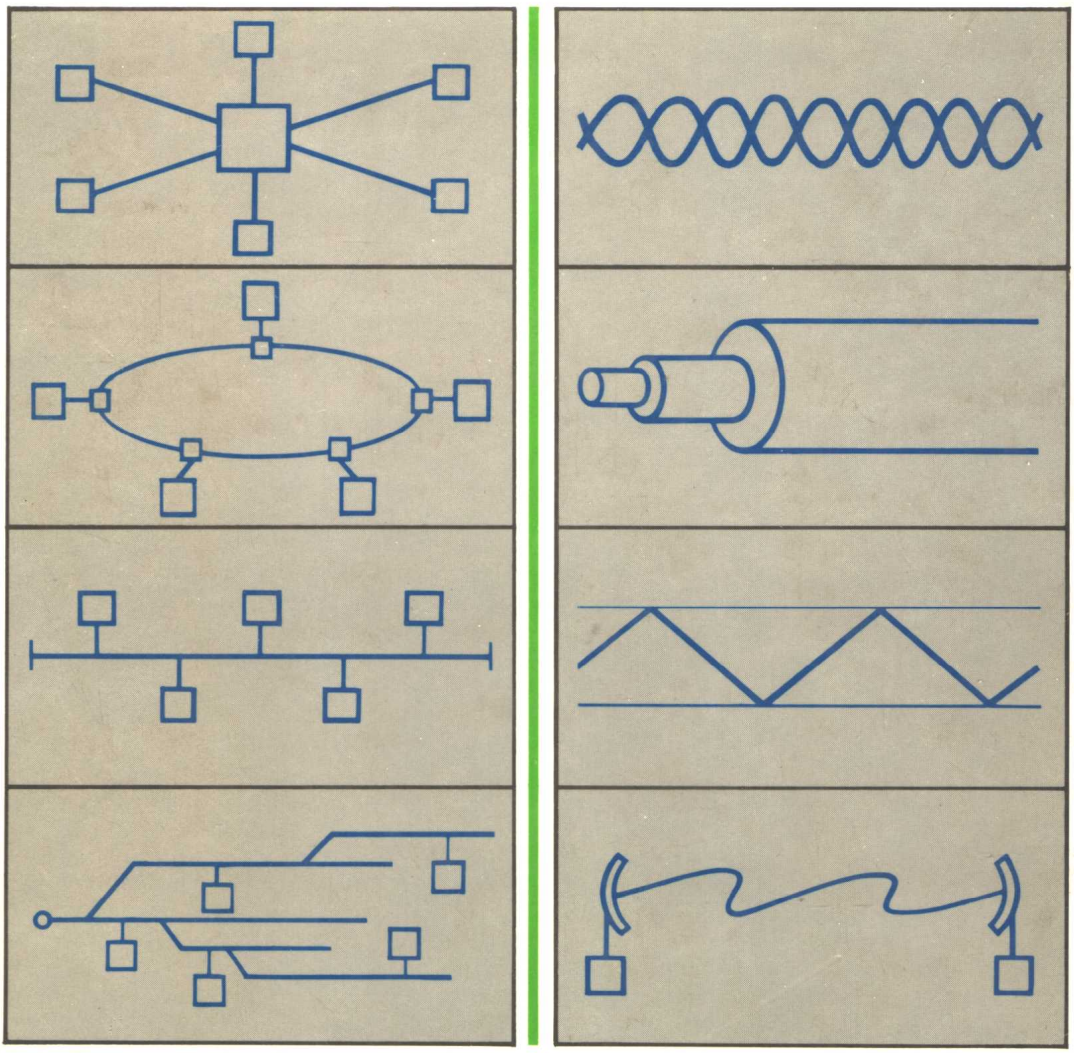
SECOND EDITION

LOCAL NETWORKS

An Introduction

WILLIAM STALLINGS



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SECOND EDITION

Macmillan Publishing Company
New York

Collier Macmillan Publishers
London

PRINTED IN THE UNITED STATES OF AMERICA

Macmillan Publishing Company
866 Third Avenue, New York, New York 10022

Collier Macmillan Canada, Inc.

