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Excerpt

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Part I

Wireless Communications: Networking and Management

1 Wireless Communications and Networking

1.1 Communications Networks

Communications by voice and physical signaling are common means of interaction between human beings. In the simplest forms, there is an emitting entity of information and a receiving entity of information. As the sources move apart the need for telecommunications appears self-evident. This simple model of communications becomes more complex when the information transmitted is not just sound, speech, or music, but full motion video images or various forms of data such as text, shared files, facsimile, graphics, still images, computer animation or instrumentation measurements. This information can be transmitted using electrical or optical signals, the native analog information undergoing numerous conversions and switching to accommodate various communications technologies. Telecommunications can take place over various media be that twisted copper pairs, coaxial cable, fiber optic, or wireless radio, microwave, satellite, and infrared links. Communication can be limited to a small group of people or extended to departments, compounds, or campuses and covering whole metropolitan areas, regions, countries, or continents. Hence, a shared infrastructure is needed, i.e., a communications network.

Communications networks can be classified in many ways, as there are distinct technologies and network equipment needed for voice communications, data/computer communications, and video communications. Among these types of communications, data communications, by the virtue of digitization of any type of information, has become the convergent system. Classification can also be done corresponding to the kind of media used, i.e. wired and wireless communications or by the underlying technologies such as circuit-switched networks (traditional voice communications), packet-switched networks (essentially data communications), broadcast networks (direct video broadcast, cable TV), or message switched networks (store-and-forward electronic mail, voice mail, web serving). Networks classification can go even further, looking at geographical coverage, from wide area networks, to metropolitan area, local area, and to personal area networks.

A typical telecommunications network, historically focused on voice processing and voice communications, is presented in Figure 1.1. The network, a symmetric infrastructure that connects Customer Premises Equipment (CPE) as the source and destination of information (telephones), consists of four major systems: **access**, **transmission**, **switching**, and **signaling**. The access systems are part of the local loop and consist of

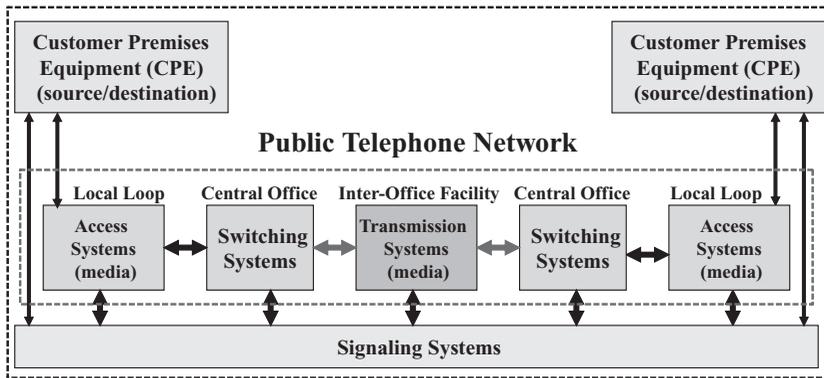


Figure 1.1 Telecommunications Network Model

copper-based twisted pair media or a combination of fiber optic and twisted pairs. The switching systems are part of the Central Office equipment connected on one end to the local loop lines and on the other end to the trunks that are part of the transmission systems. Last, but not least, signaling systems provide call control facilities for the whole network through a specialized overlay network. Currently, the same infrastructure is used to support not only voice but also data communications and other multimedia services.

A typical data communications network with clear roots in computer communications networks is presented in Figure 1.2.

