DESIGN AND ANALYSIS OF COMPUTER COMMUNICATION NETWORKS

Vijay Ahuja, Ph.D.

DESIGN AND ANALYSIS OF COMPUTER COMMUNICATION NETWORKS

Vijay Ahuja, Ph.D.

International Business Machines Corporation

McGraw-Hill Book Company

New York St. Louis San Francisco Auckland Bogotá Hamburg
Johannesburg London Madrid Mexico Montreal New Delhi
Panama Paris São Paulo Singapore Sydney Tokyo Toronto

TO MY RESPECTED PARENTS
Dr. Yog Dhyan
and
Mrs. Shakuntla Ahuja

This book was set in Times Roman by Santype-Byrd.
The editors were James E. Vastyan and James B. Armstrong;
the production supervisor was Phil Galea.
The drawings were done by Danmark & Michaels, Inc.
R. R. Donnelley & Sons Company was printer and binder.

**DESIGN AND ANALYSIS OF
COMPUTER COMMUNICATION NETWORKS**

1234567890 DODO 8987654321

ISBN 0-07-000697-0

Library of Congress Cataloging in Publication Data

Ahuja, Vijay.
Design and analysis of computer communication networks.

(McGraw-Hill computer science series)
Includes index.
1. Computer networks. I. Title. II. Series.
TK5105.5.A39 001.64'404 81-11826
ISBN 0-07-000697-0 AACR2

McGraw-Hill Computer Science Series

Ahuja: *Design and Analysis of Computer Communication Networks*
Allen: *Anatomy of LISP*
Bell and Newell: *Computer Structures: Readings and Examples*
Donovan: *Systems Programming*
Feigenbaum and Feldman: *Computers and Thought*
Gear: *Computer Organization and Programming*
Givone: *Introduction to Switching Circuit Theory*
Goodman and Hedetniemi: *Introduction to the Design and Analysis of Algorithms*
Hamacher, Vranesic, and Zaky: *Computer Organization*
Hamming: *Introduction to Applied Numerical Analysis*
Hayes: *Computer Architecture and Organization*
Hellerman: *Digital Computer System Principles*
Hellerman and Conroy: *Computer System Performance*
Kain: *Automata Theory: Machines and Languages*
Katzan: *Microprogramming Primer*
Keller: *A First Course in Computer Programming Using PASCAL*
Kohavi: *Switching and Finite Automate Theory*
Liu: *Elements of Discrete Mathematics*
Liu: *Introduction to Combinatorial Mathematics*
MacEwen: *Introduction to Computer Systems: Using the PDP-11 and Pascal*
Madnick and Donovan: *Operating Systems*
Manna: *Mathematical Theory of Computation*
Newman and Sproull: *Principles of Interactive Computer Graphics*
Nilsson: *Problem-Solving Methods in Artificial Intelligence*
Payne: *Introduction to Simulation: Programming Techniques and Methods Analysis*
Rice: *Matrix Computations and Mathematical Software*
Rosen: *Programming Systems and Languages*
Salton: *Automatic Information Organization and Retrieval*
Salton and McGill: *Introduction to Modern Information Retrieval*
Siewiorek, Bell, and Newell: *Computer Structures: Principles and Examples*
Stone: *Introduction to Computer Organization and Data Structures*
Stone and Siewiorek: *Introduction to Computer Organization and Data Structures: PDP-11 Edition*
Tonge and Feldman: *Computing: An Introduction to Procedures and Procedure-Followers*
Tremblay and Bunt: *An Introduction to Computer Science: An Algorithmic Approach*

Tremblay and Bunt: *An Introduction to Computer Science: An Algorithmic Approach, Short Edition*
Tremblay and Manohar: *Discrete Mathematical Structures with Applications to Computer Science*
Tremblay and Sorenson: *An Introduction to Data Structures with Applications*
Tucker: *Programming Languages*
Wiederhold: *Database Design*
Winston: *The Psychology of Computer Vision*

