Upkar Varshney and Ron Vetter

Emerging Mobile and Wireless Networks

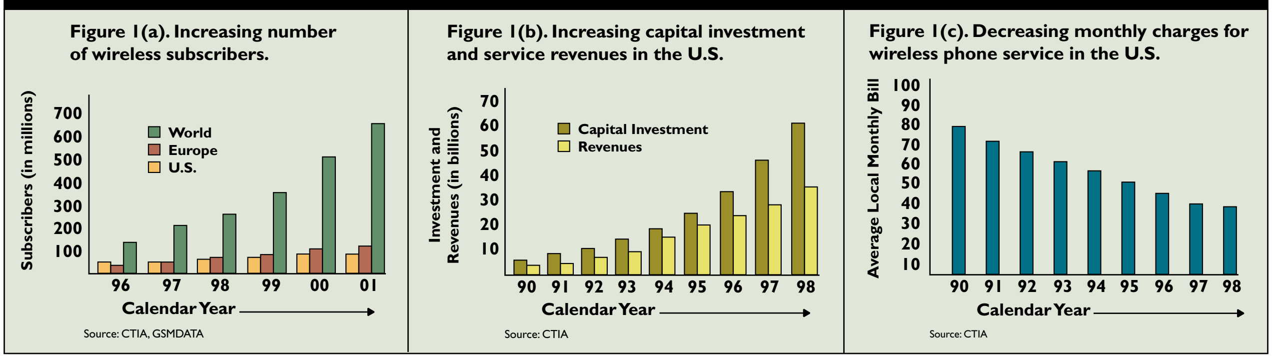
Wireless and mobile networks are quickly becoming the networks of choice, not only because of large bandwidth, but due to the flexibility and freedom they offer.

With the 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 nomadic computing [3]. Also referred to as anytime/anywhere computing, mobile computing has several interesting and important applications for business (such as instant claim processing and e-commerce), telecommunications and personal communications, national defense (tracking troop movements), emergency and disaster management, real-time control systems, remote operation of appliances, and in accessing the Internet. Since a user may not maintain a fixed position in such environments, the mobile and wireless networking support allowing mobile users to communicate with other users (fixed or mobile) becomes crucial. A possible scenario may involve several different networks that can support or can be modified to support mobile users. When dealing with different wireless networks, a universal mobile device should be able to select the network (LAN, the Internet, PCS, or satellite) that best meets user requirements.

Wireless and mobile networks have provided the flexibility required for an increasingly mobile workforce. As shown in Figure 1(a), the worldwide number of cellular, GSM, and PCS subscribers increased from 140 million in 1996 to over 300 million in 1999 and is expected to grow to 650 million by 2001 (see www.gsmdata.com). In the U.S., capital investment increased from $6.3 billion in 1990 to $66.8 billion in 1999 and service revenues were up from $4.5 billion to $38.7 billion in 1999 (see www.wow-com.com) as shown in Figure 1(b). During the same period, the average local monthly bill diminished from $80 to $39 as shown in Figure 1(c), indicating the technological maturity and the tremendous competition among service providers.

Many general remarks can be made about wireless systems. First, the channel capacity typically available in wireless systems is much lower than what is

Figure 1. Recent changes in usage.



available in wired networks due to the limited spectrum available, power restrictions, and noise levels. Even with advances in coding schemes, the capacity remains limited due to these reasons and also because users share the available capacity in one way or another. Second, noise and interference have more impact on systems design for wireless systems than on wired systems. Third, before building a wireless system some sort of frequency allocation (by the Federal Communications Commission in the U.S.) is required. Fourth, security is a greater concern in wireless systems than in wired systems since information may be traveling in free space (with the exception of infrared LANs). More details on these issues can be found in [2, 9, 10].

Mobile users do not necessarily need to use wireless interfaces and wireless interfaces do not necessarily support mobility. A mobile user can simply connect to fixed networks using wired interfaces as he or she moves. Likewise, a fixed-location user might use a wireless interface (via a LAN) while sitting in an office. Therefore, mobile and wireless systems are not the same even though there is considerable overlap. Mobile networks provide support for routing (how to maintain communication with mobility) and location management (keeping track of the location) functions. Wireless networks provide wireless interfaces to users (both mobile and stationary) by supporting bandwidth allocation and error-control functions. When combined, there are several interesting issues that arise, including optimal use of low bandwidth channels due to limited frequency allocation, management of large bit-error rates due to high noise levels, application-level quality of service support, increased security concerns, and failure or malfunctioning of equipment (Table 1).

