Why Study “Internet and Intranet Protocols and Applications”?
– Same systems used in the two major types of networks, the public Internet and internal (corporate) Intranets
– Accessible for study, because protocol standards are published and their design is publicly debated
Systems to study

- **Protocols**
  - Web (HTTP, SSL)
  - Email (SMTP, POP3, IMAP)
  - File Transfer (FTP)
  - Reliable Multicast (PGM)

- **Client and server software** (and intermediate systems, like caching proxies, gateways and firewalls)

- **Object formats** for documents and programs (embedded in protocols)

Challenges

- **Heterogeneity**
- **Client and server system architecture**
- **Performance** (in protocols and applications)
- **Interoperability** (with existing protocols and applications)
- **End-user application design**

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### Highly Heterogeneous Computing Environment

<table>
<thead>
<tr>
<th>Issue</th>
<th>Smallest</th>
<th>Largest</th>
<th>(\log_{10} (L/S))</th>
</tr>
</thead>
<tbody>
<tr>
<td>CPU speed</td>
<td>50 MIPS</td>
<td>5000</td>
<td>3</td>
</tr>
<tr>
<td>RAM</td>
<td>10 MB</td>
<td>10 GB</td>
<td>3</td>
</tr>
<tr>
<td>BW</td>
<td>10^7 bps</td>
<td>10^9</td>
<td>6</td>
</tr>
<tr>
<td>Num CPUs</td>
<td>2</td>
<td>2 x 10^7</td>
<td>7</td>
</tr>
<tr>
<td>Latency</td>
<td>1 micro sec</td>
<td>1 sec</td>
<td>6</td>
</tr>
</tbody>
</table>

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### Other Heterogeneous Dimensions

- **OS**
  - Palm Pilot … DOS … MVS … WAP phone
- **Architecture**
  - x86 … CRAY
- **Spoken language**
- **Legal entity**
Let’s begin ....

What is:

The Internet?
A protocol?

What’s the Internet: A Nuts and Bolts View

- Millions of connected computing devices: hosts, end-systems
  - PCs, workstations, servers
  - PDAs, phones, toasters
  - running network apps
- Communication links
  - fiber, copper, radio, satellite
- Routers: forward packets (chunks) of data thru network

What’s the Internet: A Service View

- Communication infrastructure
  - enables distributed applications:
  - WWW, email, games, e-commerce, database, voting
  - more?
- Communication services provided:
  - connectionless
  - connection-oriented
- Cyberspace [Gibson]:
  “a consensual hallucination experienced daily by billions of operators, in every nation, ....”

From Computer Networking: A Top-Down Approach Featuring the Internet by Kurose & Ross
Internet structure: network of networks

- roughly hierarchical
- national/international backbone providers (NBPs)
  - e.g. Sprint, MCI (previously UUnet/WorldCom), AT&T, Level3 (which acquired Genuity), Qwest and Cable & Wireless
  - interconnect (peer) with each other privately, or at public Network Access Point (NAPs)
- regional ISPs
  - connect into NBPs
- local ISP, company
  - connect into regional ISPs

What’s a protocol?

A human protocol and a computer network protocol:

Human protocols:
- “what’s the time?”
- “I have a question”
- introductions

Network protocols:
- machines rather than humans
- all communication activity in Internet governed by protocols

protocols define format, order of messages sent and received among network entities, and actions taken on messages receipt

In Summary, a protocol is ....

- An agreement about communication between two or more entities
- It specifies
  - Format of messages
  - Meaning of messages
  - Rules for exchange
  - Procedures for handling problems
Protocol Specification

- As designers, we typically specify a protocol in a document, such as an Internet RFC.
- Many formal and semi-formal representations can describe protocols:
  - Space-Time Diagrams
  - Finite State Machines (FSM)

Space-Time Diagrams

- Describes causal ordering
- Defines indication/request/response actions
- This diagram shows 'send and wait' protocol

Finite State Machine Transition Diagram for TCP

- Defines
- States
- Input (the event that causes transition)
- Transitions (to new states)

Networking Review

Layered protocol model of computer networks

- Reduce complexity by “layering” protocols
- Solve at most a few challenges in each layer
- E.g.
  - Lower layer (link) eliminates all physical noise errors
  - Upper layer (transport in TCP) resends lost messages
- Each layer offers services to the layer above
- Enable improvements to PART of the network
Why layering?

