPERATION OF MOBILE IP

In mobile IP, the network is divided into several areas (or small networks) and each mobile host is given an area termed home area. Typically a home area may cover a subnetwork. The mobile host is also allocated a permanent IP address based on its point of attachment in a subnetwork. Each area is served by home and by foreign agents. The home agent maintains information about all the mobile hosts permanently registered in its area. A foreign agent keeps track of all visiting mobile hosts in the area who are not permanently registered in the area.

When the mobile host moves from one place to another, it detects the presence of a foreign agent and sends a registration request. T

he registration request includes the mobile host's IP address and the IP address of its home agent. The foreign agent forwards the request to the home agent of the mobile host. The home agent sends back a registration reply and the foreign agent registers the mobile host and sends the registration information to the mobile host (Figure 6).

The packets (datagrams) are still sent first to the original location of mobile host, where the home agent copies the packets and forwards them to the current foreign agent, which in turn sends them to the mobile host. The packets from the mobile host to the other (fixed) host can be routed directly from mobile host to the fixed host without any home agent involvement.

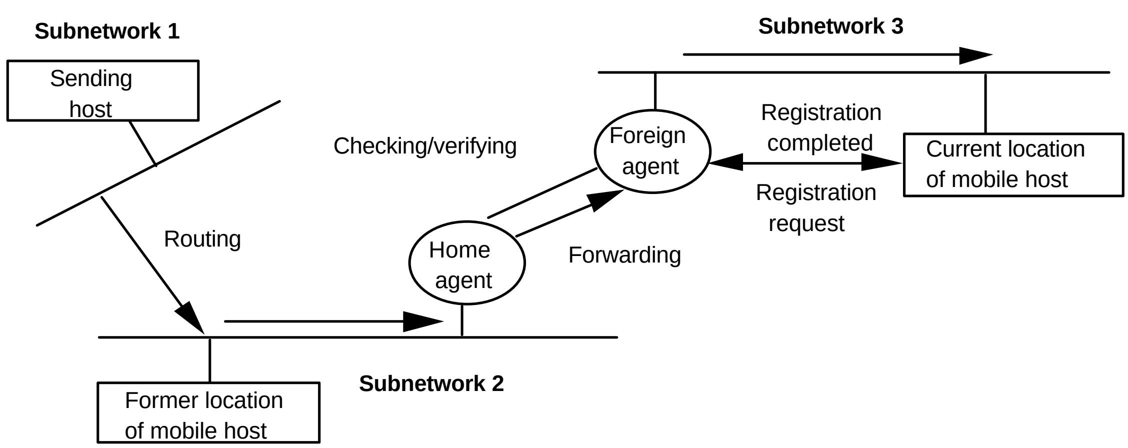


Figure 6. Basic Operation of Mobile IP

Mobile IP is primarily designed to extend the IP support for mobile hosts that are running typical Internet applications. However, this protocol is scalable and is therefore suitable for a wide area environment such as the Internet.

TRIANGULAR ROUTING

As shown in Figure 7, the packets to a mobile host may have to be routed to the home agent and then forwarded to the current location of the mobile hosts. However, the packets from the mobile host are routed directly to the fixed host. Thus, the routes between two communicating hosts would be different. This arrangement is called triangular routing and causes some problems, such as increased and uneven load on the network, and increased delay in delivering packets. Since all the traffic to a mobile host coming from all correspondent hosts is being routed on the same route (the route between home agent and the mobile host), it may create several hot points (areas with unusually high traffic) in the Internet. Delays are increased because packets are routed to the home agent, processed and then forwarded to the current location of the mobile host.

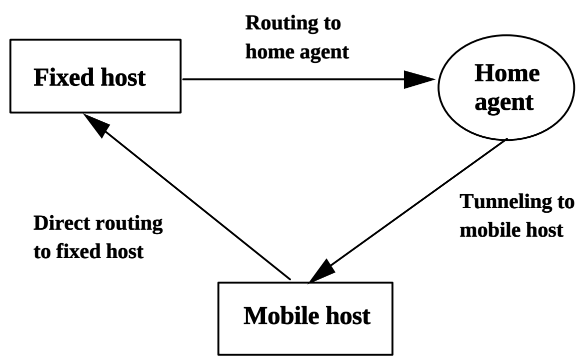


Figure 7. Triangular Routing

ROUTE OPTIMIZATION

If the sending host can be informed about the current address (care-of address) of the mobile host, then its possible that the sending host can send the datagrams to the current location of the mobile host directly without going through the home agent. This approach is called route optimization. Triangular routing can be avoided through route optimization.