McGraw-Hill Advanced Computer Science Series

Davis and Lenat: *Knowledge-Based Systems in Artificial Intelligence*
Feigenbaum and Feldman: *Computers and Thought*
Kogge: *The Architecture of Pipelined Computers*
Lindsay, Buchanan, Feigenbaum, and Lederberg: *Applications of Artificial Intelligence for Organic Chemistry: The Dendral Project*
Nilsson: *Problem-Solving Methods in Artificial Intelligence*
Winston: *The Psychology of Computer Vision*
Wulf, Levin, and Harbison: *HYDRA/C.mmp: An Experimental Computer System*

PREFACE

In this era of a growing confluence of communications and computing, it is becoming increasingly important for computer scientists, programmers, engineers, and network designers to understand the concepts used to design efficient and viable communication networks. Such concepts range from understanding the ever-growing variety of network components to observing total network behavior. There exists a need to provide a concise description of the various network components, strategies to put them together, and approaches to analyze and improve network behavior. It is our intent to familiarize the reader with the concepts and approaches required for the design and analysis of computer communication networks.

This book is intended for students and professionals who have some background in computer software or in computer or communication hardware. For those associated with networks, the book should provide an introduction to the fundamentals of computer communication networks and their analysis as well as an insight into diverse approaches and algorithms. The book provides both descriptive and analytic treatment of various aspects of network design. The emphasis is on the components of networks, such as transmission links and network nodes, and on network analysis problems, such as routing and flow control. It is hoped that this book will also serve as the textbook for a first course in computer communications in an undergraduate or graduate curriculum.

The book consists of eight chapters and an appendix. Chapter 1 provides an introduction to networks, including packet switching and

circuit switching. Chapters 2 through 7 use several concepts in probability theory and queuing theory, and Chap. 8 presents these concepts together. Readers requiring a background in probability theory or queuing theory are suggested to review Chap. 8 before proceeding to study Chaps. 2 through 7.

Chapters 2 and 3 describe the network components. Chapter 2 treats transmission links, namely, terrestrial, radio, and satellite channels and optical fiber. It also includes treatment of various polling strategies for terrestrial links, and approaches for efficient utilization of satellite links and radio channels. Chapter 3 addresses the functions and design aspects of a network node. It also provides approaches used to estimate processor capacity, memory size, and frequency of overruns on message buffers. Chapter 4 describes various algorithms for the topological design of a network. Chapter 5 contains a description of network protocols for internode communications and for managing network resources. Chapter 6 addresses network congestion and deadlock problems, and describes several algorithms that control message flow in a network. Chapter 7 provides a description of various approaches for selecting and defining message routes in a network. Chapter 8 describes techniques to estimate network performance parameters, such as response time and throughput. It also includes an introduction to elementary concepts of probability theory that are used in other parts of the book. The appendix contains a description of some public networks, such as DATAPAC and TYMNET.

ACKNOWLEDGMENTS

The task of writing a book requires cooperation, contribution, and sacrifice on the part of numerous individuals. I wish to express my deep gratitude to the reviewers—George A. Deaton, Jr., IBM Corporation; John Spragins, Clemson University; Harold S. Stone, University of Massachusetts; and Safwat Zaky, University of Toronto—who contributed significantly to improving the quality of my manuscript. My employer, IBM Corporation, and its management, provided typing help and encouragement throughout this effort. A special thanks is due to my wife, Neeta, for her moral support, and to my children, for always offering complete cooperation to my unconventional working hours during evenings, weekends, and holidays.

Vijay Ahuja

CONTENTS

CHAPTER ONE

INTRODUCTION

CHAPTER OUTLINE

The further backward you can look, the further forward you can see.

