Communication Networks

Last week on Communication Networks

Part 1: General overview

What is a network made of?
How is it shared?
How is it organized?
How does communication happen?
How do we characterize it?

Networks are composed of three basic components:
- End-systems
- Links
- Switch/routers

There exist two approaches to sharing:
- Reservation
- On-demand

In practice, the approaches are implemented using circuit-switching or packet-switching.
Pros and cons of circuit switching

<table>
<thead>
<tr>
<th>advantages</th>
<th>disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>predictable performance</td>
<td>inefficient if traffic is bursty or short</td>
</tr>
<tr>
<td>simple &amp; fast switching</td>
<td>complex circuit setup/teardown</td>
</tr>
<tr>
<td>once circuit established</td>
<td>which adds delays to transfer</td>
</tr>
<tr>
<td></td>
<td>requires new circuit upon failure</td>
</tr>
</tbody>
</table>

Pros and cons of packet switching

<table>
<thead>
<tr>
<th>advantages</th>
<th>disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>efficient use of resources</td>
<td>unpredictable performance</td>
</tr>
<tr>
<td>simpler to implement</td>
<td>requires buffer management and congestion control</td>
</tr>
<tr>
<td>than circuit switching</td>
<td></td>
</tr>
<tr>
<td></td>
<td>route around trouble</td>
</tr>
</tbody>
</table>

Communication Networks
Part 1: General overview

What is a network made of?
How is it shared?
How is it organized?
How does communication happen?
How do we characterize it?

List any technologies, principles, applications used after typing in:

> www.google.ch

and pressing enter in your browser

You have a lot of networking knowledge already!
... and this, across all the layers

<table>
<thead>
<tr>
<th>Transport</th>
<th>TCP</th>
<th>72%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Application</td>
<td>DNS</td>
<td>65%</td>
</tr>
<tr>
<td>Network</td>
<td>IP</td>
<td>56%</td>
</tr>
<tr>
<td>Network</td>
<td>Router</td>
<td>44%</td>
</tr>
<tr>
<td>Application</td>
<td>HTTP</td>
<td>41%</td>
</tr>
<tr>
<td>Application</td>
<td>HTML</td>
<td>31%</td>
</tr>
<tr>
<td>Server</td>
<td>26%</td>
<td></td>
</tr>
<tr>
<td>Link</td>
<td>Ethernet</td>
<td>19%</td>
</tr>
<tr>
<td>Transport</td>
<td>UDP</td>
<td>17%</td>
</tr>
<tr>
<td>Encryption</td>
<td>15%</td>
<td></td>
</tr>
</tbody>
</table>

+72 other

This week on Communication Networks

What is a network made of?
How is it shared?
How is it organized?
How does communication happen?
How do we characterize it?
Communication Networks
Part 1: General overview

What is a network made of?

How is it shared?

How is it organized?

How does communication happen?

How do we characterize it?

The Internet should allow processes on different hosts to exchange data. Everything else is just commentary...

http://www.opte.org

How do you exchange data in a network as complex as this?

To exchange data, Alice and Bob use a set of network protocols:

- Alice
  - hello
  - give me http://comm-net.ethz.ch/
  - here it is

- Bob

A protocol is like a conversational convention: who should talk next and how they should respond?

Sometimes implementations are not compliant...
Each protocol is governed by a specific interface.

In practice, there exists a lot of network protocols. How does the Internet organize this?

Modularity is a key component of any good system.

To provide structure to the design of network protocols, network designers organize protocols in layers and the network hardware/software that implement them.

Internet communication can be decomposed in 5 independent layers (or 7 layers for the OSI model).

Each layer provides a service to the layer above.
Each layer provides a service to the layer above by using the services of the layer directly below it.