WIRELESS ASYNCHRONOUS TRANSFER MODE (WIRELESS ATM)

ATM is an emerging technology for high-speed networking (any resemblance to automatic teller machines is purely intentional!). ATM requires that all users transmit information in a 53 byte long packet (called cell) that can be prepared, transmitted and switched by networks at very high speeds. The 53 bytes of an ATM cell are divided into 5 bytes of overhead (carrying control information) and 48 bytes of data. The 48 byte size for data is a compromise between US and European members of the standard bodies who wanted 64 and 32 bytes, respectively. An ATM cell is shown in Figure 8.

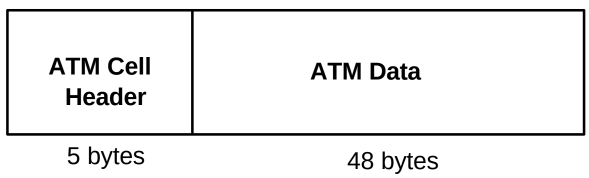


Figure 8. A Simple ATM Cell

ATM is designed to support both real time and non-real time traffic. The traffic includes voice, video, imaging, and Internet traffic. These traffic types have different delay, loss, and throughput requirements. In addition to supporting these diverse traffic requirements, ATM has the major advantage of being scalable. As a result, ATM can be used in local area as well as in wide area environments at very high bit rates. In June 1998, Sprint, the third largest US telecom carrier, announced a 25 Mbps residential ATM service will be offered beginning in summer 1999. Other carriers are also expected to offer similar service to residential and business customers. Deployment of ATM technology in both the local and wide area environments has been increasing in the last few years. Many ATM Local Area Networks (LANs) have been designed and implemented. With increasing proliferation of ATM in local and wide area networks, future networks can be expected to have even higher ATM penetration. To support emerging mobile computing applications, the use of wireless ATM technology should be considered [Raychaudhuri et al, 1997, Raychaudhuri and Wilson, 1994, Varshney, 1997].

The use of “Wireless ATM” has been motivated by an increasing deployment of ATM technology in backbone networks and by the need to support mobile multimedia services in wireless networks. These could include terrestrial cellular systems, emerging wireless local loop and high speed satellite systems. Wireless ATM is an emerging technology where ATM cells are transmitted over wireless channels and part(s) of the ATM connection lies in the wireless network (Figure 9).

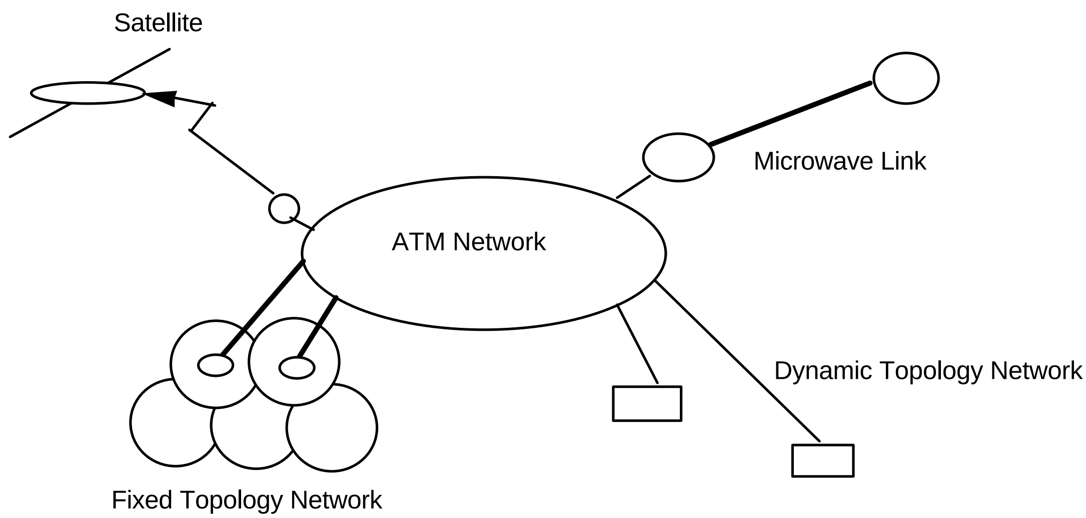


Figure 9. A Wireless ATM Network

ATM was designed for networking environments involving high bandwidth, low error rate and stationary users. The introduction of ATM in wireless environment creates many challenges such as:

- how to maintain the end-to-end connection as the user moves from one location to the other,
- how to deal with lossy wireless links and
- how to support different types of traffic over limited bandwidth wireless links [Varshney 1998b].

