



15-441  
15-641 **Computer Networking**

Lecture 2 – Protocol Stacks

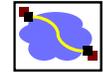
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Fall 2017

[www.cs.cmu.edu/~prs/15-441-F17](http://www.cs.cmu.edu/~prs/15-441-F17)

## Today's Lecture



- Packet versus circuit switching
- How to design a large Internet
  - Protocols
  - Strawman designs
  - A layered design
  - Life of a packet

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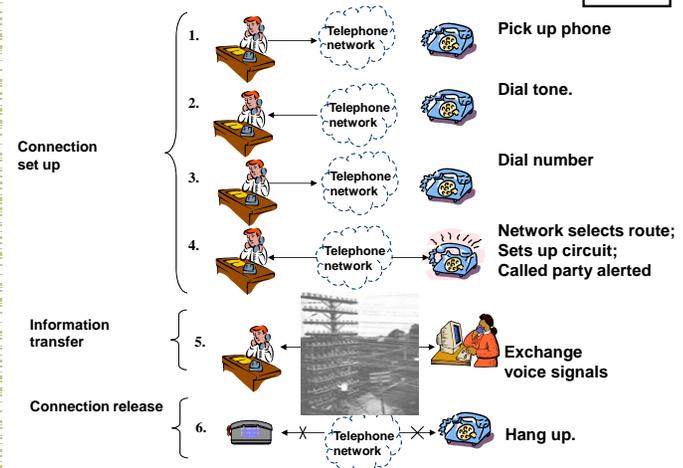
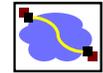
## What is the Objective of the Internet?



- Enable communication between diverse applications on diverse devices ...
  - Web, peer-to-peer, video streaming, distributed processing, transactions, map-reduce, video and audio conferencing, ...
- ... over very diverse infrastructures
  - The "Internet", WiFi and cellular, data center networks, corporate networks, dedicated private networks, ...
- In contrast: previous networks were special purpose and fairly homogeneous in terms of technology
- Context: it is the 1960's and you are asked to design an Internet ...
- ... your starting point is the telephone network

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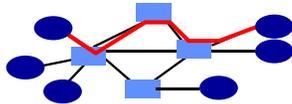
## Three Phases of a Connection



## Circuit Switching



- Source first establishes a connection (circuit) to the destination
  - Each switch along the way stores info about connection, i.e., two wires are connected
- Source sends the data over the circuit
  - No need to include the destination address with the data since the switches know the path
- The connection is explicitly torn down
- Example: telephone network (analog – remember 1960's)



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## Circuit Switching Discussion



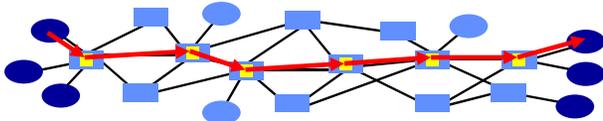
- Circuits have some very attractive properties.
  - Fast and simple data transfer, once the circuit has been established
  - Predictable performance since the circuit provides isolation from other users
  - E.g. guaranteed bandwidth
- But it also has some shortcomings.
  - How about bursty traffic?
    - Do you need a permanent circuit to Facebook?
      - And are you willing to pay for it
    - Circuit will be idle for significant periods of time
  - In practice you will need circuits to many destinations
  - How about users with different bandwidth needs?

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## Contrast this with Packet Switching (our focus)



- Source sends information as self-contained messages that have an address.
  - Source may have to break up single message in multiple packets
- Each packet travels independently to the destination host.
  - Switches use the address in the packet to determine how to forward the packets
  - Store and forward
- Analogy: a letter in surface mail.



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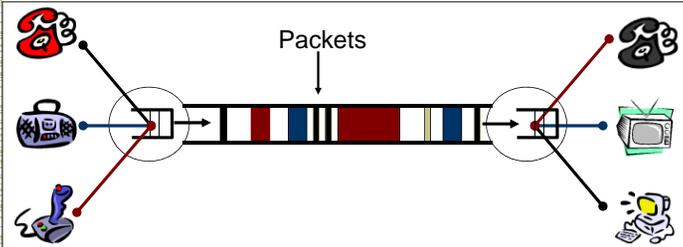
## Packet Switching Discussion



- General: Multiple types of applications
- Efficient: Can send from any input that is ready
- Accommodates bursty traffic efficiently
  - Statistical multiplexing
- Store and forward architecture
  - Packets are self contained units
  - Can use alternate paths – potentially more robust
  - Requires buffering to absorb bursts
- Many challenges, e.g., contention (no isolation)
  - Congestion
  - Delay

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## Statistical Multiplexing



- Users share the wires at a fine grain - packets
- Links are never idle when there is traffic - Efficient!
- Requires queues to buffer packets
  - Creates challenges: congestion, losses, fairness, ...

