Note: We will start at 12:53 pm ET

Course Summary:

Date	Details	
Mon Feb 1, 2021	18-441/741 Lecture 1	12:50pm to 2:50pm
Wed Feb 3, 2021	18-441/741 Lecture 2	12:50pm to 2:50pm
Mon Feb 8, 2021	18-441/741 Lecture 3	12:50pm to 2:50pm
Wed Feb 10, 2021	18-441/741 Lecture 4	12:50pm to 2:50pm
Fri Feb 12, 2021	18-441/741 Recitation 1 (Hybrid) -- Project-1 Intro -- Zoom / In-person (A-L)	12:50pm to 1:40pm
Sun Feb 14, 2021	Quiz 1	due by 11:59pm
Mon Feb 15, 2021	18-441/741 Lecture 5	12:50pm to 2:50pm
Wed Feb 17, 2021	18-441/741 Lecture 6	12:50pm to 2:50pm
Mon Feb 22, 2021	18-441/741 Lecture 7	12:50pm to 2:50pm
Wed Feb 24, 2021	18-441/741 Lecture 8	12:50pm to 2:50pm
Fri Feb 26, 2021	18-441/741 Recitation 2 (Hybrid) -- Project 2 Intro -- Zoom / In-person (M-Z)	12:50pm to 1:40pm
Sun Feb 28, 2021	Quiz 2	due by 11:59pm
	Project 1	due by 11:59pm

18-441/741: Computer Networks

Lectures 3: Layers II & PHY I

Swarun Kumar

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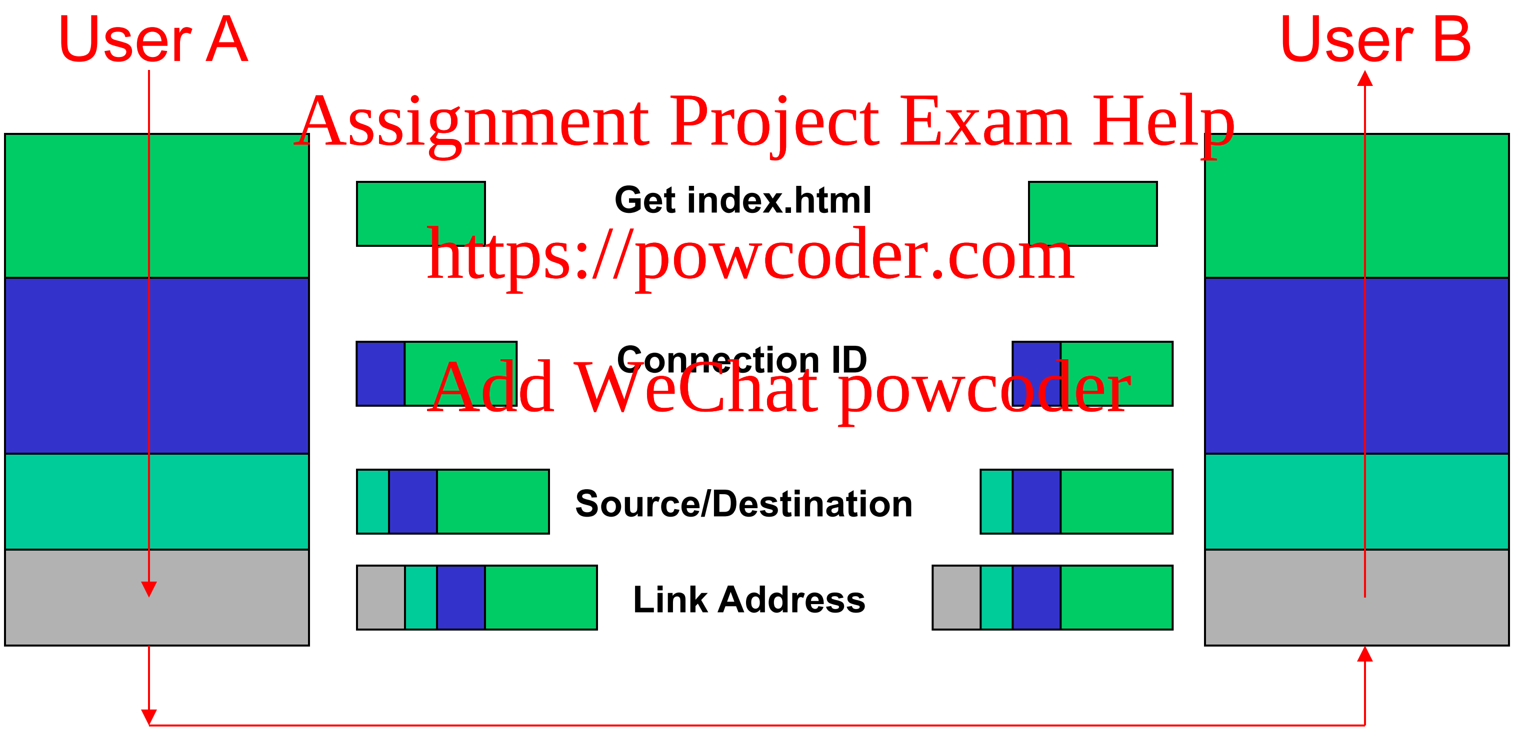
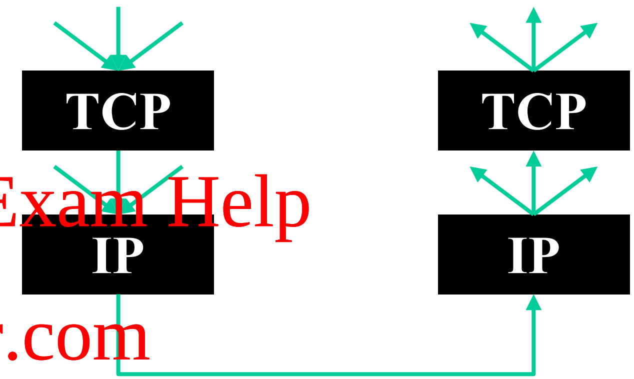
Layer Encapsulation



