CS4450

Computer Networks: Architecture and Protocols

Lecture 3
- Packet Delays
- How the Internet works

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Context for and Goals of Today’s Lecture

• Today’s lecture is going to be one of the hardest lectures
• If you understand everything
  • There is something wrong!

• Goals:
  • Wrap up discussion on transmission and propagation delays
  • How does the Internet work?
    • An end-to-end view
But, as usual, lets start with:
what we have learnt so far
Recap: What is a computer network?

A set of network elements connected together, that implement a set of protocols for the purpose of sharing resources at the end hosts.
Recap: network can be abstractly represented as a graph
Recap: Sharing the network

Source

Path

Destination

Source

Path

Destination

Facebook

Google
Recap: Performance metrics in computer networks!

- **Bandwidth**: Number of bits sent per second (bits per second, or bps)
  - Depends on hardware, network traffic conditions, ...

- **Delay**: Time for all bits to go from source to destination (seconds)
  - Depends on hardware, distance, traffic from other sources, ...

- Many other performance metrics
  - Reliability, fairness, etc.
  - We will come back to other metrics later ...
Recap: Two approaches to sharing networks

• First: Reservations
  • Reserve (peak) bandwidth needed in advance

• One way to implement reservations: circuit switching
  • Source sends a reservation request for peak demand to destination
  • Switches/routers establish a “circuit”
  • Source sends data
  • Source sends a “teardown circuit” message
Recap: Circuit switching (reservation-based sharing) summary

- **Goods:**
  - Predictable performance
  - Reliable delivery
  - Simple forwarding mechanism

- **Not-so-goods**
  - Handling failures
  - Resource underutilization
  - Blocked connections
  - Connection set up overheads
  - Per-connection state in switches (scalability problem)
Recap: Solution: Packet switching

- Break data into smaller pieces
  - Packets!

- Transmit the packets without any reservations
  - And, hope for the best
Recap: Packet switching summary

• **Goods:**
  - With proper mechanisms in place
    - Easier to handle failures
  - No resource underutilization
    - A source can send more if others don’t use resources
  - No blocked connection problem
  - No per-connection state
  - No set-up cost

• **Not-so-goods:**
  - Unpredictable performance
  - High latency
  - Packet header overhead
Summary of network sharing
Statistical multiplexing

• **Statistical multiplexing**: combining demands to share resources efficiently

• Long history in computer science
  • Processes on an OS (vs every process has own core)
  • Cloud computing (vs every one has own datacenter)

• Based on the premise that:
  • **Peak of aggregate load is << aggregate of peak load**

• Therefore, it is better to share resources than to strictly partition them ...
Two approaches to sharing networks

Both embody statistical multiplexing

• Reservation: sharing at connection level
  • Resources shared between connections currently in system
  • Reserve the peak demand

• On-demand: sharing at packet level
  • Resources shared between packets currently in system
  • Resources given out on packet-by-packet basis
  • No reservation of resources
Understanding delay/latency
Packet delay/latency

- Consists of six components
  - Link properties:
    - Transmission delay
    - Propagation delay
  - OS internals:
    - Processing delay
    - Queueing delay
  - Traffic matrix and switch internals:
    - Processing delay
    - Queueing delay
- First, consider transmission, propagation delays
- Queueing delay and processing delays later in the course
Transmission delay

• How long does it take to push all the bits of a packet into a link?

• = Packet size / Link bandwidth

• Example:
  • Packet size = 1500Byte
  • Bandwidth = 100Mbps
  • $1500 \times 8 / 100 \times 1024 \times 1024$ seconds

• Independent of the link length (distance that the packet traverses)
Propagation delay

- How long does it take to move **one bit** from one end of a link to the other?

- \( \text{Delay} = \frac{\text{Link length}}{\text{Propagation speed of link}} \)
  - Propagation speed \( \sim \) some fraction of speed of light

- Example:
  - Length = 30,000 meters
  - \( \text{Delay} = \frac{30 \times 1000}{3 \times 100,000,000} \) second = 100us

- Independent of packet size and bandwidth
Group Exercise:

How long does it take for a packet on a link?

Constraints:

• Packet size = 1000Byte
• Bandwidth = 100Mbps
• Length = 30,000m
Solution to Group Exercise:

How long does it take for a *packet* on a link?

\[ \sim 180 \text{us} \]

Why?
Questions?
Today’s lecture: How does the Internet work?

1. Dive into **end-to-end**: from source to destination
2. First look into switches: routing, queueing, forwarding
3. First look into network stack: sockets, ports, “the stack”
How does the Internet work?

An end-to-end view
Four fundamental problems!

- **Naming, addressing**: Locating the destination

- **Routing**: Finding a path to the destination

- **Forwarding**: Sending data to the destination

- **Reliability**: Handling failures, packet drops, etc.
Four fundamental problems!

Naming, Routing, Forwarding, Reliability

• Each is motivated by a clear need

• The solutions are not always clean or deep

• But if you keep in mind what the problem is
  • You’ll be able to understand the solutions
  • When the right time comes :-) 

Will take the entire course to learn these:

Lets get an end-to-end picture!
Fundamental problem #1: Naming and Addressing

• Network Address: where host is located
  • Requires an address for the destination host

• Host Name: which host it is
  • why do we need a name?

• Answer: When you move a host to new building
  • Address changes
  • Name *does not* change

• Same thing with your own name and address!