Dealing with complex systems:
- explicit structure allows identification, relationship of complex system’s pieces
  - layered reference model for discussion
- modularization eases maintenance, updating of system
  - change of implementation of layer’s service transparent to rest of system
  - e.g., change in gate procedure doesn’t affect rest of system
- layering considered harmful?

Layers And Protocol Software

- Protocol software follows layering model
- One software module per layer
- Modules cooperate
- Incoming or outgoing data passes from one module to another
- Entire set of modules known as stack

Internet protocol stack

- application: supporting network applications
  - ftp, SMTP, HTTP
- transport: host-host data transfer
  - TCP, UDP
- network: routing of datagrams from source to destination
  - IP, routing protocols
- link: data transfer between neighboring network elements
  - PPP, ethernet
- physical: bits “on the wire, in the fiber, or as electromagnetic waves”

Protocol layering and data

Each layer takes data from above
- adds header information to create new data unit
- passes new data unit to layer below
Potential Drawbacks to Layering

Some researchers and networking engineers are vehemently opposed to layering [Wakeman 1992].

- Potential drawbacks: A layer may duplicate lower-layer functionality (the classic End to End issue).
- A layer may need information that is present in another layer (violates isolation principle).

Internet Protocol (IP)

- Only data transmission protocol at Layer 3
- Defines
  - Internet addressing
  - Internet packet format
  - Internet routing

IP Address Details

- 32 Bits - divided into two parts
  - Prefix identifies network
  - Suffix identifies host
- Global authority assigns unique prefix to network (IANA)
- Local administrator assigns unique suffix to host

IP Addresses

given notion of “network”, let’s examine IP addresses:

"class-full" addressing:

<table>
<thead>
<tr>
<th>class</th>
<th>network</th>
<th>host</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1.0.0.0 to 127.255.255.255</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>128.0.0.0 to 191.255.255.255</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>192.0.0.0 to 223.255.255.255</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>224.0.0.0 to 239.255.255.255</td>
<td></td>
</tr>
</tbody>
</table>

32 bits
### Classes And Network Sizes

<table>
<thead>
<tr>
<th>Address Class</th>
<th>Prefix Bits</th>
<th>Max Nets</th>
<th>Suffix Bits</th>
<th>Max Hosts Per Net</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>7</td>
<td>128</td>
<td>24</td>
<td>16777216</td>
</tr>
<tr>
<td>B</td>
<td>14</td>
<td>16384</td>
<td>16</td>
<td>65536</td>
</tr>
<tr>
<td>C</td>
<td>21</td>
<td>2097152</td>
<td>8</td>
<td>256</td>
</tr>
</tbody>
</table>

- Maximum network size determined by class of address
  - Class A: large
  - Class B: medium
  - Class C: small

### IP Addressing Example

- **IP addressing: CIDR**
  - Classful addressing:
    - Inefficient use of address space, address space exhaustion
    - E.g., class B net allocated enough addresses for 65K hosts, even if only 2K hosts in that network
  - **CIDR**: Classless InterDomain Routing
    - Network portion of address of arbitrary length
    - Address format: `a.b.c.d/x`, where `x` is # bits in network portion of address
      
      ```
      11001000 00010111 00010000 00000000
      200.23.16.0/23
      ```

### Internet Packets

- Contains sender and destination addresses
- Size depends on data being carried
- Called **IP datagram**
- Two Parts Of An IP Datagram

  **Header**
  - Contains source and destination address
  - Fixed-size fields

  **Data Area (Payload)**
  - Variable size up to 64K
  - No minimum size
**IP V4 Datagram format**

- **IP protocol version**
- **header length (bytes)**
- **“type” of data**
- max number remaining hops (decremented at each router)
- upper layer protocol to deliver payload to

