



Walter Goralski

# The **Illustrated** **Network**

How TCP/IP Works  
in a Modern Network

Second Edition

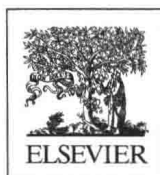
**MK**  
MORGAN KAUFMANN

# The Illustrated Network

## How TCP/IP Works in a Modern Network

**Second Edition**

**Walter Goralski**



**MK**

MORGAN KAUFMANN PUBLISHERS

AN IMPRINT OF ELSEVIER

Morgan Kaufmann is an imprint of Elsevier  
50 Hampshire Street, 5th Floor, Cambridge, MA 02139, United States

Copyright © 2017, 2009 Elsevier Inc. All rights reserved.

No part of this publication may be reproduced or transmitted in any form or by any means, electronic or mechanical, including photocopying, recording, or any information storage and retrieval system, without permission in writing from the publisher. Details on how to seek permission, further information about the Publisher's permissions policies and our arrangements with organizations such as the Copyright Clearance Center and the Copyright Licensing Agency, can be found at our website: [www.elsevier.com/permissions](http://www.elsevier.com/permissions).

This book and the individual contributions contained in it are protected under copyright by the Publisher (other than as may be noted herein).

### Notices

Knowledge and best practice in this field are constantly changing. As new research and experience broaden our understanding, changes in research methods, professional practices, or medical treatment may become necessary.

Practitioners and researchers must always rely on their own experience and knowledge in evaluating and using any information, methods, compounds, or experiments described herein. In using such information or methods they should be mindful of their own safety and the safety of others, including parties for whom they have a professional responsibility.

To the fullest extent of the law, neither the Publisher nor the authors, contributors, or editors, assume any liability for any injury and/or damage to persons or property as a matter of products liability, negligence or otherwise, or from any use or operation of any methods, products, instructions, or ideas contained in the material herein.

### British Library Cataloguing-in-Publication Data

A catalogue record for this book is available from the British Library

### Library of Congress Cataloging-in-Publication Data

A catalog record for this book is available from the Library of Congress

ISBN: 978-0-12-811027-0

For Information on all Morgan Kaufmann publications  
visit our website at <https://www.elsevier.com/books-and-journals>



Working together  
to grow libraries in  
developing countries

[www.elsevier.com](http://www.elsevier.com) • [www.bookaid.org](http://www.bookaid.org)

*Publisher:* Jonathan Simpson

*Acquisition Editor:* Todd Green

*Editorial Project Manager:* Lindsay Lawrence

*Production Project Manager:* Punithavathy Govindaradjane

*Cover Designer:* Miles Hitchen

Typeset by MPS Limited, Chennai, India

# The Illustrated Network



# About the Author

Walter Goralski has worked in the telecommunications and networking industry since 1970. He spent 14 years in the Bell System. After that he worked with mini-computers and LANs at Wang Laboratories and with the Internet at Pace University, where he was a graduate professor for 15 years. He joined Juniper Networks as a senior staff engineer in 2000 after 8 years as a technical trainer. Goralski is the author of 10 books about networking, including the bestselling *SONET/SDH* (now in its third edition). He has a master's degree in computer science from Pace University and several certificates in new areas of technology.



# Foreword

I am excited and honored to provide this brief foreword to the Second Edition of Walter Goralski's marvelous *The Illustrated Network: How TCP/IP Works in a Modern Network*. I have known Walter for over 25 years, having first met him when we worked together as technical instructors, where he delivered in-depth courses, seminars, and workshops on the inner workings of every aspect of networking to the world's largest providers of telecommunications systems and networks. Walter is one of those gifted individuals who is able to take complex subjects and explain them, often visually, in ways that make them much easier to grasp and understand. Sitting in a class room with Walter at the whiteboard is a delightful experience, in which layers of technological obscurity are peeled away by his easy explanations and use of diagrams and other visual aids. The book you hold in your hands is the ready and portable embodiment of that experience and will deliver clarity, understanding, and insights to the reader in a similar fashion.

This book is not just another dense compendium of facts, standards, and details. Rather, it tells a story that will engage you in a journey of discovery from the beginnings, along various paths, and to many destinations on today's modern internet. Along the way, you will find the journey to be quite fascinating and, when you get to the end, you will fully understand exactly how you got there.