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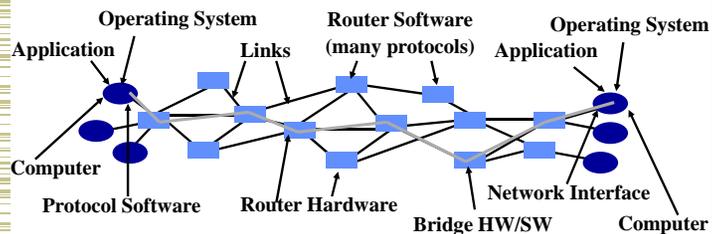
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## Why is Designing an Internet Hard?

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

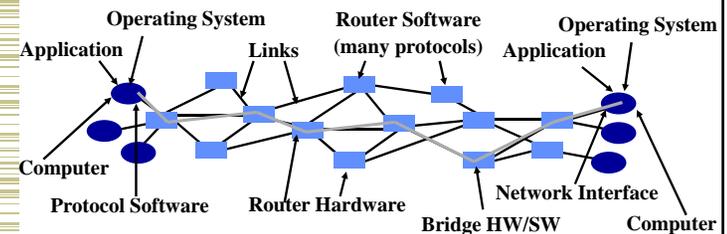


**Oh, and it is really big!**

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## But is it harder than Telephone 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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## But We Can Handle It! What Do We Definitely Need?



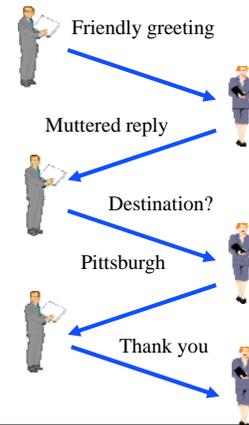
We must have communication hardware and applications:

- • Two “devices” must be able to talk to each other
- Applications since they make the network useful and fun
  - Nobody cares if there are no applications
- • We also need to design the network so it can grow very big and is always available
  - We need to be able to expand, fix, and improve it ...
  - While it is up and running: you cannot reboot the Internet

## Protocol: Enable Communication



- An agreement between parties on how communication should take place.
- Protocols have to define many aspects of the communication:
  - Syntax:
    - Data encoding, language, etc.
  - Semantics:
    - Error handling, termination, ordering of requests, etc.
- Example: Asking for directions
  - English, facial expression, ...
- Example: Buying airline ticket by typing.
  - English, ascii, lines delimited by “\n”

