Digital Communication Networks

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Digital Communication Networks

Introduction

Eytan Modiano
Course syllabus

• Monday
  – AM: Introduction to layering, the physical layer
  – PM: The data link layer

• Tuesday
  – AM: Delay models and queueing
  – PM: Higher layer protocols: TCP/IP, ATM

• Wednesday
  – AM: Routing
  – PM: More routing, flow control

• Thursday
  – AM: Multiple access
  – PM: LANs, MANs, SANs, and switching

• Friday
  – AM: Wireless Networks
  – PM: Optical Networks
Logistics

• Morning lectures: 9:00am - 12:00pm (break around 10:15)

• Lunch: on your own, 12:00 - 1:30pm

• Afternoon lecture: 1:30 - 4:30 (break around 2:45)

• Friday: start at 9:00 and end at 3:30pm (lunch: 11:45 - 12:30)

• Social: Dinner on Thursday evening
Reference textbooks

• Computer Networks, by Peterson and Davie
  – Most current on the internet

• Data Networks, by Bertsekas and Gallager
  – Strong on probabilistic modeling and analysis

• Network Optimization: Continuous and Discrete Models, by Dimitri P. Bertsekas
  – Network algorithms and routing, network flows, optimization theory

• Introduction to Probability, by Dimitri P. Bertsekas and John N. Tsitsiklis
Data Networks

• Fundamental aspects of network Design and Analysis:
  – Architecture
    Layering
    Topology design
  – Protocols
    Pt.-to-Pt.
    Multiple access
    End-to-end
  – Algorithms
    Error recovery
    Routing
    Flow Control
  – Analysis tools
    Probabilistic modeling
    Queueing Theory
Network Applications

• Resource sharing
  – Computing
  – Mainframe computer (old days)
    Today, computers cheaper than comm (except LANS)
    Printers, peripherals
  – Information
    DB access and updates
    E.g., Financial, Airline reservations, etc.

• Services
  – Email, FTP, Telnet, Web access
  – Video conferencing
  – DB access
  – Client/server applications
Network coverage areas

• **Wide Area Networks (WANS)**
  - Span large areas (countries, continents, world)
  - Use leased phone lines (expensive!)
    - 1980’s: 10 Kbps, 2000’s: 2.5 Gbps
    - User access rates: 56Kbps – 155 Mbps typical
  - Shared comm links: switches and routers
    - E.g., IBM SNA, X.25 networks, Internet

• **Local Area Networks (LANS)**
  - Span office or building
  - Single hop (shared channel) (cheap!)
  - User rates: 10 Mbps – 1 Gbps
    - E.g., Ethernet, Token rings, Apple-talk

• **Metro Area networks (MANS)**

• **Storage area networks**
Network services

- **Synchronous**
  - Session appears as a continuous stream of traffic (e.g., voice)
  - Usually requires fixed and limited delays

- **Asynchronous**
  - Session appears as a sequence of messages
  - Typically bursty
  - E.g., Interactive sessions, file transfers, email

- **Connection oriented services**
  - Long sustained session
  - Orderly and timely delivery of packets
  - E.g., Telnet, FTP

- **Connectionless services**
  - One time transaction (e.g., email)

- **QoS**
Switching Techniques

• Circuit Switching
  – Dedicated resources

• Packet Switching
  – Shared resources
  – Virtual Circuits
  – Datagrams
Circuit Switching

• Each session is allocated a fixed fraction of the capacity on each link along its path
  – Dedicated resources
  – Fixed path
  – If capacity is used, calls are blocked
    E.g., telephone network

• Advantages of circuit switching
  – Fixed delays
  – Guaranteed continuous delivery

• Disadvantages
  – Circuits are not used when session is idle
  – Inefficient for bursty traffic
  – Circuit switching usually done using a fixed rate stream (e.g., 64 Kbps)
    Difficult to support variable data rates
Problems with circuit switching

- Many data sessions are low duty factor (bursty),
  \[(\text{message transmission time})/(\text{message interarrival time}) << 1\]
  Same as: \((\text{message arrival rate}) \times (\text{message transmission time}) << 1\)

- The rate allocated to the session must be large enough to meet the delay requirement. This allocated capacity is idle when the session has nothing to send

- If communication is expensive, then circuit switching is uneconomic to meet the delay requirements of bursty traffic
  - More of a problem in high-speed networks
Circuit Switching Example

L = message lengths
\( \lambda = \) arrival rate of messages
R = channel rate in bits per second
X = message transmission delay = \( \frac{L}{R} \)

- R must be large enough to keep X small
- Bursty traffic \( \Rightarrow \lambda x \ll 1 \Rightarrow \) low utilization

• Example
  - \( L = 1000 \) bytes (8000 bits)
  - \( \lambda = 1 \) message per second
  - \( X < 0.1 \) seconds (delay requirement)
  - \( \Rightarrow R > 8000/0.1 = 80,000 \) bps
    Utilization = \( \frac{8000}{80000} = 10\% \)

• With packet switching channel can be shared among many sessions to achieve higher utilization
Packet Switched Networks

Messages broken into Packets that are routed To their destination

Packet Network

Buffers

Packet Switch
• Datagram packet switching
  – Route chosen on packet-by-packet basis
  – Different packets may follow different routes
  – Packets may arrive out of order at the destination
  – E.g., IP (The Internet Protocol)

