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1 – Introduction

Computer Communications Networks
CSI 516

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This course is to provide a combined applied/theoretical background in Networks and Data Communications, which will focus on the fundamentals of good science and engineering:

1. Measurement — How much better is one solution than another?
2. Prediction — What is the expected behavior?
3. Understanding — Why is one solution better than another?
4. Design and Implementation — Construct a good solution.
5. Control — Ensure that your solution is used effectively.

Your users/employers (and professorq) will care about these things.
The design of this course and its policies attempts to:

1. Prepare and reward good students because
   (a) Networks impact quality of life
   (b) Unskilled practitioners are dangerous!
   (c) Skilled practitioners are valuable.

2. Improve the students skills in:
   (a) Network design and analysis,
   (b) Network systems software design and implementation,
   (c) Performance analysis,
   (d) Performance tuning,
   (e) Documentation design.

This should help your academic/professional reputation and career.
4 – So What is a good Student?

A good student is a good practitioner, who:

1. Is Motivated (tries hard)
2. Has Aptitude (can do the work)
3. Has good background (knows the prerequisites/basics).
This course is not intended to:

1. Train you as a network administrator

2. Focus on the implementation specifics of a particular vendor

3. Provide Cisco/3com/Novell (or any other brand) certification.

But it may make these things easier to learn once you know the general principles and the “Big Picture”.

5 – NonGoals of the Course
6 – Why You Should Not Take This Course

If one or more of these applies to you, you are unlikely to do well.

- You are not ready for the hard work.
- You don’t have 15 hours a week to devote to this class.
- You will not attend class regularly.
- You lack prerequisites.
- You just want to sit and listen.
- You are not ready to take the initiative.
  Since only key concepts are covered, you will need to read ahead and do research on your own.
- The content is not what you want.
7 – Some Prerequisites

The Study of Networked Systems relies on many areas:

1. Mathematics
   (a) Basic Calculus/Numerical Analysis
   (b) Probability (Exponential Distribution, Poisson Processes)
   (c) Scheduling

2. Computer Science — You Must be able to Program!
   (a) Computer Architecture
   (b) Basic Performance Analysis
   (c) Operating Systems and Systems Programming
   (d) Software Design
   (e) Data Structures/Algorithms

3. Technical Writing Skills
8 – How to Succeed

1. Review prerequisite topics as needed.

2. Start projects early.

3. If stuck, try:
   
   (a) To formulate a clear problem statement

   (b) Check your resources (including the frequently asked questions (FAQ))

   (c) If you are still stuck, ask a classmate (if appropriate) or us.

   but don’t resort to cheating!

4. Try the in class exercises and ungraded problems. They might help come exam time!
Some good approaches to attack problems are traditional methods:

1. The Scientific Method — Used to understand/predict a processes behavior
   (a) Problem statement — Select which process you want to understand.
   (b) Hypothesis — Make a measurable guess (prediction) about the behavior.
   (c) Experiment — Test the hypothesis and statistically confirm or refute it.

2. Engineering/applied math — focuses on controlling a process or deriving a solution:
   (a) Problem statement — There is a math problem to solve or a phenomena to control.
   (b) Design — Come up with a solution
   (c) Analysis — Measure the effectiveness of the solution.
We will focus on the foundations of good engineering solutions:

1. Cost — How expensive is the solution
2. Performance — How efficiently does it solve the problem
3. Correctness — How accurate is the results of the solution method

These features make or break technologies, and impact your marketability.
11 – What is Networking?

Communication networks support information transfer between remote users/machines.

Common Network Technology:

1. Profoundly impacts the quality of life!
2. Is Digital (encodes data in discrete values)
3. Affected by analog phenomena
4. Drives and Uses Theory/Experiment
5. Is used in ways not forseen by designers.
   - E.G. WWW was a surprise to internet designers.
Some well known networks include:

1. Postal (non-electronic).
3. Telephone (now with DSL, etc.)
4. Broadcast (Radio and Television)
5. Cable Television (now with modems)
6. The Internet
Networking (research, theory, practice and industry) has many motivations.
Telephone network service has evolved:

1. *Circuits* are formed between sender and receiver.

2. Initially point to point (in the lab).

3. Introduced a “switch” (reducing number of lines needed).

4. *POTS* — plain old telephone service

5. *ATM* — Supports QoS guarantees (losing to TCP/IP?).

6. Now have ISDN, DSL, ADSL, etc....


8. Getting competition (voice over IP).
The caller picks up the phone, triggering the flow of current in wires that connect to the telephone office.

The current is detected and a dial tone is transmitted by the telephone office to indicate that it is ready to receive the destination number.

The caller sends this number by pushing the keys on the telephone set. Each key generates a pair of tones that specify a number. The telephone office decodes these tones and sends them over the network to an exchange.