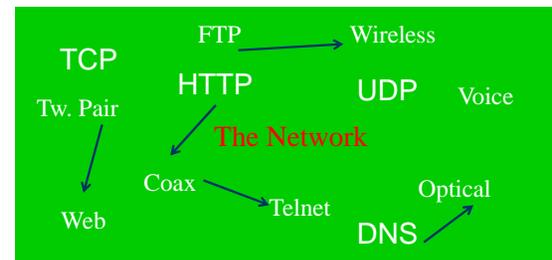


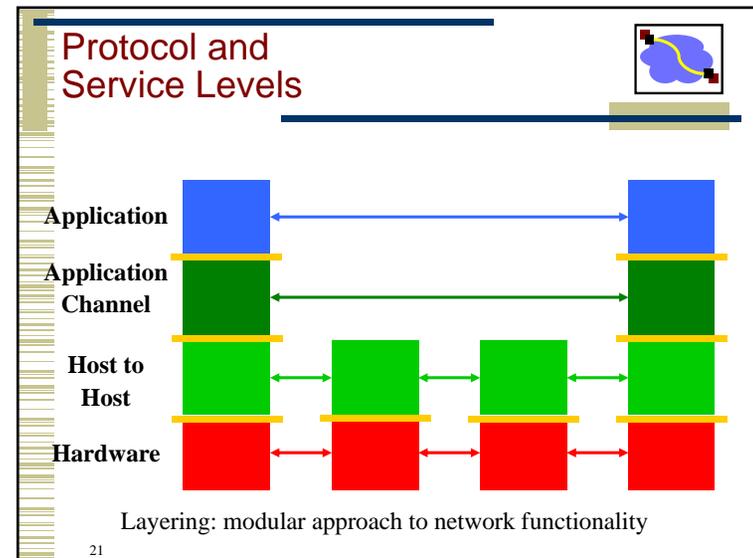
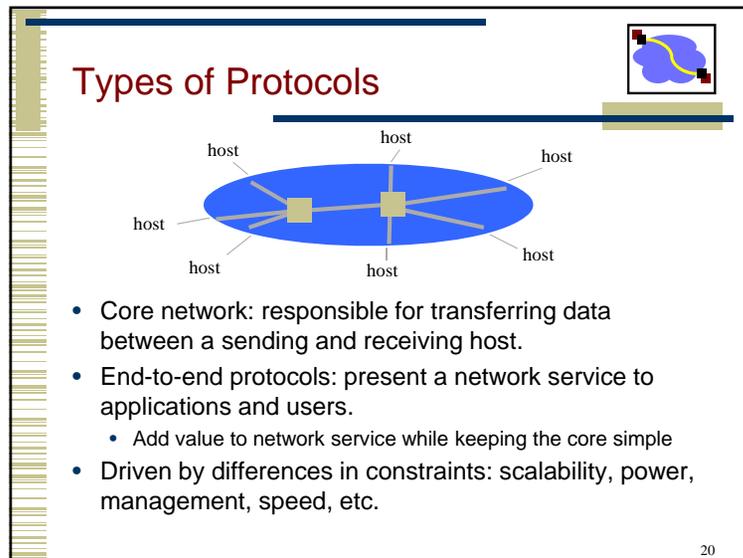
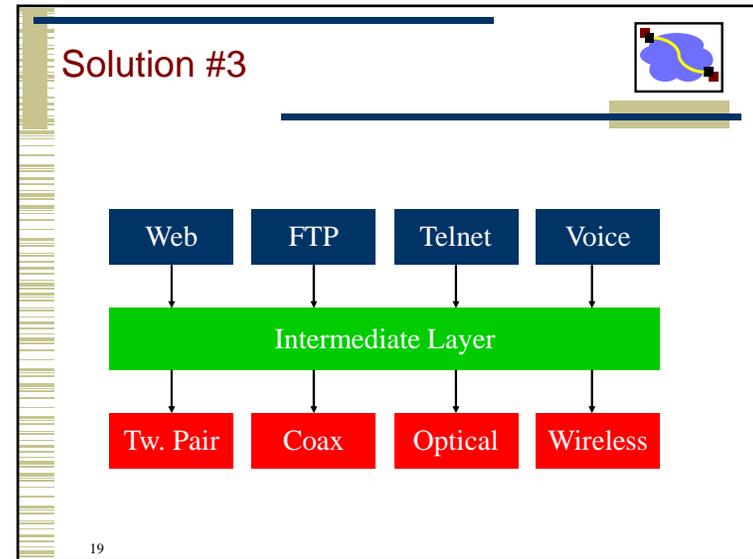
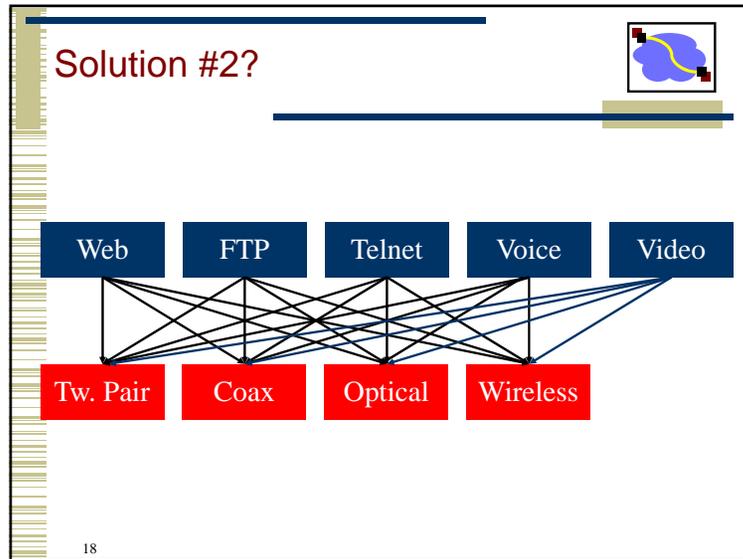
## But Two Nodes do Not make a Network!



