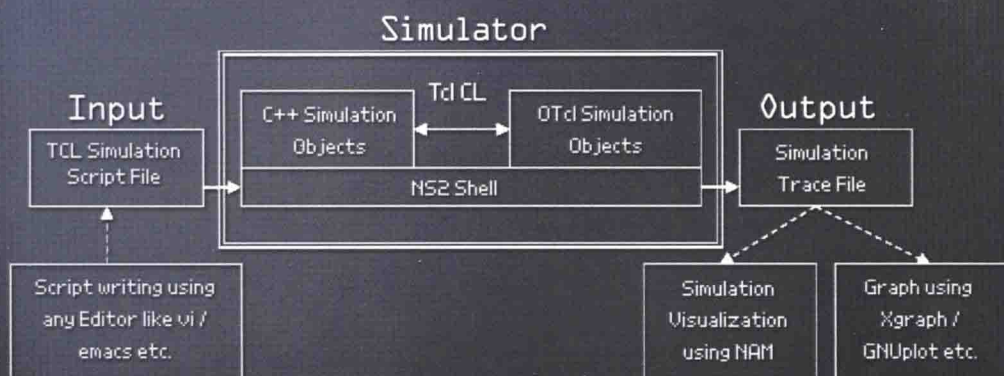


Computer Network Simulation Using NS2



Ajit Kumar Nayak
Satyananda Champati Rai
Rajib Mall



CRC Press
Taylor & Francis Group



Computer Network Simulation Using NS2

Ajit Kumar Nayak
Satyananda Champati Rai
Rajib Mall



CRC Press

Taylor & Francis Group

Boca Raton London New York

CRC Press is an imprint of the
Taylor & Francis Group, an **informa** business

MATLAB® is a trademark of The MathWorks, Inc. and is used with permission. The MathWorks does not warrant the accuracy of the text or exercises in this book. This book's use or discussion of MATLAB® software or related products does not constitute endorsement or sponsorship by The MathWorks of a particular pedagogical approach or particular use of the MATLAB® software.

CRC Press
Taylor & Francis Group
6000 Broken Sound Parkway NW, Suite 300
Boca Raton, FL 33487-2742

© 2016 by Taylor & Francis Group, LLC
CRC Press is an imprint of Taylor & Francis Group, an Informa business

No claim to original U.S. Government works

Printed on acid-free paper
Version Date: 20160421

International Standard Book Number-13: 978-1-4987-6854-2 (Hardback)

This book contains information obtained from authentic and highly regarded sources. Reasonable efforts have been made to publish reliable data and information, but the author and publisher cannot assume responsibility for the validity of all materials or the consequences of their use. The authors and publishers have attempted to trace the copyright holders of all material reproduced in this publication and apologize to copyright holders if permission to publish in this form has not been obtained. If any copyright material has not been acknowledged please write and let us know so we may rectify in any future reprint.

Except as permitted under U.S. Copyright Law, no part of this book may be reprinted, reproduced, transmitted, or utilized in any form by any electronic, mechanical, or other means, now known or hereafter invented, including photocopying, microfilming, and recording, or in any information storage or retrieval system, without written permission from the publishers.

For permission to photocopy or use material electronically from this work, please access www.copyright.com (<http://www.copyright.com/>) or contact the Copyright Clearance Center, Inc. (CCC), 222 Rosewood Drive, Danvers, MA 01923, 978-750-8400. CCC is a not-for-profit organization that provides licenses and registration for a variety of users. For organizations that have been granted a photocopy license by the CCC, a separate system of payment has been arranged.

Trademark Notice: Product or corporate names may be trademarks or registered trademarks, and are used only for identification and explanation without intent to infringe.

Library of Congress Cataloging-in-Publication Data

Names: Nayak, Ajit Kumar, author. | Rai, Satyananda Champati, author. | Mall, Rajib, author.
Title: Computer network simulations using NS2 / Ajit Kumar Nayak, Satyananda Champati Rai, and Rajib Mall.
Description: Boca Raton : Taylor & Francis, CRC Press, 2016. | Includes bibliographical references and index.
Identifiers: LCCN 2016003396 | ISBN 9781498768542 (alk. paper)
Subjects: LCSH: Computer networks--Computer simulation. | NS (Electronic resource)
Classification: LCC TK5105.5 .N393 2016 | DDC 004.60285/53--dc23
LC record available at <https://lccn.loc.gov/2016003396>

Visit the Taylor & Francis Web site at
<http://www.taylorandfrancis.com>

and the CRC Press Web site at
<http://www.crcpress.com>

Printed and bound in the United States of America by Publishers Graphics, LLC on sustainably sourced paper.

