Wireless communications have become very pervasive. The number of mobile phones and wireless Internet users has increased significantly in recent years. Traditionally, first-generation wireless networks were targeted primarily at voice and data communications occurring at low data rates.

Recently, we have seen the evolution of second- and third-generation wireless systems that incorporate the features provided by broadband. In addition to supporting mobility, broadband also aims to support multimedia traffic, with quality of service (QoS) assurance. We have also seen the presence of different air interface technologies, and the need for interoperability has increasingly been recognized by the research community.

Wireless networks include local, metropolitan, wide, and global areas. In this chapter, we will cover the evolution of such networks, their basic principles of
operation, and their architectures.

1.1 Evolution of Mobile Cellular Networks

1.1.1 First-Generation Mobile Systems

The first generation of analog cellular systems included the Advanced Mobile Telephone System (AMPS) [1] which was made available in 1983. A total of 40MHz of spectrum was allocated from the 800MHz band by the Federal Communications Commission (FCC) for AMPS. It was first deployed in Chicago, with a service area of 2100 square miles [2]. AMPS offered 832 channels, with a data rate of 10 kbps. Although omnidirectional antennas were used in the earlier AMPS implementation, it was realized that using directional antennas would yield better cell reuse. In fact, the smallest reuse factor that would fulfill the 18db signal-to-interference ratio (SIR) using 120-degree directional antennas was found to be 7. Hence, a 7-cell reuse pattern was adopted for AMPS. Transmissions from the base stations to mobiles occur over the forward channel using frequencies between 869-894 MHz. The reverse channel is used for transmissions from mobiles to base station, using frequencies between 824-849 MHz.

In Europe, TACS (Total Access Communications System) was introduced with 1000 channels and a data rate of 8 kbps. AMPS and TACS use the frequency modulation (FM) technique for radio transmission. Traffic is multiplexed onto an FDMA (frequency division multiple access) system. In Scandinavian countries, the Nordic Mobile Telephone is used.

1.1.2 Second-Generation Mobile Systems

Compared to first-generation systems, second-generation (2G) systems use digital multiple access technology, such as TDMA (time division multiple access) and CDMA (code division multiple access). Global System for Mobile Communications, or GSM [3], uses TDMA technology to support multiple users.

Examples of second-generation systems are GSM, Cordless Telephone (CT2), Personal Access Communications Systems (PACS), and Digital European Cordless Telephone (DECT [4]). A new design was introduced into the mobile switching center of second-generation systems. In particular, the use of base station controllers (BSCs) lightens the load placed on the MSC (mobile switching center) found in first-generation systems. This design allows the interface between the MSC and BSC to be standardized. Hence, considerable attention was devoted to interoperability and standardization in second-generation systems so that carriers
could employ different manufacturers for the MSC and BSCs.

In addition to enhancements in MSC design, the mobile-assisted handoff mechanism was introduced. By sensing signals received from adjacent base stations, a mobile unit can trigger a handoff by performing explicit signalling with the network.

Second generation protocols use digital encoding and include GSM, D-AMPS (TDMA) and CDMA (IS-95). 2G networks are in current use around the world. The protocols behind 2G networks support voice and some limited data communications, such as Fax and short messaging service (SMS), and most 2G protocols offer different levels of encryption, and security. While first-generation systems support primarily voice traffic, second-generation systems support voice, paging, data, and fax services.

1.1.3 2.5G Mobile Systems

The move into the 2.5G world will begin with General Packet Radio Service (GPRS). GPRS is a radio technology for GSM networks that adds packet-switching protocols, shorter setup time for ISP connections, and the possibility to charge by the amount of data sent, rather than connection time. Packet switching is a technique whereby the information (voice or data) to be sent is broken up into packets, of at most a few Kbytes each, which are then routed by the network between different destinations based on addressing data within each packet. Use of network resources is optimized as the resources are needed only during the handling of each packet.

The next generation of data heading towards third generation and personal multimedia environments builds on GPRS and is known as Enhanced Data rate for GSM Evolution (EDGE). EDGE will also be a significant contributor in 2.5G. It will allow GSM operators to use existing GSM radio bands to offer wireless multimedia IP-based services and applications at theoretical maximum speeds of 384 kbps with a bit-rate of 48 kbps per timeslot and up to 69.2 kbps per timeslot in good radio conditions. EDGE will let operators function without a 3G license and compete with 3G networks offering similar data services. Implementing EDGE will be relatively painless and will require relatively small changes to network hardware and software as it uses the same TDMA (Time Division Multiple Access) frame structure, logic channel and 200 kHz carrier bandwidth as today’s GSM networks. As EDGE progresses to coexistence with 3G WCDMA, data rates of up to ATM-like speeds of 2 Mbps could be available.

