PART X

PROTOCOL LAYERING
Motivation For Layering

- Communication is difficult to understand
- Many subproblems
  - Hardware failure
  - Network congestion
  - Packet delay or loss
  - Data corruption
  - Data duplication or inverted arrivals
Solving The Problem

- Divide the problem into pieces
- Solve subproblems separately
- Combine into integrated whole
- Result is *layered protocols*
Protocol Layering

- Separates protocol functionality
- Each layer solves one part of the communication problem
- Intended primarily for protocol designers
- Set of layers is called a protocol stack
Concept Of Layering

![Diagram of network layering](image-url)
More Realistic Layering

Conceptual Layers

(a)

High-Level Protocol Layer

Internet Protocol Layer

Network Interface Layer

Software Organization

Protocol

Protocol

Protocol 3

IP Module

Interface 1

Interface 2

Interface 3

RECEIVERS
Layering In An Internet

Sender
other...
IP Layer
Interface

Net 1

Net 2

Net 3

IP Layer
Interface

IP Layer
Interface

Receiver
other...
IP Layer
Interface
Examples Of Layering

- Two models exist
- ISO 7-layer reference model for *Open System Interconnection (OSI)*
  - Predates TCP/IP
  - Does not include an Internet layer
  - Prescriptive (designed before protocols)
- Internet 5-layer reference model
  - Designed for TCP/IP
  - Descriptive (designed along with actual protocols)
# ISO 7-Layer Reference Model

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<th>Layer</th>
<th>Functionality</th>
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<td>Application</td>
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<td>6</td>
<td>Presentation</td>
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<td>5</td>
<td>Session</td>
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<td>Transport</td>
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<td>3</td>
<td>Network</td>
</tr>
<tr>
<td>2</td>
<td>Data Link (Hardware Interface)</td>
</tr>
<tr>
<td>1</td>
<td>Physical Hardware Connection</td>
</tr>
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</table>
TCP/IP 5-Layer Reference Model

- Only four layers above hardware
TCP/IP Layer 1: Physical Hardware

- Defines electrical signals used in communication (e.g., voltages on wires between two computers)
- Uninteresting except to electrical engineers
TCP/IP Layer 2: Network Interface

- Defines communication between computer and network hardware
- Isolates details of hardware (MAC) addressing
- Example protocol: ARP
- Code is usually in the operating system
TCP/IP Layer 3: Internet

- Protocol is IP
- Provides machine to machine communication
- Defines best-effort, connectionless datagram delivery service for the Internet
- Code is usually in the operating system
TCP/IP Layer 4: Transport

- Provides end-to-end connection from application program to application program
- Often handles reliability, flow control
- Protocols are TCP and UDP
- Code is usually in the operating system
TCP/IP Layer 5: Application

- Implemented by application programs
- Many application-specific protocols in the Internet
- Built on top of transport layer
Two Differences Between TCP/IP
And Other Layered Protocols

- TCP/IP uses end-to-end reliability instead of link-level reliability
- TCP/IP places the locus of intelligence and decision making at the edge of the network instead of the core
The Layering Principle

Software implementing layer $n$ at the destination receives exactly the message sent by software implementing layer $n$ at the source.
Illustration Of Layering Principle

MACHINE TO MACHINE

Host A

Application

Transport

Internet

Network Interface

Physical Net

Host B

Application

Transport

Internet

Network Interface

identical message

identical packet

identical datagram

identical frame
When A Datagram Traverses The Internet

- All layers involved at
  - Original source
  - Ultimate destination
- Only up through IP layer involved at
  - Intermediate routers
Illustration Of Layering In An Internet

Host A
Application
Transport
Internet
Network Interface
Physical Net 1

Host B
Application
Transport
Internet
Network Interface
Physical Net 2

Router R
identical message
identical packet
identical datagram
identical frame

END TO FIND
TTL
CS FRAGMENTATION
SIP

MACHINE TO MACHINE
A Key Definition

- A protocol is classified as *end-to-end* if the layering principle applies from one end of the Internet to the other.

- Examples
  - IP is *machine-to-machine* because layering principle only applies across one hop.
  - TCP is *end-to-end* because layering principle from original source to ultimate destination.
Practical Aspect Of Layering

- Multiple protocols at each layer
- One protocol used at each layer for given datagram
Example Of Two Protocols At Network Interface Layer: SLIP And PPP

• Both used to send IP across
  – Serial data circuit
  – Dialup connection
• Each defines standards for
  – Framing (encapsulation)
  – Addressing
• Incompatible
Notion Of Multiple Interfaces And Layering
Boundaries In The TCP/IP Layering Model

• High-level protocol address boundary
  – Division between software that uses hardware addresses and software that uses IP addresses

• Operating system boundary
  – Division between application program running outside the operating system and protocol software running inside the operating system
The Consequence Of An Address Boundary

Application programs as well as all protocol software from the Internet layer upward use only IP addresses; the network interface layer handles physical addresses.
Illustration Of The Two Boundaries

Conceptual Layer

- Application
- Transport
- Internet
- Network Interface
- Hardware

Boundary

- Software outside the operating system
- Software inside the operating system
- Only IP addresses used
- Physical addresses used
Handling Multiple Protocols Per Layer

- Sender places field in header to say which protocol used at each layer
- Receiver uses field to determine which protocol at next layer receives the packet
- Known as multiplexing and demultiplexing
Example Of Demultiplexing An Incoming Frame
Example Of Demultiplexing Performed By IP
Example Of Demultiplexing Performed By TCP

- TCP is part of operating system
- Transfer to application program must cross operating system boundary
Discussion

- What are the key advantages and disadvantages of multiplexing/demultiplexing?
- Can you think of an alternative?
Summary

- Layering
  - Intended for designers
  - Helps control complexity in protocol design
- TCP/IP uses 5-layer reference model
- Conceptually, a router only needs layers 2 and 3, and a host needs all layers
- IP is machine-to-machine protocol
- TCP is end-to-end protocol
- Demultiplexing used to handle multiple protocols at each layer