Winston Churchill

1-1 NETWORKS—A PERSPECTIVE

Networks first appeared under the guise of time-shared systems in the late 1960s. In a time-shared system, each of the several terminal users has exclusive use of the system resources on a time-sliced basis. Operating systems, such as those for the IBM System/360, GECOS III for the Honeywell 600 series, and the Univac 1108, offered the options of time-shared systems. Some operating systems were entirely devoted to time sharing, such as the PDP-8 Time Sharing System (TSS/8). Time-sharing operating systems were followed by a variety of communication-oriented software packages. Several communication access methods, terminal system software, and interactive system software packages were introduced in the 1960s and early 1970s. Some of the well-known packages are those for the airline reservations, the information retrieval systems for libraries, and the general-purpose database management systems, such as the IBM Information Management System/360. The computer and communication industries were introducing asynchronous (start/stop) and synchronous (binary synchronous) line protocols. By the late 1970s, several types of terminals, terminal controllers, front-end processors, line concentrators, and related equipment had grown to a sizeable portion of the data processing market.

The early networking years saw new strides in connecting computing equipment to existing communication facilities. A courtship of the computing and communication technologies was taking place. Line multiplexers, such as the IBM 270X and 370X series, and modems provided a computer interface for several communication links. By 1972, several computer networks had emerged. Important characteristics of some of them are tabulated in Table 1-1. Experimental networks, such as the Distributed Computing System (DCS) in California and Triangle Universities Computation Center (TUCC) in North Carolina, were being developed by universities to serve their student communities. The DCS network uses a ring interface for each node, and connects all the nodes by a loop [7],* while TUCC is a centralized (star-connected) network serving three universities and other educational institutions in North Carolina.

* Bracketed numbers refer to the references at the end of this chapter.

Table 1-1 Early networks and their characteristics

	ARPA	CYBERNET	DCS	MERIT	OCTOPUS	TSS	TUCC
Organization	Distributed	Distributed	Distributed	Distributed	Mixed	Distributed	Centralized
Number of nodes	23	36	9	3	10	9	4
Communication interface	Honeywell DDP 516	CDC 3300 PPU	Ring interface	PDP-11	CDC PPU	IBM 2701	IBM 2701
Communication protocol	Message-switched	Message-switched	Mixed	Message-switched	Point-to-point	Point-to-point	Point-to-point
Message format	Variable length	Fixed length	Variable length	Variable length	Variable length	Variable length	Variable length

Source: D. J. Farber, "Networks: An Introduction," *Datamation*, April 1972, p. 37. Reprinted with permission of *Datamation* magazine.

In the mid-1970s, there was a phenomenal growth in nearly every aspect of communication networks. In the case of terminals, the early typewriter terminals were replaced by a wide range of function-rich terminals. The new terminals ranged from memory-less display units to the so-called front-end processors with disks, memory, tapes, printer, and display. Display terminals now include novel features such as color and multidimensions. Terminals or terminal systems have been developed for specific applications, such as text editing, office mail, banking, supermarket checkouts, point-of-sales systems, hospital systems, securities, production control, inventory control, computer-aided instructions and design, and the like.

An important aspect of communication network development has been the reduction in cost and improvement in speed and quality of transmission links. In the early years, terminals were connected through low-speed start-stop lines. Several innovations in communication technology have led to faster and more reliable links. Today, networks are using terrestrial links (with speeds on the order of megabits per second), satellite links, and radio channels.

The concept of a network node has grown from a simple communication line multiplexer to programmable minicomputers. Network nodes now provide several additional functions, such as message- or packet-switching, routing, flow control, network monitoring, and management. The concept of offloading the host processors has culminated in a new class of network nodes—the *front-end processors*—that also provide data management and transaction processing functions.

Concurrent with the above developments, several groups started to investigate various problems in connecting terminal networks to more than one host computer. The objective of one of the groups was to provide resource sharing by interconnecting several host computers. In early 1969, a contract for the Advanced Research Project Agency (ARPA) network was awarded to Bolt, Beranek and Newman, Inc. (BB&N), a Massachusetts-based engineering firm. The ARPA network, or ARPANET, grew from a small four-node net in 1969 to a network providing computing to about 100 computers by 1975 [10, p. 305], Figure 1-1 shows the ARPANET topology in 1969; Fig. 1-2 shows a more recent topology [12].

Networks can transmit messages by *circuit switching* or *store-and-forward message switching*. In circuit switching, networks transmit messages over a group of temporarily dedicated links on the message route, which are allocated simultaneously for message transfer. In store-and-forward message switching, the networks store and then