15-441 15-641 Computer Networking

Lecture 2 – Applications and Protocol Stacks

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www.cs.cmu.edu/~prs/15-441-F14

Today's Lecture

- Network applications
  - Requirements
  - Latency and bandwidth
- Internet architecture
  - A layered design
  - Protocols
  - Life of a packet
- Review of papers

Yesterday's Applications

- FTP: transfer files to a host
  - No distributed file systems!
  - Mostly replaced by "the web" – http
- Telnet: use a computer remotely
  - Similar to ssh today (minus the security)
- Mail: exchange electronic e-mail
  - Similar today (kind of)
  - Initially host-to-host: name@my.computer.edu
- Already very useful!

Today's Applications

- Amazon, Facebook, etc.
  - What matters most?
  - 2009 quote: "*Amazon* found every 100ms of *latency* cost them 1% in sales"
- Video streaming
  - Accounts for very high percentage of bandwidth
  - Interactive versus broadcast versus playback
  - What matters most?
- Skype audio and video conferencing
  - Traditional telephone app
  - What matters most?

Requirements

- Performance: latency and throughput
- Network reliability
  - Network service must always be available
- Security: for users and the network itself
  - Privacy, authentication, deal with various attacks, …
  - Attacks on the network, versus enabled by the network
- Scalability.
  - Scale to large numbers of users, traffic flows, …
- Manageability: monitoring, enforcing policies, billing, …

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What Service Does an Application Need?

Data loss

Timing

Bandwidth

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Transport Service Requirements of Common Apps

Application	Data loss	Bandwidth	Time Sensitive
file transfer	no loss	elastic	no
e-mail	no loss	elastic	no
web documents	no loss	elastic	no
real-time audio/ video	loss-tolerant	audio: 5Kb-1Mb video:10Kb-5Mb	yes, 100's msec
stored audio/video	loss-tolerant	same as above	yes, few secs
interactive games	loss-tolerant	few Kbps	yes, 100's msec
financial apps	no loss	elastic	yes and no

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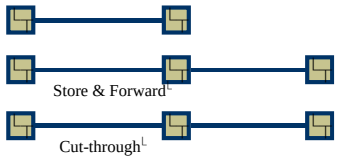
A Closer Look at Packet Delay



Prop + xmit

2*(Prop + xmit)

2*prop + xmit

When does cut-through matter?

Next: Routers have finite speed (processing delay)

Routers may buffer packets (queueing delay)

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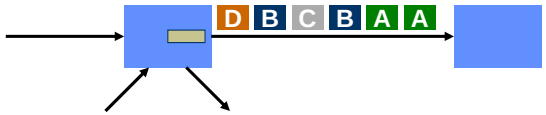
Packet Delay Components

- Sum of a number of different delay components.
- Propagation delay on each link.
  - Proportional to the length of the link
- Transmission delay on each link.
  - Proportional to the packet size and 1/link speed
- Processing delay on each router.
  - Depends on the speed of the router
- Queuing delay on each router.
  - Depends on the traffic load and queue size



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A Word about Units

- What do “Kilo” and “Mega” mean?
  - Depends on context
- Storage works in powers of two.
  - 1 Byte = 8 bits
  - 1 KByte = 1024 Bytes
  - 1 MByte = 1024 Kbytes
- Networks work in decimal units.
  - Network hardware sends bits, not Bytes
  - 1 Kbps = 1000 bits per second
  - To avoid confusion, use 1 Kbit/second
- Why? Historical: CS versus ECE.

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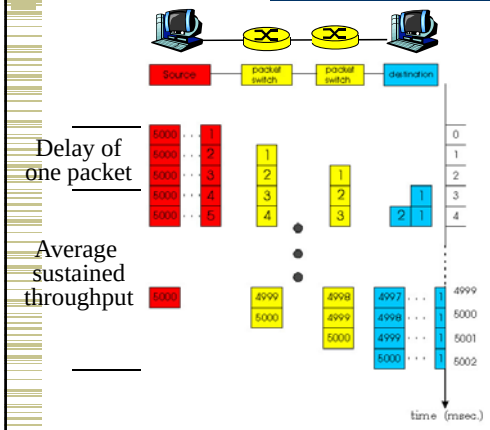
Application-level Delay



Delay of one packet

Average sustained throughput

$$\text{Delay}^{*} + \frac{\text{Size}}{\text{Throughput}}$$

Units: seconds + bits/(bits/seconds)

* For minimum sized packet

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Some Examples

- How long does it take to send a 100 Kbit file?
  - Assume a perfect world
- Is the transfer latency or throughput limited?
- What about a 10 Kbit file?