• Remember the analogy: human names, addresses, post office, letters
Names versus addresses

• Consider when you access a web page
  • Insert URL into browser (eg, www.cornell.edu)
  • Packets sent to web site (reliably)
  • Packet reach application on destination host

• How do you get to the website?
  • URL is user-level name (eg, www.cornell.edu)
  • Network needs address (eg, where is www.cornell.edu)?

• Must map names to addresses
  • Just like we use an address book to map human names to addresses
Mapping Names to Addresses

- On the Internet, we only name hosts (sort of)
  - URLs are based on the name of the host containing the content (that is, www.cornell.edu names a host)

- Before you can send packets to www.cornell.edu, you must resolve names into the host’s address

- Done by the **Domain Name System (DNS)**

**The source knows the name;**

Maps that name to an address using DNS!
Questions?
Routing packets through network elements (e.g., routers) to destination

• Given destination address (and name), how does each switch/router know where to send the packet so that the packet reaches its destination?

• When a packet arrives at a router
  • a routing table determines which outgoing link the packet is sent on
  • Computed using routing protocols
Routing protocols (conceptually)

- Distributed algorithm that runs between routers
  - Distributed means no single router has “full” view of the network
  - Exchange of messages to gather “enough” information ...

- ... about the network topology

- Compute paths through that topology

- Store forwarding information in each router
  - If packet is destined for X, send out using link l1
  - If packet is destined for Y, send out using link l2
  - Can packets going to different destinations sent out to same link?

- We call this a routing table
Questions?
Fundamental problem #3

Queueing and Forwarding of packets at switches/routers

Input queue

Virtual output queue

Output queue
Queueing and Forwarding of packets at switches/routers

**Queueing:** When a packet arrives, store it in “input queues”
- Each incoming queue divided into multiple virtual output queues
- One virtual output queue per outgoing link
- When a packet arrives:
  - Look up its destination’s address (how?)
  - Find the link on which the packet will be forwarded (how?)
  - Store the packet in corresponding virtual output queue

**Forwarding:** When the outgoing link free
- Pick a packet from the corresponding virtual output queue
- Forward the packet!
What must packets carry to enable forwarding?

- Packets must describe where it should be sent
  - Requires an address for the destination

- Packets must describe where its coming from
  - For handling failures, etc.
  - Requires an address for the source

- Packets must carry data
  - can be bits in a file, image, whatever
Switch Processing and Queueing delay

- **Processing delay**
  - Easy; each switch/router needs to decide where to put packet
  - Requires checking header, etc.

- **Queueing delay**
  - Harder; depends on “how many packets are in front of me”
  - Depends on network load
  - As load increases, queueing delay increases

- **In an extreme case, increase in network load**
  - results in packet drops

- We will return to this in much more depth later ...
Questions?
Fundamental problem #4

How do you deliver packets reliable?

- Packets can be dropped along the way
  - Buffers in router can overflow
  - Routers can crash while buffering packets
  - Links can garble packets

- How do you make sure packets arrive safely on an unreliable network?
  - Or, at least, know if they are delivered?
  - Want no false positives, and high change of success
Two questions about reliability

• Who is responsible for this? (architecture)
  • Network?
  • Host?

• How is it implemented? (engineering)

• We will consider both perspectives
Questions?
Finishing our story

• We now have the address of the web site
• And, a route/path to the destination
• And, mechanisms in place to forward the packets at each switch/router
• In a reliable manner
  • So, we can send packets from source to destination
  • Are we done?

• When a packet arrives at a host, what does the host do with it?
  • To which process (application) should the packet be sent?

• If the packet header only has the destination address, how does the host know where to deliver packet?
  • There may be multiple applications on that destination
And while we are finishing our story ....

• Who puts the source address, source port, destination address, destination port in the packet header?
The final piece in the game: End-host stack

Of Sockets and Ports

• When a process wants access to the network, it opens a socket, which is associated with a port

• **Socket**: an OS mechanism that connects processes to the network stack

• **Port**: number that identifies that particular socket

• The port number is used by the OS to direct incoming packets
Implications for Packet Header

- Packet Header must include:
  - Destination address (used by network)
  - Destination port (used by network stack)
  - And?
  - Source address (used by network)
  - Source port (used by network stack)

- When a packet arrives at the destination host, packet is delivered to the socket associated with the destination port

- More details later
Separation of concerns

- **Network**: Deliver packets from host to host (based on address)
- **Network stack (OS)**: Deliver packets to appropriate socket (based on port)
- **Applications**:
  - Send and receive packets
  - Understand content of packet bodies

**Secret of the Internet’s success is getting these and other abstractions right**
The end-to-end story

• Application opens a **socket** that allows it to connect to the **network stack**

• Maps **name** of the web site to its **address** using **DNS**

• The network stack at the source embeds the address and **port** for both the source and the destination in **packet header**

• Each **router** constructs a **routing table** using a distributed algorithm

• Each router uses destination address in the packet header to look up the **outgoing link** in the routing table
  • And when the link is free, forwards the packet

• When a packet arrives the destination:
  • The network stack at the destination uses the port to forward the packet to the right application
Today’s lecture

• The Internet is a huge, complicated system

• One can study the parts in isolation
  • Routing
  • Ports, sockets
  • Network stack
  • ...

• But the pieces all fit together in a particular way

• Today was quick overview of how pieces fit...
  • Don’t worry if you didn’t understand much of it
  • You probably absorbed more than you realize