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Matthew N. O. Sadiku, Mohammad Ilyas

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Dedicated to our families:

Chris, Ann, and Joyce

Parveen, Safia, Omar, and Zakia

PREFACE

One of the growing areas in the communication industry is the internetworking of the increased proliferation of computers, particularly via local area networks (LANs). A LAN is a data communication system, usually owned by a single organization, that enables similar or dissimilar digital devices to talk to each other over a common transmission medium.

Establishing the performance characteristics of a LAN before putting it into use is of paramount importance. It gives the designer the freedom and flexibility to adjust various parameters of the network at the planning stage. This way the designer eliminates the risk of unforeseen bottlenecks, underuse or overuse of resources, and failure to meet targeted system requirements.

The common approaches to performance evaluation apply analytical models, simulation models, or hybrid models. Simulation models allow systems analysts to evaluate the performance of existing or proposed systems under different conditions that lie beyond what analytic models can handle. Unlike analytic models, simulation models can provide estimates of virtually any network performance measure.

So far there are two categories of texts on simulation. Texts in the first category cover the general principles of simulation and apply them to a specific system for illustration purposes; they are not specific enough to help a beginner apply those principles in developing a simulation model for a LAN. Texts in the second category instruct readers on how to apply special-purpose languages (such as GPSS, GASP, SIMSCRIPT, SIMULA, SLAM, and RESQ) in constructing a simulation model for computer systems including LANs. Besides the fact that these languages are still evolving and are limited, the reader must first learn the specific simulation language before a simulation model can be developed.

This text has two major advantages over these existing texts. First, it uses C, a well developed general-purpose language that is familiar to most analysts. This avoids the need for learning a new simulation language or package. Second, the text specifically applies the simulation principles to local area networks. In addition, the text is student oriented and is suitable for classroom use or self-learning.

The text is intended for LAN designers who want to analyze the performance of their designs using simulation. It may be used for a one-semester course on simulation of LANs. The main requirements for students taking such a course are introductory LAN course and a knowledge of a high-level language, preferably C. Although familiarity with probability theory and statistics is useful, it is not required.

The book consists of eight chapters. Each chapter has a list of references to the literature, and there is bibliography at the end of the book. Chapter 1 provides a brief review of local area networks, and Chapter 2 gives the analytical models of popular LANs—token-passing bus and ring networks, CSMA/CD, and star network. Chapter 3 covers the general principles of simulation, and Chapter 4 deals with fundamental concepts in probability and statistic relating to simulation modeling. Materials in Chapters 3 and 4 are specifically applied in developing simulation models on token-passing LANs, CSMA/CD LANs, and Star LANs in Chapters 5, 6, and 7 respectively. The computer codes in Chapters 5 to 7 are divided into segments and a detailed explanation of each segment is presented to give a thorough understanding of the simulation models. The entire codes are put together in the appendices. It is hoped that the ideas gained in learning how to simulate these common LANs can be applied to other communication systems.

The authors are indebted to various students and colleagues who have contributed to this book. We are particularly indebted to George Paramanis and Sharuhk Murad for working on some of the simulation models as special graduate projects. Special thanks are due to Robert Stern of CRC Press for providing expert editorial guidance on the manuscript. Finally, we owe much to our families for their patience and support while preparing the material. To them this book is dedicated.

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Chapter 1

Local Area Networks

Successful people make decisions quickly as soon as all the facts are available and change them very slowly if ever. Unsuccessful people make decisions very slowly, and change them often and quickly.

—Napoleon Hill

In order to fully participate in the information age, one must be able to communicate with others in a multitude of ways. Everyone is familiar with telephone communications and the use of television as a medium for transmitting information. However, the greatest interest today is centered on computer generated data, and its transmission has become the most rapidly developing facet of the communication industry. The overall communication problem may be viewed as involving three types of networks:

- Local area networks (LANs) providing communications over a relatively small area
- Metropolitan area networks (MANs) operating over a few hundred kilometers
- Wide area networks (WANs) providing communications over several kilometers, across the nation, or around the globe

WANs, such as the ARPANET in the US, have existed for several years, but the need for LANs has been identified much more recently. Although the two types of communication networks employ identical principles, their characteristics are quite different. In a WAN, which may span continents, the transmission media are relatively expensive because of the large extent of the networks. Transmission rates in a WAN may range from 2,400 to about 50,000 bits per second, whereas in a LAN they are much higher, typically from 1 to 10 million bits per second.