Latency \ Throughput	100 Kbit/s	1 Mbit/s	100 Mbit/s
500 µsec			
10 msec			
100 msec			

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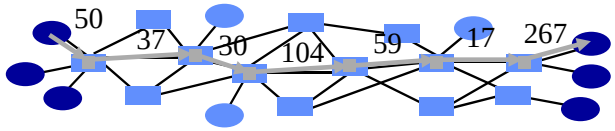
A Closer Look at Throughput

- When streaming packets, the network works like a pipeline.
  - All links forward different packets in parallel
- Throughput is determined by the slowest stage.
  - Called the bottleneck link
- Does not matter why the link is slow!
  - Low link bandwidth
  - Many users sharing the link bandwidth



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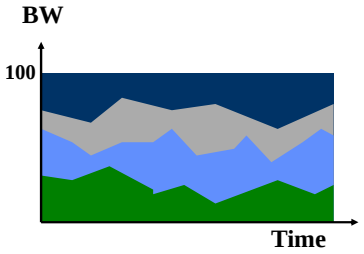
Bandwidth Sharing

- Bandwidth received on the bottleneck link determines end-to-end throughput.
- Router before the bottleneck link decides how much bandwidth each user gets.
  - Users that try to send at a higher rate will see packet loss
- User bandwidth can fluctuate quickly as flows are added or end, or as flows change their transmit rate.



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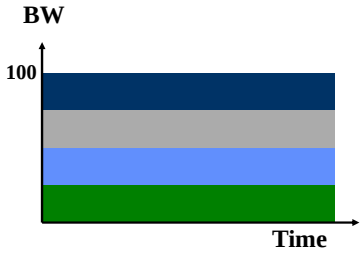
Fair Sharing of Bandwidth

- All else being equal, fair means that users get equal treatment.
  - Sounds fair
- When things are not equal, we need a policy that determines who gets how much bandwidth.
  - Users who pay more get more bandwidth
  - Users with a higher "rank" get more bandwidth
  - Certain classes of applications get priority



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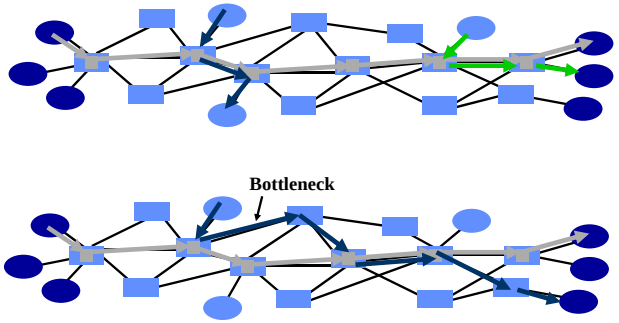
But It is Not that Simple



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  - Protocols
  - Life of a packet
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Announcements

- Getting questions answered:
  - Administrative: start with web site
  - Course material: class, office hours
  - Projects: piazza, office hours
- Waiting list has been cleared
  - Some people are short on credits or have a conflict – you should have received e-mail
  - New people: you will be cleared
- Recitation sessions … a work in progress

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Project Announcements

- Project 1 has been posted – start early!
- We require you to use git and autolab
  - Use of git is for educational reasons
  - Autolab is to simplify testing and grading, but ..
- Pre-autolab era
  - We provided simple test scripts but expected students to write more complex tests (educational)
  - Grading was based on an expanded test set
- Post-autolab era
  - We provided a autograder with simple tests but expect students to write more complex tests (educational)
  - Grading is based on an autograder with an expanded test set
  - We may limit autolab runs to enforce testing discipline

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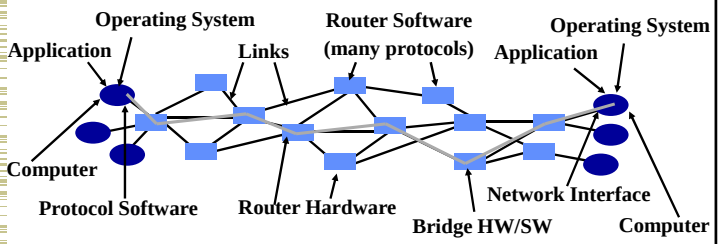
How to Design a Network?