The choice of media access control (MAC) can affect both performance and use of wireless networks. The MAC protocols used in cellular and PCS systems in the U.S. and Europe differ considerably. For example, the U.S. standards use FDMA (in AMPS), TDMA (in PCS), and CDMA (IS-95), while GSM uses TDMA/FDMA over different frequencies. This directly affects the interoperability and global roaming of mobile users. These differences are also affecting the standardization of the next (third) generation—3G—of wireless/mobile systems where North American companies are pushing for CDMA (or Wideband CDMA) to allow for backward compatibility with CDMA-based IS-95 while Europe is supporting TDMA for GSM compatibility. Some agreements on 3G systems have been reached, allowing all of the previously mentioned networks to interoperate with or evolve into 3G wireless networks (www.itu.org).

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Mobile and wireless networks are also experiencing significant progress in the form of wireless local area networks (WLANs) [4], satellite-based networks [5], Wireless Local Loops (WLL) [6], mobile Internet Protocol (IP) [7], and wireless Asynchronous Transfer Mode (ATM) networks [8, 11]. A comparison is shown in Table 2. One emerging wireless technology is Bluetooth (www.bluetooth.net), which provides low-cost and short-range radio links for wireless connectivity among computers, printers, and scanners. Since the range is small, it can use the unlicensed ISM band in 2.4GHz.

Wireless LANs

Wireless local area networks are designed to provide coverage in a small area, such as a building, hallway, park, or office complex by extending or replacing wired LANs (such as Ethernet). The main attraction is the flexibility and mobility supported by a wireless LAN; bandwidth considerations are secondary. Unlike cellular networks where a frequency (channel) is allocated, users in WLANs have to share fre-

Table 1. Mobile and wireless networking issues.

Issues	Possible Choices		Comments
Network Configuration	Infrastructure-based configuration		More scalable but less flexible
	Ad-hoc configuration		Less scalable but more flexible
Limitations of Devices	New protocols to handle device limitations		Interworking with existing protocols
	Content adaptation to device capabilities		Additional complexity at network/server
Bandwidth and Frequency of Operation	Use of existing frequencies (regulated/unregulated)		Lower bandwidth, higher interference, lower signal loss, lower cost
	Use of higher frequencies		Higher bandwidth possible, lower interference, higher signal loss, higher cost
Handoffs	Type of handoffs	Hard handoff	Device can communicate with one access point
		Soft handoff	Device can communicate with several access points
	Handoff Implementation	Network initiated	Network to compare signal strength at several points
		Mobile assisted	Mobile to compare signals from several base stations and report to the current one
	Priority	User-based	Keep track of different classes of users
		Application-based	Keep track of different classes of applications
	Channel assignment	Fixed-size	Easy but not suitable to all applications
		Variable	Difficult but suitable to applications
MAC Protocols	Frequency Division Multiple Access (FDMA)		Analog and amount of interference
	Time Division Multiple Access (TDMA)		Synchronization and slot speed match requirements
	Code Division Multiple Access (CDMA)		Difficult to satisfy varying bandwidth requirements
Error Control	Error detection and retransmission		Impact on delay (not used for real-time applications)
	Error correction		Amount of excess bandwidth required
	Error correction and retransmission		Adaptive to the channel conditions
QOS Management	Admission control techniques		Amount of processing (micro-cellular environment)
	Priority to existing user's resource request		Knowledge of the traffic in nearby cells/clusters
	Dynamic advance reservation		Difficult to match user's future needs with network resources
	Adaptive error control techniques		Complexity and resource requirements
	QOS-oriented MAC protocols		Amount of protocol processing
	Channel borrowing from underloaded regions		Difficult to implement
Mobility Management	Addressing and Routing	Same address in different locations for a mobile user	Exact location information is required for communications
		Different addresses	Complex routing
	Modification of existing protocols to deal with loss over wireless links		Differentiation between packet loss due to congestion and due to wireless links/user movement
Location Tracking	Broadcasting (paging) to locate a user		Delay, Amount of paging overhead
	Location updating by a user after every move		Amount of updating overhead
	Combination of paging and updating		
Applications and Middleware	Applications to adapt to varying QOS		Requires development of new applications
	Wireless middleware to deal with mobility allowing no changes in existing applications		Cost of building middleware to deal with heterogeneous wireless networks
Security	Encryption		Processing requirements at mobile devices
	Frequency hopping		Complex
	Use of infrared (indoors only)		Limited use
Failure	Deployment of back-up systems		High initial cost