The exchange then emits a series of ringing signals, which are detected by the destination telephone. The telephone user answers, and the call is connected.

Either the caller or the called party terminates the call by hanging up their phone.
16 – What is a Protocol?

A protocol is the set of rules governing how two or more parties communicate.

1. Comes from the Greek words “First Sheet” (meaning the table of contents of a document)

2. Parliamentary procedure (non computational).

3. Can provide:
   - Services — E.G. HTTP relies on TCP which relies on IP.
   - Management — SNMP.
17 – WEB Browsers and Protocols

1. The user clicks on a link to indicate which document is to be retrieved.

2. The browser must determine the address that contains the document. It does this by sending a query to its local name server.

3. Once the address is known the browser establishes a connection to the specified machine, usually a TCP connection. In order for the connection to be successful, the specified machine must be ready to accept TCP connections.

4. The browser runs a client version of HTTP, which issues a request specifying both the name of the document and the possible document formats it can handle.

5. The machine that contains the requested document runs a server version of HTTP. It reacts to the HTTP request by sending an HTTP response which contains the desired document in the appropriate format.

6. The TCP connection is then closed and the user may view the document.
Deployment dominates network costs (for large installations).

This means that:

1. Backward Compatibility is critical
2. De Facto Standardization occurs
Data is encoded using *signals*, which are either:

- Digital (discrete) waves
- Analog (continuous) waves

Signals are described by their:

- Frequency — Cycles per unit time. Frequency’s reciprocal is the *period*.
- Amplitude — Distance between crest and bottom
- Phase — Horizontal Displacement
Signals propagate over *media*, which can be:

- Air/Space (e.g. radio, cellular telephone, wireless networks).
- Wires (ethernet, traditional telephone, optical fiber, ATM).
Multiplexing shares (expensive) lines.

- Multiplexor (MUX) — Maps many inputs to one output.
- Demultiplexor (DEMUX) — Maps one input to many outputs.
- Switch — Maps many inputs to many outputs.

(a) A switch provides the network to a cluster of users

(b) A multiplexer connects two access networks
Consider a link connecting two devices, the link can be:

- **Half Duplex** — Supports communication in only one direction.
- **Full Duplex** — Supports bidirectional communication.

Switching describe the unit of data transfer.

- **Circuit Switching** — Connection oriented, establish a connection, send messages, remove the connection.
- **Message Switching** — Transfer whole messages (not common).
- **Packet Switching** — Break each message into one or more *packets* (the largest unit of transfer).
23 – Circuit vs. Packet Switching

The word *switching* describe the unit of data transfer.

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# 24 - Circuit vs. Packet Switching

There are trade-offs between circuit and packet switching:

<table>
<thead>
<tr>
<th>Property</th>
<th>Circuit Switching</th>
<th>Packet Switching</th>
</tr>
</thead>
<tbody>
<tr>
<td>Route Selection</td>
<td>Static</td>
<td>Dynamic (per Packet)</td>
</tr>
<tr>
<td>Possible Reordering?</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Response to link failure</td>
<td>Data Loss</td>
<td>Rerouting/Retransmission</td>
</tr>
<tr>
<td>Delivery (Qos)</td>
<td>Guaranteed</td>
<td>Depends on network</td>
</tr>
</tbody>
</table>
25 – Heirarchy and Addressing

- Backbone — Expensive fast long haul network (heavily multiplexed).

- WAN, MAN, LAN, SAN — Wide/Metropolitan/Local/System area networks. Multiplexing decreases as locality increases.

- Addressing — Allows sender of data to specify the recipient (and allows recipient to recognize their data).

- Challenges:
  - Congestion — when too many senders compete for a multiplexed resource.
  - Traffic Control — limit individuals access for the general good
Metropolitan network $A$ consists of access subnetworks $a$, $b$, $c$, $d$.

National network consists of regional subnetworks $\alpha$, $\beta$, $\gamma$.

Metropolitan network $A$ is part of regional subnetwork $\alpha$. 
27 – A Simple Performance Model

Classic models of fluid flowing through pipes (percolation) have been used to model data flowing through a network.
Hennessy and Patterson [1] use the notation:

*FIGURE 7.5 Performance parameters of interconnection networks.*
28.1 – Performance Measures Defined

Where the terms mean:

- **Bandwidth** — Rate at which data throughput (ignoring latency).
- **Time of Flight** — How long until the first flit reaches the receiver.
- **Transmission Time** — The time required for the message to arrive after time of flight.
- **Transport Latency** — How long the message is in the network.
- **Sender Overhead** — How long the sender takes to prepare the message.
- **Receiver Overhead** — How long the receiver takes to process the message.
28.2 – Computing Total Latency

From the above, we can see that the total latency is then:

\[
\text{Total Latency} = \text{Sender Overhead} + \text{Time of Flight} + \frac{\text{Message Size}}{\text{Bandwidth}} + \text{Receiver Overhead}
\]
Suppose a user receives 125 byte message across a Transatlantic fiber optic cable. Assume the cable is $10^4$ kilometers long, and that signals propagate at the speed of light in this medium, which is $2.3 \times 10^5$ kilometers per second. Suppose the fiber can transfer 1 Gbits/second. How long does it take to arrive. Suppose that sender overhead was 250 microseconds, and receiver overhead was 300 microseconds.

