网络与通信技术影印版系列

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Second Edition

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Darren L . Spohn

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The first edition of this book was dedicated to my parents, Karl and Regina, and my best friend (now wife), Becky. For this edition I add a dedication to my son, Alexander. There is nothing better in this world than family.

Preface

PURPOSE OF THIS BOOK

The primary objective of this book is to teach the principles and science of designing a data network through the presentation of a *broad scope* of data and computer communications standards, architectures, hardware, software, protocols, technologies, and services as they relate to designing data networks. The book attempts to take the reader through the entire network design process, from compiling the requirements through design and into optimization techniques. Tried and true methods are presented, augmented by new developments in the industry, thus providing a tome complete with referenced technical details and real world experience.

Emphasis is placed on the predominant technologies of the 1990s and emerging technologies of the next century, including X.25 packet switching, frame relay, SMDS, ATM, and SONET. This book is designed to walk the reader through the process of a data-network design using these technologies, paying attention to both the technical and business decisions required. It is the author's intent to provide a broad overview of these topics with insight into practical design aspects of each, allowing the reader to perform an end-to-end network design. Standards and reference pointers are provided to the reader for further detailed study.

The logical and physical design of hardware and software is not the only process in a network design. Network designs encompass many aspects including making the business case, compiling the requirements, choosing the technology, planning for capacity, vendor selection, and weighing all the issues before the actual design begins. After these efforts have produced a workable design plan, there are additional issues which must be addressed, including operations, maintenance, and management support structures. While resolution of many of these additional tasks often falls to the project manager, many other people must be involved in the many processes affecting the integrity of the design, and must assess the impact of each decision as it relates to the overall network design.

This book will concentrate on the science and art of data-network design, and will include detailed operational descriptions of:

- X.25 packet switching
- Frame relay
- SMDS
- ATM
- SONET

A detailed design book, resplendent with addressing schemes, detailed bus structures, discrete circuit operations, and protocol specifics would take volumes. In fact, one book could be published on each protocol and technology. The primary purpose of this text, however, is to provide a *global view* of these technologies and how they can play a key role in the data-network design process.

INTENDED AUDIENCE

This text is designed for data communications novices through advanced design engineers, including all levels of communications management. Some business and data communications basics are provided in the beginning chapters. The text presents design material at a high level, assuming the reader has access to resources or colleagues with a background in basic data communications and a working knowledge of transmission basics. Although this skill level is assumed, some discussion on hardware and protocol basics is provided. The book serves as professional reading as well as a desktop reference guide, and has been used in many college classrooms across the United States.

It is important to note that this entire text has been rewritten from the first edition. Thanks to everyone for their submissions, corrections, and comments over the past three years.

OVERVIEW OF THIS BOOK

Data Network Design, Second Edition, is divided into six parts.

Part 1 provides the business drivers and networking directions that have shaped data communications.

Chapter 1 defines data-network design through the evolution and history of communications along with the recent move to outsourcing and out-tasking.

Chapter 2 presents the changes in corporate infrastructures and the applications and communications technologies that have enabled us to move in new directions in computer and information networking.

Part 2 provides a broad overview of the standards and services that define data networking: organizations, architectures, circuits, hardware, and protocols.

Chapter 3 presents national and global industry standards organizations, current forums, and the processes of standardization.

Chapter 4 presents the seven-layer OSI Reference Model (OSIRM), standard computer and protocol architectures, the digital hierarchy, the history of ISDN, and the definition of network services.

Part 3 introduces the reader to the basics of transmission, networks, hardware, and switching.

Chapter 5 provides a thorough coverage of network topologies, circuit types and services, a study of private versus switched networks, asynchronous and synchronous transmission methods, and an in-depth review of the predominant types of data-networking hardware.

Chapter 6 provides the reader with a study of multiplexing and switching technologies, including circuit and packet switching.

Part 4 presents a detailed study of protocols and interfaces.

Chapter 7 starts with the first two layers of the OSIRM including the physical layer and the data-link layer, along with its Media Access Control (MAC) and Logical Link Control (LLC) sublayers. The chapter concludes with a study of switching in the LAN environment.

Chapter 8 presents a study of bridging and routing protocols, as well as network and transport layer protocols of the OSIRM. Legacy SNA protocols are presented, including a study of internetworking SNA protocols over routed and switched environments. At this point the reader should understand the basics.

Chapter 9 is devoted solely to the principles and application of packet switching.

Chapters 10 and 11 present the definition, standards, protocols, transmission theory, operation, and service provided by frame relay.

Chapter 12 then presents the theory and application behind SMDS.

Chapters 13 and 14 provide a study of ATM theory and application.

Chapter 15 presents SONET.

These technology chapters in Part 3 explain protocol structure, format, interfaces, and theory. They also contain software, hardware, and design recommendations.

Part 5 steps the reader through defining data-network design requirements, performing the traffic analysis and capacity-planning process, and comparing circuit-, packet-, frame-, and cell-switched technologies.

Chapter 16 assists the designer in analyzing the complete set of user requirements.