quencies, which may lead to collisions. It is difficult to detect collisions in WLANs because the power levels of signals coming to a mobile user may be different and a station may not detect a potential competitor for the medium (the hidden station problem). The choice of frequency depends on whether microwave, spread spectrum, or infrared communication will be used. Interference and security depend on the type of communications method used in the WLAN. Because infrared cannot penetrate walls, it encounters little interference from external sources but is limited in its coverage (typically indoors). Spread spectrum spreads the signal over a wide frequency range to reduce interference present at certain frequencies. For security, some form of encryption may be used. If the unlicensed ISM band is used, some interference is likely to occur because the band is open to other users and agencies.

Wireless LAN standards. There are several wireless LANs that have been proprietary in the past, such as Motorola's Altair and AT&T's WaveLAN. Fortunately, some progress has been made in standardizing wireless LANs: two wireless standards are IEEE 802.11 and HIPERLAN. The 802.11 standard sup-

Table 2. A comparison of several mobile and wireless networks.						
Issues	**Wireless LANs**	**Wireless Loops**	**Cellular/ PCS**	**Mobile IP**	**Wireless ATM**	**Satellites**
Coverage	Local Area	Local* or Metropolitan	Metropolitan	Wide Area	Wide Area	Wide Area
User bandwidth	1–20Mbps	1–20Mbps	19.2Kbps	Network Dependent**	1–20Mbps	19–2Kbps to few Mbps***
Application	Data/Voice	Voice/Data	Voice/Data	Data/Voice	All	Voice/Data
Major issue	Limited area	Interference	Bandwidth	Limited Applications	Cost	Initial cost
Status	In use	Emerging	In use	Emerging	Emerging	Emerging

*: Depending on the underlying technology such as 3–10 miles for LMDS.
**: Bandwidth depends on the underlying wireless network.
***: Higher limit for satellites such as Teledesic.

Table 3. Some emerging satellite systems for mobile communications.							
System Name	**Orbit (height)**	**Satellites (channels)**	**Frequency of operation**	**Applications**	**Coverage**	**Charges**	**Start Date**
Globalstar	LEO 1400Km	48 (130,000)	1.6, 2.4GHz users 5GHz up	Voice/Data	Worldwide (except poles)	$1000 (terminal) $.50 airtime	1999
ICO	MEO 10,355Km	10	7GHz down 5GHz up	Voice/Data	Worldwide	$1000 (terminal) $1 airtime	2000
Teledesic	LEO 1400Km	(45,000) 288 (unspecified)	7GHz down 28GHz	Video/Voice Data	Worldwide	Unspecified	2003

ports 1Mbps; HIPERLAN can be used to support 23.5Mbps channel rates. The 802.11 also supports several choices of physical medium such as spread spectrum and infrared while HIPERLAN only allows spread spectrum. Like HIPERLAN, 802.11 supports prioritized access to the medium. One additional feature of 802.11 is battery conservation for inactive or idle wireless users. Many universities and companies are encouraging the use of IEEE 802.11-based LANs for accessing campus computing systems and the Internet. Another emerging wireless LAN standard is HIPERLAN2, which is being standardized by ETSI and expected to be ready by 2000. An exciting part of HIPERLAN2 is the use of connections providing different levels of quality of service for applications. It will likely operate in a 5GHz band that is unlicensed in the U.S. and Asia and a dedicated unlicensed band in Europe, using time-division multiplexing of unicast, multicast, and broadcast connections. Many major players in the wireless LAN area have formed HIPERLAN2 Global Forum (www.Hiperlan2.com) to advance and complement the ETSI standardization process. Not to be outdone by HIPERLAN2, IEEE 802.11 is being enhanced to support 11Mbps.