**IP Semantics**

- **IP is connectionless**
  - Datagram contains identity of destination
  - Each datagram sent/handled independently
- Routes can change at any time

**IP Semantics (continued)**

- IP allows datagrams to be
  - Delayed
  - Duplicated
  - Delivered out-of-order
  - Lost
- Called **best effort delivery**
- **Motivation**: accommodate all possible networks

**Requests For Comment (RFC)**

- Describe formally (and sometimes not so formally) everything about the Internet.
- Actually, RFCs are really a form of Memo.
- For amusement, try RFC 968 (“’Twas the Night Before Startup”)
- All are available on-line: www.ietf.org/rfc.html
- We use RFCs to learn about SMTP (2821), HTTP (2616), for example.
RFC Characteristics

- RFC Statuses (2026)
  - Standard track
    - PS - proposed standard
    - DS - draft standard
    - S - standard
  - Non-standards track
    - E - experimental
    - I - information only
    - H - Historic
    - BC - Best current practices

Example

Network Working Group                               D. Waitzman
Request for Comments: 1149                              BBN STC 1 April 1990
A Standard for the Transmission of IP Datagrams on Avian Carriers

Status of this Memo

This memo describes an experimental method for the encapsulation of IP datagrams in avian carriers. This specification is primarily useful in Metropolitan Area Networks. This is an experimental, not recommended standard.

Overview and Rational

Avian carriers can provide high delay, low throughput, and low altitude service. The connection topology is limited to a single point-to-point path for each carrier, used with standard carriers, but may carriers can be used without significant interference with each other, outside of early spring. This is because of the 5G ether space available to the carriers, in contrast to the 1G ether used by IEEE802.3. The carriers have an intrinsic collision avoidance system, which increases Frame Format.

The IP datagram is printed on a small scroll of paper, in hexadecimal, the body of the scroll is separated by ultrasound and biostatic. The scroll of paper is wrapped around one leg of the avian carrier. A band of duct tape is used to secure the datagram's edges. The bandwidth is limited to the leg length.

RFC citations

- RFC citations appear in this format:
  - #### Title of RFC. Author 1, Author 2, Author 3. Issue date. (Format: ASCII) (Obsoletes xxx) (Obsoleted by xxx) (Updates xxx) (Updated by xxx) (Also FYI ####) (Status: ssssss)

- Good searchable index
  - http://www.rfc-editor.org/rfcsearch.html

Internet Engineering task Force

IETF

- Open organization - anyone may join
- Primarily dedicated to development of the Internet protocols.
- Ideas are presented as RFCs and go through a review process
- RFC standards described in RFC 1602
  - Proposed
  - Draft
  - Standard
More Alphabet Soup

- IAB - Internet Architecture Board
- IANA - Internet Assigned Numbers Authority
- IESG - Internet Engineering Standards Group

Conclusions

- Layering a key concept in computer network design
  - Determines design and modularity of network software
- Major design decision in building a network architecture
  - Connection-oriented vs. connectionless
  - Both popular
- This course focuses on Application layer software

EXTRA SLIDES

Finite State Machine Representation

- Visualize as a 2D Array of functions
  - Rows represent states
  - Columns represent events
  - Current State is an index i
  - New Event is some index j
- For each State/Event pair specify
  - An action to take (a function to execute)
  - A next state
Protocol Model

- Intended for protocol designers
- Divides protocols into layers
- Each layer devoted to one sub-problem
- Example: ISO 7-layer reference model

OSI Layered protocol model

- Application (We focus on activity here)
- Presentation - Data representation
- Session - Login and passwords
- Transport - Reliability
- Network - Packet forwarding
- Data Link - Hardware frame definitions
- Physical - Underlying hardware

TCP/IP Model vs. OSI

IP Fragmentation & Reassembly

- network links have MTU (max transfer size) - largest possible link-level frame.
  - different link types, different MTUs
- large IP datagram divided (“fragmented”) within net
  - one datagram becomes several datagrams
  - “reassembled” only at final destination
  - IP header bits used to identify, order related fragments
IP Fragmentation and Reassembly

One large datagram becomes several smaller datagrams