

Communication Networks

A Concise Introduction

Second Edition

Praise for *Communication Networks: A Concise Introduction*

This book is a welcome addition to the Networking literature. It presents a comprehensive set of topics from an innovative and modern viewpoint that observes the rapid development that the field has undergone. It is informed, informative, and useful to students, faculty, and practitioners in the field. This book is a must have!

-Anthony Ephremides, *University of Maryland*

Computer networks are extremely complex systems, and university-level textbooks often contain lengthy descriptions of them that sacrifice basic conceptual understanding in favor of detailed operational explanations. Walrand and Parekh depart from this approach, offering a concise and refreshing treatment that focuses on the fundamental principles that students can (and should) carry forward in their careers. The new edition has been updated to cover the latest developments and is of great value for teaching a first upper-division course on computer networks.

-Massimo Franceschetti, *University of California, San Diego*

The book presents the most important principles of communication network design, with emphasis on the Internet, in a crisp and clear fashion. Coverage extends from physical layer issues through the key distributed applications. The book will be a valuable resource to students, instructors, and practitioners for years to come.

-Bruce Hajek, *University of Illinois at Urbana-Champaign*

Conceptual clarity, simplicity of explanation, and brevity are the soul of this book. It covers a very broad swathe of contemporary topics, distills complex systems into their absolutely basic constituent ideas, and explains each idea clearly and succinctly. It is a role model of what a classroom text should be. I wish there had been such a book when I was learning about communication networks.

-P. R. Kumar, *Texas A&M University*

This book focuses on the basic principles that underlie the design and operation of the Internet. It provides a holistic account of this critical yet complex infrastructure and explains the essential ideas clearly and precisely without being obscured by unessential implementation or analytical details. It is the best introduction to networking from which more specialized treatment of various topics can be pursued.

-Steven Low, *California Institute of Technology (Caltech)*

Communication Networks: A Concise Introduction by Jean Walrand and Shyam Parekh is an amazing book. Jean and Shyam are in the unique position for writing this book because of the foundational contributions they made to the area and their many years of teaching this course at UC Berkeley. This book covers many important topics ranging from the architecture of the Internet, to today's wireless technologies, and to emerging topics such as SDN and IoT. For each topic, the book focuses on the key principles and core concepts, and presents a concise discussion of how these principles are essential to scalable and robust communication networks. Mathematical tools such as Markov chains and graph theory are introduced at a level that is easily understandable but also adequate for modeling and analyzing the key components of communication networks. The comprehensive coverage of core concepts of communication networks and the intuition/principle-driven approach make this book the best textbook for an introductory course in communication networks for those students who are interested in pursuing research in this field. It is certainly a must-have book for students and researchers in the field.

-Lei Ying, *Arizona State University*

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Communication Networks

A Concise Introduction

Second Edition

Jean Walrand and Shyam Parekh
University of California, Berkeley

SYNTHESIS LECTURES ON COMMUNICATION NETWORKS #20

ABSTRACT TO THE SECOND EDITION

This book results from many years of teaching an upper division course on communication networks in the EECS department at the University of California, Berkeley. It is motivated by the perceived need for an easily accessible textbook that puts emphasis on the core concepts behind current and next generation networks. After an overview of how today's Internet works and a discussion of the main principles behind its architecture, we discuss the key ideas behind Ethernet, WiFi networks, routing, internetworking, and TCP. To make the book as self-contained as possible, brief discussions of probability and Markov chain concepts are included in the appendices. This is followed by a brief discussion of mathematical models that provide insight into the operations of network protocols. Next, the main ideas behind the new generation of wireless networks based on LTE, and the notion of QoS are presented. A concise discussion of the physical layer technologies underlying various networks is also included. Finally, a sampling of topics is presented that may have significant influence on the future evolution of networks, including overlay networks like content delivery and peer-to-peer networks, sensor networks, distributed algorithms, Byzantine agreement, source compression, SDN and NFV, and Internet of Things.

KEYWORDS

Internet, Ethernet, WiFi, Routing, Bellman-Ford algorithm, Dijkstra algorithm, TCP, Congestion Control, Flow Control, QoS, LTE, Peer-to-Peer Networks, SDN, NFV, IoT

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Preface

These lecture notes are based on an upper division course on communication networks that the authors have taught in the Department of Electrical Engineering and Computer Sciences of the University of California at Berkeley.

Over the thirty years that we have taught this course, networks have evolved from the early Arpanet and experimental versions of Ethernet to a global Internet with broadband wireless access and new applications from social networks to sensor networks.

We have used many textbooks over these years. The goal of this book is to be more faithful to the actual material we present. In a one-semester course, it is not possible to cover an 800-page book. Instead, in the course and in these notes we focus on the key principles that we believe the students should understand. We want the course to show the forest as much as the trees. Networking technology keeps on evolving. Our students will not be asked to re-invent TCP/IP. They need a conceptual understanding to continue inventing the future.

Besides correcting the known errors and adding some clarifications, the main changes in this second edition are as follows. Chapter 4 on WiFi has been updated to cover recent advances. Chapter 7 on Transport includes a discussion of alternative congestion control schemes. Chapter 8 on Models has been expanded with sections on graphs and queues. Furthermore, the chapter now explains the formulation of TCP and of sharing a wireless link as optimization problems. Chapter 9 on LTE now discusses the basics of cellular networks and a further exposition of a number of key aspects of LTE. It also includes presentations of LTE-Advanced and 5G. Discussion of WiMAX has been dropped in light of the overwhelming acceptance of LTE. In the Additional Topics chapter (Chapter 12), we have added the following topics: Switches (including Modular Switches, Switched Crossbars, Fat Trees), SDN and NFV, and IoT.

These lecture notes have an [associated website](https://bit.ly/2zPXD3)¹ that we plan to use for future updates. In recent years, our Berkeley course has also included a research project where the students apply the fundamental concepts from the course to a wide variety of topics related to networking. Interested readers can also find the extended abstracts from these research projects on this website.

Many colleagues take turns teaching the Berkeley course. This rotation keeps the material fresh and broad in its coverage. It is a pleasure to acknowledge the important contributions to the material presented here of Kevin Fall, Randy Katz, Steve McCanne, Abhay Parekh, Vern Paxson, Sylvia Ratnasamy, Scott Shenker, Ion Stoica, David Tse, and Adam Wolicz. We also thank the many teaching assistants who helped us over the years and the inquisitive Berkeley students who always keep us honest.

¹<https://bit.ly/2zPXD3>

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Most importantly, as always, we are deeply grateful to our families for their unwavering support.

Jean Walrand and Shyam Parekh
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