Chapter 17 then provides the traffic-analysis calculations that turn these requirements into a capacity plan. These two chapters lead directly into the access design.

Chapter 18 provides numerous comparisons of every aspect of each technology and service.

Chapter 19 provides guidelines for the RFI and RFP processes as well as criteria for choosing a service provider and the future relationship with that service provider.

Part 6 deals with the design and management of networks.

Chapter 20 starts with the access design – the point where the user accesses the network or public network service.

Chapter 21 continues with the backbone design. The backbone is often a switched-network service. This chapter also contains some valuable practical insights on network tuning.

Chapter 22 presents addressing, including a primer on IP and IPX address design.

Chapter 23 presents operations and maintenance issues, as well as network-management protocols and techniques including SNMP and RMON.

Chapter 24 describes design and management tool types, components, and capabilities.

Chapter 25 presents a study of international private and public data networking.

This book also contains several appendixes. *Appendix A* lists the major acronyms and abbreviations used in the book. *Appendix B* provides a reference of national and international standards sources. *Appendix C* gives a reference table for creating IP network address masks. *Appendix D* provides a summary of all IP address subnet mask types. And, finally, the *Glossary* defines common terms associated with the technologies, architectures, services, and protocols encountered throughout the book.

INTRODUCTION

Voice, data, and video – which of these three methods of communications do you use every day? The answer is probably all three. Every day we talk on a fixed or cellular phone, interface with some form of personal or mainframe computer or server (even an ATM cash machine!), or watch television and video tapes at home and at work. But how is information "networked" between those human interface devices – phones, computers, and video display or recorders? Often there are complex data communications networks that aggregate and then transmit and receive this "data" across the neighborhood or across the world. It is with these data-communications networks, or more specifically their design, that we deal with in this book.

Data-communications users are constantly demanding and using more bandwidth or network resources. Portable cellular phones, Internet access from the home, and video phones are just a few examples where the consumer requires more network resources or bandwidth. Distributed computing with client-server applications, voice-data-video integration at the desktop, huge cross-country file transfers of medical imaging files and databases, and desktop video conferencing are a few corporate applications that are driving the need for more bandwidth. And it is not just more bandwidth that consumers want, but cheaper and more flexible bandwidth, and not only dedicated, but on-demand! The data-transfer bandwidths for text, video, voice, and imaging traffic increase exponentially, as do the networks required to transport that traffic.

We are now living in a distributed data world. Everyone needs access to everyone else's data. Networks made of many meshed dedicated circuits are quickly becoming the exception as switched public and private data networks span the globe. Computers need to talk to one another the same way people pick up the phone and dial anyone in the world. Telecommuting is on the rise and mobile computing is a necessity. Because of these needs, the market for high-speed data transport is exploding. The age of gigabit-per-second data transport is here. Local and metropolitan area networks (LANs and MANs) have crossed the 100 Mbps threshold and wide area network (WAN) communication speeds in the megabits and soon gigabits per second are becoming commonplace. Technologies such as ATM are offering the key WAN platforms over which multimegabit services such as frame relay, SMDS, and IP are being offered. And IP networks continue to proliferate.

Many businesses' bandwidth requirements are exploding, such as medical institutions that transfer multimegabit imaging files, and film-making companies that store and transport video images recorded directly into a computer and digitized. The most important aspect of these style networks is their ability to store and retrieve large image files. For large networks requiring flexible addressing and transfer of data of this type, SMDS and ATM offer alternatives to dedicated private lines. And it seems that ATM-based platforms offering frame relay, IP, SMDS, circuit emulation, and LAN extension and emulation services will provide the longer term solution.

LANs and client-server applications have become an integral element of almost every major corporation. The move is toward visual-oriented end-user interfaces in computer software packages that are becoming icon-based through the use of Graphical User Interfaces (GUIs). As the number of LANs continues to grow, so do their local and wide area interconnectivity requirements. Router networks have replaced the older private line bridge network infrastructures, and they themselves are being somewhat replaced with switching hub technology. Frame relay emerged in the 1990s as the first high-speed, bandwidth-on-demand service to compete directly with private lines. But LAN-to-LAN is not the only technology best served by frame relay. Many businesses have an imbedded SNA traffic base. Much of this traffic is also ideal for frame relay transport. One thing is constant across all of these trends – the need for more bandwidth.

In the search for new technology to provide data transport bandwidths and internetworking of this scale, we often rely on versions of older packet technology. Packet switching has moved into the 1990s in the form of frame relay and cell switching. As services such as frame relay and ATM gain increasing support from equipment vendors and carriers, and IP networks continue to proliferate, the user — as usual — seems to be the driving factor as to which technology will succeed.