In a WAN, the data arrival rate is low enough to permit processors to ensure error-free transmission and message integrity. This is not the case with a LAN because of its much higher data rate. Typically WANs use the existing telephone network for communications (or more recently the national packet data network), whereas LANs use privately installed coaxial cable or twisted-pair wires.

In this and the next chapter, we briefly review the fundamentals of local area networks necessary for the rest of the book. The material in the chapter is also discussed in many journal papers and textbooks which are given in the reference list at the end of the chapter.

1.1 Definition of a LAN

A LAN is a data communication system, usually owned by a single organization, that allows similar or dissimilar digital devices to talk to each other over a common transmission medium. According to the IEEE,

> *A local area network is distinguished from other types of data networks in that communication is usually confined to a moderate geographic area such as a single office building, a warehouse, or a campus, and can depend on a physical communications channel of moderate-to-high data rate which has a consistently low error rate.*

Thus we may regard a LAN as a resource-sharing data communication network with the following characteristics [1, 2]:

- Short distances (0.1 to 10 km)
- High speed (1 to 16 Mbps)
- Low cost (in the region of $3,000)
- Low error rate (10^{-8} to 10^{-11})
- Ease of access
- High reliability/integrity.

The network may connect data devices such as computers, terminals, mass storage devices, and printers/plotters. Through the network these devices can interchange data information such as file transfer, electronic mail, and word processing.

1.2 Evolution of LANs

LANs, as data communication networks, resulted from the marriage of two different technologies: telecommunications and computers. Data communication takes advantage of CATV technology to produce better performance at lower costs. Recent developments of large scale and very large scale (LSI and VLSI) integrated circuits have rapidly reduced the cost of computation and memory hardware. This has resulted in widely available low-cost personal computers, intelligent terminals, workstations, and minicomputers. However, other expensive resources such as high-quality printers, graphic plotters, and disk storage are best shared in a geographically limited area using a LAN.

Research in LANs began in the early 1970s, spurred by increasing requirements for resource sharing in multiple processor environments. In many cases these requirements first appeared in university campuses or research laboratories [3]. Ethernet, the first bus contention technology, originated at Xerox Corporation's Palo Alto Research Center, in the mid-1970s [4]. Called *Ethernet* after the concept in classical physics of wave transmission through an ether, the design borrowed many of the techniques and characteristics of the Aloha network, a packet radio network developed at the University of Hawaii. Since the introduction of Ethernet, networks using a number of topologies and protocols have been developed and reported. Typical examples are the token-ring topology developed in the US, mainly at MIT, but now the subject of IBM development work in Europe, and the Cambridge ring, which was produced at Cambridge University Computer Laboratory in the UK. The 1980s have been a decade of rapid maturation for LANs.

LANs represent a comparatively new field of activity and continue to hold the public interest. This is mirrored by the numerous courses being offered in the subject, by the many conference sessions devoted to LANs, by the research and development work on LANs being pursued both at the universities and in industries, and by the increasing amount of literature devoted to LANs.

All this interest is generated by the LAN's promise as a means of interconnecting various computers or computer-related devices into systems that are more useful than their individual parts. The goal of LANs is to provide a large number of devices with inexpensive yet high-speed local communications.

Communication between computers is becoming increasingly important as data processing becomes a commodity. Local area networking is a very rapidly growing field. Continued efforts are being made for further technological developments and innovations in the organization of these networks for maximal operational efficiency.

Today's LANs are on the edge of broadband speeds, and new LAN proposals call for higher speeds—e.g., a proposed 16 Mbps token ring LAN and a 100 Mbps fiber distributed data interface (FDDI). Higher speeds are needed to match the increasing speed of the PCs and to support diskless workstations and computer-aided design/manufacturing (CAD/CAM) terminals that rely on LANs for interconnection of file servers. Also, the success of LANs has led to several attempts to extend high-speed data networking beyond the local premises, across metropolitan and wide area environments.