- Has many users
- Offers diverse services
- Mixes very diverse technologies
- Components built by many companies
- Diverse ownership
- Can evolve over time



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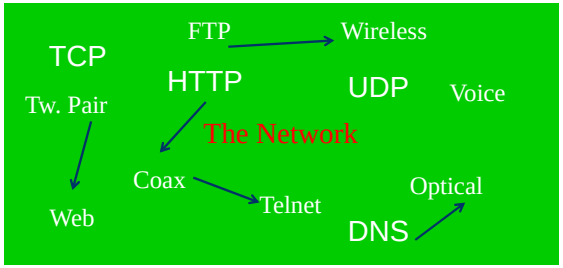
Solution #1



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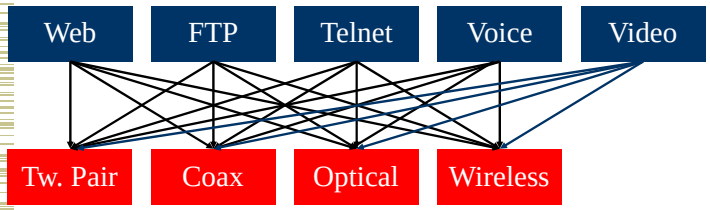
Solution #2?



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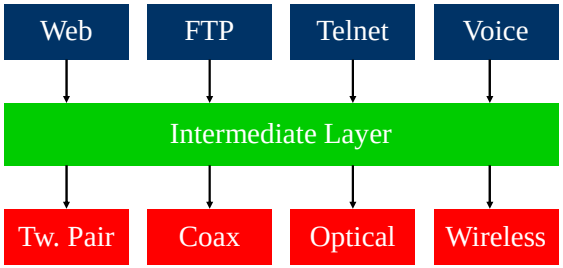
Solution #3



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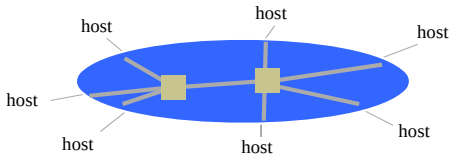
Types of Protocols



- Core network: responsible for transferring data between a sending and receiving host.
- End-to-end protocols: present a network service to applications and users.
  - May add value to the core network protocols
- Driven by differences in constraints: scalability, power, management, speed, etc.

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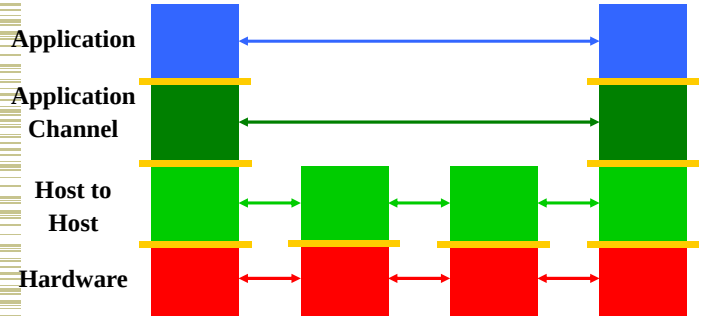
Protocol and Service Levels



Layering: modular approach to network functionality

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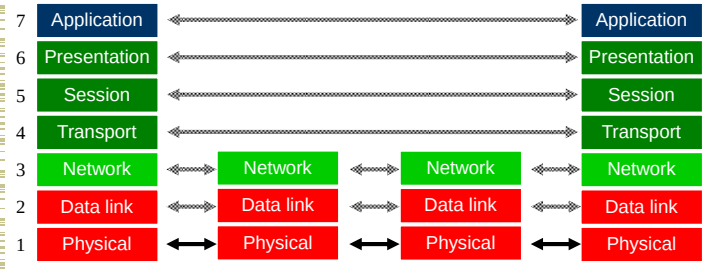
A Layer Network Model