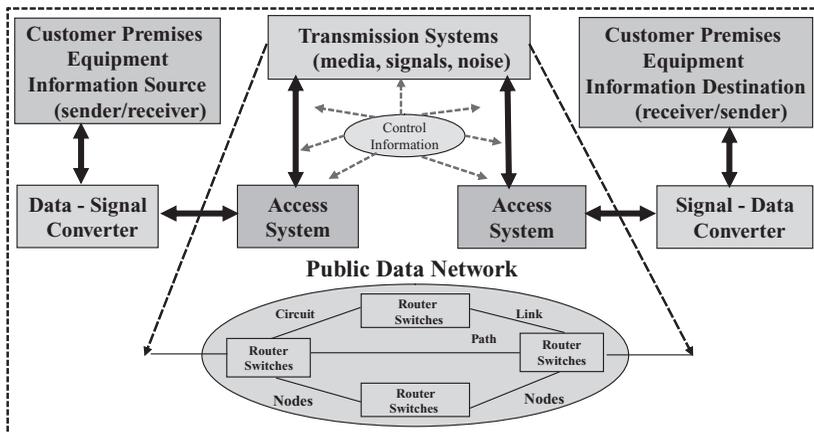


Figure 1.2 Data Communications Network Model

The data communications network model is a symmetric infrastructure that connects Customer Premises Equipment (CPE), as source and destination of information (desktop computer, laptop, server, fax machine, or instrumentation). It consists of four major systems: **conversion**, **access**, **transmission**, and **control systems**. The conversion systems (modems, coders/decoders, multiplexers) provide data-signal and signal-data conversion to accommodate the existent local loop infrastructure that was initially designed

for voice communication. The access systems are mostly part of the same local loop used in telecommunications and consist of copper-based twisted pair media or a combination of fiber optic and twisted pairs. Security functions, service access, and billing components might be built into access systems. In many instances the access and conversion systems components and functions are bundled in real networking products. There are no circuit-switching systems involved since the information is packetized and the packets are routed as part of the transmission systems, a vast network of interconnected nodes, essentially packet routers. Depending on the transmission procedures adopted, a dedicated system may establish, control, and terminate the connection between the sender and receiver of information. Currently, to minimize cost, the same infrastructure is used to support not only data but also digitized and packetized voice and other multimedia services.

Both voice and data communications networks have evolved as part of the overall technical progress in telecommunications with the invention of alternative technologies, implementation of various architectural designs, and multiple service offerings. The ultimate goal of this evolution is the integration of voice and data, a multidimensional concept that combines IT infrastructures, networks, applications, user interfaces, and management aimed at supporting all forms of information media on all forms of networks. A narrower view of this integration is aimed at supporting voice and video over packet-based Internet networks.

1.2 Communications Architectures and Protocols

Communication between various network components requires a common understanding between sender and receiver regarding the transmission procedures, the types of signals carrying the useful information, and the format of the data transmitted. There are four major aspects involved in communications services: communication interfaces, communication protocols, layered communication stacks, and information models. **Communication interfaces** are connection points between network components designed according to standard or proprietary specifications. An interface is defined by mechanical, electrical, and functional characteristics that allow communication to take place between adjacent network devices. **Communication protocols** are formal descriptions of data unit formats and transmission rules for message exchange between network entities. Communication protocols are organized in multiple **layered communication stacks** where each layer provides services to the layer above. The **information models** are collections of abstracted managed object definitions and attributes for devices having common characteristics. Currently, there are many communications architectures and protocols in use.

The **transmission procedures** used to provide connectivity between network devices may include three distinct phases, as indicated in Figure 1.3. The first is the **establishment** phase which arises as a result of an inquiry about the availability and ability of the corresponding party to exchange information. Affirmative responses open the next phase of **data transfer** that takes place by continuous acknowledgement of data received and

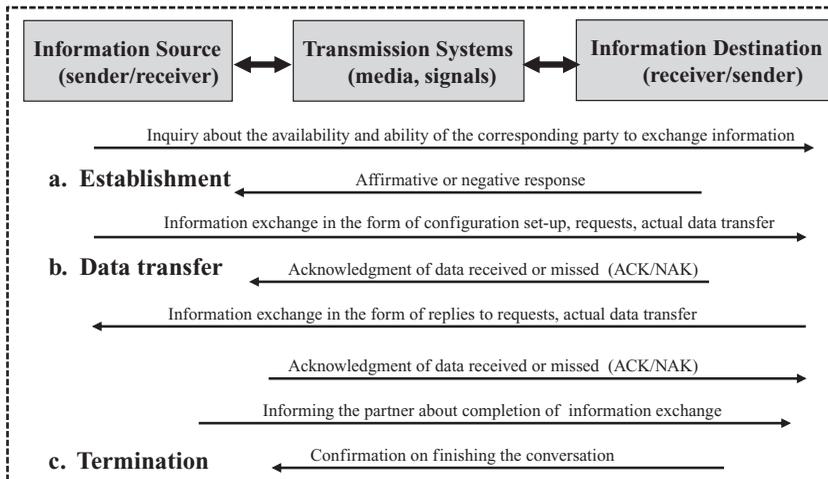


Figure 1.3 Data Transmission Procedures

its accuracy. At the completion of information exchange, the **termination** phase of connection is initiated.