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, …



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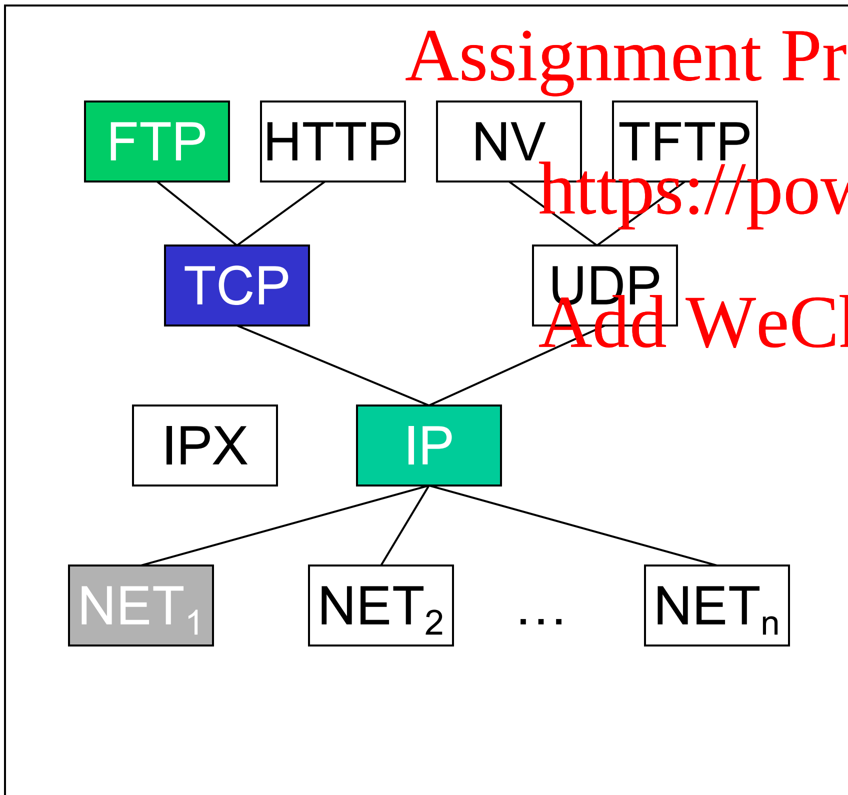
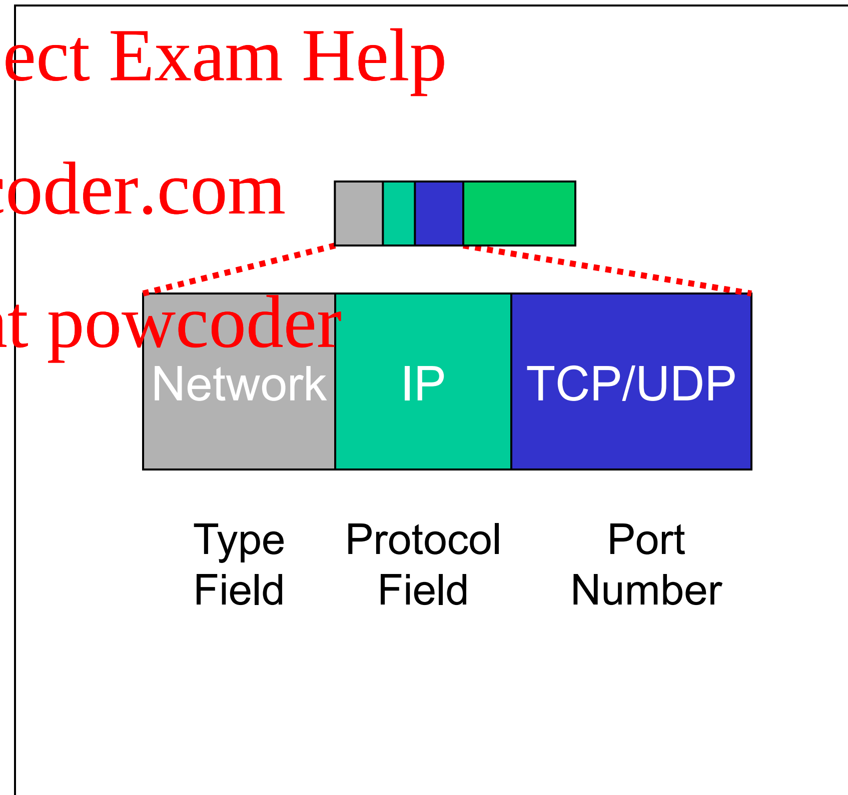
Protocol Demultiplexing

- Multiple choices at each layer





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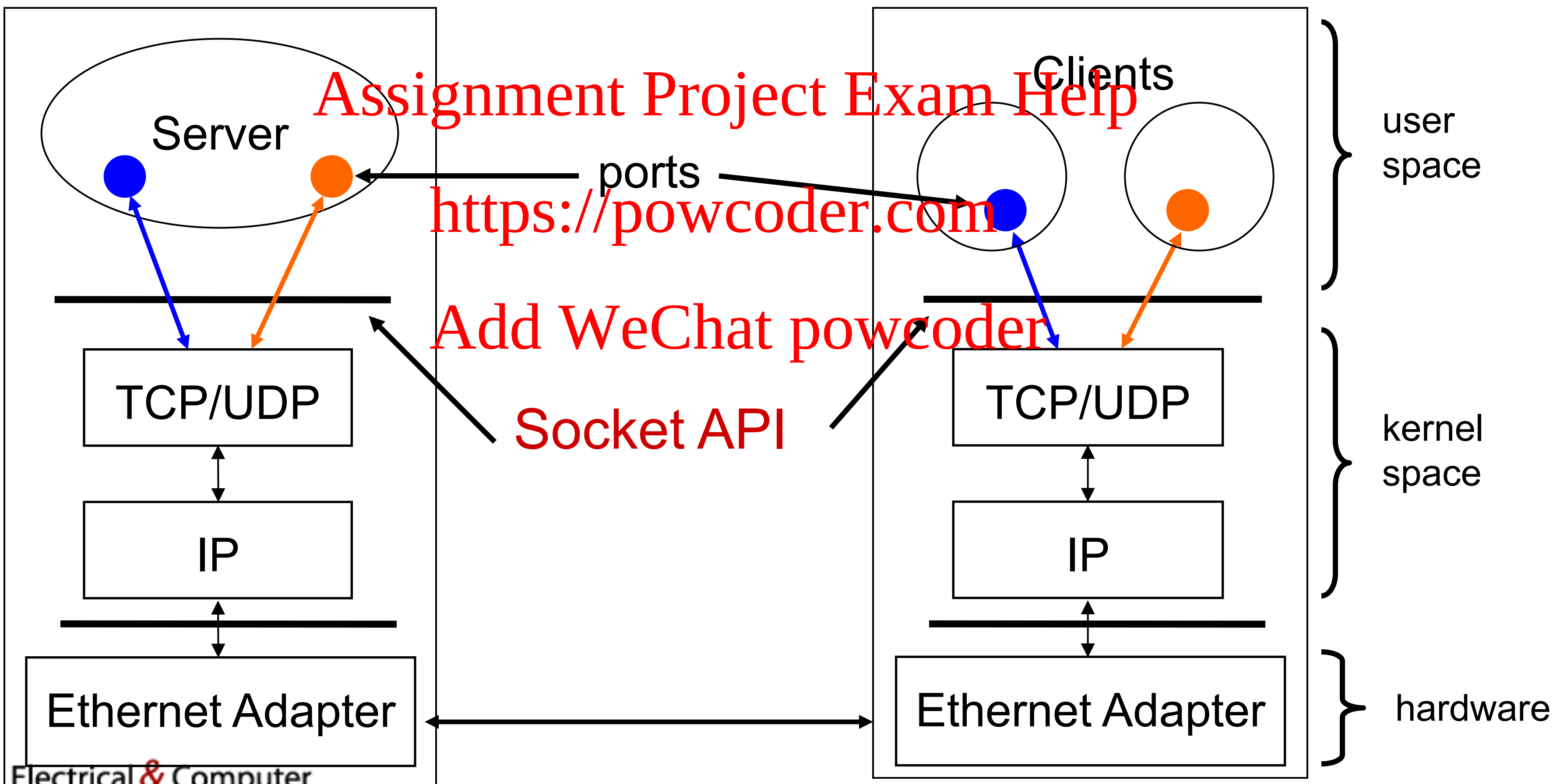
Server and Client