**Mark Fei**

*Lead Instructor, Big Data and Analytics, Amazon Web Services Training and Certification*





# Preface

This is not a book on how to use the Internet. It is a book about how the Internet is made *useful for you*. The Internet is a public global network that runs on TCP/IP, which is frequently called the Internet Protocol Suite. A networking protocol is a set of rules that must be followed to accomplish something, and TCP/IP is actually a synthesis of the first two protocols that launched the Internet in its infancy, the Transmission Control Protocol (TCP) and the Internet Protocol (IP), which of course, allowed the transmission of information across the then youthful Internet. TCP/IP is the heart and soul of modern networks, and this book illustrates how that is accomplished. By using TCP/IP, we can observe how modern networks operate by following the transmission of modern data across all sorts of Internet connections.

However, this book is not limited to TCP and IP. UDP is becoming more and more popular, especially for streaming video and audio services, and sometimes even in data centers (you'll learn why). We poke into corners many foundational books do not: packet optical error control, wireless systems, virtualized networks with TCP/IP, and so on.

I hope you enjoy the journey.

---

## AUDIENCE

This book is intended as a technical introduction into networking in general and the Internet in particular. I will not pretend that someone who has had no previous experience with either can easily plow through the entire book. But anyone who is experienced enough to check their email online, browse a Web site, download a movie or song, or chat with people around the world should have no trouble tackling the content of this book.

There are questions at the end of each chapter, but this is not a textbook *per se*. It can be used as a textbook as a first course in computer networking at the high school or undergraduate level. It will fit in with the computer science and electrical engineering departments. It is also explicitly intended for those entering the telecommunications industry or working for a company where the Internet is an essential part of the business plan (of which there are more and more each day). Only one chapter uses C language code, and that only to provide information for the reader. Mathematical concepts that are not taught in high school are not used. There are no calculus, probability theory, and stochastic process concepts used in any chapter. The “pocket calculator” examples of public key encryption and Diffie–Hellman key distribution were carefully designed to illustrate the concepts, and yet make the mathematics as simple as possible.

---

## WHAT IS UNIQUE ABOUT THIS BOOK?

What's in this book that you won't find in a half-dozen other books about TCP/IP? The list is not short.

1. This book uses the same network topology and addresses for every example and chapter.
2. This book treats IPv4 and IPv6 as equals.
3. This book covers the routing protocols as well as TCP/IP applications.
4. This book discusses ISPs as well as corporate LANs.
5. This book covers services provided as well as the protocols that provide them.
6. This book covers topics (MPLS, IPsec, etc.) not normally covered in other books on TCP/IP.

Why was the book written this way? Even in the Internet-conscious world we live in today, few study the entire network, the routers, TCP/IP, the Internet, and a host of related topics as part of their general education. What they do learn might seem like a lot, but when considered in relation to the enormous complexity of each of these topics, what is covered in general computer “literacy” or basic programming courses is really only a drop in the bucket.

As I was writing this book, and printing it out at my workplace, a silicon chip engineer-designer found a few chapters on top of the printer bin, and he began reading it. When I came to retrieve the printout, he was fascinated by the sample chapters. He wanted the book then and there. And as we talked, he made me realize that thousands of people are entering the networking industry every day, many from other occupations and disciplines. As the Internet grows, and society's dependence on the digital communication structure continues, more and more people need this overview of how modern networks operate.

The intellectually curious will not be satisfied with this smattering of and condensation of networking knowledge in a single volume. I'm hoping they will seek ways to increase their knowledge in specific areas of interest. This book covers hundreds of networking topics, and volumes have been written devoted to the intricacies of each one. For example, there are 20–30 solid books written on MPLS complexities and evolution, while the chapter here runs at about the same number of pages. My hope is that this book and this method of “illustrating” how a modern network works will contribute to more people seeking out those 20–30 books now that they know how the overall thing looks and works.

Like everyone else, I learned about networks, including routers and TCP/IP, mostly from books and from listening to others tell me what they knew. The missing piece, however, was being able to play with the network. The books were great, the discussions led to illumination of how this or that operated, but often I never “saw” it working. This book is a bit of a synthesis of the written and the seen. It attempts to give the reader the opportunity to see common tasks in a real, working, hands-on environment of the proper size and scale, and follow what

happens behind the scenes. It's one thing to read about what happens when a Web site is accessed, but another to see it in action.