Wireless Local Loops

Because local carriers own the local loop in the U.S., long distance companies have to pay access charges every time someone makes a long distance or international call. The Telecom Reform Act of 1996 has attempted to change this situation but since long distance companies have not yet built their local loops, they continue to pay access charges (or excess charges as they are often called—approximately $20 billion last year alone). In many developing countries, there is little or no infrastructure in place. The situation can be changed with the introduction of the Wireless Local Loop (WLL). In the U.S., long-distance companies are looking to build their WLLs to avoid paying access charges. Since WLLs provide fixed wireless access (as opposed to mobile access provided by cellular and PCS), they can provide several MHz of bandwidth that can be used for high-speed Internet access and data transfer in addition to the basic phone service. In developing nations where laying millions of miles of copper is impractical, WLLs can provide phone and low-speed data transfer.

Among many choices of technologies that can be used in WLL environments, cellular and microcellular systems can be used in the 900, 1800, and 1900MHz ranges with 9.6Kbps for 10–100 users within a few kilometers or smaller area. Wireless LANs can be deployed to support WLL for users in smaller areas but with higher bandwidth requirements. Systems that are especially designed for fixed wireless access, such as LMDS, can provide very high bandwidth (tens of Mbps) in large areas for large numbers of users but require a direct line of sight.

LMDS. Local Multipoint Distribution Systems (LMDS) is an emerging technology for serving point-to-multipoint applications. It uses a 28–31GHz band and recently 1.3GHz of spectrum has been allocated in the U.S. by the FCC to several hundred providers. LMDS is based on spread spectrum and can support very high bit rates for two-way data transfer. Possible applications are high-speed Internet data, telephony, and cable TV programming transmission at several hundred Mbps.

Satellites

Geosynchronous satellites are in wide use providing 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 antenna design, signal reception, and other related technologies, it is becoming possible to provide mobile services using satellites. Several such projects are in different stages of implementation. Some of these are shown in Table 3.

Iridium. Iridium is a low-earth orbit (LEO) system that uses 66 satellites to provide mobile communications to every point on earth and within 50 miles above it. Since wireless users may have widely different needs—some may need global roaming capabilities, while others may only want to supplement their cellular service in areas not served by existing cellular carriers—it is intended to provide many different products and services. In Iridium, the same satellite may not serve a user throughout the duration of a call; a call may be handed off to another approaching satellite. The satellites, in concentric orbits, maintain links with up to four satellites in neighboring orbits. But handoffs are necessary among satellites in counter-rotating orbits to maintain cross-links among satellites. The Iridium service started in January 1999, but due to technical problems and complaints about high prices, the number of customers that adopted the service was much smaller than needed to maintain this multibillion-dollar network—which has been officially declared bankrupt and has terminated commercial services. To avoid a similar fate, other emerging LEO-based networks must do a better job advertising and marketing their services and products, combined with lower initial and per-minute costs. It is difficult to derive the size of the market for such services, but there is a large market for satellite phone service especially in places where no cellular service exists or that experience heavy call blocking.

The most notable among the other LEO-based networks is the $9 billion Teledesic project funded by Microsoft and McCaw Cellular. The project originally planned to launch 840 LEO satellites but has been scaled down to 288 satellites. The Boeing Co. has recently been named as a major equity investor and a prime contractor. Worldwide licenses for frequency spectrums (29GHz uplink and 19GHz downlink) have been issued in 1998. Each satellite will handle up to 155.52Mbps to and from the ground and 622.08Mbps to and from other satellites, so this will be the first time a satellite system will provide "fiber-like" connectivity. A typical Teledesic terminal (used by most people) will operate at 64Mbps downlink and 2Mbps uplink speeds. Teledesic is expected to be operational in 2003 (www.teledesic.com).