1. How long does it take for the signal to travel across the cable?

2. What if the machines were instead 1 kilometer apart?

3. What if the message size were $1.25 \times 10^5$ bytes.

Note: To simplify, you can treat the speed of light in this medium as approximately $2 \times 10^5$ km per second.
30 – Solution $10^4$ km 125 byte Case

For the transatlantic case we get:

$$\text{Total Latency} = \text{Sender Overhead} + \text{Time of Flight} + \frac{\text{Message Size}}{\text{Bandwidth}} + \text{Receiver Overhead}$$

$$= 250 \mu\text{sec.} + \frac{10^4\text{km}}{2 \times 10^5\text{km/sec}} \times \frac{10^6\mu\text{sec}}{\text{sec}} +$$

$$\frac{125\text{bytes} \times 8\text{bits/byte}}{1 \times 10^9\text{bits/sec}} \times \frac{10^6\mu\text{sec}}{\text{sec}} + 300\mu\text{sec.}$$

$$= (250 + 50000 + 1 + 300)\mu\text{sec.} = 50351\mu\text{sec.}$$
The time of flight for the 1 km trip is $1\mu\text{sec.}$, so:

\[
\text{Total Latency} = 250\mu\text{sec.} + \frac{1\text{km}}{2 \times 10^5\text{km/sec}} \times \frac{10^6\mu\text{sec}}{\text{sec}} + \frac{125\text{bytes} \times 8\text{bits/byte}}{1 \times 10^9\text{bits/sec}} \times \frac{10^6\mu\text{sec}}{\text{sec}} + 300\mu\text{sec}.
\]

\[
= (250 + 5 + 1 + 300)\mu\text{sec.} = 556\mu\text{sec.}
\]
32 – Solution $10^4$ km 125000 byte Case

For the transatlantic case we get:

Total Latency \[=\] Sender Overhead + Time of Flight + 
\[
\frac{\text{Message Size}}{\text{Bandwidth}} + \text{Receiver Overhead}
\]

\[= 250\mu\text{sec.} + \frac{10^4\text{km}}{2 \times 10^5\text{km/sec}} \times \frac{10^6\mu\text{sec}}{\text{sec}} +
\]

\[\frac{125000\text{bytes} \times 8\text{bits/byte}}{1 \times 10^9\text{bits/sec}} \times \frac{10^6\mu\text{sec}}{\text{sec}} + 300\mu\text{sec.}
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$\frac{125000\text{bytes} \times 8\text{bits/byte}}{1 \times 10^9 \text{bits/sec}} \times \frac{10^6 \mu\text{sec}}{\text{sec}} + 300\mu\text{sec.}$

$= (250 + 5 + 1000 + 300)\mu\text{sec.} = 1555\mu\text{sec.}$
34 – Effective Bandwidth

Users tend to care about how long they wait and how fast their share of the network is.

The network’s effective bandwidth measures the user perceived rate of data transmission:

\[
\text{Effective Bandwidth} = \frac{\text{Message Size}}{\text{Total Latency}}
\]

For the 125 byte case the user sees effective bandwidths:

\[
\frac{1000\text{bits}}{50351\mu\text{sec.}} \approx 0.0199\frac{\text{Mbits}}{\text{sec.}} \quad \text{for the } 10^4\text{ km link and}
\]

\[
\frac{1000\text{bytes}}{556\mu\text{sec.}} \approx 1.79\frac{\text{Mbits}}{\text{sec.}} \quad \text{for the } 1\text{ km link.}
\]

For the 125000 byte case, we get:

\[
\frac{10^6\text{bits}}{51350\mu\text{sec.}} \approx 19.47\frac{\text{Mbits}}{\text{sec.}} \quad \text{for the } 10^4\text{ km link and}
\]

\[
\frac{10^6\text{bytes}}{1555\mu\text{sec.}} \approx 643\frac{\text{Mbits}}{\text{sec.}} \quad \text{for the } 1\text{ km link.}
\]
We have observed:

1. Latency matters
   (a) Time of flight dominates in long distance networks.
   (b) For short distance networks sender and receiver overhead can dominate

2. Large message sizes helps amortize out these costs.

3. The longer the distance the more message size matters.
References