The purpose of this book is to allow you to see what is happening on a modern network when you access a Web site, write an email, download a song, or talk on the phone over the Internet. From that observation you will learn how a modern network works.

---

## AN AUDIENCE NOTE FOR THE SECOND EDITION

The first edition of this book, as I recall, started with a pile of junk. More than ten years ago, Juniper Networks, like many other companies, was transitioning from desktops in every cubicle to laptops. As a result, the IT department and labs had piles of old equipment in every corner. Richard Hendricks and I, along with Jason Lloyd, managed to talk several other employees into combining a core lab router network (similar to the one I had used as a technical trainer) with these old "servers" into a network for testing TCP/IP not only in the network, but end-to-end. The core network would have provider edge routers, provider core routers, multiple autonomous systems (if we wanted), and so on. We fired up Windows, FreeBSD, and Linux operating systems and I got to play as much as I wanted over the next year or so.

The resulting configurations and results such as routing tables were duly recorded and packet captures of many protocols and applications were made available to readers to download from the book web site for free. (I did this after some packet-tracing company wanted to charge me 400 dollars for a log file containing "live network" packet captures...the people who desperately need to know this stuff don't have 400 dollars to toss around, I figured.)

I mention the humble roots of the first edition on *The Illustrated Network* for one good reason. When I was asked by Morgan-Kaufmann/Elsevier to put together an updated second edition of the book, Juniper Networks, like many other companies, was transitioning from an environment of physical equipment connected by various types of cross-over cables (often hand-made right on the spot) to an environment of virtual machines, virtual routers, and virtual networks. This transition put all of the labs in flux, so I was not able to redo all of the applications and protocols in a virtual environment. However, the transition in networking did give the basis for the four new chapters in the book: packet optical links, new roles for BGP, Ethernet VPNs, and cloud concepts and implementations.

But I soon found, even after some initial probes, that the contents of the book had aged very well. The thing that makes this possible is the fundamental nature of the topics explored. I found that FTP is still basically FTP, email is still email, routing protocols still carry metrics around the network, and so on. The biggest difference, I found, is that the level of trust we extend to clients and servers on

the network has changed a lot. Who has used anonymous FTP recently? I even managed to explore some of this in the new chapter on BGP, although I have not made this into a security book in any way. But knowing how security expectations have changed will help readers pick up current practices, I am sure of it.

Let me close this section with something I realized as I went about updating the material: there is a tremendous need today for a companion volume to *The Illustrated Network*. I call it *The Illustrated Data Center*. The initial chapters would build two or more data centers with thousands of servers and virtual machines and top-of-rack switches on two continents. Then the chapters would explore how a simple query from a web client could trigger hundreds of NoSQL queries to find the information needed to create the desired web page on the fly. What TCP/IP protocols and applications fit nicely and what pieces do not? Now, that's a book I would read... perhaps my colleagues in the technical training business are already hard at work on this. I hope so.

---

## WHAT YOU WON'T FIND IN THIS BOOK

It might seem odd to list things that the book does not cover. But rather than have readers slog through and then find they didn't find what they were after, here's what you will not find in this edition of the book.

You will find no mention of the exciting new peer-to-peer protocols that distribute the server function around the network. There is no mention of the protocols used by chat rooms or services. The book does not explore music or movie download services. In other words, you won't find YouTube, IRC, iTunes, or even eBay mentioned in this book.

These topics are, of course, interesting and/or important. But the limitations of time and page count forced me to focus on essential topics. The other topics could easily form the foundation for *The Illustrated Network, Volume II: Beyond the Basics*.

## AND ONE MORE THING BEFORE I GO

For some reasons, some people are fond of going to book review sites and criticizing my books as not being technical enough for the down-in-the-trenches network engineers who deal with route leaking or SONET/SDH pointer shifts or web page structure every day. That's their right, but I think there is still a place for technical books for people who might be interested in how the concept is implemented without needing to know the nitty-gritty of internal equipment operation. I'd like to use an analogy from old automobile maintenance to show what I mean. Realize that there are more computers in a car today than in *the whole world in 1950*. I think everyone should know that as you accelerate, the ignition advances to keep up with the increased RPMs. But I don't think everyone needs to know how often the points wear out (or shake loose) or just what dead bottom center is.