Server and Client exchange messages over the network through a common Socket API



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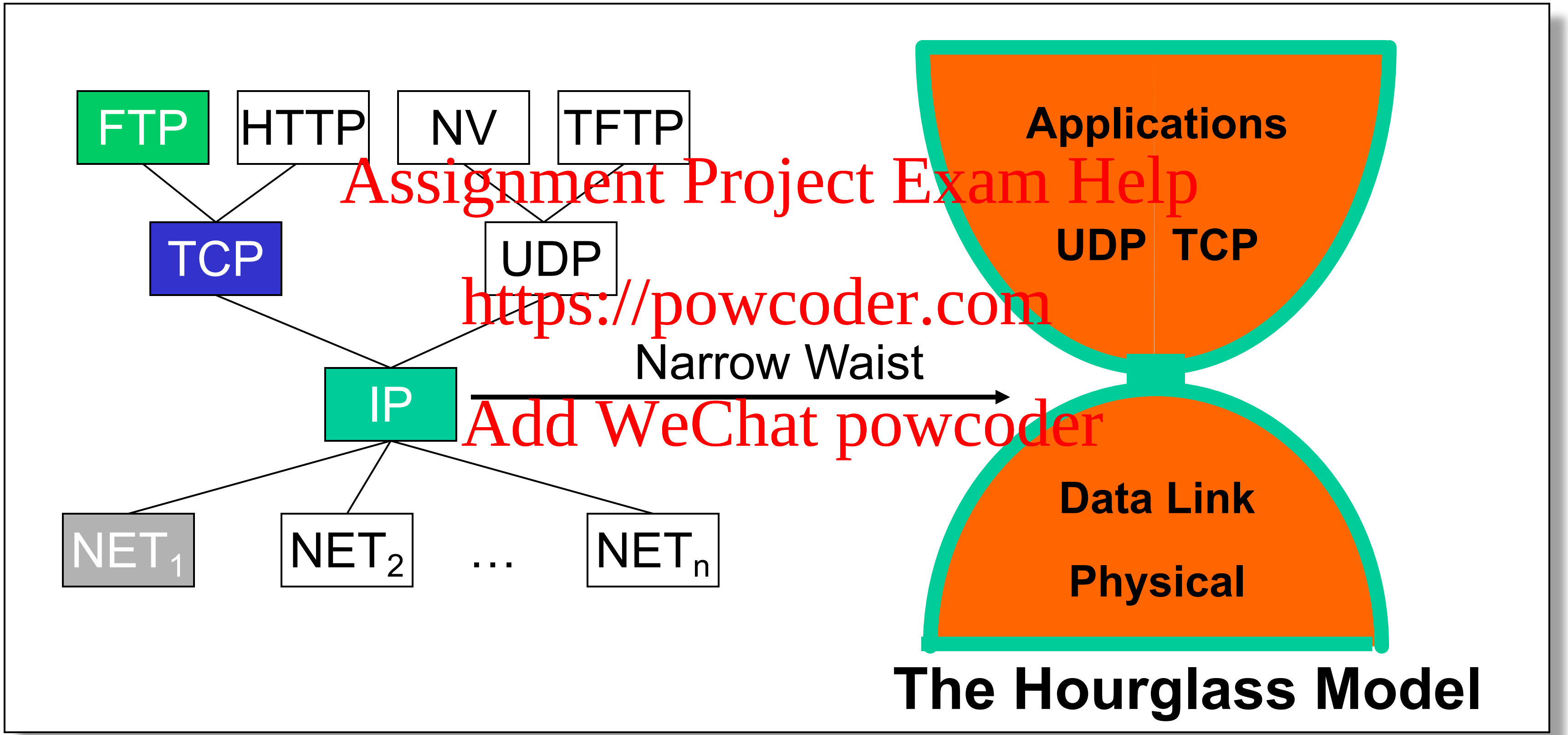
The Internet Protocol Suite



The waist facilitates interoperability
… but evolution is hard

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IP based on a 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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Sample Quiz Question

- Question: Which of these will be hardest launch at Internet-scale:

  [Option A] a new version of TCP,
  [Option B] a new version of IP
  [Option C] or a new version of WiFi

- Answer: New IP (why?)

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Today's Lecture

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

Protocol Stack (cotd.)

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

Network tools

- ping
- traceroute
- ipconfig
- tcpdump
- …

ping

- Application to determine if host is reachable
- Based on Internet Control Message Protocol
  - ICMP informs source host about errors encountered in IP packet processing by routers or by destination host
  - ICMP Echo message requests reply from destination host
- PING sends echo message & sequence #
- Determines reachability & round-trip delay
- Sometimes disabled for security reasons

```
PING google.com (68.65.124.59): 56 data bytes
64 bytes from 68.65.124.59: icmp_seq=0 ttl=60 time=13.022 ms
64 bytes from 68.65.124.59: icmp_seq=1 ttl=60 time=16.723 ms
64 bytes from 68.65.124.59: icmp_seq=2 ttl=60 time=16.057 ms
64 bytes from 68.65.124.59: icmp_seq=3 ttl=60 time=13.777 ms
64 bytes from 68.65.124.59: icmp_seq=4 ttl=60 time=17.644 ms
^C
--- google.com ping statistics ---
5 packets transmitted, 5 packets received, 0.0% packet loss
round-trip min/avg/max/stddev = 13.022/15.445/17.644/1.760 ms
```

```
Swaruns-MacBook-Pro-4:~ swarun$ ping weibo.com
PING weibo.com (123.125.104.197): 56 data bytes
64 bytes from 123.125.104.197: icmp_seq=0 ttl=41 time=232.848 ms
64 bytes from 123.125.104.197: icmp_seq=1 ttl=41 time=297.449 ms
64 bytes from 123.125.104.197: icmp_seq=2 ttl=41 time=316.311 ms
64 bytes from 123.125.104.197: icmp_seq=3 ttl=41 time=235.104 ms
^C
--- weibo.com ping statistics ---
4 packets transmitted, 4 packets received, 0.0% packet loss
round-trip min/avg/max/stddev = 232.848/270.428/316.311/37.066 ms
```

