Computer Networks and the Internet

Gerry Howser

Computer Networks and the Internet

A Hands–On Approach

Springer

Gerry Howser
Kalamazoo College
Kalamazoo, MI, USA

ISBN 978-3-030-34495-5 ISBN 978-3-030-34496-2 (eBook)
https://doi.org/10.1007/978-3-030-34496-2

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

This book is dedicated to my muse, first reader, and loving spouse Patricia Berens.

It is also dedicated to all my students who acted as guinea pigs through this idea in its many half-baked forms. It has been great fun.

Preface

"Any sufficiently advanced technology is indistinguishable from magic."

Arthur C. Clark [21]

The Internet

Everyone uses the Internet[1], so of course everyone knows how it works: from the user's point of view. However, I have found over the years that few people really understand what happens behind the scenes. Oddly enough it is not all "smoke and mirrors" or some arcane knowledge that can only be understood by a chosen few. Anyone with the ability to plug in a few cables and edit a text file (see Section 8.9) can build a self–contained Internet or Intranet.

The goal of this book is to provide enough background into the inner–workings of the Internet to allow a novice to understand how the various protocols on the Internet work together to accomplish simple tasks such as a search. The hope is that in building an Internet with all the various services a person uses everyday, one will gain an appreciation not only of the work that goes on unseen but also of the choices made by the designers to make life easier for the user. This has not always been the case in the computer industry.

Hopefully you will find this book useful in many different ways. It can be used as a step–by–step guide to build your own Intranet. It can also be used as a text for a course in Internet protocols and services. Or it can be used as a reference guide for how things work on the global Internet[2].

[1] Throughout this book, Internet will be used to refer to the global network we all know and love and internet (lowercase) will be used to refer to any generic Internet or intranet that does not require access to the public Internet to fully function.

[2] This book draws heavily on my experience teaching CompTIA Network+ [23] classes using Tamara Dean's excellent book [27].

To the instructor

This book is designed for dual purposes. Each chapter consists of background information on a specific topic or Internet service and where appropriate a final section on how to configure a Raspberry Pi to provide that service. If these configuration sections are skipped, This book can be used for a course on the Internet and routing.

When used with the suggested equipment, the main part of this book can be used for background material for a hands–on lab course in building a fully–functional Internet using inexpensive Raspberry Pi's. If you have access to a number of "white box" computers running Linux (Debian [28] is a good choice), this book can be used with minor adjustments to build an Internet of Linux boxes.

One possible approach to using this book would be to assign the chapters to be read before class. Class time would be used to answer questions from the reading and go over the chapters that relate specifically to the configuration of the Raspberry Pi. The bulk of the class time should be reserved for actually configuring the network in a lab setting. This has proved successful in the past[3].

Additional resources can be found at:
https://www.springer.com/book/9783030344955/
https://www.gerryhowser.com/book/9783030344955/.

To the student or hobbyist

I hope that this textbook provides you an enjoyable introduction to the inner workings of the Internet. If you already have some familiarity with a topic, you will find the chapters organized so that you can skim introductory sections and proceed quickly to the more advanced material. My intent is to provide you with a clear text that you will find useful in building your own networks and as a first reference for understanding the many Internet protocols.

This book is designed as a project for groups of four students each with their own Raspberry Pi; however, smaller groups can easily run all of the required protocols on as few as one Raspberry Pi. In fact, you will be encouraged to install and configure all of the services so that the group can still function when a member is unavailable. While it may be possible to use just the configuration sections to build an Intranet, it is still best to read the background material first.

At the end of each chapter are exercises relevant to that topic. As usual the easier exercises are first with progressively more challenging problems as the numbers grow larger. You will find solutions to some of the exercises at the end of this book.

[3] This book was inspired by courses taught at Loy Norrix High School and Kalamazoo College. Both are in Kalamazoo, Michigan.

What are the prerequisites for this book?

- You should have some familiarity with computers beyond simply using applications, but you can get by without it.
- Programming experience is helpful but not necessary. The same is true of experience installing and configuring software.
- You should be comfortable with the Internet as a user.
- You must be willing to think before you start making changes. Raspian is a Linux distribution and as such it is sometimes difficult to reverse changes made in haste. If you backup each configuration file before you change it you can always back-out any changes.
- You *must* be curious and fearless. Remember: the worst that can happen is you may need to reinstall the operating system. If there is a chance of harming your hardware, you will be warned in advance.
- Simple solutions are usually the fastest, least difficult to understand, and least prone to fail.
- In networking the goal is usually to move data as fast as possible (high throughput) and correctly as long as that does not slow things down. This seems counter intuitive at first, but the end–points of the conversation are tasked with handling errors, not the network.

Additional resources can be found at:
https://www.springer.com/us/book/9783030344955/
https://www.gerryhowser.com/book/9783030344955/.