The Open Systems Interconnection (OSI) Model



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OSI Model: 7 Protocol Layers

- Physical: how to transmit bits
- Data link: how to transmit frames
- Network: how to route packets
- Transport: how to send packets end2end
- Session: how to tie flows together
- Presentation: byte ordering, security
- Application: everything else

- TCP/IP has been amazingly successful, and it is not based on a rigid OSI model. The OSI model has been very successful at shaping thought

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Layering Characteristics

- Each layer relies on services from layer below and exports services to layer above
- Interface defines interaction with peer on other hosts – called protocols
- Modules hide implementation - layers can change without disturbing other layers (black box)

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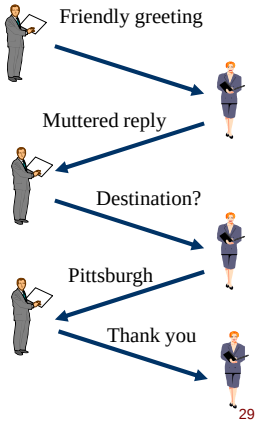
What are Protocols?

- An agreement between parties on how communication should take place
- Module in layered structure
- Protocols define: Interface to peer (syntax & semantics)
  - Actions taken on receipt of a messages
  - Format and order of messages
  - Error handling, termination, ordering of requests, etc.
- Example: Buying airline ticket



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The Internet Engineering Task Force

- Standardization is key to network interoperability
  - The hardware/software of communicating parties are often not built by the same vendor → yet they can communicate because they use the same protocol
- Internet Engineering Task Force
  - Based on working groups that focus on specific issues
- Request for Comments
  - Document that provides information or defines standard
  - Requests feedback from the community
  - Can be "promoted" to standard under certain conditions
    - consensus in the committee
    - interoperating implementations
  - Project 1 will look at the Internet Relay Chat (IRC) RFC

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Other Relevant Standardization Bodies

- ITU-TS - Telecommunications Sector of the International Telecommunications Union.
  - government representatives (PTTs/State Department)
  - responsible for international "recommendations"
- T1 - telecom committee reporting to American National Standards Institute.
  - T1/ANSI formulate US positions
  - interpret/adapt ITU standards for US use, represents US in ISO
- IEEE - Institute of Electrical and Electronics Engineers.
  - responsible for many physical layer and datalink layer standards
- ISO - International Standards Organization.
  - covers a broad area

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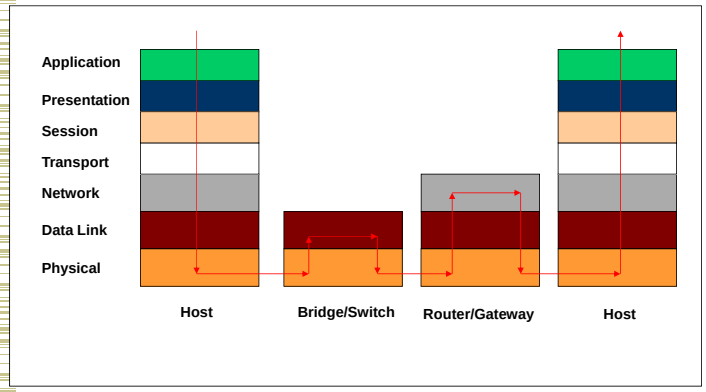
Life of Packet