traceroute

- Find route from local host to a remote host
- Time-to-Live (TTL)
  - IP packets have TTL field that specifies maximum # hops traversed before packet discarded
  - Each router decrements TTL by 1
  - When TTL reaches 0 packet is discarded
- Traceroute
  - Send UDP to remote host with TTL=1
  - First router will reply ICMP Time Exceeded Message
  - Send UDP to remote host with TTL=2, …
  - Each step reveals next router in path to remote host
- **`tracert`** (windows), **`tracepath`** (linux)

```
Swaruns-MacBook-Pro-4:~ swarun$ traceroute facebook.com
traceroute to facebook.com (31.13.69.228), 64 hops max, 52 byte packets
 1  pod-w-vl75.gw.cmu.net (128.237.128.1)  62.820 ms  5.246 ms  1.859 ms
 2  core255-pod-w-cyh.gw.cmu.net (128.2.255.241)  1.966 ms  1.548 ms  1.755 ms
 3  pod-i-dcns-core255.gw.cmu.net (128.2.255.194)  86.446 ms  2.744 ms  1.807 ms
 4  100.121.0.37 (100.121.0.37)  2.053 ms  2.089 ms  2.169 ms
 5  tr-cps.pennren.3rox.net (147.73.18.143)  2.336 ms  2.851 ms  2.020 ms
 6  et-4-0-0.512.sdn-sw.pitt.net.internet2.edu (198.71.47.181)  9.345 ms  4.421 ms  3.444 ms
 7  et-8-3-0.4079.sdn-sw.ashb.net.internet2.edu (162.252.70.52)  12.930 ms  12.143 ms  12.822 ms
 8  lo-0.8.rtr.ashb.net.internet2.edu (64.57.29.131)  12.823 ms  12.352 ms  12.783 ms
 9  ae14.pr06.iad3.tfbnw.net (103.4.97.230)  14.077 ms
    dc5.pr01.iad2.tfbnw.net (206.126.236.191)  13.729 ms
    ae21.pr05.iad3.tfbnw.net (103.4.97.144)  13.153 ms
10  po104.psw04.iad3.tfbnw.net (31.13.28.99)  12.135 ms
    po106.psw04.iad3.tfbnw.net (157.240.43.131)  12.683 ms
    po105.psw01.iad3.tfbnw.net (31.13.31.169)  11.950 ms
11  173.252.67.27 (173.252.67.27)  12.508 ms
    173.252.67.111 (173.252.67.111)  13.686 ms
    173.252.67.139 (173.252.67.139)  12.432 ms
12  edge-star-mini-shv-01-iad3.facebook.com (31.13.69.228)  12.942 ms  12.665 ms  12.358 ms
```

ipconfig

- Utility in Microsoft Windows to display TCP/IP information about a host

- Many options

  - Simplest: IP address, subnet mask, default gateway for the host

  - Information about each IP interface of a host
    - DNS hostname, IP addresses of DNS servers, physical address of network card, IP address, …
  - Renew IP address from DHCP server

```
Swaruns-MacBook-Pro-4:~ swarun$ ifconfig en0
en0: flags=8863<UP,BROADCAST,SMART,RUNNING,SIMPLEX,MULTICAST> mtu 1500
        ether b8:f6:b1:1b:9a:d5
        inet6 fe80::32:6dc1:b470:7030%en0 prefixlen 64 secured scopeid 0x7
        inet 128.237.142.42 netmask 0xfffff000 broadcast 128.237.143.255
        nd6 options=201<PERFORMNUD,DAD>
        media: autoselect
        status: active
```

netstat

- Queries a host about TCP/IP network status
- Status of network drivers & their interface cards
  - #packets in, #packets out, errored packets, …
- State of routing table in host
- TCP/IP active server processes
- TCP active connections