LIBRARY OF CONGRESS CATALOGING IN PUBLICATION DATA

Stallings, William.
Local networks.

Includes index.
1. Local area networks (Computer networks)
I. Title.
TK5105.7.S73 1987 004.6'8 86-12857
ISBN 0-02-415520-9

Printing: 3 4 5 6 7 8 Year: 7 8 9 0 1 2 3 4 5 6

ISBN 0-02-415520-9

BIOGRAPHY

William Stallings received a PhD from M.I.T. in computer science and a B.S. from Notre Dame in electrical engineering. He is an independent consultant and president of Comp/Comm Consulting of Great Falls, VA. He has been vice president of CSM Corp., a firm specializing in data processing and data communications for the health-care industry. He has also been director of systems analysis and design for CTEC, Inc., a firm specializing in command, control, and communications systems. He has also been senior communications consultant for Honeywell, where he was involved in the planning and design of communications and network products.

Dr. Stallings is the author of numerous technical papers and the following books:

Local Networks: An Introduction, second edition, Macmillan, 1987
Computer Organization and Architecture, Macmillan, 1987
Data and Computer Communications, Macmillan, 1985
Reduced Instruction Set Computers, IEEE Computer Society Press, 1987
Computer Communications: Architectures, Protocols, and Standards, IEEE Computer Society Press, 1985
Integrated Services Digital Networks (ISDN), IEEE Computer Society Press, 1985
Local Network Technology, second edition, IEEE Computer Society Press, 1985
A Manager's Guide to Local Networks, Prentice-Hall, 1983

Preface

Perhaps no other major innovation in data processing or data communications has been so widely discussed or so eagerly anticipated before its maturity as local networks. Local networks are attractive for such features as high availability and the ability to support multiple vendor equipment. And, although the technology is rapidly evolving, the principal architectural forms and design approaches have emerged.

Objectives

This book focuses on the broad and constantly changing field of local networks. The aim of the text is to provide a reasoned balance among breadth, depth, and timeliness. The book emphasizes topics of fundamental importance concerning the technology and architecture of local networks. Certain key areas, such as the network interface and performance, are treated in some detail. Others, such as security and reliability, can only be treated in an introductory fashion.

The book explores the key topics in the field in the following general categories:

- *Technology and architecture:* There is a small collection of ingredients that serves to characterize and differentiate local networks, including transmission

medium, network topology, communication protocols, switching technique, and hardware/software interface.

- *Network type:* It is convenient to classify local networks into three types, based partly on technology and partly on application. These are local area network (LAN), high-speed local network (HSLN), and digital switch/digital private branch exchange (PBX).
- *Design approaches:* While not attempting to be exhaustive, the book exposes and discusses important issues related to local network design.

Conspicuously missing from this list is a category with a title such as "typical systems." This book focuses on the common principles underlying the design and implementation of all local networks. It should, therefore, give the reader sufficient background to judge and compare local network products. A description of even a small sample of such systems is beyond the scope of this book. Discussions of specific systems are included herein only when they are the best vehicle for communicating the concepts and principles under discussion.

In terms of style, the book is primarily:

- *Descriptive:* Terms are defined and the key concepts and technologies are discussed in some detail.
- *Comparative:* Wherever possible, alternative or competing approaches are compared and their relative merits, based on suitable criteria, are discussed.

On the other hand, analytic and research-oriented styles are present to a much lesser degree. Virtually all of the mathematical content is confined to the chapters on performance, and even there, the emphasis is on results rather than derivations.

Intended Audience

This book is intended for a broad range of readers interested in local networks:

- *Students and professionals in computer science and data communications:* The book is intended as both a textbook for study and a basic reference volume for this exciting area within the broader fields of computer science and data communications.
- *Local network designers and implementors:* The book discusses the critical design issues and illustrates alternative approaches to meeting user requirements.
- *Local network customers and system managers:* The book alerts the reader to some of the key issues and tradeoffs, and what to look for in the way of network services and performance.