GPRS will support flexible data transmission rates as well as continuous connection to the network. GPRS is the most significant step towards 3G.
1.1.4 Third-Generation Mobile Systems

Third-generation mobile systems are faced with several challenging technical issues, such as the provision of seamless services across both wired and wireless networks and universal mobility. In Europe, there are three evolving networks under investigation: (a) UMTS (Universal Mobile Telecommunications Systems), (b) MBS (Mobile Broadband Systems), and (c) WLAN (Wireless Local Area Networks).

The use of hierarchical cell structures is proposed for IMT2000. The overlaying of cell structures allows different rates of mobility to be serviced and handled by different cells. Advanced multiple access techniques are also being investigated, and two promising proposals have evolved, one based on wideband CDMA and another that uses a hybrid TDMA/CDMA/FDMA approach.

![Diagram](image.png)

**Figure 1.1.** The architecture of a cellular wireless network based on ATM.
1.2 Global System for Mobile Communications (GSM)

GSM is commonly referred to as the second-generation mobile cellular system. GSM has its own set of communication protocols, interfaces, and functional entities. It is capable of supporting roaming, and carrying speech and data traffic.

Figure 1.2. The network architecture of GSM.

The GSM network architecture (see Figure 1.2) comprises several base transceiver stations (BTS), which are clustered and connected to a base station controller (BSC). Several BSCs are then connected to an MSC. The MSC has access to several databases, including the visiting location register (VLR), home location register (HLR), and equipment identity register (EIR). It is responsible for establishing, managing, and clearing connections, as well as routing calls to the proper radio cell. It supports call rerouting at times of mobility. A gateway MSC provides an interface to the public telephone network.

The HLR provides identity information about a GSM user, its home subscription base, and service profiles. It also keeps track of mobile users registered within its home area that may have roamed to other areas. The VLR stores information
Table 1.1. The IMSI in GSM

|---------------------|---------------------|---------------------------------------|

about subscribers visiting a particular area within the control of a specific MSC.

The authentication center (AC) is used to protect subscribers from unauthorized access. It checks and authenticates when a user powers up and registers with the network. The EIR is used for equipment registration so that the hardware in use can be identified. Hence if a device is stolen, service access can be denied by the network. Also, if a device has not been previously approved by the network vendor (perhaps subject to the payment of fees by the user), EIR checks can prevent the device from accessing the network.

In GSM, each mobile device is uniquely identified by an IMSI (international mobile subscriber identity). It identifies the country in which the mobile system resides, the mobile network, and the mobile subscriber. The IMSI is stored on a subscriber identity module (SIM), which can exist in the form of a plug-in module or an insertable card. With a SIM, a user can practically use any mobile phone to access network services.

1.3 General Packet Radio Service (GPRS)

The GSM general packet radio service (GPRS) is a data overlay over the voice-based GSM cellular network. It consists of a packet wireless access network and an IP-based backbone. GPRS is designed to transmit small amounts of frequently sent data or large amounts of infrequently sent data. GPRS has been seen as an evolution toward UMTS (Universal Mobile Telecommunications Systems). Users can access IP services via GPRS/GSM networks.

GPRS services include both point-to-point and point-to-multipoint communications. The network architecture of GPRS is shown in Figure 1.3. Gateway GSN (GGSN) nodes provide interworking functions with external packet-switched networks. A serving GPRS support node (SGSN), on the other hand, keeps track of an individual mobile station’s location and provides security and access control. As shown in Figure 1.3, base stations (BSSs) are connected to SGSNs, which
Figure 1.3. Architecture of GSM general packet radio service.

are subsequently connected to the backbone network. SGSNs interact with MSCs and various databases to support mobility management functions. The BSSs provide wireless access through a TDMA MAC protocol. Both the mobile station (MS) and SGSNs execute the SNDCP (Subnetwork-Dependent Convergence Protocol), which is responsible for compression/decompression and segmentation and reassembly of traffic. The SGSNs and GGSNs execute the GTP (GPRS Tunnelling Protocol), which allows the forwarding of packets between an external public data networks (PDN) and mobile unit (MU). It also allows multiprotocol packets to be tunneled through the GPRS backbone.

1.4 Personal Communications Services (PCSs)

The FCC defines PCS [5] as “Radio communications that encompass mobile and ancillary fixed communication that provides services to individuals and business and can be integrated with a variety of competing networks.” However, the Telecommunications Industry Association (TIA) has a different definition for PCS:

A mobile radio voice and data service for the provision of unit-to-unit communications, which can have the capability of public switched telephone network access, and which is based on microcellular or other technologies
that enhance spectrum capacity to the point where it will offer the potential of essentially ubiquitous and unlimited, untethered communications.