- We need many needs and:
  - Many pieces of functionality and of significant complexity
  - Many parties involved building and running the network
  - A very long life time
- The solution for dealing with complexity is modularity: break up the Internet “system” in a set of modules with well-defined interfaces
  - Each module performs specific functions
  - Implementation of module can change
  - Can build a large complex system from modules implemented by many parties
- Let us start with multiple protocols ...

## Solution #1





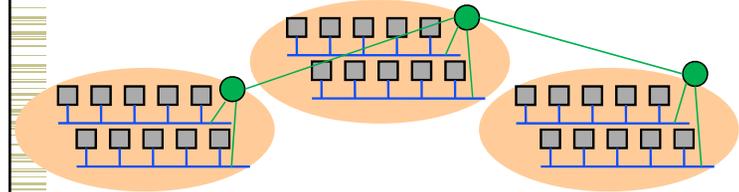
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## Let Us Try Again a Bit More Systematically

- Two or more hosts talk over a "wire" **Physical**
- Groups of hosts can talk at two levels **Datalink**
  - Hosts talk in a network is homogeneous in terms of administration and technology
  - Hosts talk across networks that have different administrators and may use different technology **Internet**
- We run some applications over that



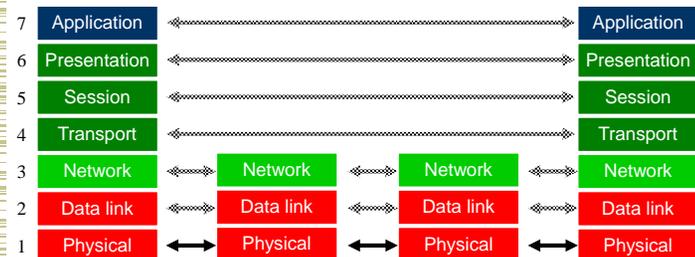
## A Bit More Detail

- Physical layer delivers bits between the two endpoints of a "link"
  - Copper, fiber, wireless, visible light, ...
- Datalink layer delivers packets between two hosts in a local area network
  - Ethernet, WiFi, cellular, ...
  - Best effort service: should expect a modest loss rate
  - "Boxes" that connect links are called bridges or switches
- Network layer connects multiple networks
  - The Inter-net protocol (IP)
  - Also offers best effort service
  - Boxes that forward packets are called routers

Different Organizations  
Scaling up the network

## 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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## Example: Retrieving a Web Page



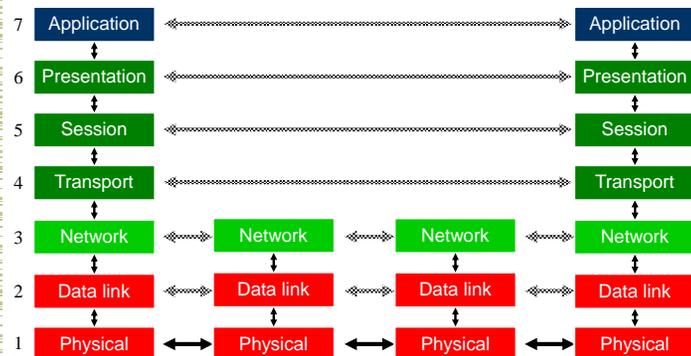
- Application: HTTP – GET files specified by URL and deal with web features (attributes, cookies, ...)
- Presentation: MIME - specify format of the content
- Session: sockets and TCP – maintain state to optimize data transfer, security, ...
- Transport: TCP – recover from errors, flow and congestion control, ...
- Network: IP – best effort datagram service
- Datalink: Ethernet, .. – best effort packet transfer over different link technologies
- PHY: Twisted pair, fiber, .. – exchange bits between hosts