I'd like readers to keep this in mind as they wander through the chapters.

## OH, ONE MORE THING

Let me tell you one more thing, and this is something I came to understand only a few years ago. People often ask me why I can't resist telling other people about something when I think I've figured out how it works. The easy answer, the one I always gave, is that this is how I teach myself something new. I've always said that the ability to explain a concept to someone who knows nothing about the topic is the *essence* of understanding. I have little patience with the "I understand it but I can't explain it to you" crowd: I always ask to speak to the person *they* learned it from because, obviously, someone explained it to *them*.

But now, I know the "hard answer." Years ago, a brilliant science fiction writer with a doctorate in biochemistry named Isaac Asimov wrote a monthly column in *The Magazine of Fantasy & Science Fiction (F&SF)* in which he explained complex topics in physics, astronomy, mathematics, and more in simple terms. (Martin Gardiner's column in *Scientific American* was similar for mathematics, but much more challenging.) Asimov's books collecting these essays are still available, and I heartily recommend them, even after all these years.

Anyway, when I met Asimov at a sort of dinner conference in the early 1980s, I asked him why no one was doing that kind of thing to explain networks and computers. And he said to me "Why don't you do it?" A couple of years later, I wrote my first article on network technology, then I wrote another, and then someone called me up and asked me to expand that article into a book. I had forgotten all about my brief comment and Asimov's reply until I took some courses in science fiction writing and someone said, almost off-handedly, "Asimov was the most encouraging person you would ever want to meet." And it all came rushing back.

I am the first to say that I know I am not Isaac Asimov. But I will always be grateful for the few times I was able to speak with him.