Computer Network Simulation Using NS2

PREFACE

This book is intended to help students understand certain practical aspects of computer networking. We focus on simulation of basic computer networking protocols for a deeper understanding of the workings of the protocols as well as for performance evaluation. We have also included socket programming taught at the undergraduate level to help students develop skills for network programming. Considering that students may have widely different backgrounds, we have included certain basics of networking to make the book self-contained. However, the introductory treatment on networking issues is given as a refresher of the basic concepts involved, and thorough learning of the relevant concepts from a networking book is a necessity before this book can be used.

It is well accepted that the knowledge acquired from a theoretical reading, especially in a subject such as computer networking, is incomplete when not accompanied by hands-on practice. The book is sprinkled with examples of simulations of both wired and wireless networking protocols. The assignments have been designed to be suitable for undergraduate and postgraduate levels of learning. For the advanced learner, suitable hints have been provided throughout the text to develop the skills for evaluation of new protocols.

Salient Features

- (i) Emphasis on implementation and simulation of real-world network protocols.
- (ii) Covers a wide ranging set of topics, starting from certain basic operating system commands to socket programming, wired network simulation, wireless network simulation, performance evaluation, and visualization.
- (iii) Plenty of example programs have been provided (around ninety odd programs and scripts along with their explanations and outputs). Also many exercises (both theory and programming) requiring investigation

and application of the learned concepts have been provided across all the chapters for practice.

- (iv) We have tried our best to explain the concepts using simple language and analogies.

Content & Structure

Chapter 1 Discusses the evolution of data communication techniques and the fundamental issues associated with performance evaluation. It then provides an overview of simulation and other performance evaluation techniques.

Chapter 2 Introduces computer network protocols along with TCP/IP and OSI models. It also provides a brief overview of the networking devices used.

Chapter 3 Explains a socket and its use in network programming. This gives an idea of developing network applications using C and socket API.

Chapter 4 Introduces the NS2 network simulator, and exhibits the internal architecture of NS2 and its constituent software packages. It also provides pointers to installation of the package in different operating systems.

Chapter 5 Provides basic knowledge about simulation using NS2. It elaborates on the use of Tcl and OTcl scripts along with an introduction to AWK scripting and plotting with Gnuplot.

Chapter 6 Deals with the simulation of wired networks in detail. It shows how to simulate different protocols in different layers.

Chapter 7 Deals with the simulation of wireless networks in detail. It also discusses the idea of simulation, very large networks and measuring the various network parameters and plotting them in suitable graphs.

Acknowledgments

It is with great pleasure and pride that we thank all those who have given their unselfish help and support in many different ways in the preparation of the manuscript for this book. We thank our colleagues for their inspiration and valuable suggestions to improve the content and our staff members for their timely help. We are thankful to our students, as their feedback and comments helped to enrich the contents and to design new programs for

the book. We are extremely thankful to our family members for their unconditional and emotional support during the preparation of the manuscript. Finally, we thank the editorial team of Taylor & Francis Books India Pvt. Ltd. and in particular Dr. Gagandeep Singh for their constant support.

MATLAB[®] is a registered trademark of The MathWorks, Inc. For product information, please contact:

The MathWorks, Inc.
3 Apple Hill Drive
Natick, MA, 01760-2098 USA
Tel: 508-647-7000
Fax: 508-647-7001
E-mail: info@mathworks.com
Web: www.mathworks.com

AUTHOR BIOGRAPHIES

Ajit Kumar Nayak is professor and head of the Department of Computer Science and Information Technology, Institute of Technical Education and Research, Siksha 'O' Anusandhan University, Bhubaneswar. He earned his M. Tech. and Ph.D. in computer science at Utkal University in 2001 and 2010, respectively. He has published more than 20 research articles in conference proceedings and journals. He is a member of IEEE and IET and a life member of the Orissa Information Technology Society (OITS). He has guided more than 15 M. Tech. students, and 5 research students are currently pursuing a Ph.D. under his guidance. His current research interests include mobile ad hoc networks, wireless sensor networks, and language computing.



Satyananda Champati Rai is currently working as an associate professor and head of the Department of Information Technology at the Silicon Institute of Technology, Bhubaneswar. He earned his M. Tech. (CS) and Ph.D. (computer science) from Utkal University in 2001 and 2012, respectively. He has published 20 research articles in national and international conference proceedings as well as in journals. He has written a monograph titled *QoS Provisioning in Mobile Ad Hoc Networks: Principles, Practices and Models*, published by LAMBERT Academic Publishing, Germany in 2013. He is a member of IEEE and a life member of the Orissa Information Technology Society (OITS) and ISTE. He has guided 22 M. Tech. students and served as a program committee member in several international conferences. His current research interests include mobile ad hoc networks, wireless sensor networks, and mobile cloud computing related to quality of service and performance analysis.