Wireless ATM (Asynchronous Transfer Mode). ATM is an emerging technology for high-speed networking, where information is transmitted in a 53-byte packet (called a cell) that can be prepared, transmitted, and switched by networks at very high speeds [12]. The 53 bytes of an ATM cell are divided into 5 bytes of overhead (carrying control information) and 48 bytes of data. ATM is designed to support both real-time and non–real-time traffic with different delay, loss, and throughput requirements. In addition, ATM has the major advantage of being scalable; therefore ATM can be used in local-area as well as wide-area environments at very high bit rates.

Motivation for Wireless ATM. Wireless ATM is an emerging and promising technology where ATM cells are transmitted over wireless channels and part(s) of the ATM connection lies in the wireless network. The reasons behind the introduction of ATM in wireless include seamless interconnection with backbone ATM networks, support for QOS of wireless and mobile users, and suitability of small packets over wireless channels. However, the introduction of ATM in wireless environments creates many interesting challenges because ATM was not originally designed to operate over channels of varying characteristics. These challenges include how to maintain the end-to-end ATM connection as the user moves from one location to the other, how to implement support for quality of service, and how to deal with wireless links to support mobile computing applications. The ATM Forum, a worldwide consortium of companies interested in ATM implementation, is expected to release final standards in the near future. Therefore early commercial deployment of such systems may only be a few years away. Some of the obstacles include the present lack of standards, cost and complexity in implementation, and the amount of overhead. We believe increased radio bandwidth allocation, emerging reliable and QOS-oriented protocols, along with error-control protocols for wireless ATM, will help in deploying wireless ATM to support mobile applications. It is also one of several technologies under consideration

Figure 2. Four major location update schemes.

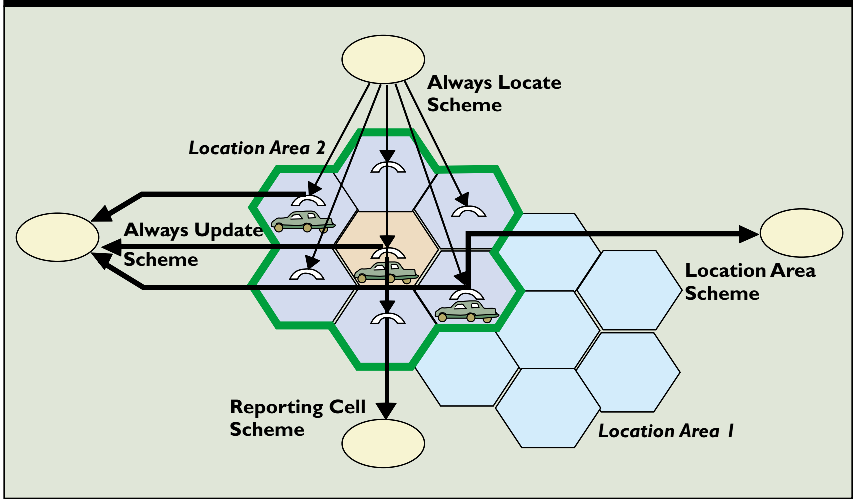
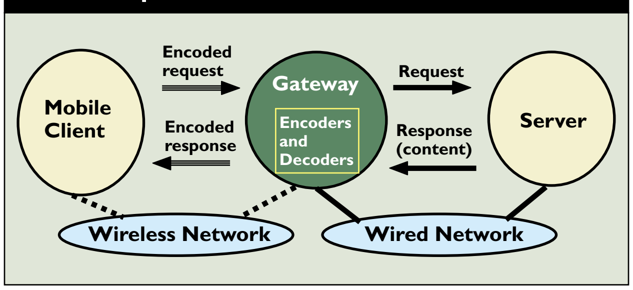


Figure 3. Wireless application protocol basic architecture.



for third-generation wireless networks.

ATM is a connection-oriented technology, so after a mobile user moves to a new location connection rerouting has to be performed. The connection rerouting schemes can be based on (a) setting up a new connection, (b) providing multiple paths to a mobile user, (c) forwarding ATM cells, or (d) dynamically rerouting the connection.

To route or reroute ATM connections, the wireless ATM network should have the information about the current location of mobile hosts. Any change in location information should be reflected in the storage system, usually a location database. And the new location information should be available to the network when a connection to a mobile host needs to be set up (routed) or rerouted. Four major location management schemes are shown in Figure 2.