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## A Layer Network Model



The Open Systems Interconnection (OSI) Model



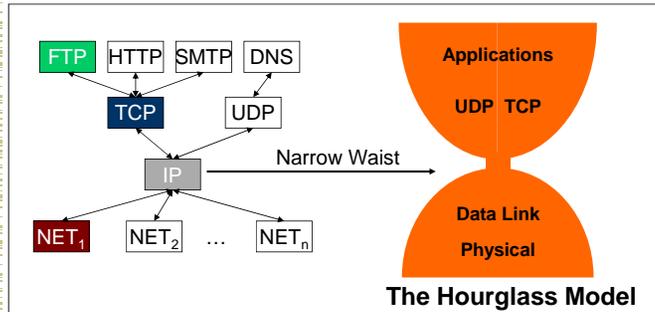
## Layering Characteristics



- The stack has two types of interfaces
  - Service: each layer relies on services from layer below and exports services to layer above
  - Protocol: defines interaction with peer on other hosts
- Modules hide implementation - layers can change without disturbing other layers
- A layer can implement multiple protocols that offer the same/similar or different services
  - Datalink: Wifi versus Ethernet
  - Transport: TCP versus UDP

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## The Internet Protocol Suite



The waist facilitates interoperability  
... but evolution is hard

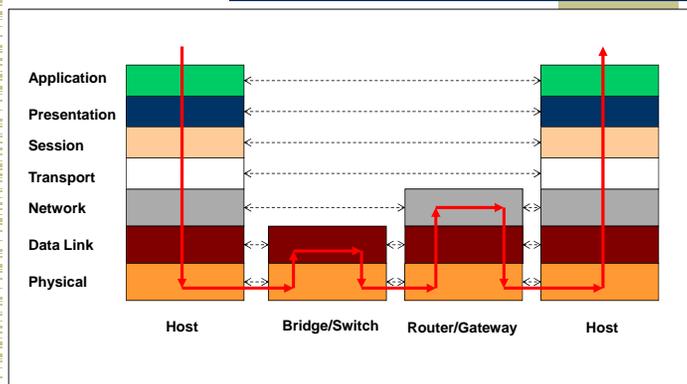
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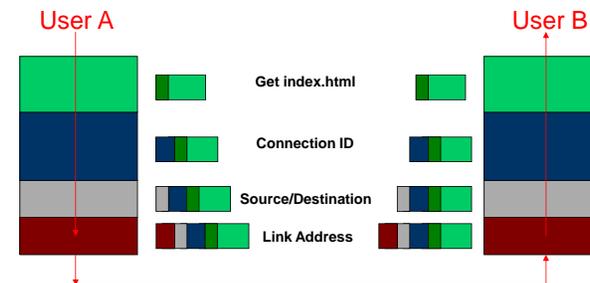
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## Life of Packet



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## How do Peers Communicate: Headers and Layer Encapsulation

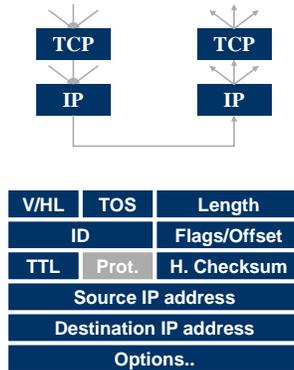


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## Multiplexing and Demultiplexing

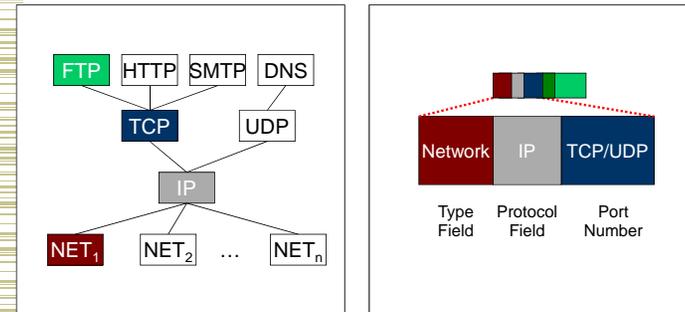


- Multiple choices at each layer: how does a protocol on receiver know what protocol is next?
- Headers include a demultiplexing field that is by receiver used to identify the protocol in the next layer.
  - Filled in by the sender
  - Used by the receiver



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## Protocol Demultiplexing



- What layers do not need a protocol field?

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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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