1.3 LAN Technology

The types of technologies used to implement LANs are as diverse as the 200 or so LAN vendors. Both vendors and users are compelled to make a choice. This choice is usually based on several criteria such as [5–10]:

- Network topology and architecture
- Access control
- Transmission medium
- Transmission technique
- Adherence to standards
- Performance in terms of channel utilization, delay, power, and effective transmission ratio

The first four criteria are the major technological issues and are of great concern when discussing LANs. These issues are sometimes interrelated. For example, some access methods are only suitable for some topologies or with certain transmission techniques.

1.3.1 Network Topology and Access Control

The topology of a network is the way in which the nodes (or stations) are interconnected. In spite of the proliferation of LAN products, the vast majority of LANs conform to one of three topologies and one of a handful of medium-access control protocols summarized in Table 1.1. The basic forms of the topologies are shown in Figure 1.1.

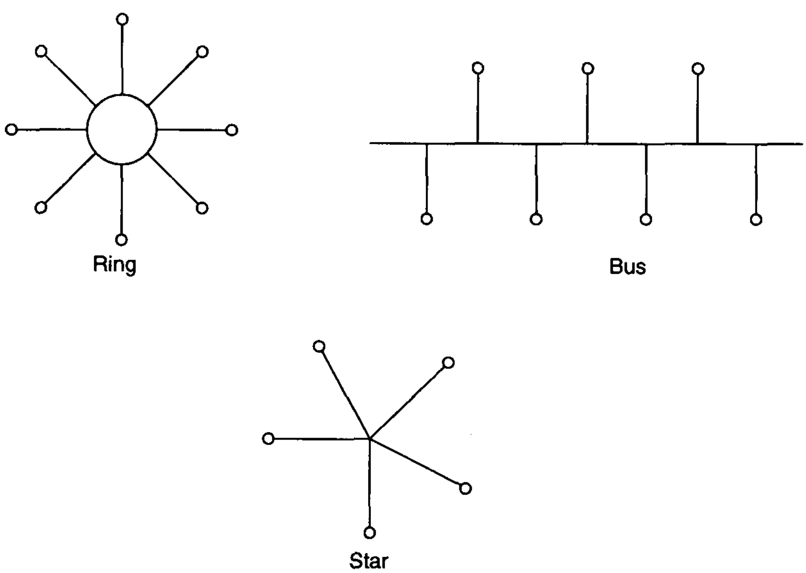

Figure 1.1 Local network topologies.

In the ring topology, all nodes are connected together in a closed loop. Information passes from node to node on the loop and is regenerated (by repeaters) at each node (called an *active* interface). A bus topology uses a single, open-ended transmission medium. Each node taps into the medium in a way that does not disturb the signal on the bus (thus it is called a *passive* interface). Star topology consists of a central controlling node with star-like connections to various other nodes. Although the ring topology is popular in Europe, the bus is the most common topology in the US.

Table 1.1 LAN Topology and Medium-Access Protocol.

1. Ring topology
   Controlled Access
   - Token
   - Slotted
   - Buffer/Register Insertion
2. Bus topology
   Controlled Access
   - Token
   - Multilevel Multiple Access (MLMA)

   Random Access
   - Carrier Sense Multiple Access (CSMA) (1-persistent, p-persistent, nonpersistent)
   - Carrier Sense Multiple Access with Collision Detection (CSMA/CD)
   - CSMA/CD with Dynamic Priorities (CSMA/CD-CP)
   - CSMA/CD with Deterministic Contention Resolution (CSMA/CD-DCR)
3. Star topology
4. Hybrid topology
   - Ring–star
   - Ring–bus
   - Bus–star
   - CSMA/CD–token ring
   - CSMA/CD–token bus

Both ring and bus topologies, lacking any central node, must use some distributed mechanism to determine which node may use the transmission medium at any given moment. Various flow control and access strategies have been proposed or developed for inserting and removing messages from ring and bus LANs. The most popular ones are the Carrier Sense Multiple Access with Collision Detection (CSMA/CD) for broadcast buses and token passing for rings and buses.

In CSMA/CD, each bus interface unit (BIU), before attempting to transmit data onto the channel, first listens or senses if the channel is idle. An active BIU transmits its data only if the channel is sensed idle. If the channel is sensed busy, the BIU defers its transmission until the bus becomes clear. In this contention-type access scheme, collision occurs when two or more nodes attempt to transmit at the same time. During the collision, the two or more messages become garbled and lost.