Virtual LAN capability is appearing in LAN switches to redefine communication flows and reduce routing requirements within the customer premises environment. Routers still play a key role, but now the user must decide not only when to bridge or route but also when to route or switch. A number of 100 Mbps technologies such as Fiber Distributed Data Interface (FDDI) and 100 Mbps Ethernet are allowing existing LAN users to increase their transfer speeds in the LAN almost tenfold. LAN segmentation down to single user LANs is also helping. Synchronous Optical NETwork (SONET) standards are now providing fiber-optic, virtually error-free MAN and WAN transport in speeds in the gigabit-per-second range for these high-bandwidth services, and ATM hubs and switches are now on the market to offer new levels of user quality of service and traffic segmentation and optimization.

Designing a data network to handle a diverse user application and technology base is a complex task. Capacity requirements begin to boggle the mind as LAN users project peak traffic periods of up to 50:1. With X.25 packet switching, the network provided many services that made the user rely on the network for error correction of data and end-to-end link-level data integrity. Frame and cell networks push this requirement to the end-user CPE and the devices running the applications, and require the end user to apply much more intelligence with higher-layer protocols when transporting data. Now, computer users who once had to worry only about how long it would take to move or access data are now faced with data-transport protocols which promise to deliver a majority of the data, while leaving the discovery of lost data and subsequent retransmission to the transport through application layers. Two very different ways of viewing data communications have merged — the computer user who looks at data transport in the view of delay, and the telecommunications user who views data transport is terms of acceptable levels of lost data, error correction, retransmission, and quality of service. Couple this with multiple protocol and architecture environments and you have quite a challenge in designing a single homogeneous network.

The data-network designer must now bridge the gap between data-transport services and user applications and services, physical and data-link layer protocols and higher-layer protocols. This means building a network which involves both local area and wide area communications. The new developments discussed will bridge the gap between these historically separate LAN and WAN domains and provide the end user with the information required to perform a design that spans both environments. Large-scale, wide-area public networks and services are available that provide connectivity that is flexible and easy to install, with a small amount of delay and high throughput, while offering pricing that is both fixed (like private line service) and usage-based (like IP service). This allows for cost efficiencies while providing higher transport speeds for larger data volumes.

After learning the technologies and services available, many users ask the classic question, "Which service or technology should I use?" This book will show that the answer to this question is based on many factors and may have several answers. There is rarely a single solution, and the decision of technology and service generally come down to what is best for the application and what is affordable — price versus performance — as well as what entails the least change for the user and best positions them for future expansion.

HOW TO USE THIS BOOK FOR COURSES

Many state universities use Data Network Design in their engineering curriculum. The book is designed similar to a textbook in that it teaches the science of data network design in a chronological order, with technology examples augmented by numerous graphics.

Chapters to be taught in a basic architectures, protocols, technologies, and services course (PT1) are Chapters 1 through 15, and 18. Chapters to be taught in an advanced protocols and technologies course (PT2) are Chapters 7 through 25. The student should have a minimum working knowledge of the material contained in Chapters 1 through 6.

Chapters to be included in a pure design course (ND1) are the entire book, with focus on Chapters 16 through 25. The student should have a minimum working knowledge of Chapters 1 through 6, and some knowledge of the material covered in Chapters 7 through 15.

The material in this book can be taught and covered in two or three semesters. Three semesters' worth of study, along with the suggested course outlines and guidelines for selecting the course material, are outlined above. There is some overlap, and the recommended progression is from the basic course PT1, to the advanced course PT2, and finally to the pure design course ND1, with both design tool and test scenario hand calculated network design labs. PT2 and ND1 should begin with the overview chapters shown to reaffirm a working knowledge of basic protocols and their operation, since the advanced protocols are modifications or perturbations of simpler or more complex protocol operations. Labs should contain design problems based on the cumulative knowledge gained from the class reading and outside reading assignments (recent technology updates). The exercises should involve multiple design tool exposure and problems. Special or final exams (all or a portion) should include at least one multiprotocol or multitechnology network design problem. Students should be encouraged to use the text as a "working document", noting any changes as the standards are revised and updated. The author plans to publish updated editions of this book as appropriate technology changes may warrant, and welcomes suggested changes or corrections from readers in writing (current address may be obtained from McGraw-Hill) or via e-mail (dspohn@netsolve.net). Supplemental documentation and instructional tools may be obtained from the author at extra charge.

AUTHOR'S DISCLAIMER

Accurate and timely information is provided up to the date of publication. While many of the standards presented in the First Edition are now final, some of the standards used in this Second Edition are recommendations at the time of writing and are assumed will become final soon after publication. At times, the author will present material that is practical in a large-scale design, but is simply not possible in the normal small-business communications environment. Also, in many cases, examples are presented on a larger scale. The presented material must be scaled down on a case-by-case basis. Many data communications networks operate, and will continue to run, quite well on dedicated private lines, but eventually the economics of switched technologies and services, even on the smallest scale, are worth investigating. Please excuse the blatant assumption that the user is ready to implement these advanced technologies – in many cases it will take some time before they can be implemented. Also, please excuse any personal biases which may have crept into the text.

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Much of the networking and computer clip art used in this book was provided by NetDraw. The NetDraw product provides over 1600 high-quality, full color images and symbols. NetDraw is a registered trademark of Network World, Inc. and can be reached at 800-643-4668.

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Darren L. Spohn

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