Applications... built on...
Reliable (or unreliable) transport... built on...
Best-effort global packet delivery... built on...
Best-effort local packet delivery... built on...
Physical transfer of bits

Applications
Reliable (or unreliable) transport
Best-effort global packet delivery
Best-effort local packet delivery
Physical transfer of bits

Each layer has a unit of data

<table>
<thead>
<tr>
<th>layer</th>
<th>role</th>
</tr>
</thead>
<tbody>
<tr>
<td>L5</td>
<td>Application exchanges messages between processes</td>
</tr>
<tr>
<td>L4</td>
<td>Transport transports segments between end-systems</td>
</tr>
<tr>
<td>L3</td>
<td>Network moves packets around the network</td>
</tr>
<tr>
<td>L2</td>
<td>Link moves frames across a link</td>
</tr>
<tr>
<td>L1</td>
<td>Physical moves bits across a physical medium</td>
</tr>
</tbody>
</table>

Each layer (except for L3) is implemented with different protocols

<table>
<thead>
<tr>
<th>layer</th>
<th>protocol</th>
</tr>
</thead>
<tbody>
<tr>
<td>L5</td>
<td>Application HTTP, SMTP, FTP, SIP, ...</td>
</tr>
<tr>
<td>L4</td>
<td>Transport TCP, UDP, SCTP</td>
</tr>
<tr>
<td>L3</td>
<td>Network IP</td>
</tr>
<tr>
<td>L2</td>
<td>Link Ethernet, Wifi, (A/V)DSL, WiMAX, LTE, ...</td>
</tr>
<tr>
<td>L1</td>
<td>Physical Twisted pair, fiber, coaxial cable, ...</td>
</tr>
</tbody>
</table>

The Internet Protocol (IP) acts as an unifying, network, layer

<table>
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<th>layer</th>
<th>protocol</th>
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<td>L1</td>
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</tr>
</tbody>
</table>

Each layer (except for L3) is implemented with different protocols and technologies

<table>
<thead>
<tr>
<th>layer</th>
<th>technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>L5</td>
<td>Application software</td>
</tr>
<tr>
<td>L4</td>
<td>Transport hardware</td>
</tr>
<tr>
<td>L3</td>
<td>Network software</td>
</tr>
<tr>
<td>L2</td>
<td>Link hardware</td>
</tr>
<tr>
<td>L1</td>
<td>Physical hardware</td>
</tr>
</tbody>
</table>

Network stack challenges at increasing speeds
The 100Gbits challenge

Jesper Dangaard Brouer
Red Hat inc.
Linux Conf Au, New Zealand, January 2015


Each layer takes messages from the layer above, and encapsulates with its own header and/or trailer

Application HTTP(S)
Transport TCP/UDP
Network IP
Link Ethernet
In practice, layers are distributed on every network device.

Since when bits arrive they must make it to the application, all the layers exist on a host.

Routers act as L3 gateway as such they implement L2 and L3.

Switches act as L2 gateway as such they only implement L2.

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Let's see how it looks like in practice on a host, using Wireshark

https://www.wireshark.org

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A network connection is characterized by its delay, loss rate and throughput

How long does it take for a packet to reach the destination
What fraction of packets sent to a destination are dropped?
At what rate is the destination receiving data from the source?

Each packet suffers from several types of delays at each node along the path

transmission delay
@ propagation delay
due to link properties
@ processing delay
due to traffic mix & switch internals
@ queuing delay

= total delay

Overall, the main culprits for the overall delay are the transmission, propagation and queuing delays

transmission delay
@ propagation delay
tend to be tiny
@ processing delay
@ queuing delay

= total delay
The transmission delay is the amount of time required to push all of the bits onto the link

\[
\text{Transmission delay} = \frac{\text{packet size}}{\text{link bandwidth}} \quad \text{(in sec)}
\]

Example:

<table>
<thead>
<tr>
<th>Bit Rate</th>
<th>Packet Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 Mbps</td>
<td>1000 bits</td>
</tr>
<tr>
<td></td>
<td>10 μsec</td>
</tr>
</tbody>
</table>

The propagation delay is the amount of time required for a bit to travel to the end of the link

\[
\text{Propagation delay} = \frac{\text{link length}}{\text{propagation speed}} \quad \text{(in sec)}
\]

Example:

<table>
<thead>
<tr>
<th>Bandwidth</th>
<th>Link Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.10^8 m/sec</td>
<td>30,000 m</td>
</tr>
<tr>
<td></td>
<td>150 μsec</td>
</tr>
</tbody>
</table>

How long does it take for a packet to travel from A to B? (not considering queuing for now)

\[
\text{Time to transmit one bit} = 10^{-6} \text{s}
\]

\[
\text{Time to transmit } 800 \text{ bits} = 800 \times 10^{-6} \text{s}
\]