Depending on the procedure adopted for connectivity, we may have two types of communication services, as indicated in Figure 1.4.

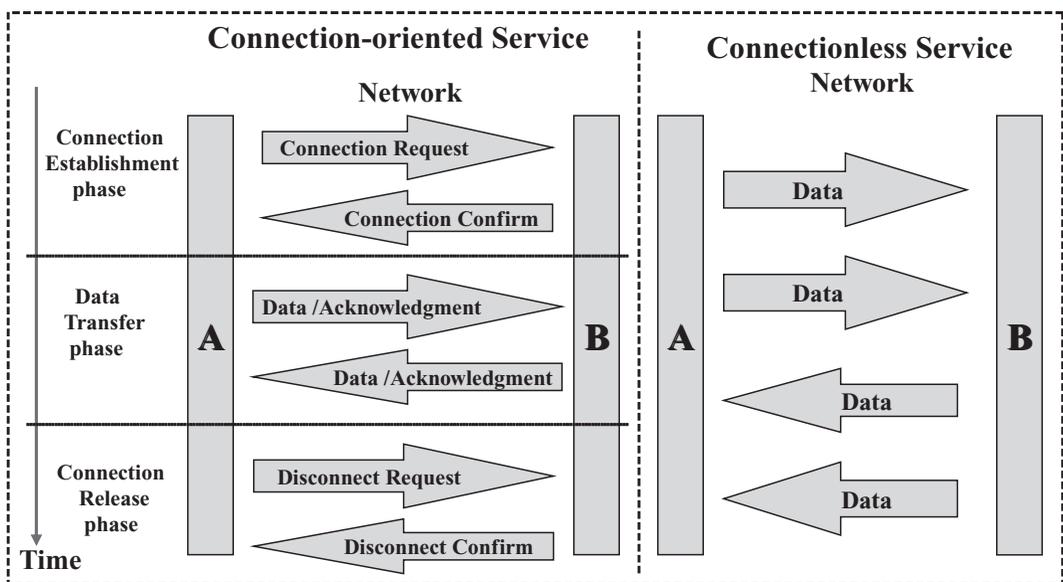


Figure 1.4 Connection-oriented and Connectionless Transmission Services

The first, **connection-oriented layer service** implies the requirement to establish a layer connection between the parties prior to the information exchange. At the end of data transfer, the layer connection will be terminated. This type of transmission gives full

assurance about the ability of both communicating parties to exchange information with full control of every aspect of data transfer. Examples: phone calls, X.25 packet networks, Internet Transmission Control Protocol (TCP). The second, **connectionless layer service** assumes that no association between the transmitting parties takes place prior to actual data transfer, i.e. no connection establishment or connection termination takes place. This type of transmission does not give either party a guarantee that they are able to exchange information or, as a matter of fact, the data transfer has been successfully completed. Examples are the Open Systems Interconnection (OSI) Connectionless Network Protocol (CLNP) and Internet User Datagram Protocol (UDP).

Multiple layer protocols are aggregated into communication stacks. The communication between two applications across recognized interfaces takes place through identical peer protocol stacks as indicated in Figure 1.5. There is no direct communication between layers, except the physical layer. Peer relationships are established between corresponding layers via dedicated protocols/services. In the most common layered communication architecture, the International Organization for Standardization (ISO) Open Systems Interconnection (OSI) standards, the Physical, Data Link, and Network Layers are grouped and known as lower layers; the Transport, Session, Presentation, and Application Layers are also grouped and known as upper layers [1].