The book is intended to be self-contained. For the reader with little or no background in data communications, a brief primer is included.

Plan of the Text

The book is organized to clarify both the unifying and differentiating concepts underlying the field of local networks. The organization of the chapters is as follows:

1. *Introduction:* This chapter defines the term local network and looks at some of the applications and advantages and disadvantages.
2. *Topics in data communications and computer networking:* This necessarily brief survey explains the relevant concepts used throughout the book.
3. *Local network technology:* Focuses on the key characteristics of transmission medium and topology. The classification of local networks used in this book is presented and discussed.

4, 5. *Local area networks:* The term local area network (LAN) is often mistakenly identified with the entire field of local networks. LANs are general-purpose in nature and most of the better-known local networks fall into this class. The major types of LANs—baseband bus, broadband bus/tree, and ring—are described and compared. The important issue of medium access control protocols is explored. The standards for LANS are also described.

6. *High-speed local networks:* This chapter focuses on a special purpose high-speed type of local network, examining current technology and standards and possible future directions.
7. *Circuit-switched local networks:* Networks in this category constitute the major alternative to LANS for meeting general local interconnection needs. The category includes the data-only digital switch and the voice/data digital private branch exchange (PBX). This chapter explores the technology and architecture of these devices and examines their pros and cons relative to LANs.
8. *The network interface:* The nature of the interface between an attached device and LAN or HSLN is an important design issue. This chapter explores some alternatives.

9, 10. *Network performance:* The purpose of these chapters is to give some insight into the performance problems and the differences in performance of various local networks.

11. *Internetworking:* In the majority of cases, local networks will be connected in some fashion to other networks. Some alternatives are explored.

12. *Local network design issues:* The purpose of this chapter is to give the reader some feel for the breadth of design issues that must be addressed in implementing and operating local networks.

In addition, the book includes an extensive glossary, a list of frequently-used acronyms, and a bibliography. Each chapter includes problems and suggestions for further reading.

The book is suitable for self-study and can be conveniently covered in a one-semester course. It covers the material in Module 7 (Local Area Networks) of Subject Area 25 (Computer Communications Networks) of the 1983 IEEE Computer Society Model Program in Computer Science and Engineering. It also covers portions of CS 24 (Computer Communication Networks and Distributed Processing) of the 1981 ACM Recommendations for Master's Level Programs in Computer Science.

A final note: a considerable fraction of the material is organized with reference to the Open Systems Interconnection (OSI) model and to local network standards. This structure is suggestive of the certain future direction of local network architecture, and, equally important, it provides a terminology and frame of reference that is becoming universal in networking discourses.

Related Materials

The author has produced other material that may be of interest to students and professionals. *Local Network Technology, Second Edition* (1985, IEEE Computer Society Press, P.O. Box 80452, Worldway Postal Center, Los Angeles, CA 90080; telephone 800-272-6657) is a companion to this text, and follows the same topical organization. It contains reprints of many of the key references used herein, these are indicated by an asterisk when cited in the recommended reading section of each chapter.

A set of videotape courses specifically designed for use with this book is available from Instructional Television Department, College of Engineering, University of Maryland, College Park, MD 20742; telephone (301) 454-7451. The author has also prepared a vidoetape course on communication networks. About half the course is devoted to local networks and the digital PBX; the remainder covers packet-switched, packet-radio, and satellite networks. It is available from the Association for Media-Based Continuing Education for Engineers, 500 Tech Parkway NW, Suite 200A, Atlanta, GA 30313; telephone (404) 894-3362.

Data and Computer Communications (1985, Macmillan) covers fundamental concepts in the areas of data transmission, communication networks, and computer-communications protocols.