To the professional

You should find this book useful as an overview to how the Internet works and how many of the protocols work. However, this is not an exhaustive reference to the Internet as the Internet is growing and changing at a staggering rate. Indeed, the only true references for the Internet, the final authority as it were, are the current RFCs which can only be found on the web. The most reliable place to look is on the IETF website https://tools.ietf.org/rfc/index.

If this book is used as a guide to set up an Intranet, please pay close attention to the sections marked "**Security**". These actions should be taken along with any other security actions required by your organization[4].

[4] In my opinion, perfect security is not possible if your network is connected to anything.

Acknowledgments for the first edition

I would like to thank the anonymous first readers of this book. Their suggestions made this a better work. Thank you.

This work would not be possible without the help of my many students over the years. This course was first taught as a second year program under the Kalamazoo Regional Education Service Area (KRESA) as part of Education for Employment (EFE). These poor students were subjected to working with antiquated equipment, Linux (which they were *not* usually familiar with), very limited outside resources, and many difficult challenges[5]. They loved it.

A more structured version of this course was taught in 2016 at Kalamazoo College in Kalamazoo, Michigan as *Building the Internet in a Room* using Raspberry Pi computers as described in this book. Apparently all went well as some students wanted to take the course again.

To all these students I would like to say: you put a lot of sweat into the classes upon which this book is built. I can't thank you enough.

Kalamazoo, Michigan *Gerry Howser*
Fall, 2019

[5] Things never worked out as planned. That was part of the attraction and challenge.

Contents

List of Acronyms

A
A: Administrative Authority record (IPv4)
A-PDU: Application Layer PDU
AAAA: Administrative Authority record (IPv6 or NSAP)
ABR: Area Border Router
ACK: Acknowledge transmission
AFI: Authority and Format Identifier (NSAP)
AFXR: Asynchronous Full Transfer
ANSI: American National Standards Institute
API: Application Program Interface
APIPA: Automatic Private IP Addressing
ARP: Address Resolution Protocol
ARPA: Advanced Research Projects Agency
ARPANET: Advanced Research Projects Agency Network
AS: Autonomous System
ASCII: American Standard Code for Information Interchange
ASIC: Application Specific Integrated Circuit
ASN: Autonomous System Number
ATM: Asynchronous Transfer Mode

B
BDR: Backup Designated Router
BGP: Border Gateway Protocol
BIND: Berkeley Internet Name Domain service
BIOS: Basic Input/Output System
BITNET: Because It's Time Network
BNA: Burroughs Network Architecture
BOOTP: Bootstrap Protocol
Bps: Bytes per second
bps: Bits per second
BTOS: Burroughs Task Operating System

C
CAT: Category (Structured Wiring)
CIDR: Classless Inter–Domain Routing
CNAME: Canonical Name
CPU: Central Processing Unit
CRC: Cyclical Redundancy Check
CSMA/CA: Carrier Sense Media Access/Collision Avoidance
CSMA/CD: Carrier Sense Media Access/Collision Detection

D
D-PDU: Data Link Layer PDU
DARPA: Defense Advanced Research Projects Agency
DDNS: Dynamic Domain Name System
DDOS: Distributed Denial of Service attack
DFI: DSP Format Identifier
DHCP: Dynamic Host Configuration Protocol
DIG: Domain Information Groper
DIS: Designated Intermediate System
DMZ: Demilitarized Zone
DNS: Domain Name Service
DNSSEC: Secure Domain Name Service
DOS: Disk Operating System
DOS attack: Denial of Service attack
DR: Designated Router
DS0: Data Stream Zero
DS1: Data Stream 1
DS3: Data Stream 3
DSP: Domain Specific Part

E
EBGP: External BGP session
EIA: Electronic Industries Alliance
EIGRP: Enhanced Internal Gateway Routing Protocol
ESMTP: Enhanced Simple Mail Transfer Protocol

F
FAT: File Allocation Table (16 bit version)
FAT32: File Allocation Table (32 bit Version)
FCS: Frame Check Sequence
FDDI: Fiber Data Distribution Interface
FIFO: First In, First Out
FQDN: Fully Qualified Domain Name
FRR: Free Range Routing
FTP: File Transfer Protocol

G

GUI: Graphical User Interface

H
HDMI: High Definition Multimedia Interface
HTML: HyperText Markup Language
HTTP: Hyper–Text Transfer Protocol
HTTPS: Secure Hyper–Text Transfer Protocol