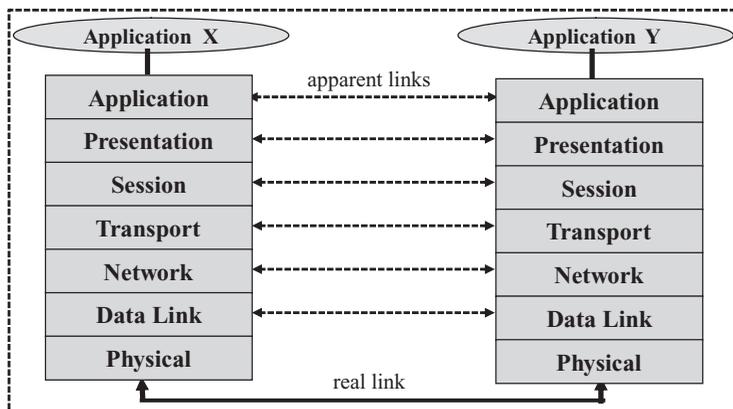


Figure 1.5 OSI Layered Communications Stack

The OSI Reference Model of seven layered communications architecture is an abstract concept of data communication that divides the functions required to exchange information into well-defined layers, services, access points, and standard protocols. There are numerous partial implementations and variations of the OSI architectural model. Some of these configurations pose serious interconnectivity and interoperability problems. A simplified view of OSI layer functions and services is given in Table 1.1. In most instances, the functions performed at the Data Link Layer are implemented in the hardware while the Network Layer functions and those associated with upper layers are implemented in software.

The basic format of information exchanged, which allows the communicating parties to understand and interpret the transmitted information, is the **Protocol Data Unit (PDU)**.

Table 1.1 OSI Layers Main Functions and Services

OSI Layer	Main Functions and Services
Application	Provides means of application processes to access the OSI layered environment.
Presentation	Provides data format structure and representation according to an agreed syntax.
Session	Provides establishment and control of the dialog between applications in end systems.
Transport	End-to-end reliable mechanism for information exchange between processes or systems.
Network	Addressing, routing, and relaying of information transmitted across the networks.
Data Link	Data transfer flow control, error detection and correction mechanism, data recovery.
Physical	Functional, electrical, mechanical, and procedural interfaces to the communications media.

The seed of any PDU is the actual user/business/application/service information. This seed is augmented with a succession of distinct data fields specific to each layer to perform specific functions and services such as synchronization, addressing, sequencing, flow control, and error detection. More than that, the PDU can be changed at the same layer as the message passes different network interfaces. Each OSI layer is defined by a peer-to-peer protocol that operates across an apparent link (distinct PDUs for each layer) and by the services provided to the next higher layer. A header is appended to the user data or to the next lower layer PDU by encapsulation. The construct of OSI Protocol Data Units layer by layer is given in Figure 1.6.

In the message exchange between two end-systems represented by Application X (sender) and Application Y (receiver), User Data is encapsulated by the Application Header (AH) to create an Application PDU (A-PDU). Similarly, operations take place at the Presentation Layer (P-PDU), Session Layer (S-PDU), and Transport Layer (T-PDU). The next encapsulation, at the Network Layer, results in a Network PDU (N-PDU) that contains in the Network Header (NH) critical information that allows routing of packets between network nodes. The last encapsulation takes place at the Data Link Layer where a Link Header (LH) and a Link Trailer (LT) are added before the Data Link PDU (DL-PDU) is delivered to the Physical Layer. This is the PDU that is carried across the physical link connecting the two nodes using various types of physical signals.

At the other end of this link, the reverse process of deconstructing the message takes place as the message is passed through successive layers. Each layer removes the corresponding header and analyzes the remaining content before passing the resulting PDU to the layer above. This continues until the PDU reaches the Application Layer. Once the header of the A-PDU is removed, the pure user information is delivered to Application Y. A similar operation of constructing and deconstructing takes place when Application Y becomes the sender and Application X the receiver. In reality, multiple nodes might be used as the message crosses the network and this process of partial deconstructing and constructing the PDU might be repeated in many nodes. Therefore, each end-system or