Acknowledgments

Many people have helped me during the preparation of this book. I would like particularly to acknowledge and thank the following people. K.C. Houston first introduced me to this fascinating field and provided me with the opportunity to pursue my interest. George Arnovick, Lynn DeNoia, Donald DeVorkin, Harvey Freeman, Kathy Hanson, Mary Loomis, Ira Pohl, Bart Stuck, and Gene Swystun reviewed all or a portion of the manuscript. Dave Carlson, George Jelatis, and Bob Donnan of the IEEE 802 Committee and Dolan Toth of the ANS X3T9.5 Committee reviewed the descriptions of the respective standards; of course, any errors remaining in the text are my responsibility. My editor, Sally Elliott, shepherded the book through all the stages from proposal to printing in as rapid and professional a manner as one could wish for. Alice Wilding-White did an amazingly fast job of typing the manuscript. And, finally, my wife Tricia provided the two ingredients essential to the writing of this book: her patience and encouragement.

The Second Edition

In the three years since *Local Networks: An Introduction* was published, the field has continued to evolve and expand, necessitating an early second edition. The same chapter organization has been retained, but much of the material has been revised and new material has been added. The coverage of the IEEE 802 and ANS X3T9.5 local network standards has been expanded to include more detail on the final standards and a description of forthcoming additions. Perhaps the most noteworthy addition is the coverage of optical fiber local networks, reflecting the fact that this most promising of transmission media is at last arriving on the local network scene. The chapter on high-speed local networks has been expanded; what was once virtually a one-product industry is blossoming with a variety of approaches and products. Other chapters, notably those on the network interface and on internetworking, have enjoyed updating and expansion, and no chapter has escaped revision. The revision of this text has been an interesting and rewarding experience and I hope that its readers find it a useful guide to this fascinating field.

W.S.

CONTENTS

CHAPTER 1

Introduction

1.1

A DEFINITION OF LOCAL NETWORKS

To formulate a definition of the term *local network,* and to characterize the purposes of such networks, it is important to understand the trends that have brought about local networks.

Of most importance is the dramatic and continuing decrease in computer hardware costs, accompanied by an increase in computer hardware capability. Today's microprocessors have speeds, instruction sets, and memory capacities comparable to the most powerful minicomputers of a few years ago. This trend has spawned a number of changes in the way information is collected, processed, and used in organizations. There is increasing use of small, single-function systems, such as word processors and small business computers, and of general-purpose microcomputers, such as personal computers and Unix-based multiuser workstations. These small, dispersed systems are more accessible to the user, more responsive, and easier to use than large central time-sharing systems.

All of these factors lead to an increased number of systems at a single site: office building, factory, operations center, and so on. At the same time there

is likely to be a desire to interconnect these systems for a variety of reasons, including:

- To share and exchange data between systems
- To share expensive resources

The ability to exchange data is a compelling reason for interconnection. Individual users of computer systems do not work in isolation, and will want to retain some of the benefits provided by a central system. These include the ability to exchange messages with other users, the ability to access data from several sources in the preparation of a document or for an analysis, and the opportunity for multiple users to share information in a common file.

To appreciate the second reason, consider that although the cost of data processing hardware has dropped, the cost of essential electromechanical equipment, such as bulk storage and line printers, remains high. In the past, with a centralized data processing facility, these devices could be attached directly to the central host computer. With the dispersal of computer power, these devices must somehow be shared.

We will elaborate on these and other reasons later in this chapter. For now, the discussion above should be enough to motivate the following definition of a *local network:*

A local network is a communications network that provides interconnection of a variety of data communicating devices within a small area.

There are three elements of significance in this definition. First, a local network is a communications network. That is, it is a facility for moving bits of data from one attached device to another. The application-level software and protocols that are required for attached devices to function cooperatively are beyond the scope of this book. As a corollary to this definition, note that a collection of devices interconnected by individual point-to-point links is not included in the definition nor in this book.

Second, we interpret the phrase *data communicating devices* broadly, to include any device that communicates over a transmission medium. Examples:

- Computers
- Terminals
- Peripheral devices
- Sensors (temperature, humidity, security alarm sensors)
- Telephones
- Television transmitter and receivers
- Facsimile

Of course, not all types of local networks are capable of handling all of these devices.