In the token-passing protocol, an empty or idle token (some unique bit pattern or signal) is passed around the ring or bus. Any node may remove the token, insert a message, and append the token. When a node has data to transmit, it grabs the token, changes the token to a busy state (another bit pattern) and appends its packet to the busy token. At the end of the transmission, the node issues another idle token. A node has channel access right only when it gets the idle token. Figure 1.2 shows the packet format for token bus and token ring topologies.

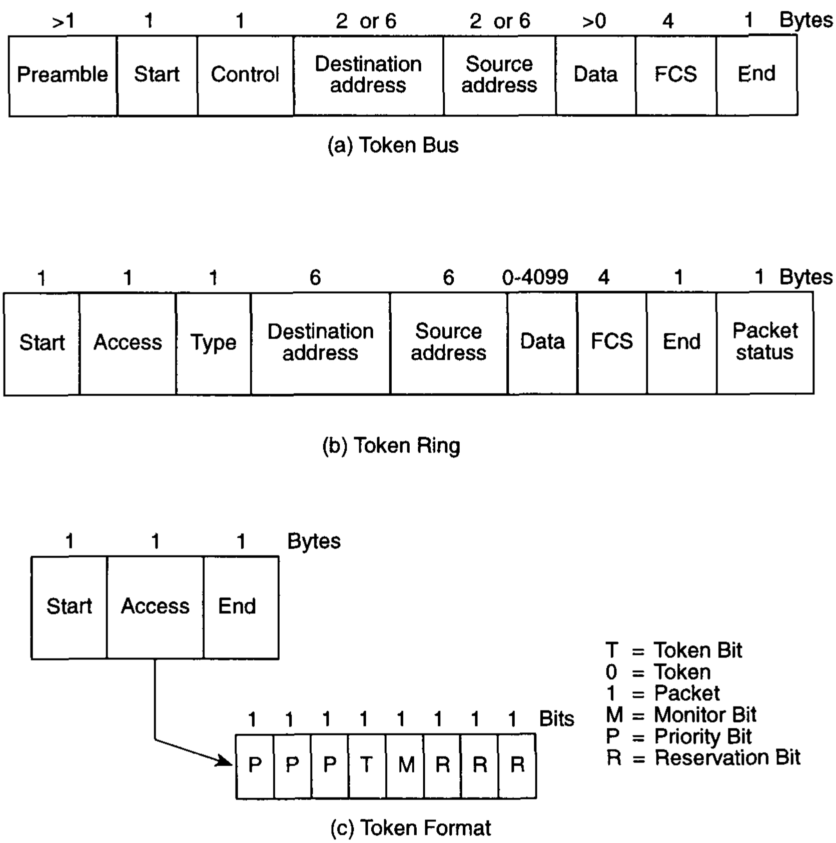

Figure 1.2 Packet format for token bus and token ring.

A number of attempts have been proposed to develop hybrid topologies and access techniques that combine random and time-assignment access.

1.3.2 Transmission Media

The transmission medium is the physical path connecting the transmitter to the receiver. Any physical medium that is capable of carrying information in an electromagnetic form is potentialy suitable for use on a LAN. In practice, the media used are twisted-pair cable, coaxial cable, and optical fiber.

Twisted-pair cable is generally used for analog signals but has been successfully used for digital transmissions. It is limited in speed to a few megabits and is often susceptible to noise. Ring, bus, and star networks can all use twisted-pair cable as a medium.

Coaxial cable consists of a central conductor and a conducting shield. It provides a substantial performance improvement over twisted-pair: it has higher capacity, can support a larger number of devices, and can span greater distances.

Optical fiber transmits light or infrared rays instead of electrical signals. It demonstrates higher capacity than coaxial cable and is not susceptible to noise or electrical fluctuations. Although there are still some technical difficulties with optical fiber, it may well be the medium choice of future networks.

1.3.3 Transmission Techniques

There are two types of transmission techniques: baseband signaling and broadband signaling. In spite of the hot debate and controversy about the merits of one technique over the other, it appears that the two techniques will coexist for some time, filling different needs.

Baseband signaling literally means that the signal is not modulated at all. It is totally digital. The entire frequency spectrum is used to form the signal, which is transmitted bidirectionally on broadcast systems such as buses. Baseband networks are limited in distance due to signal attenuation.