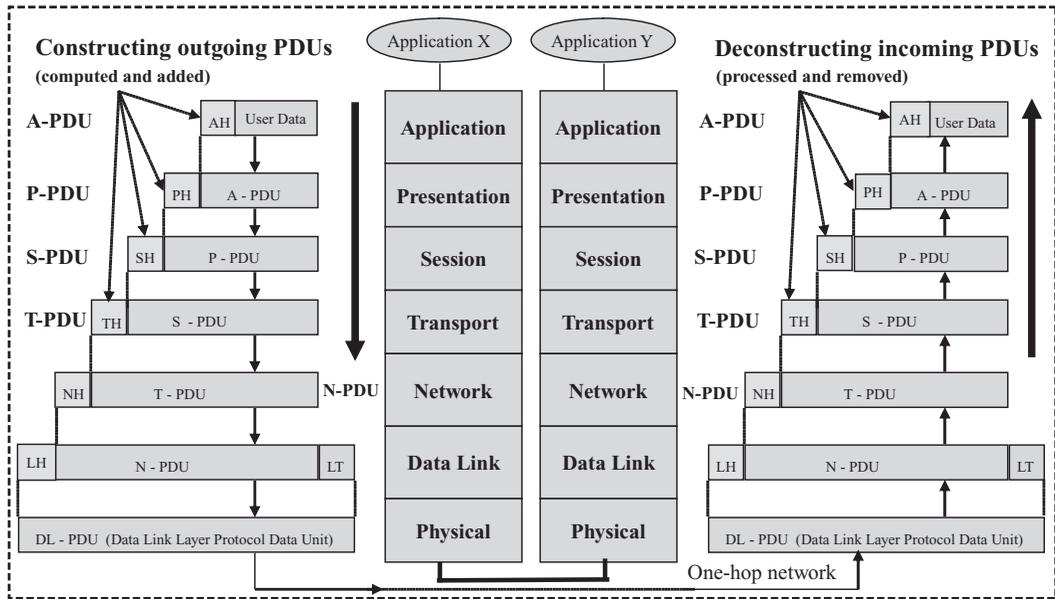


Figure 1.6 OSI Protocol Data Units Layer by Layer

intermediary node should have the same understanding of this process and the functions and information embedded in PDU headers.

1.3 Wireless Communications

Wireless communications, as the name indicates, is communication using wireless connectivity means between network components (as opposed to wired) to transmit information. Wireless networks can provide network access to phones, computers, applications, databases, and the Internet, within buildings, between buildings, within campuses, and between remote locations, giving the users the ability to move, roam, or work virtually from any location.

There are four main means used for wireless communications: **radio**-based, **microwave**-based, **satellite**-based, and free space optics **infrared**-based. Each of these means is based on distinct communications technologies, network elements, and distinct frequency spectrums for communications. The oldest wireless applications are those using radio waves for broadcasting and individual reception. **Radio Frequency (RF)**-based technologies have evolved from analog systems to digital systems and from voice to data communications. Two major areas of development took place. The first was the highly popular **cellular mobile** radio networking and services, initially geared to support voice communications. The second was radio-based **fixed wireless** technologies, such as Wireless Local/Personal/Metropolitan Area Networks WLAN, WPAN, WMAN, and near-field sensor networks, initially geared to support data communications. The

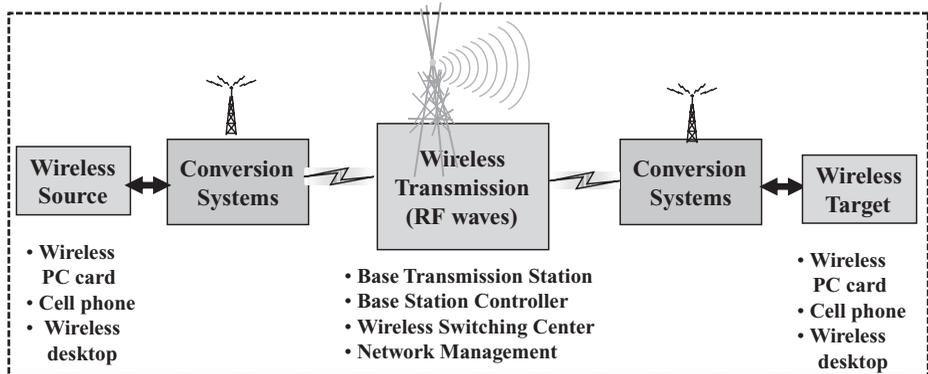


Figure 1.7 Wireless Communications Model

relationship between cellular mobile radio and fixed wireless networks will be examined as part of **Fixed Mobile Convergence (FMC)**, the very subject of this book. However, there is a plethora of other radio-based communications technologies and networks such as paging, push to talk, two-way radio communications, air-to-ground, Global Positioning Satellite (GPS), and cordless telephony that support niche applications born out of specific needs. These will be less examined in this book.