When ATM cells are transmitted over wireless links, a high rate of cell loss may occur. Possible ways to counteract the cell loss include the use of forward error-correction algorithms or the use of an error-detection scheme (Cyclic Redundancy Control, for example) followed by buffering and selective retransmission of ATM cells. The retransmission and possible resequencing of ATM cells will require the use of sequence number in ATM cells. It may be possible to package sequence number, error-control overhead, and a 53-byte ATM cell together in a larger WATM cell.

Middleware and Applications

Mobile middleware can be defined as an enabling layer of software that is used by applications developers to connect their applications with different mobile networks and operating systems without introducing mobility awareness in the applications. The use of middleware may allow applications to run with better response times and much greater reliability. Typically, middleware uses optimization techniques, such as header compression, delayed acknowledgements, and concatenation of several smaller packets into one, to reduce the amount of traffic on the wireless networks. The middleware does introduce additional complexity and significant initial cost (10–300K is a range for most wireless and mobile middleware). ExpressQ (www.nettechRF.com) is a mobile messaging middleware product that enables developers to extend their non-IP applications to mobile users. It stores messages when a mobile user is out of the network range and forwards them the next time the mobile user comes into range.

Wireless Application Protocol. Currently, many different wireless access technologies exist that are not interoperable. Designing and building network and business applications for each technology would be a nightmare for developers. This problem, combined with redesigning all Web sites to support downloading by mobile users is even more difficult. Even if all of this can be achieved, the information content still has to be adapted for transmission over wireless links and is an effort to solve these problems: it allows development of applications that are independent of the underlying wireless access technology. WAP also adapts the existing Web site contents for transmission over wireless links and display on mobile devices. WAP specifications have been developed by the WAP Forum (www.wapforum.org), a consortium of leading wireless companies. The main contribution is the interoperability of different wireless networks, devices and applications using a common set of application and network protocols. The protocol architecture is similar to that of the Web, such as the use of Wireless

Table 4. WAP layers, protocols, and functions.

WAP layer	Protocol	Functions
Application Layer	Wireless Application Environment (WAE)	Provides micro browser environment and wireless markup language (WML) and script
Session Layer	Wireless Session Protocol (WSP)	HTTP functions and semantics Facility for reliable and unreliable data push Protocol feature negotiation
Transaction Layer	Wireless Transaction Protocol (WTP)	Provides several types of transaction services Uses delayed ACKs and concatenated PDUs
Security Layer	Wireless Transport Layer Security (WTLS)	Provides authentication and privacy
Transport Layer	Wireless Datagram Protocol (WDP)	Provides a common interface to upper layer protocols by adapting to specific features of the underlying technologies
Wireless Layer	Wireless and Mobile Networks	Provides a specific way to transmit information over a wireless link

Markup Language (WML, a cousin of HTML) optimized for mobile devices.

The architecture of WAP is shown in Figure 3, where a gateway acts as a proxy server to a mobile client and translates requests from WAP protocol stacks to protocol stacks employed by the information server on the other side. Encoders translate the content coming from the server into compact formats to reduce the size of data over the wireless network. This infrastructure ensures mobile users can access a wide variety of contents and applications and also allows application developers to build content services and applications that can run on a large base of mobile terminals. To support this configuration, the WAP forum defines several layers of protocols as presented in Table 4.

Mobile OS. A general-purpose operating system is not suitable for small handheld devices due to real-time requirements, smaller processing power, memory, and screen size, and because of the types of applications that may be running, such as voice. Therefore, an OS with a small footprint and reduced storage capacity is needed to support the computing-related functions of digital wireless devices. The available OS for mobile devices vary in footprint size from 300KB (Palm OS) to 2MB (Windows CE). For example, GEOS 3.0, the OS used in the Nokia 9000 Communicator, uses a footprint of 300KB. Many of these operating systems have attracted developers to build applications to run on handheld and other smaller devices [1].

Accessing Different Mobile and Wireless Networks

The ability to roam across several different wireless and mobile networks is necessary: in order to access different networks and services; to increase coverage for a wireless user; to be able to use a single device; to be able to have a single bill; for providing reliable wireless access to a user even under failure or loss of a network or networks; and to reduce the total cost of access to several networks. There are several important issues in accessing different wireless networks as shown in Table 5; three possible architectures for supporting access to several different mobile and wireless networks are discussed here (see Figure 4).