Third, the geographic scope of a local network is small. The most common

occurrence is a network that is confined to a single building. Networks that span several buildings, such as on a college campus or military base, are also common. A borderline case is a network with a radius of a few tens of kilometers. With appropriate technology, such a system will behave like a local network.

Another element that could be added to the definition is that a local network is generally privately owned rather than a public or commercially available utility. Indeed, typically, a single organization will own both the network and the attached devices.

Some of the typical characteristics of local networks are:

- High data rates (0.1 to 100 Mbps)
- Short distances (0.1 to 25 km)
- Low error rate (10^{-8} to 10^{-11})

The first two parameters serve to differentiate local networks from two cousins: multiprocessor systems and long-haul networks. This is illustrated in Figure 1.1. The figure indicates three types of local networks: local area networks, high speed local networks, and digital private branch exchanges. These will be defined in Chapter 3.

Other distinctions can be drawn between local networks and its two cousins, and these have a significant impact on design and operation. Local networks generally experience significantly fewer data transmission errors and significantly lower communications costs than those of long haul networks. Cost-performance tradeoffs are thus significantly different. Also, because local networks are generally owned by the same organization as the attached devices, it

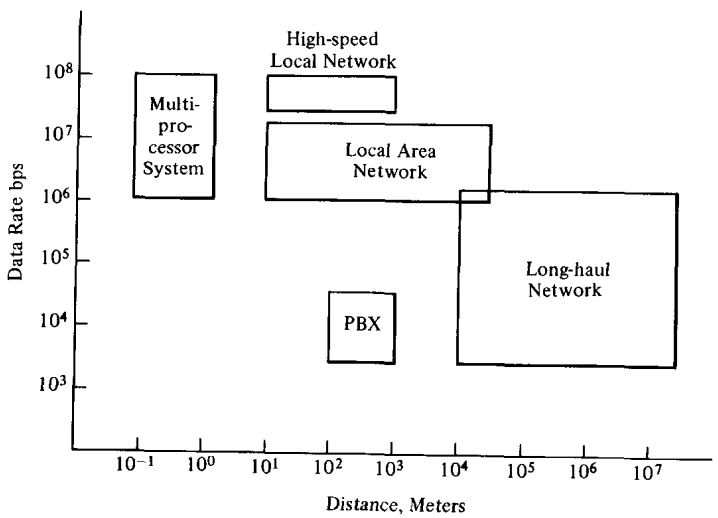

FIGURE 1-1. Comparison of Multiprocessor Systems, Local Networks, and Long-Haul Networks

is possible to achieve greater integration between the network and the devices; this topic is explored in Chapter 8.

A distinction between local networks and multiprocessors systems is the degree of coupling. Multiprocessor systems are tightly coupled, usually have some central control, and completely integrate the communications function. Local networks tend to exhibit the opposite characteristics.

1.2 BENEFITS AND PITFALLS

Table 1.1 lists some of the major benefits of a local network. Whether these are realized or not, of course, depends on the skill and wisdom of those involved in selecting and managing the local network.

One of the most important potential benefits of a local network relates to system evolution. In a nonnetworked installation such as a time-sharing system, all data processing power is in one or a few systems. In order to upgrade hardware, existing applications software must be either converted to new hardware or reprogrammed, with the risk of error in either case. Even adding new applications on the same hardware, or enhancing those that exist, involves the risk of introducing errors and reducing the performance of the entire system. With a local network it is possible to gradually replace applications or systems,

TABLE 1.1 Benefits and Pitfalls of Local Networks

Potential Benefits
System evolution: incremental changes with contained impact
Reliability/availability/survivability: multiple interconnected systems disperse functions and provide backup capability
Resource sharing: expensive peripherals, hosts, data
Multivendor support: customer not locked in to a single vendor
Improved response/performance
User needs single terminal to access multiple systems
Flexibility of equipment location
Integration of data processing and office automation
Potential Pitfalls
Interoperability is not guaranteed: software, data
A distributed data base raises problems of integrity, security/privacy
Creeping escalation: more equipment will be procured than is actually needed
Loss of control: more difficult to manage and enforce standards