Broadband signaling is a technique by which information is frequency modulated onto analog carrier waves. This allows voice, video, and data to be carried simultaneously. Although it is more expensive than baseband because of the need for modems at each node, it provides larger capacity.

1.4 Standardization of LANs

The incompatibility of LAN products has left the market small and undecided. One way to increase the market size is to develop standards that can be used by the numerous LAN product manufacturers. The most obvious advantage of standards is that they facilitate the interchange of data between diverse devices connected to LAN. The driving force behind the standardization efforts is the desire by LAN users and vendors to have “open systems” in which any standard computer device would be able to interoperate with others. Attempts to standardize LAN topologies, protocols, and modulation techniques have been made by organizations such as those shown in Table 1.2.

Table 1.2 LAN Standardization Activities

Organization	Standards
ISO	TC 97/SC6 CSMA/CD, token bus, token ring, slotted ring
CCITT	SG 18 Connection between ISDN and LAN
IEEE	802 Logical link control, CSMA/CD, token bus, token ring, metropolitan area network
ECMA	TC 24 CSMA/CD, token bus, token ring

The International Standards Organization (ISO) is perhaps the most prominent of these, and it is responsible for the seven-layer model of network architecture, initially developed for WANs, called the reference model for open systems interconnection (OSI). The International Telegraph and Telephone Consultative Committee (CCITT), based in Geneva, is a part of the International Telecommunications Union (ITU) and is heavily involved in all aspects of data transmission. It has produced standards in Europe but not in the US. In the US the American National Standard Institute (ANSI), the National Bureau of Standards (NBS), and the IEEE are perhaps the most important bodies. The IEEE 802 committee has developed LAN protocol standards for the lower two layers of the ISO's OSI reference model, namely the physical and link control layers. The physical standard defines what manufacturers must provide in terms of access to their hardware for a user or systems integrator. More recently, the European Computer Manufacturers Association (ECMA) has followed along the same lines. Although network standards are being developed by the various organizations, standardization is still up to the manufacturers. The ISO protocols have the advantage of international backing, and most manufacturers have made the commitment to implement them eventually.

1.5 LAN Architectures

A network architecture is a specification of the set of functions required for a user at a location to interact with another user at another location. These interconnect functions include determination of the start and end of a message, recognition of a message address, management of a communication link, detection and recovery of transmission errors, and reliable and regulated delivery of data. A general network architecture thus describes the interfaces, algorithms, and protocols by which processes at different locations and/or at heterogeneous machines could communicate. Although the architectures developed by different vendors are functionally equivalent, they do not provide for easy interconnection of systems of different make.

1.5.1 The OSI Model

As mentioned in the previous section, the need for standardization and compatibility at all levels has compelled the International Standards Organization (ISO) to establish a general seven-layer hierarchical model for universal intercomputer communication. This arhitecture, known as the Open Systems Interconnection model (see Figure 1.3), defines seven layers of communication protocols, with specific functions isolated at each level. The OSI model is a reference model for the exchange of information among systems that are *open* to one another for this purpose by virtue of their mutual use of the applicable standards. The seven hierarchical layers are hardware and software functional groupings with specific well-defined tasks. The OSI model states the purpose of each layer and describes the services provided by each within its layer and to the adjacent higher and lower layers. Details of the implementation of each layer of OSI model depend on the specifics of the application and the characteristics of the communication channel employed.

1.5.2 The Seven OSI Layers

The *application layer*, level 7, is the one the user sees. It provides services directly comprehensible to application programs: login, password checks, network transparency for distribution of resources, file and document transfer, and industry-specific protocols.

The *presentation layer*, level 6, is concerned with interpreting the data. It restructures data to or from the standardized format used within a network, text compression, code conversion, file format conversion, and encryption.

The *session layer*, level 5, manages address translation and access security. It negotiates to establish a connection with another node on the network and then to manage the dialogue. This means controlling the starting, stopping, and synchronization of the conversion.

The *transport layer*, level 4, performs error control, sequence checking, handling of duplicate packets, flow control, and multiplexing. Here it is determined whether the channel is to be point-to-point (virtual) with ordered messages, isolated messages with no order, or broadcast messages. It is the last of the layers concerned with communications between peer entities in the systems. The transport layer and those above are referred to as the upper layers of the model, and they are