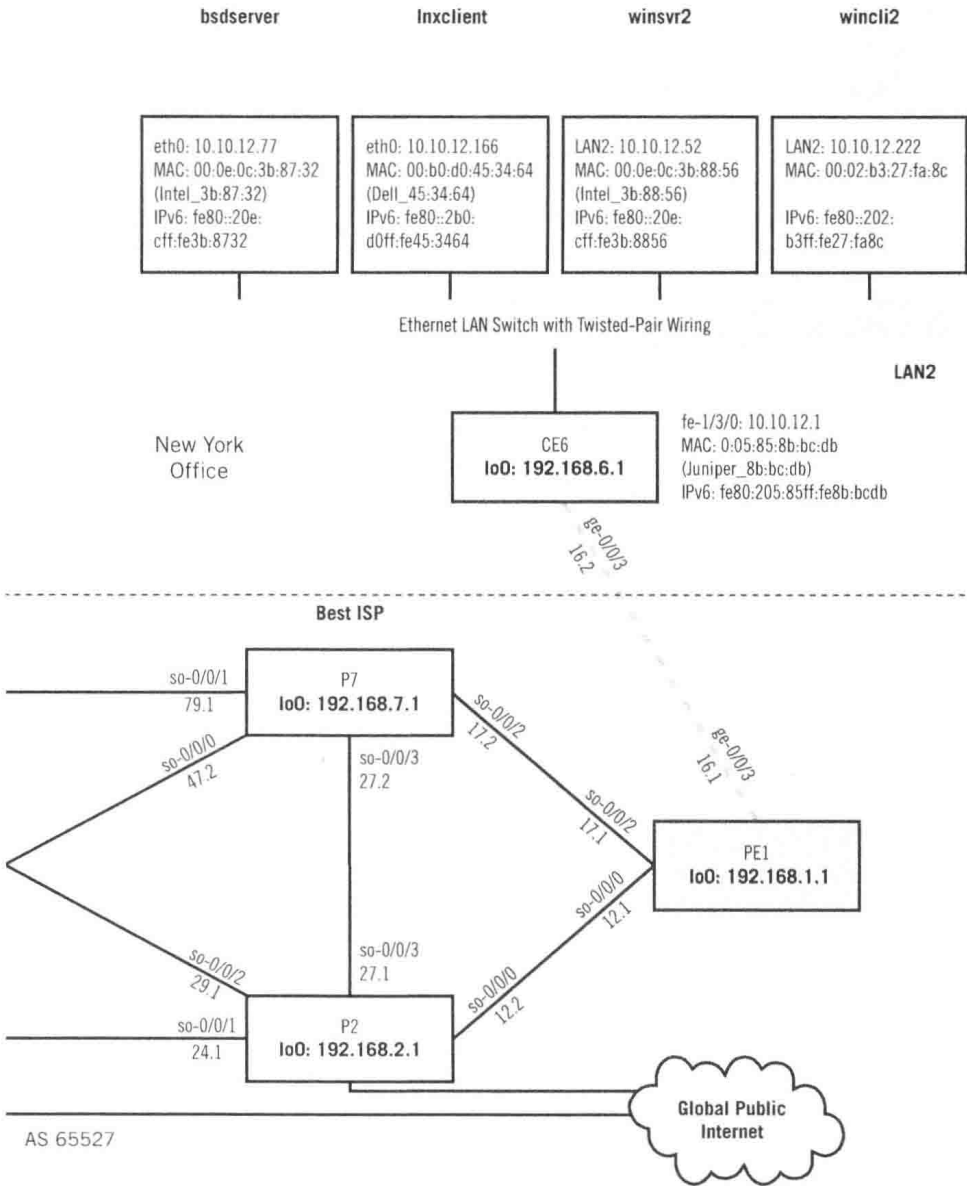
---

## THE ILLUSTRATED NETWORK

Many people frustrated with simple lab setups and restricted "live" networks have wished for a more complex and realistic yet secure environment where they can feel free to explore the TCP/IP protocols, layers, and applications without worrying that what they are seeing is limited to a quiet lab, or what they do might bring the whole network to its knees.

The days are long gone when an interested party could take over the whole network, from clients to servers to routers, and play with them at night or over the weekend. Networks are run on a normal business-hour schedule, especially now that the Web makes "prime time" on one side of the world when the other half is trying to get some sleep.







Many times I have encountered a new feature or procedure and said to myself, “I wish I could play with this and see what happens.” But only after nearly 40 years of networking experience (I hooked up my first modem, about the size of a microwave oven, in 1966), have I finally arrived at the point where I could say, “I want to do this . . .,” and someone didn’t tell me it could not be done.

Juniper Networks Inc., my employer, was in a unique position to help me with my plans to not merely talk about TCP/IP or show contrived examples of the protocols in action, but to “illustrate” each piece with a series of clients, servers, routers, and connections (including the public Internet). They had the routers and links, and employed all the Unix and Windows-based hosts that I could possibly need. (In retrospect, there was probably some overkill in the network, as most chapters used only a couple of routers.) We decided not to upgrade the XP hosts to Vista, which was relatively new at the time, and I kept Internet Explorer 6 active, more or less out of convenience.

In any case, with the blessings of Juniper Networks, I set about creating the kind of network I needed for this book. It took a while, but in the end it was well worth it. We assembled a collection of five routers connected with SONET links, two Ethernet LANs, two pairs of Windows clients and servers, one pair of Red Hat Linux hosts (running the RH 9 kernel 2.4.20-8), and a pair of FreeBSD (release 4.10) hosts.

For this Second Edition, I have updated some of the screen captures to Windows 10 and “modern” Linux distros, but all-in-all, the material shown in many screen captures has not changed one bit. The capture files are the same as from the First Edition, but the basic protocols remain as solid as ever.

Figure P.1 shows the network that we built and that is used in every chapter of this book to illustrate the networking concepts discussed.

---

## USING THIS BOOK

This book is designed to be read from start to finish, chapter by chapter, sequentially. It seems funny to say this, because a lot of technical books these days are not meant to be “read” in the same way as a novel or a biography. Readers tend to look things up in books like this, and then browse from the spot they land on, which you can certainly do with this book, but probably more on a chapter-by-chapter level.

But I hope that the story in this book is as coherent as a mystery, if not as exciting as an adventure tale. From the first chapter, which offers readers a unique look at layered protocols, to the last, this book presents a story that proceeds in a logical fashion from the bottom of the Internet protocol suite to the top (and beyond, in some cases). So if you can, read from start to finish, as the chapters depend on previous ones. If you are new to networking concepts, or just beginning, I recommend this consecutive approach. For those more experienced,