Accessing several wireless networks using multimode/multifunction devices. In this configuration, the access to different services on different networks is supported using a single physical terminal with multiple interfaces. Some very early examples of this architecture are the existing dual-function cell phone AMPS/CDMA and the emerging GSM/DECT (cordless) architecture. This architecture may lead to higher completion of calls and/or increase in the effective coverage area. Since there may be overlapped coverage, this architecture will also provide reliable wireless coverage in case of network, link, or switch failure. The network design may include factors such as the type of other networks, their pricing, regulations, and bandwidth. The handoff between networks may be initiated by the user, the device, or the network. Most of the additional complexity is introduced in the device as neither wireless networks are modified nor interworking devices are employed. Each individual network can deploy a database that keeps track of user locations, device capabilities, network conditions, and user preferences. The location information will be needed to complete calls to the user, for alerting services, and to implement E-911, which is required by 2001 in the U.S.

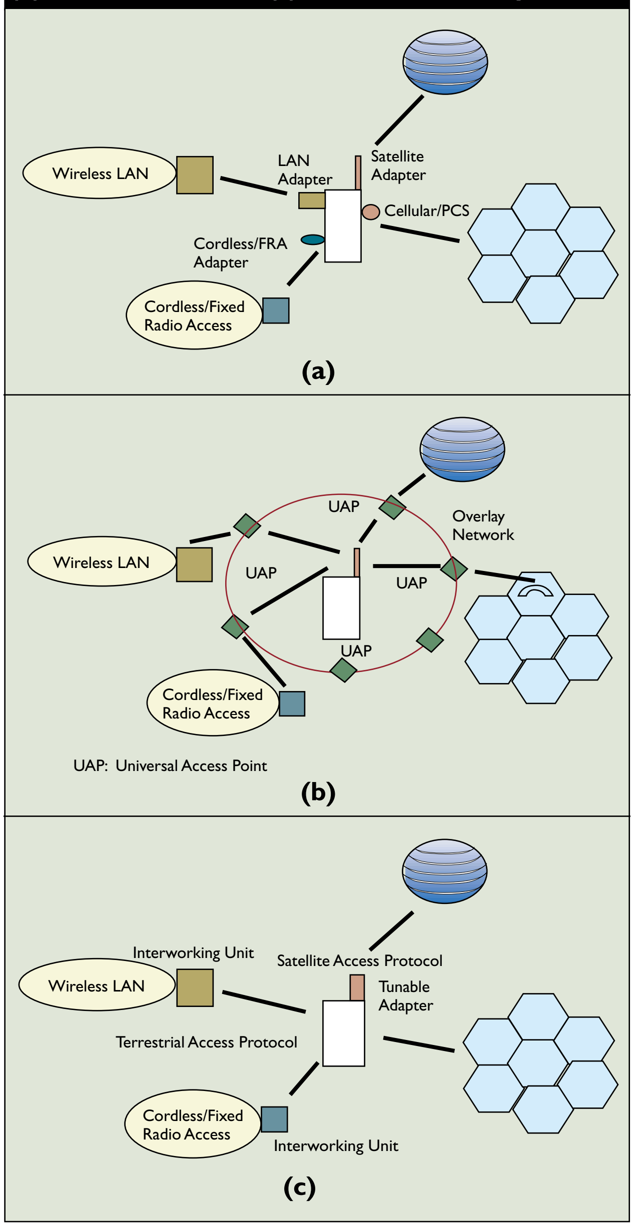
Accessing several wireless networks using an overlay network. In this architecture, a user accesses