Rajib Mall earned B.E., M.E., and Ph.D. degrees from the Indian Institute of Science, Bangalore. He worked for nearly 3 years for Motorola India Ltd. before he joined the Department of Computer Science and Engineering, Indian Institute of Technology, Kharagpur in 1994 as a faculty member. He is currently a professor and the head of the CSE Department and the School of IT. His current research interests include program testing and software engineering issues in large systems and those in real-time embedded systems. He has published about 200 research papers and refereed international journals and conference proceedings and has carried out a number of sponsored projects in the areas of program analysis and program testing. He is a senior member of IEEE (USA).



CONTENTS

Preface	ix
Author Biographies	xiii
1 Introduction	1
1.1 Rapid Evolution of Voice and Data Communication Techniques	1
1.2 Evolution of Computer Communication Networks	3
1.3 Convergence of Data and Telecommunication Networks . . .	5
1.4 Integration of TCP/IP into Unix	6
1.4.1 POSIX	6
1.5 Queueing Theory	7
1.6 Overview of Simulation	13
1.6.1 Advantages of simulation	14
1.6.2 Disadvantages of simulation	15
1.6.3 Types of simulation	16
1.7 A Few Basic Concepts in Simulation	18
1.7.1 Monte Carlo simulation	19
1.7.2 Confidence intervals	20
1.7.3 A brief history of computer-aided simulation	24
1.7.4 Simulation versus other evaluation techniques	25
1.7.5 Writing your simulation program versus using a simulation tool	26
1.7.6 Basic simulation terminology	27
1.8 Discrete-Event Simulation	27
1.8.1 Model validation techniques	29
1.9 Basics of Network Simulation	30
1.10 Introduction to NS2	31
1.11 Common Mistakes in Simulation	32
2 Network Protocols	37
2.1 TCP/IP Protocol Suite	37
2.2 Terminology	39
2.3 Architecture of TCP/IP	41
2.4 Overview of the Operation of TCP	43

2.5	Application Layer Protocols of TCP	45
2.6	TCP/IP versus the ISO/OSI Model	45
2.7	Adaptation of the TCP Window	46
2.8	Improvement of TCP Performance	48
2.8.1	Traditional networks	49
2.8.2	TCP in mobile networks	50
2.9	Networking Devices	53
3	Network Programming Using Socket API	61
3.1	Introduction	61
3.2	Socket Interface	62
3.3	Socket API	71
3.3.1	Data structures	71
3.3.2	System calls	74
3.3.3	Byte ordering functions	78
3.3.4	Address conversion functions	78
3.3.5	Functions for protocol addresses	79
3.3.6	Functions for hostname	80
3.4	I/O Multiplexing	83
3.4.1	Synchronous I/O multiplexing using select() call . . .	84
3.5	Concurrency	94
3.6	Broadcasting	101
4	Introduction to NS2	107
4.1	Simulator Structure	108
4.2	Simulator Input and Output	109
4.3	NS2 Installation Steps	110
4.3.1	Fedora Linux	112
4.3.2	Ubuntu Linux	114
4.3.3	Windows 7	115
4.4	NS2 Directories and Files	118
4.5	Network Animator (NAM)	119
4.6	NS2 Program Structure	123
4.7	Summary	125
5	Basics of Protocol Simulation Using NS2	143
5.1	Tcl	143
5.2	Program Execution	144
5.3	Basic Programming Constructs	145
5.3.1	Variables	146
5.3.2	Grouping mechanism	147
5.3.3	Mathematical expressions	149
5.3.4	Control statements	150
5.4	Arrays	156
5.5	Lists	158