PCS can also be defined in a broader sense [6] as a set of capabilities that allows some combination of personal mobility and service management. In short, PCS [7] is a commonly used term that defines the next generation of advanced wireless networks providing personalized communication services. In Europe, the term “personal communication networks (PCNs)” is used instead of PCS.

The basic requirements for a PCS are:

- Users must be able to make calls wherever they are
- Offered services must be reliable and of good quality
- Provision of multiple services such as voice, fax, video, paging, etc., must be available.

Unlike AMPS, PCS is aimed at the personal consumer industry for mass consumption. The FCC’s view of PCS is one where the public switched telephone network (PSTN) is connected to a variety of other networks, such as CATV (cable television), AMPS cellular systems, etc.

1.5 Wireless LANs (WLANS)

Wireless LAN technology has evolved to extend to existing wired networks. Local area networks (LANs) are mostly based on Ethernet media access technology that consists of an interconnection of hosts and routers. LANs are restricted by distance. They are commonly found in offices and inside buildings. Interconnection using wires can be expensive when it comes to relocating servers, printers, and hosts.

Now, more wireless LANs (WLANs) are being deployed in offices. Most WLANs are compatible with Ethernet, and hence, there is no need for protocol conversion. The IEEE has standardized 802.11 protocols to support WLANs media access. A radio base station can be installed in a network to serve multiple wireless hosts over 100-200 m. A host (for example, a laptop) can be wirelessly enabled by installing a wireless adapter and the appropriate communication driver. A user can perform all network-related functions as long as he or she is within the coverage area of the radio base station. This gives the user the capability to perform work beyond his or her office space.

As shown in Figure 1.4, several overlapping radio cells can be used to provide wireless connectivity over a desired region. If a wireless host migrates from one
radio cell to another within the same subnet, then there is no handoff. It is basically bridging, since the host’s packet will eventually be broadcast onto the same Ethernet backbone.

WLANs support existing TCP/IP-based applications. There has been considerable debate in the past as to the low throughput WLANs provide compared to high-speed wired networks. It was not long ago that switched Ethernet technology [8] evolved, bringing the communication throughput of Ethernet into the gigabit range.

The desire to support higher throughput and ad hoc mobile communications has prompted the ETSI (European Communications Standard Institute) to produce a standard for high-performance Radio LAN (HIPERLAN), at 20Mbps throughput with a self-organizing and distributed control network architecture. HIPERLAN II is a wireless ATM system operating at the 17GHz band.

1.6 Universal Mobile Telecommunications System (UMTS)

The Universal Mobile Telecommunications System (UMTS) is commonly referred to as a third-generation system. It is targeted to be deployed in 2002. UMTS employs an ATM-based switching network architecture and aims to provide services for both mobile and fixed subscribers by common call-processing procedures.
The UMTS architecture is split into core (switching) networks, control (service) networks, and access networks. The core network is responsible for performing switching and transmission functions. The control network supports roaming through the presence of mobility management functions. Finally, the radio access network provides channel access to mobile users and performs radio resource management and signalling. UMTS will include both terrestrial and global satellite components.

The UMTS network comprises: (a) the mobile terminal, (b) the base transceiver station (BTS), (c) the cell site switch (CSS), (d) mobile service control points (MSCP), and (e) the UMTS mobility service (UMS). UMTS employs a hierarchical cell structure, with macrocells overlaying microcells and picocells. Highly mobile traffic is operated on the macrocells to reduce the number of handoffs required. UMTS aims to support roaming across different networks.

The UMTS Radio Access System (UTRA) will provide at least 144 kbps for full-mobility applications, 384 kbps for limited-mobility applications, and 2.048 Mbps for low-mobility applications. UMTS terminals will be multiband and multimode so that they can work with different standards.

UMTS is also designed to offer data rate on-demand. The network will react to a user’s needs, based on his/her profile and current resource availability in the network. UMTS supports the virtual home environment (VHE) concept, where a personal mobile user will continue to experience a consistent set of services even if he/she roams from his/her home network to other UMTS operators. VHE supports a consistent working environment regardless of a user’s location or mode of access. UMTS will also support adaptation of requirements due to different data rate availability under different environments, so that users can continue to use their communication services.

To support universal roaming and global coverage, UMTS will include both terrestrial and satellite systems. It will enable roaming with other networks, such as GSM. UMTS will provide a flexible broadband access technology that supports both IP and non-IP traffic in a variety of modes, such as packet, circuit-switched, and virtual circuit.