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```
Swaruns-MacBook-Pro-4:~ swarun$ netstat
Active Internet connections
Proto Recv-Q Send-Q  Local Address          Foreign Address        (state)
tcp4       0      0  swaruns-mbp-4.wv.61551 198.98.22.58.https     ESTABLISHED
tcp4       0      0  swaruns-mbp-4.wv.61540 ec2-52-4-191-33..https ESTABLISHED
tcp4       0      0  swaruns-mbp-4.wv.61536 upload-lb.eqiad..https ESTABLISHED
tcp4       0      0  swaruns-mbp-4.wv.61535 text-lb.eqiad.wi.https ESTABLISHED
tcp4       0      0  swaruns-mbp-4.wv.61530 www.ece.cmu.edu.https  ESTABLISHED
tcp4       0      0  swaruns-mbp-4.wv.61523 172.217.3.98.http      ESTABLISHED
tcp4      31      0  swaruns-mbp-4.wv.61491 162.125.33.7.https     CLOSE_WAIT
tcp4       0      0  swaruns-mbp-4.wv.61441 172.217.10.10.https    CLOSE_WAIT
tcp4       0      0  swaruns-mbp-4.wv.61427 172.217.10.234.https   CLOSE_WAIT
tcp4       0      0  swaruns-mbp-4.wv.61420 172.217.3.106.https    CLOSE_WAIT
tcp4       0      0  swaruns-mbp-4.wv.61419 172.217.6.202.https    CLOSE_WAIT
tcp4       0      0  swaruns-mbp-4.wv.61404 151.101.202.49.https   ESTABLISHED
tcp4       0      0  swaruns-mbp-4.wv.61397 151.101.202.49.https   ESTABLISHED
```


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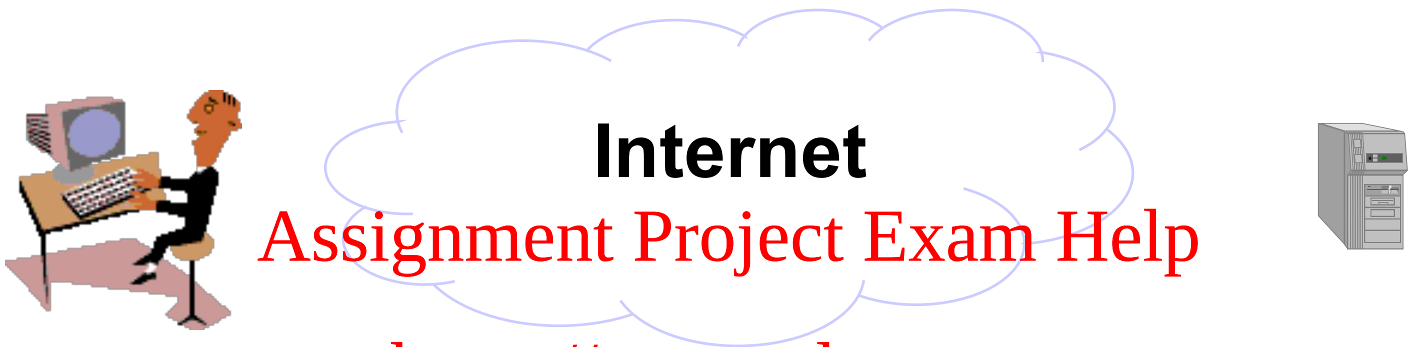
`tcpdump` and Network Protocol Analyzers

- `tcpdump` program captures IP packets on a network interface (usually Ethernet NIC)
- Filtering used to select packets of interest
- Packets & higher-layer messages can be displayed and analyzed
- `tcpdump` basis for many network protocol analyzers for troubleshooting networks
- We use the open source Ethereal analyzer to generate examples (or wireshark, etc.)
  - www.ethereal.com

How the layers work together: Network Analyzer Example