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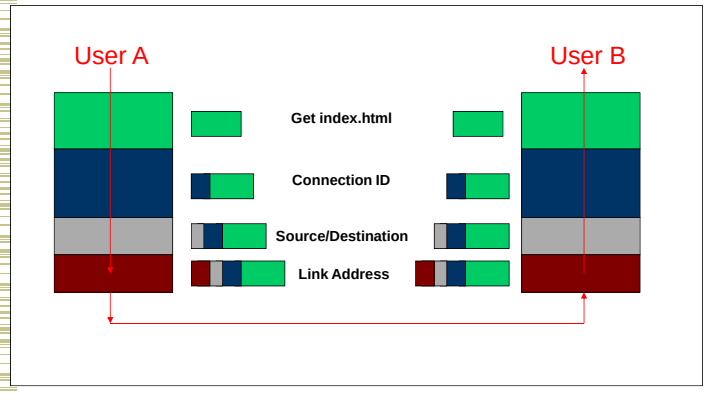
Layer Encapsulation



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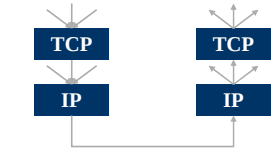
Multiplexing and Demultiplexing

- There may be multiple implementations of each layer.
  - How does the receiver know what version of a layer to use?
- Each header includes a demultiplexing field that is used to identify the next layer.
  - Filled in by the sender
  - Used by the receiver
- Multiplexing occurs at multiple layers. E.g., IP, TCP, …



V/HL	TOS	Length
ID		Flags/Offset
TTL	Prot.	H. Checksum
Source IP address		
Destination IP address		
Options..		

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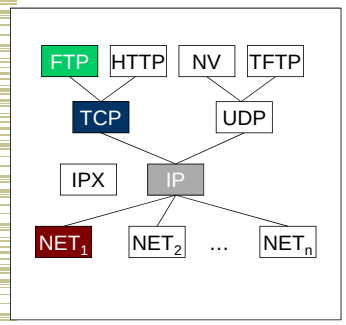
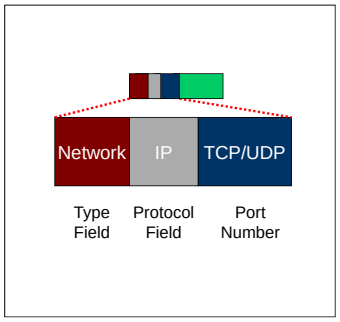
Protocol Demultiplexing

- Multiple choices at each layer





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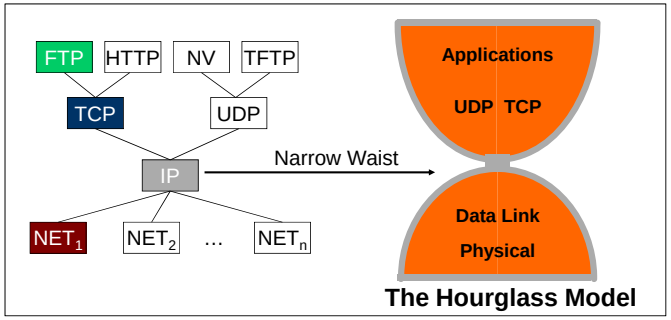
The Internet Protocol Suite



The waist facilitates interoperability
… but evolution is hard

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  - Life of a packet
- (Review of papers)
  - Postponed to IP lectures

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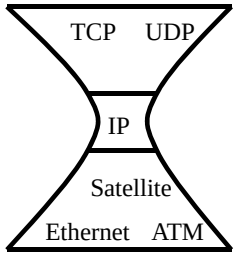
Summary: Internet Architecture

- Packet-switched datagram network
- IP is the "compatibility layer"
  - Hourglass architecture
  - All hosts and routers run IP
- Stateless architecture
  - no per flow state inside network



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Summary: Minimalist Approach

- Dumb network
  - IP provide minimal functionalities to support connectivity
    - Addressing, forwarding, routing
- Smart end system
  - Transport layer or application performs more sophisticated functionalities
    - Flow control, error control, congestion control
- Advantages
  - Accommodate heterogeneous technologies (Ethernet, modem, satellite, wireless)
  - Support diverse applications (telnet, ftp, Web, X windows)
  - Decentralized network administration

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Summary

- Successes: IP on everything!
- Drawbacks…

but perhaps they're totally worth it in the context of the original Internet. Might not have worked without them!

"This set of goals might seem to be nothing more than a checklist of all the desirable network features. It is important to understand that these goals are in order of importance, and **an entirely different network architecture would result if the order were changed**."

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