The last bit reaches B at:

\[
(800 \times 10^{-6}) + 10^{-3} \text{s} = 1.08 \text{ms}
\]

If we now exchange a 1GB file split in 100B packets

\[
10^7 \times 100B \text{ packets}
\]

Different transmission characteristics imply different tradeoffs in terms of which delay dominates

<table>
<thead>
<tr>
<th>Packet Size</th>
<th>Bit Rate</th>
<th>Delay Dominates</th>
</tr>
</thead>
<tbody>
<tr>
<td>10^7 x 100B</td>
<td>1 Gbps</td>
<td>Transmission delay</td>
</tr>
<tr>
<td>1 x 100B</td>
<td>1 Gbps</td>
<td>Propagation delay</td>
</tr>
<tr>
<td>1 x 100B</td>
<td>1 Mbps</td>
<td>Both matter</td>
</tr>
</tbody>
</table>

In the Internet, we can’t know in advance which one matters!

Queuing delay is the hardest to evaluate as it varies from packet to packet.

It is characterized with statistical measures, e.g., average delay & variance, probability of exceeding x.
Queuing delay depends on the traffic pattern

No overload

Transient overload!

Queue

Queues absorb transient bursts, but introduce queueing delays
The time a packet has to sit in a buffer before being processed depends on the traffic pattern.

Queueing delay depends on:
- arrival rate at the queue
- transmission rate of the outgoing link
- traffic burstiness

When the traffic intensity is \( >1 \), the queue will increase without bound, and so does the queuing delay.

Golden rule: Design your queuing system, so that it operates far from that point.

A network connection is characterized by its delay, loss rate and throughput.

In practice, queues are not infinite. There is an upper bound on queuing delay.

If the queue is persistently overloaded, it will eventually drop packets (loss).

A network connection is characterized by its delay, loss rate and throughput.
The throughput is the instantaneous rate at which a host receives data.

\[
\text{Average throughput} = \frac{\text{data size}}{\text{transfer time}} \quad \text{[bits/sec]}
\]

To compute throughput, one has to consider the bottleneck link:

\[
\text{Average throughput} = \min(R_S, R_L)
\]

A network connection is characterized by its delay, loss rate and throughput.

As technology improves, throughput increase & delays are getting lower except for propagation (speed of light).

Because of propagation delays, Content Delivery Networks move content closer to you.

The Internet history starts in the late 50’s, with people willing to communicate differently.

Telephone network is the communication system entirely based on circuit switching

People start to want to use networks for other things, defense, (not personal) computers, …

… but knew that circuit-switching will not make it too inefficient for bursty loads and not resilient

A brief overview of Internet history
From this wish arose three crucial questions

- How can we design a more efficient network? (also lead to the invention of packet switching)
- How can we design a more resilient network? (also lead to the invention of packet switching)
- How can we connect all these networks together? (lead to the invention of the Internet as we know it)

Paul Baran, RAND
Len Kleinrock, UCLA
Bob Kahn, DARPA

The 60s saw the creation of packet switching and the Advanced Research Projects Agency Network

The first message ever exchanged on the Internet was “lo”

Oct. 29 1969
Leonard Kleinrock @UCLA tries to log in a Stanford computer

We typed the L... Do you see it? Yes! We see the L
We typed the O... Do you see it? Yes! We see the O
We typed the G... system crashes

UCLA
Stanford


The 70s saw the creation of Ethernet, TCP/IP and the e-mail

1971 Network Control Program predecessor of TCP/IP
1972 Email & Telnet
1973 Ethernet
1974 TCP/IP paper by Vint Cerf & Bob Kahn

In the 80s, TCP/IP went global

1983 NCP to TCP/IP Flag day
1983 Domain Name Service (DNS)
1985 NSFNet (TCP/IP) succeeds to ARPANET
1986 Van Jacobson saves the Internet (with congestion control)

1989 Arpanet decommissioned
1989 Birth of the Web Tim Berners Lee (CERN)
1993 Search engines invented (Excite)
1995 NSFNet is decommissioned
1998 Google reinvents search

The 90s saw the creation of the Web as well as the Internet going commercial

1989 Arpanet is decommissioned
1995 Birth of the Web

Communication Networks
Spring 2017
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February, 27 2017