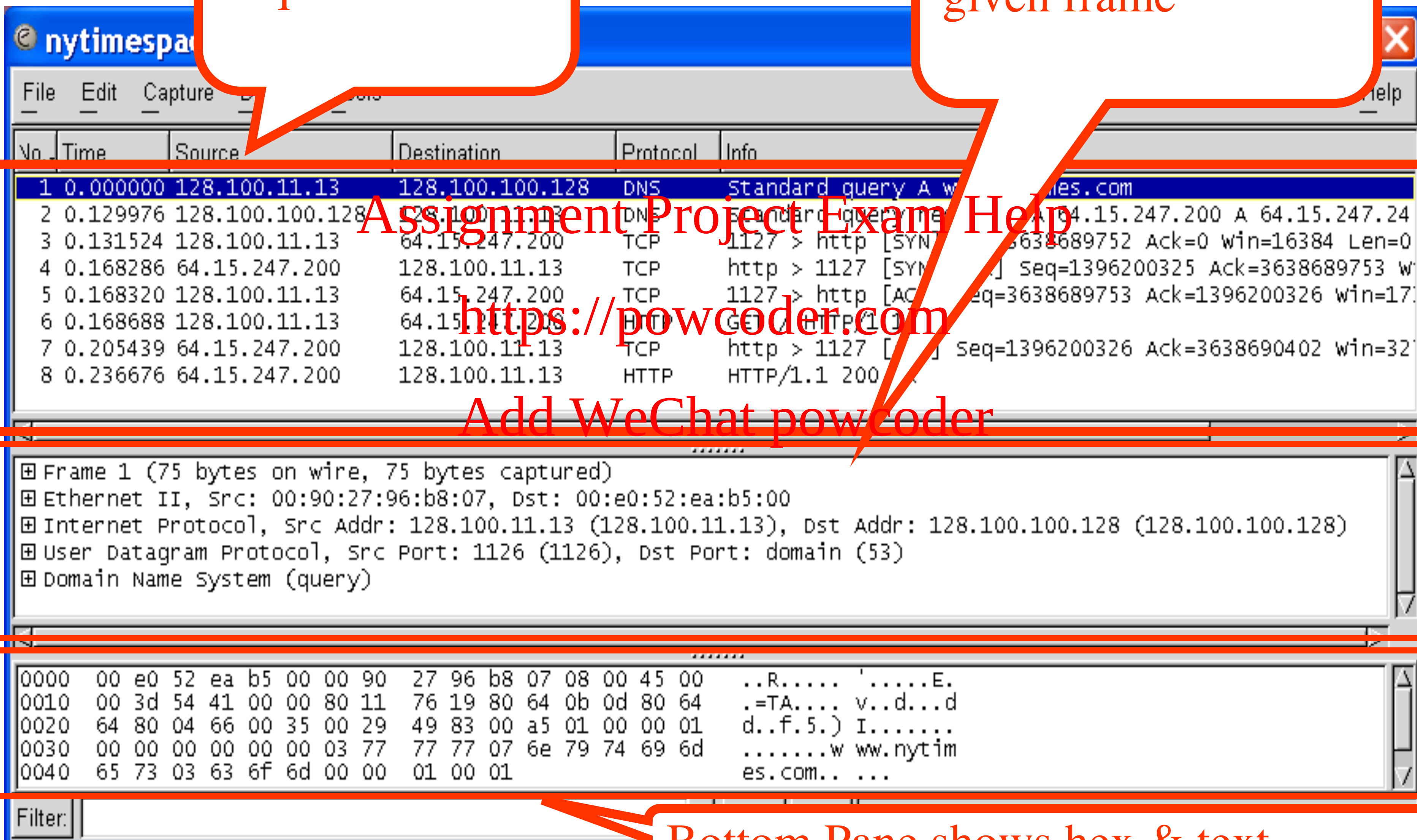


- User clicks on http://www.nytimes.com/
- *Ethereal* network analyzer captures all frames observed by its Ethernet NIC (or Wireshark)
- Sequence of frames and contents of frame can be examined in detail down to individual bytes

real wind

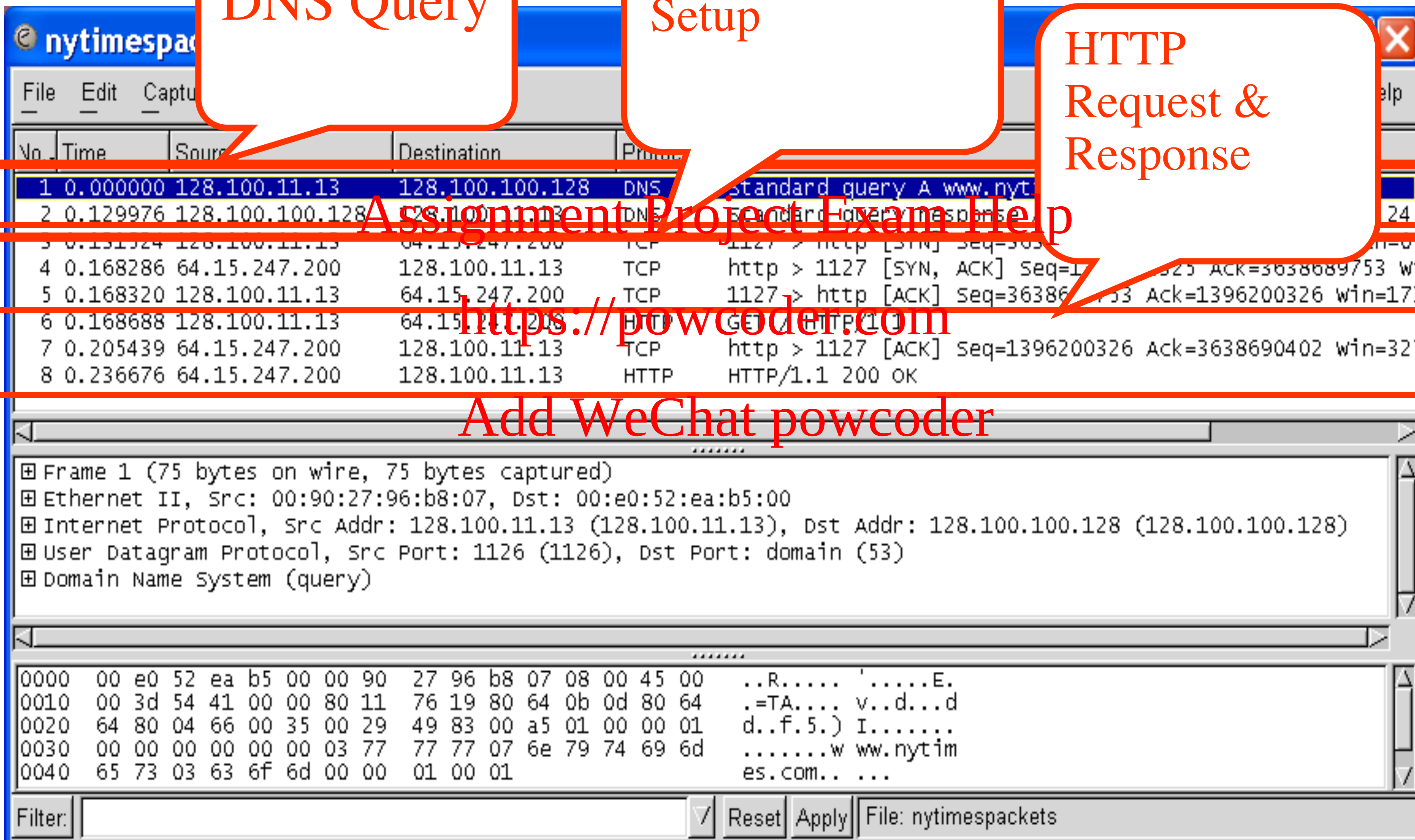
Top Pane shows frame/packet sequence

Middle Pane shows encapsulation for a given frame

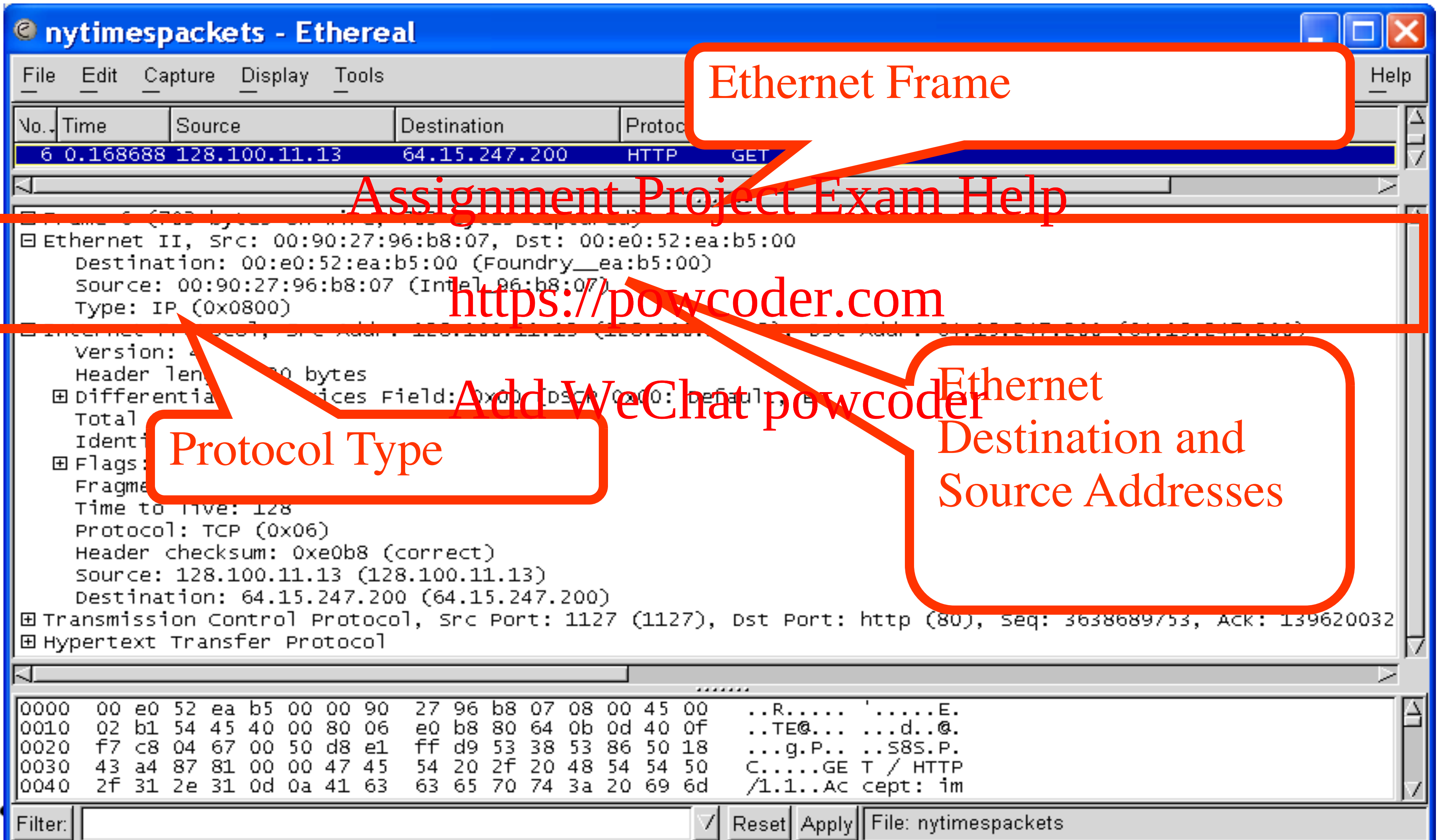


Bottom Pane shows hex & text

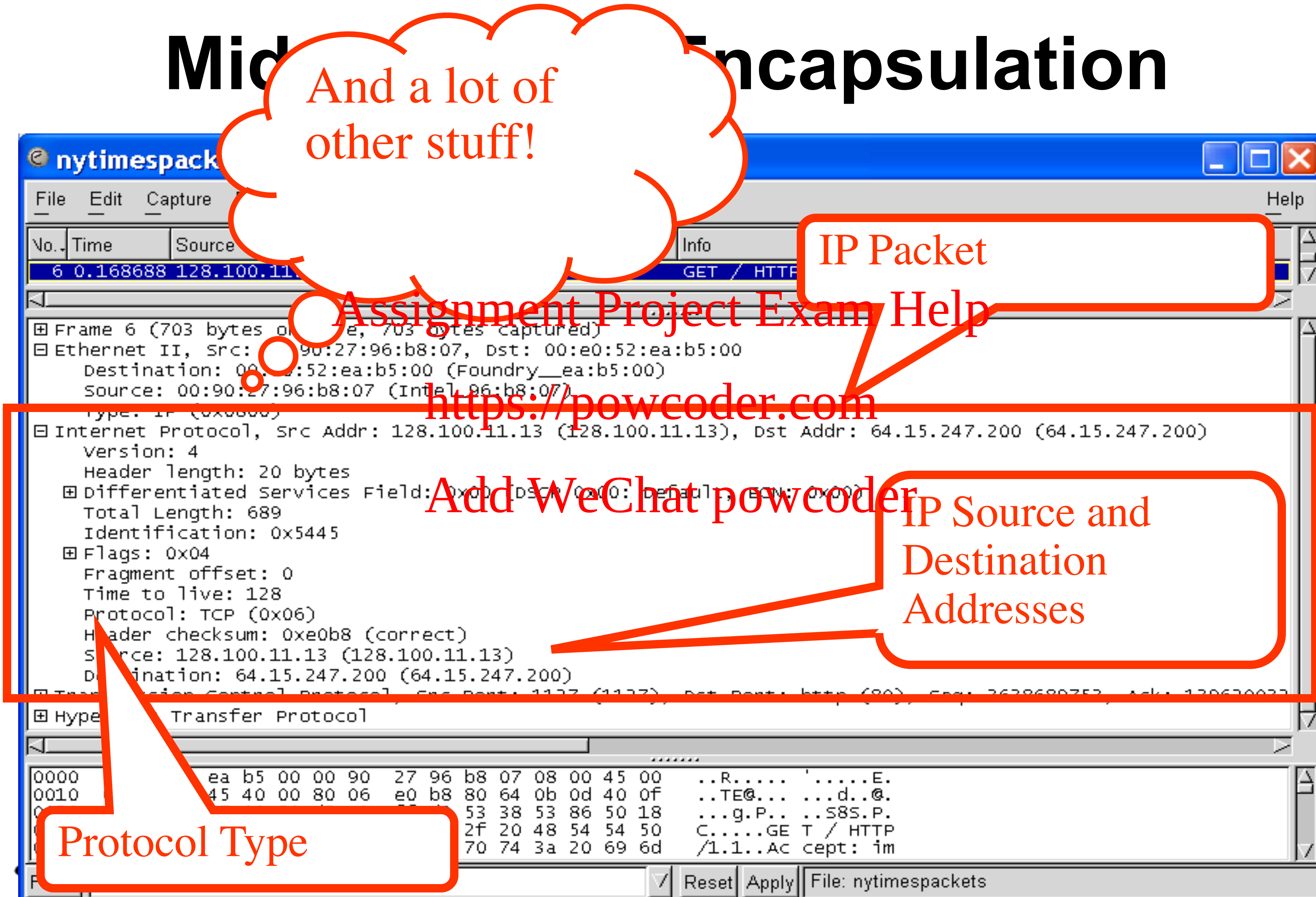
Top pane: f quence



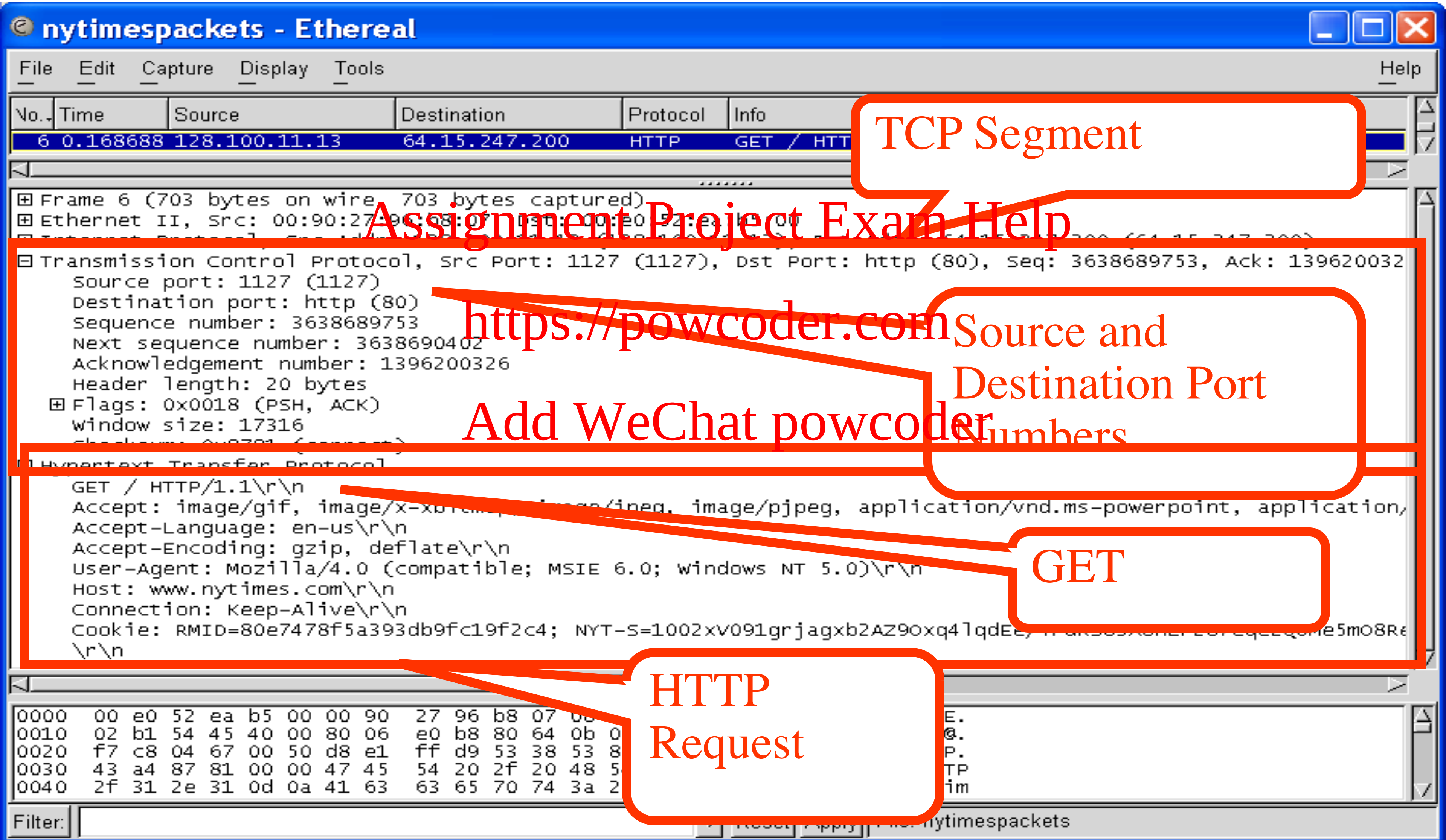
Middle pane: Encapsulation



Mid Encapsulation



Middle pane: Encapsulation



Goals [Clark88]

0 **Connect existing networks**

initially ARPANET and ARPA packet radio network

1. Survivability

ensure communication service even in the presence of network and router failures

2. Support multiple types of services

3. Must accommodate a variety of networks