• Virtual Circuit packet switching
  – All packets associated with a session follow the same path
  – Route is chosen at start of session
  – Packets are labeled with a VC# designating the route
  – The VC number must be unique on a given link but can change from link to link
    Imagine having to set up connections between 1000 nodes in a mesh
    Unique VC numbers imply 1 Million VC numbers that must be represented
    and stored at each node
  – E.g., ATM (Asynchronous transfer mode)
Virtual Circuits Packet Switching

• For datagrams, addressing information must uniquely distinguish each network node and session
  – Need unique source and destination addresses

• For virtual circuits, only the virtual circuits on a link need be distinguished by addressing
  – Global address needed to set-up virtual circuit
  – Once established, local virtual circuit numbers can then be used to represent the virtual circuits on a given link: VC number changes from link to link

• Merits of virtual circuits
  – Save on route computation
    Need only be done once at start of session
  – Save on header size
  – Facilitate QoS provisioning
  – More complex
  – Less flexible

Node 5 table

(3,5) VC13 -> (5,8) VC3
(3,5) VC7    -> (5,8) VC4
(6,5) VC3    -> (5,8) VC7
Circuit vs packet switching

- Advantages of packet switching
  - Efficient for bursty data
  - Easy to provide bandwidth on demand with variable rates

- Disadvantages of packet switching
  - Variable delays
  - Difficult to provide QoS assurances (Best-effort service)
  - Packets can arrive out-of-order

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<th>Switching Technique</th>
<th>Network service</th>
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<tr>
<td>Circuit switching</td>
<td>Synchronous (e.g., voice)</td>
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<tr>
<td>Packet switching</td>
<td>Asynchronous (e.g., Data)</td>
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<td>Virtual circuits</td>
<td>Connection oriented</td>
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<tr>
<td>Datagram</td>
<td>Connectionless</td>
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</table>
Circuit vs Packet Switching

- Can circuit switched network be used to support data traffic?

- Can packet switched network be used for connection oriented traffic (e.g., voice)?

- Need for Quality of service (QoS) mechanisms in packet networks
  - Guaranteed bandwidth
  - Guaranteed delays
  - Guaranteed delay variations
  - Packet loss rate
  - Etc...
Layers

- **Presentation layer**
  - Provides character code conversion, data encryption, data compression, etc.

- **Session layer**
  - Obtains virtual end to end message service from transport layer
  - Provides directory assistance, access rights, billing functions, etc.

- Standardization has not proceeded well here, since transport to application are all in the operating system and don't really need standard interfaces

- **Focus:** Transport layer and lower
Transport Layer

• The network layer provides a virtual end to end packet pipe to the transport layer.

• The transport layer provides a virtual end to end message service to the higher layers.

• The functions of the transport layer are:
  1) Break messages into packets and reassemble packets of size suitable to network layer
  2) Multiplex sessions with same source/destination nodes
  3) Resequence packets at destination
  4) recover from residual errors and failures
  5) Provide end-to-end flow control
The network layer module accepts incoming packets from the transport layer and transit packets from the DLC layer.

It routes each packet to the proper outgoing DLC or (at the destination) to the transport layer.

Typically, the network layer adds its own header to the packets received from the transport layer. This header provides the information needed for routing (e.g., destination address).

Each node contains one network layer module plus one link layer module per link.
Link Layer

• Responsible for error-free transmission of packets across a single link
  – Framing
    Determine the start and end of packets
  – Error detection
    Determine which packets contain transmission errors
  – Error correction
    Retransmission schemes (Automatic Repeat Request (ARQ))
Physical Layer

• Responsible for transmission of bits over a link

• Propagation delays
  – Time it takes the signal to travel from the source to the destination
    Signal travel approximately at the speed of light, $C = 3 \times 10^8$ meters/second
    – E.g.,
      LEO satellite: $d = 1000$ km $\Rightarrow$ 3.3 ms prop. delay
      GEO satellite: $d = 40,000$ km $\Rightarrow$ 1/8 sec prop. delay
      Ethernet cable: $d = 1$ km $\Rightarrow$ 3 $\mu$s prop. delay

• Transmission errors
  – Signals experience power loss due to attenuation
  – Transmission is impaired by noise
  – Simple channel model: Binary Symmetric Channel
    $P =$ bit error probability
    Independent from bit to bit
  – In reality channel errors are often bursty
Internet Sub-layer

- A sublayer between the transport and network layers is required when various incompatible networks are joined together
- This sublayer is used at gateways between the different networks
- It looks like a transport layer to the networks being joined
- It is responsible for routing and flow control between networks, so looks like a network layer to the end-to-end transport layer
- In the internet this function is accomplished using the Internet Protocol (IP)
  - Often IP is also used as the network layer protocol, hence only one protocol is needed
Internetworking with TCP/IP


TCP <-> TCP Protocol <-> IP Protocol <-> Ethernet Protocol <-> Ethernet driver

FTP server

TCP

IP

token ring

ROUTER

IP

token ring driver
Encapsulation

User data → Appl header → TCP header → application data → IP header → TCP header → application data → Ethernet header → Ethernet trailer

- Application
- TCP
- IP
- Ethernet driver
- Ethernet

<table>
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<tr>
<th>Ethernet header</th>
<th>IP header</th>
<th>TCP header</th>
<th>application data</th>
<th>Ethernet trailer</th>
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</thead>
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<tr>
<td>14</td>
<td>20</td>
<td>20</td>
<td></td>
<td>4</td>
</tr>
</tbody>
</table>

- Ethernet frame: 46 to 1500 bytes