Table 5. Important issues in accessing several different wireless networks.	
Issue	**Possible Solutions**
Ways to access several different networks	1. Use of multifunction devices 2. Use of an overlay network 3. Use of common access protocol
Type of handoff	1. Allow user to access one network at a time (Hard handoff) 2. Allow user to access more than one network at a time (Soft handoff)
Handoff detection (how to decide when one wireless network is not available and start using other one)	1. Continuous monitoring of Signal-to-Noise ratio 2. Monitoring of delay
Location coordination among networks	1. Use of a centralized location database and local database for every network 2. Location updating by broadcasting/paging when necessary
Adding new users (no longer depends on one network as adding new users will affect several networks)	Network interaction problem (difficult to find out how much traffic will be increased on other networks by adding a user to one network)
Adding new services (multicasting and other emerging services and features)	1. Development of minimum capability set 2. Hardware/software/implementation compatibility 3. New econometric models to divide revenue among multiple networks
Access and bandwidth allocation	1. Dynamic bandwidth division among single and multiple-network users 2. Dynamic bandwidth division among native and guest users 3. Resource allocation to high priority users
Addressing	1. Network specific 2. Uniform 3. Logical (using mapping) 4. One number
Effect on upper layer protocols	Adaptation required during handoff or delayed access to a new network
Security	1. Verification with a home location register 2. Single name, password to access different networks
Failure and backup	1. Internal controller in a device constantly monitoring for continued availability to networks 2. Intelligent interworking device to notify user in case of network failure
Network independence (so a user may be unaware of the underlying physical network)	1. Common interface by using mobile middleware 2. Adaptive application to adjust to change in network characteristics
Regulation	1. New regulation may be required on how and what information may be exchanged between different wireless networks 2. Wireless carriers may be required to provide FCC with data on failure and loss of access
Pricing issues	1. New models for dividing revenues among different wireless networks (using total time a user was connected, number of packets/bytes transmitted, and total overhead caused) 2. Single bill (flat pricing, usage-sensitive pricing, pricing based on QOS delivered, pricing using guest and native networks)

an overlay network consisting of several Universal Access Points (UAPs). These access points choose a wireless network for the user based on availability, QOS-specified, and user-specified choices. A UAP performs protocol and frequency translation, and content adaptation. By using an overlay network, the handoffs are not performed by the user or the device but by the overlay network as the user moves from one UAP to the other. UAP stores user, network, and device information/capabilities and preferences. This architecture will support single billing and single subscription for users as UAPs can keep track of various resources that have been used by a user.

Accessing several wireless networks using the Common Access Protocol. This architecture can be used if wireless networks can support one or two standard access protocols, and requires interworking between different networks. One possible way to support this architecture is to use wireless ATM, meaning every wireless network must allow the transmission of ATM cells with additional headers (or WATM cells) requiring changes in the wireless networks.

Figure 4. Architectures for accessing several wireless networks: (a) Multimode device; (b) Overlay network; (c) Common access protocol.



Conclusions and Future Prospects

Mobile and wireless networks represent the next wave of networking because of their usefulness in assisting an emerging mobile workforce in a growing information-oriented society. However, mobile and wireless networks also present many challenges to application, hardware, software, and network designers and implementers. During the past five years, research has focused on systematically alleviating the limitations of wireless and mobile environments. For example, several optimizations have been introduced to improve the performance of TCP/IP to make it work in slow, failure-prone, and limited bandwidth wireless networks. Additionally, proxy servers have been used to improve the performance of application-specific programs (Web browsers, file systems, database servers, and so forth) and mobile users. Over the next five years, research on enabling architectures for mobile client/proxy/servers, mobile agents, and disconnected users will be carried out. In addition, data-centric models such as mobile and location-sensitive queries, mobile transactions, and mobile workflows are also recognized as important emerging research areas.

In the near future, universal devices that can access the closest/best quality/cheapest wireless network out of several choices will be developed. Wireless networks will be able to implement a uniform addressing system in which a person has a consistent identifying number or network address that is portable across all wireless networks. Within two to three years, these networks will compete with "wired" networks for applications with low to medium bandwidth requirements. However, with increased frequency allocations, advances in semiconductor technology, and more efficient coding of information over wireless channels, mobile and wireless networks will become the networks of choice for most users and applications, making wired networks relics of the past. **C**

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Upkar Varshney (uvarshney@gsu.edu) is an assistant professor in the Department of Computer Information Systems at Georgia State University; www.cis.gsu.edu/~uvarshne.

Ron Vetter (vetterr@uncwil.edu) is a professor of Computer Science at the University of North Carolina at Wilmington; www.uncwil.edu/people/vetterr.