A high level model of wireless communications is very similar with the general model of communications, as indicated in Figure 1.7. This kind of communications can be limited to point-to-point exchange of information or just one instance of point-to-multipoint communications. It also can be a one-way communications (broadcast) or a two-way communications when the roles of **transmitter** and **receiver** are alternated, hence the name of **transceivers**. Specialized metallic devices, **antennas**, with the corresponding electronics, are used for transmitter and receiver. Conversion systems are needed to take the native information, be that voice, data, or image, and convert it into electromagnetic signals that spread out from antennas and propagate through space at the speed of light. A receiving antenna, similar to the transmitting antenna, intercepts the electromagnetic waves and converts them back into electrical signals that are decoded so the native information is delivered to the receiving party, a radio set, a cellular phone, or a television set.

Critical to the success of wireless communications are the RF antennas. There are many types, shapes, and sizes of antennas depending on the application provided, physical design, and ability to enhance the performance by concentration of RF wave energy. Further, there are two basic types: **omnidirectional antennas**, radiating signals in all directions, and **directional antennas**, radiating signals in a narrow direction or controlled pattern. Depending on their ability to concentrate the energy, there are **active** antennas and **passive** antennas. There are antennas with **diversity gain** that control radio signal fading. Antenna shapes include simple vertical antennas, folded dipole, parabolic, collinear, log periodic, or Yagi, panel or horn. There are striking differences between **source antennas**, truly towers in the sky, or hub earth stations, and **target antennas**, simple vertical

polarizing sticks or plate-size satellite dishes. Last but not least, there are **Multiple Input Multiple Output (MIMO)** antennas for truly user dense wireless communications.

Key to wireless communications are the conversion systems; they use various techniques to convert the native information into electromagnetic signals. These techniques are based on modulation processes, where the characteristics of the native signal, originating from say a microphone or a video camera are changed to a suitable carrier signal, i.e., amplitude, frequency, and phase. The frequency of the carrier signal is higher than that of the native signal. Consequently, three fundamental types of modulation techniques are used: **Amplitude Modulation (AM)**, **Frequency Modulation (FM)**, and **Phase Modulation (PM)**. However, there are many other fine-grained modulation techniques used which are variations and combinations of these basic modulation techniques.

In amplitude modulation, the amplitude of the carrier is changed according to the variations in amplitude of the native signal, e.g. voice, while the frequency of the carrier remains constant. In frequency modulation, the amplitude of the carrier signal remains constant while its frequency is changed according to the rhythm of the change in amplitude of the modulating signal. Special electronic components generate the carrier signal, a constant amplitude and frequency succession of sine waves, and control the process of modulation. On the receiving side, the radio waves are detected and demodulated to extract the original signal. Given the nature of the shared transmission environment, the earth atmosphere, we can expect natural attenuation of the transmitted signal's strengths and interference in the form of noise from other transmission sources or just from the very existence of cosmic and solar emitted rays. It is not the intent of this book to go into the details of antenna design, modulation techniques, RF equipment components and characteristics, physics of propagation, path loss, or radio link budget although they will be mentioned whenever it is necessary for the sake of clarity.

1.4 Wireless Communications Classification

The large variety of wireless networks introduced in the previous section can be classified using three major criteria: geographical coverage, level of mobility, and spectrum allocation. Figure 1.8 depicts the variety of wireless communications systems. Depending on the area of coverage, there are five main types of wireless networks as follows:

- **Wireless Wide Area Networks (WWAN):** These networks provide direct network connectivity to large areas including disparate, remote sites. Top on the list of WWANs is the large family of mobile radio cellular networks spanning three solid generations (1G, 2G, 3G) with various mobile technology and service implementations (AMPS, GSM, CDMA). They support voice and data services that have reached data rates up to 2 Mbps. Cellular mobile systems use ground-based equipment with direct horizontal RF-based wireless connectivity. Satellite networks are in the same class of wide area, global coverage, but they use ground-to-satellite-and-back type transmission between ground-based Hub/Personal Earth Station (HES/PES) and Geostationary Earth Orbit, Middle Earth Orbit, or Low Earth Orbit (GEO/MEO/LEO) satellites. They are capable