5.6	Dictionaries	159
5.7	Procedures	160
5.8	File Handling	162
5.8.1	Reading and writing files	163
5.9	Object-Oriented Tcl (OTcl)	165
5.9.1	Classes and objects	165
5.10	AWK Scripting	169
5.10.1	General structure of AWK	171
5.10.2	Other AWK constructs	171
5.11	Gnuplot	174
5.11.1	Customizing plots	176
5.11.2	Histograms	180
5.11.3	Multiplot	181
5.11.4	Saving plots into files	183
6	Wired Network Simulation	187
6.1	Introduction	187
6.2	Step-by-Step Wired Network Simulation	187
6.3	Visualization Using NAM	193
6.4	Link Layer — Links and Queueing	197
6.4.1	Point-to-point links	198
6.4.2	Multipoint links	203
6.5	Network Layer — Routing	207
6.6	Transport Layer — Transport Agents	220
6.6.1	User datagram protocol (UDP)	220
6.6.2	Transmission control protocol (TCP)	221
6.7	Packet Trace	238
6.8	Application Layer — Traffic Generators	251
6.8.1	Traffic generators	251
6.8.2	Simulated applications	254
6.9	Network Dynamics—Node/Link Failure Models	256
6.10	Error Model	257
7	Wireless Network Simulation	267
7.1	Wired versus Wireless Network Simulation	269
7.2	Step-by-Step Wireless Network Simulation	271
7.3	Wireless Networking Modules	283
7.3.1	Mobile node architecture	283
7.4	Wireless Routing	285
7.4.1	Destination sequenced distance vector (DSDV)	285
7.4.2	Dynamic source routing (DSR)	286
7.4.3	Temporally ordered routing algorithm (TORA)	287
7.4.4	Ad hoc on demand distance vector (AODV)	288
7.5	Wireless Trace	288
7.6	Network Performance Metrics	291

7.7	Practical Simulation Issues	296
7.7.1	Generating scenario	297
7.7.2	Generating a connection pattern	297
7.7.3	More performance metrics	302
7.8	A Complete Example	303
	Index	311

CHAPTER 1

INTRODUCTION

The history of computers dates back more than 60 years. In the initial two decades, computers were operated largely as standalone machines, and primarily served as powerful number crunchers. About a decade later, the need for devising techniques to let applications running on different computers share information with each other was felt. This led to the birth of computer communication networks. An interconnected set of computers made it possible to develop powerful information sharing applications. This was in contrast to the plain number crunching applications that existed. This exemplified the potential advantages that computer communication networks can bring and caused the nascent computer communication technology to evolve at a rapid pace.

The mind boggling progress achieved in the area of computing technologies over the relatively short time span of the last six decades is now folklore. But even that pales when compared to the progress that has been achieved over the last half a century in the field of computer networking technologies. The dizzying speed with which computer networking technologies have advanced can be gauged from the fact that, almost every decade, the scope and contents of every networking textbook have been dramatically revised. In the following, we recount a few milestones in this evolution.

1.1 Rapid Evolution of Voice and Data Communication Techniques

In a groundbreaking work, Samuel Morse publicly demonstrated in 1838 that pulses of electric current can be used to move an electromagnet placed in a remote machine to produce dots and dashes on a piece of paper. The crude prototype demonstrated by Morse soon evolved into the telegraph system. The telegraph system revolutionized communications with far off places. However, with its inherent dot-and-dash Morse code mechanism, its

use was largely restricted to communications of simple text messages. About 40 years later, in 1876, Alexander Graham Bell showed that voice signals can be transmitted as encoded time varying electric currents and then the current received at a remote destination can be used to reconstruct the voice signals. Bell's prototype was soon made into a simple telephone system that consisted of a pair of connected phone handsets. Such a simple telephone system could be used to connect a pair of fixed users. For example, a pair of phones could link two offices of a company. This was a network of size two (number of nodes is 2) and was obviously of very limited utility, as the utility of a telephone network is proportional to the square of the number of the nodes in the network. Shortly afterwards, on-demand connection establishment among different pairs of telephone handsets belonging to various subscribers was achieved through the use of manually operated exchanges. With the discovery of automatic telephone exchange technologies in 1879, circuit switching among different handset pairs became possible, and a subscriber could talk to other subscribers by simply dialing their numbers. This came to be known as the Public Switched Telephone Network (PSTN) system. A switch located in a telephone exchange could route calls to other exchanges. Efficient communication among subscribers residing in far away cities became possible with the invention of signal multiplexing techniques. Signal multiplexing made it possible to transmit multiple calls over the same trunk line. This led to more efficient usage of the physical medium.

Development of signal filtering techniques helped to reduce cross talk and other forms of noise in a phone call. The connection between two exchanges became known as a trunk line. The name trunk (analogous to a tree trunk) denotes that multiple communications are carried on the same line through use of either time division or frequency division multiplexing techniques. Initially, the telephone system carried only voice traffic and therefore was called a voice network. This completely analog technology is now called Plain Old Telephone Service (POTS) to differentiate it from the modern telephone systems, which, to a large extent, are carrying digital data with the help of many computing and electronic devices, rather than using analog devices such as filters, multiplexers, amplifiers, etc.

Wireless communication technology evolved independently almost over the same period of time as its wired counterpart. Wireless communication was born with the ground-breaking work of Guglielmo Marconi in 1899, when he made a bell ring at a remote place by pressing a button in the absence of any wired connections. Marconi's prototype was quickly commercialized, and it rapidly evolved into a host of technologies such as radio, wireless telegraphy, and wireless telephony.