Architecture: Definition

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Orderly arrangement of parts
The manner of construction of something and the disposition of its parts
Design, the way components fit together
Ex: railway system, airline system
A single architecture can have many implementations
Ex: hub-and-spoke and United/American/Delta
direct-flights and Southwest/JetBlue

The Internet

a system of store-and-forward packet-switched gateways
that provides internetwork packet delivery between any two
networks of store-and-forward packet-switching gateways
The Internet is one implementation of a particular architecture

Architecture Principles

Connect a number of distinguishable networks
Top-level goal:

Internet Architecture Goals

Packet-switched network
Store and forward gateways between component networks
Top-level goal:

IP Design Principles

Fate sharing
IP makes minimal assumptions about underlying medium,
and doesn’t get in the way of applications
Hourglass design
Robust way to identify communication flows
Survivability
Survive failures

Definitions are vague, so we need guiding principles - but can people agree on what these are?

Each network owned and managed separately
Autonomous systems
Routing and flow control decisions made separately

Bill Cheng

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A style and method of design and construction
Ex: railway system, airline system

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A style and method of design and construction
Ex: railway system, airline system
Perfection is achieved not when there is no longer anything to add, but when there is no longer anything to take away.

Antoine de Saint-Exupéry

The simplest explanation is the best.

Occam’s razor

Be liberal in what you accept, and conservative in what you send.

Jon Postel

In allocating resources, strive to avoid a disaster rather than to achieve an optimum.

Butler Lampson

Multiplexing via packet switching:
- multiple kinds of traffic
- multiple kinds of networks
- distributed management
- inexpensive
- low effort to add host
- resource accounting

Efficient resource usage on demand
- Interleave packets from different sources

Packet Switching

The Internet Architecture

Heterogeneous Networks

Two cans and a string

"Two cans and a string"

TDM: Full duplex, 1 line for each.

Full duplex: 2 wires (4 wires if full-duplex)

Different kinds of media
- Distribution management
- Different physical layers
- Different protocols
- Different costs
- Different lifetimes
- Different management
- Different technologies

Each can be good for different purposes

They can be changed and grow

Need to own existing networks

Packet Switching

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Packet Switching
Frequency Division Multiplexing

Code Division Multiplexing

And FDM and CDM...
Multiple Types of Service

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- Why? not just bi-directional reliable data
- "virtual circuit"
- interactive, low-latency

IP: best effort datagram

TCP
- bulk delivery
- bad if link layer wants to do too much
- lightweight

UDP
- allows out-of-order to user
- low-latency & jitter, RT possible
- for voice
- reliability is biggest source of jitter

web

Multiple Applications

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- file transfer (Napster, etc.)
- remote login
- streaming audio
- interactive audio
- streaming/interactive video
- computer appliances
- distributed games

Requirements:
- delay/jitter sensitivity
- bursty/smooth
- point-to-point vs. n-way (one-to-one, many-to-one, one-to-many, many-to-many)
- numbers of sources and sinks
- class of apps

Multiple Kinds of Networks

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- Requirements of X:
  - reasonable reliability
  - addressing
  - reliable, in-order, broadcast, multicast, QoS (or priority), internal knowledge of failures, speeds, or delays, etc.
- Non-requirements of X:
  - compare to integrated stacks (e.g., ISO, ATM, Apple Desktop Bus, USB)
  - SCSI over IP?
  - but fragmentation and reassembly

Other Goals

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- today: quite cheap
- cost effective
- but for small devices? for light-switch?
- policy routing
- Distributed management
- but limitations (ex. address space portability)

Other Goals (Cont.)

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- today: PPPoE created just for authentication
- in [Clark88a]: cost of implementing stack
- effort to deploy end-host
- distributed management
- header too big for small payloads
- inefficiencies
- retransmission of lost packets done at end hosts
- med to big for small payloads
- unreliable
- Loss resilience
- Realization: an instance of the Internet class

Architecture and Implementation

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- today: the Internet can't do X because it is Y
- corollary: not every realization is appropriate for every app
- also: custom stack will get last 5% of performance,
- but is it worth it?
- Ex: can't do streaming audio/voice over IP
- cannot do bi-directional reliable (this is why)
- Ex: can't do X over IP because it is Y
- today: the Internet can do X because it is Y
- Reassembly: an instance of the Internet class

Realization is biggest source of jitter
<table>
<thead>
<tr>
<th>Feature</th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>Connection establishment</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>Connectionless (not to overwhelm the network)</td>
<td>Y</td>
<td>N</td>
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<tr>
<td>Flow control</td>
<td>Y</td>
<td>N</td>
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<tr>
<td>Loss recovery</td>
<td>Y</td>
<td>N</td>
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<tr>
<td>Ordered data delivery</td>
<td>Y</td>
<td>N</td>
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<tr>
<td>Urgent data indication</td>
<td>Y</td>
<td>N</td>
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<tr>
<td>Congestion control (not to overwhelm the network)</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>Congestion control came later</td>
<td>N</td>
<td></td>
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<tr>
<td>PSN flag</td>
<td>Y (sort of)</td>
<td></td>
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<tr>
<td>Stream of bytes vs. stream of packets</td>
<td>Y</td>
<td>N</td>
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<tr>
<td>TCP Alternative Choices</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

TCP Features:
- Connection establishment
- Connectionless (not to overwhelm the network)
- Flow control
- Loss recovery
- Ordered data delivery
- Urgent data indication
- Congestion control (not to overwhelm the network)

Other Components of IP Success:
- BSD socket API
- Other APIs (e.g., Windows, Unix, etc.)

Features:
- Connection establishment
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- Loss recovery
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