Progress is being made towards adopting wireless ATM for the mobile computing environment. The ATM Forum, a worldwide consortium of companies interested in ATM implementation, started a working group on wireless ATM to discuss and debate some of these issues. The standards are expected by 1999. Early commercial deployment of such systems may only be a few years away.

SUPPORTING USER MOBILITY

ATM technology is designed to support connections between fixed end points. But in wireless networks, a mobile user moves from one cell to another, thus changing access points. Some researchers have started to address this user mobility problem. (A survey of these schemes can be found in [Varshney, 1998b].) These schemes involve rerouting or rearrangement of end-to-end ATM connection using the following approaches:

- setting up a new connection every time a mobile host moves,
- providing multiple paths for communications in the wireless network, where a mobile host chooses one of many paths based on its current location,
- forwarding ATM cells by a designated source base station to the current location of the mobile user,
- rerouting the connection as the mobile user moves from one location to the other.

DEALING WITH LOSSY WIRELESS LINKS

ATM technology is primarily designed for a low error rate, high bandwidth communication environment. Because wireless links are known for high and variable error rates, when ATM cells are transmitted over wireless links, a high rate of cell loss may occur. Several different ways of dealing with this cell loss problem have been suggested:

- use of forward error correction (FEC) algorithms to allow the receiver to detect and correct communication errors.

- use an error detection scheme (e.g. Cyclic Redundancy Control) followed by buffering and selective retransmission of ATM cells to make this cell loss transparent to the applications/users.

The retransmission and possible misordering of ATM cells will require the use of sequence number in ATM cells. The addition of sequence numbers (2-4 bytes long) would certainly add some overhead, which may be in addition to overhead caused by error control technique. It may be possible to package sequence number, error control overhead and 53 bytes long ATM cell together in a larger WATM cell (e.g. 64 bytes or smaller) for transmission in a wireless ATM environment [Raychaudhuri et. al. 1997].

SUPPORTING DIFFERENT TYPES OF TRAFFIC

ATM networks are designed to support a variety of traffic types, each of which may have different requirements. Some traffic types may be more tolerant to cell delay and delay variation, while some may tolerate occasional cell loss. For real time traffic, retransmission may not be used due to low delay requirements. However, wireless networks typically have low (and variable) bandwidth and may have high (and variable) error rates. Low bandwidth negatively impacts delay and the high error rates do the same to cell loss. Even if loss is reduced by retransmission schemes, a wireless network may still not support low delay due to the limited and shared bandwidth.

Wireless ATM introduces additional requirements such as reduced access delay for real time traffic and reserving some bandwidth for non real time traffic to allow the transmission of ATM cells over wireless channels. The sharing of wireless bandwidth has to be efficient to support more customers and or application requirements. A protocol should give priority to real time traffic because non-real-time traffic can wait longer. If some type of contention is used by new users to gain access to the bandwidth, then its impact in terms of delay on existing users should also be considered. Some efforts have been made in designing protocols for the wireless ATM environment [Kuhbar and Mouftah, 1997].

VII. CONCLUSIONS

Mobile computing presents interesting opportunities and challenges. It allows users to be free of location constraints and be on the move, but it presents many challenges to application, hardware, software, and network designers and implementers. In this tutorial, we presented an introduction to mobile computing and related issues. Several networking infrastructures are emerging, including wireless LANs, satellites, mobile IP and wireless ATM to support mobile computing. This tutorial presented an overview of these networks/protocols and looked into issues that are important to support mobile computing. Due to the large market for small and smaller computing devices, there is a significant commercial potential for networking hardware, software and applications that could support mobile access to various networks.

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ACRONYMS USED IN THE TUTORIAL

ATM	ASYNCHRONOUS TRANSFER MODE
CB	CITIZEN BAND
CDPD	CELLULAR DIGITAL PACKET DATA
CRC	CYCLIC REDUNDANCY CONTROL
FCC	FEDERAL COMMUNICATIONS COMMISSION
FEC	FORWARD ERROR CORRECTION
GPS	GLOBAL POSITIONING SYSTEMS
HIPERLAN	HIGH PERFORMANCE RADIO LAN
IEEE	INSTITUTE OF ELECTRICAL AND ELECTRONIC ENGINEERS
IETF	INTERNET ENGINEERING TASK FORCE
IP	INTERNET PROTOCOL
ISM	INDUSTRIAL, SCIENTIFIC AND MEDICAL
LAN	LOCAL AREA NETWORK
PBS	PORTABLE BASE STATIONS
PCS	PERSONAL COMMUNICATIONS SYSTEMS
PDA	PERSONAL DIGITAL ASSISTANTS
WATM	WIRELESS ASYNCHRONOUS TRANSFER MODE
WLAN	WIRELESS LOCAL AREA NETWORK