1.7 IMT2000

The ITU (International Telecommunications Union) has introduced a new framework of standards by the name IMT2000, which is a federation of systems for third-generation mobile telecommunications. IMT2000 aims to provide: (a) high-speed access, (b) support for broadband multimedia services, and (c) universal mo-
bility. Frequency spectrum has been allocated for IMT2000 by the ITU. Several multiple-access protocols based on code division have been proposed by many different countries. The ITU has approved the CDMA2000 radio access system as the CDMA multicarrier member of the IMT2000 family of standards. CDMA2000 is capable of supporting IS-41 and GSM-MAP to ensure backward compatibility. IS-41 is a network protocol standard that supports interoperator roaming [2]. It allows MSCs of different service providers to exchange information about their subscribers to other MSCs on-demand.

### 1.8 IS-95, cdmaOne and cdma2000 Evolution

The IS-95 [9] air interface was standardized by TIA in July 1993. Networks that utilize IS-95 CDMA [10] air interface and the ANSI-41 network protocol are known as cdmaOne networks. IS-95 networks use one or more 1.25 MHz carriers and operate within the 800 and 1900 MHz frequency bands.

Following the launch of the first cdmaOne network in Hong Kong in 1995, the number of cdmaOne subscribers has grown into millions. cdmaOne networks provide soft handoffs and higher capacity than traditional AMPS networks, with data rates up to 14.4 kbps. CdmaOne is based on IS-95A technology. IS-95B improves this technology further by providing higher data rates for packet- and circuit-switched CDMA data, with data rates up to 115 kbps.

This evolution continues with cdma2000, which is the third generation version of IS-95. This new standard is developed to support third generation services as defined by ITU. cdma2000 is divided into two parts, namely: (a) IS-2000/cdma200 1X, and (b) IS-2000A/cdma2000 3X. cdma2000 1X standard delivers twice the voice capacity of cdmaOne with a data rate of 144 kbps. The term 1X, as derived from 1XRTT (radio transmission technology), is used to signify that the standard carrier on the air interface is 1.25 MHz, which is similar to IS-95A and IS-95B. In cdma2000 3x, the term 3X, derived from 3XRTT, is used to signify three times 1.25 MHz, i.e., 3.75 MHz. cdma2000 3X offers greater capacity than 1X with data rates up to 2 Mbps while retaining backward compatibility with earlier 1X and cdmaOne deployments.

Lately, 3GPP (Third Generation Partnership Project) [11] is formed to define standards for third generation all-IP networks. It is also responsible for the production of globally applicable technical specifications and reports for a 3G mobile system based on evolved GSM core networks and the radio access technologies that they support (i.e., Universal Terrestrial Radio Access (UTRA) both Frequency Division Duplex (FDD) and Time Division Duplex (TDD) modes).
1.9 Organization of this Book

This book is organized in a manner that allows a gradual progression of the subject toward more advanced topics. Chapter 2 discusses the origin of ad hoc networks, in particular, the DARPA packet radio networks. Chapter 3 presents a current version of ad hoc networks and related challenges. Since there are no static base stations present in ad hoc wireless networks, centralized access control becomes a problem. Chapter 4 presents current channel access protocols and discusses some emerging protocols. Chapter 5 provides an overview of current ad hoc mobile routing protocols, discussing their principles, features, and operation. Chapter 6 presents a new era of routing known as longevity, or associativity-based routing. This protocol is a major deviation from traditional routing protocols, which use shortest path as the main routing metric. Chapter 7 provides a narration of the implementation of an ad hoc wireless network using a new routing protocol and current-off-the-shelf (COS) hardware. It also provides a discussion of the experimental results obtained via campus field trials. Chapter 8 continues with a discussion of the communication performance of ad hoc wireless networks so that readers can understand the capabilities of such networks and what potential applications can be supported.

The advancement in CPU technology has way surpassed that of battery technology. Hence, Chapter 9 discusses how device power life can affect communication performance and protocol design for ad hoc wireless networks. Multicasting has been widely used to support multiparty communications and conferencing. Chapter 10 provides insight on how ad hoc mobile multicasting can be achieved and presents a survey of current multicasting protocols. It also reveals how associativity or longevity can be applied to ad hoc multicasting.

Since the Internet Protocol (IP) provides unreliable datagram delivery, transmission control protocol has been introduced to provide reliable delivery of information over the internet. Chapter 11 discusses the problems associated with TCP in an ad hoc wireless network environment. Ad hoc networks should provide services to users. Chapter 12 presents existing service discovery protocols that will allow an ad hoc mobile host to discover services present in the network and to access such services.

Commercial realization of ad hoc networks has taken the form of Bluetooth. Chapter 13, therefore, presents a case study of this technology. Prior to the arrival of Bluetooth, the Wireless Access Protocol (WAP) was a popular technology since it enabled a cellular network to support data in addition to voice traffic. Chapter 14, therefore, provides a discussion of WAP. Many people have been wondering about the potential applications of ad hoc networking; Chapter 15 addresses this issue. A conclusion is finally presented in Chapter 16.