I
IANA: Internet Authority for Names and Addresses
IBGP: Internal BGP session
IBM: International Business Machines
ICANN: Internet Corporation for Assigning Names and Numbers
ICMP: Internet Control Message Protocol
ID: System Identifier (NSAP)
IDI: Initial Domain Identifier (NSAP)
IDP: Initial Domain Part (NSAP)
IEEE: Institute of Electrical and Electronics Engineers
IETF: Internet Engineering Task Force
IFXR: Incremental Zone Transfer
IGRP: Internal Gateway Routing Protocol
IHU: I Hear U message
IMAP: Internet Message Access Protocol
Internet: Interconnected Networks
Intranet: Private Internet
IOS: Internet Operating System
IP: Internet Protocol
IPng: Internet Protocol, Next Generation
IPv4: Internet Protocol, Version 4
IPv6: Internet Protocol, Version 6
IPX: Internetwork Packet Exchange
IS: Intermediate System
IS–IS: ISIS Inter–Area Routing
ISIS: Intermediate System to Intermediate System
ISO: International Standards Organization
ISP: Internet Service Provider

L
L2TP: Layer 2 Tunneling Protocol
LAMP: LAMP Web Server
LAN: Local Area Network
Layer 1: Physical Layer
Layer 2: Data Link Layer
Layer 3: Network Layer
Layer 4: Transport Layer
Layer 5: Session Layer

Layer 6: Presentation Layer
Layer 7: Application Layer
LED: Light Emitting Diode
LIFO: Last in – First out
LSA: Link State Announcement
LSD: Link State Database
LSP: Link State Packet Pseudonode

M
MAC: Media Access Control
MIME: Multipurpose Internet Mail Extensions
MobileIP: Cellular IP
MODEM: Modulator/Demodulator
MPLS: Multi-Protocol Label Switching
MST: Minimum Spanning Tree
MTA: Mail Transfer Agent
MX: Mail Exchange Resource Record (DNS)

N
N-PDU: Network Layer PDU
NAK: Negative Acknowledgment
NAT: Network Address Translation
NetBEUI: NetBIOS Extended User Interface
NetBIOS: Network BIOS
NGO: Non-Governmental Organization
NIC: Network Interface Card
NIST: National Institute of Standards and Technology
NNTP: Network News Transfer Protocol
NS: Name service
NSAP: Network Service Access Point
nslookup: Name Service Lookup
NTP: Network Time Protocol

O
OC1: Optical Carrier 1
OC12: Optical Carrier 12
OC24: Optical Carrier 24
OC3: Optical Carrier 3
OS: Operating System
OSI: Open Systems Interchange
OSPF: Open Shortest Path First (IPv4)
OSPFv3: Open Shortest Path First (IPv6)

P
P-PDU: Presentation Layer PDU
PC: Personal Computer

PDU: Protocol Datagram Unit
PHP: PHP: Hypertext Preprocessor
ping: Echo Request and Echo Response
POP3: Post Office Protocol
PPP: Point–to–Point Protocol
PPTP: Point–to–Point Tunneling Protocol
putty: Public TTY Client for Windows
PXE: Preboot eXecution Environment

Q
QoS: Quality of Service

R
RARP: Reverse Address Resolution Protocol
RD: Routing Domain Identifier
RFC: Request For Comments
RIP: Route Interchange Protocol
RIPng: Route Interchange Protocol for IPv6
RIPv1: Route Interchange Protocol, Version 1
RIPv2: Route Interchange Protocol, Version 2
RJ45: Registered Jack 45
RR: Resource Record
RSVP: Resource Reservation Protocol

S
S-PDU: Session Layer PDU
SDA: SD Association
SDH: Synchronous Digital Hierarchy
SEL: NSAP Selector
SLIP: Serial Line Internet Protocol
SMTP: Simple Mail Transfer Protocol
SOA: Start Of Authority
SOHO: Small Office/Home Office
SONET: Synchronous Optical Network
SPF: Shortest Path First
SPX: Sequenced Packet Exchange
SQL: Standard Query Language
ssh: Secure Shell (ssh)
sudo: sudo

T
T-PDU: Transport Layer PDU
T1: T–Carrier 1
T2: T–Carrier 2
T3: T–Carrier 3
TCP: Transaction Control Protocol

TCP/IP: Transaction Control Protocol over IP
TDM: Time Division Multiplexing
TFTP: Trivial File Transfer Protocol
TIA: Telecommunications Industry Association
TLD: Top Level Domain
TOR: The Onion Router
TTL: Time To Live

U
UDP: User Datagram Protocol
URL: Universal Resource Locator
USB: Universal Serial Bus

V
VERP: Variable Envelope Return Paths
vi: vi text editor
VLAN: Virtual Local Area Network
VLSM: Variable Length Subnet Mask
VOIP: Voice Over Internet Protocol
VPN: Virtual Private Network
vtysh: Virtual Terminal Shell

W
WAMP: Windows web server
WAN: Wide Area Network
WAP: Wireless Access Point
WiFi: Wireless Network
WLAN: Wireless Local Area Network
www: World Wide Web

X
XAMP: Cross–platform web server

List of Algorithms

List of Figures

List of Tables