4. Allow distributed management
5. Allow host attachment with a low level of effort
6. Be cost effective
7. Allow resource accountability

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Principle: End-to-End Argument (Saltzer'81)

- Focus of the paper is "system"
  - Not a pure networking paper
- Deals with where to place functionality
  - Inside the network (in switching elements)
  - At the edges
- Argument: Some functions can only be correctly implemented by the endpoints – do not try to implement these elsewhere
  - Not a law – more of a "best practices"

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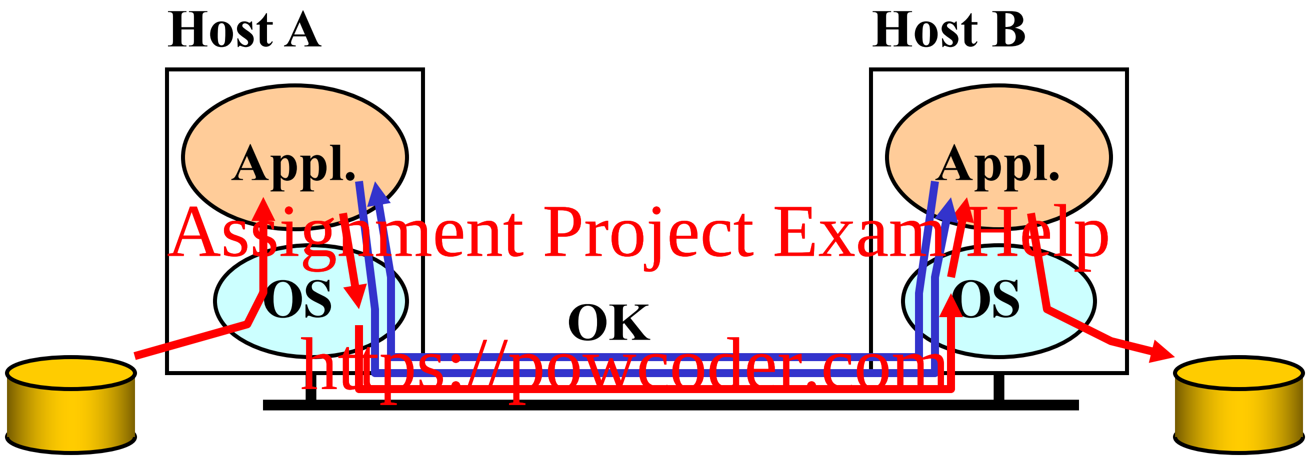
Example: Reliable File Transfer



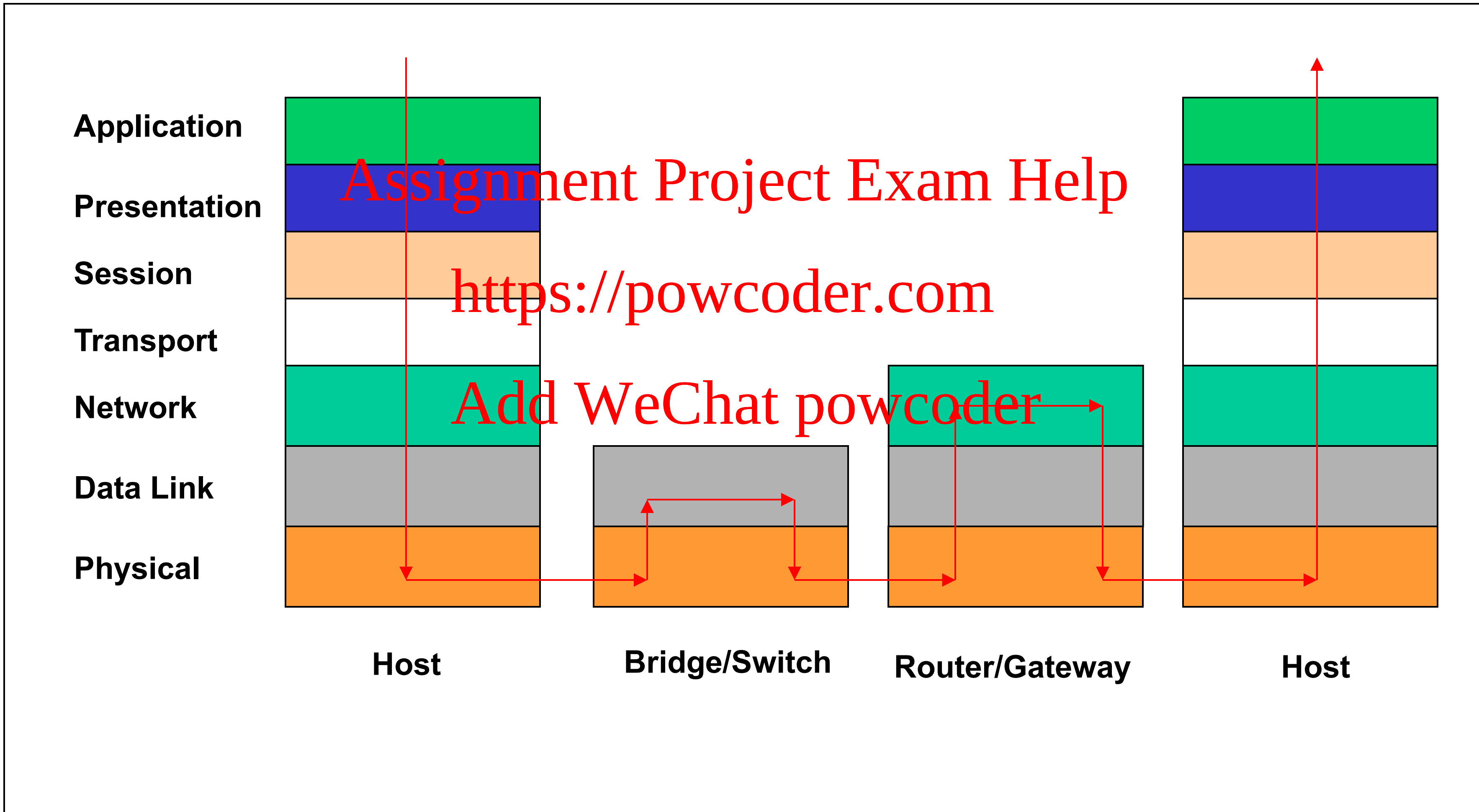
- Solution 1: make each step reliable, and then concatenate them
- Solution 2: end-to-end check and retry

Sample Quiz Question

- Question: A switch and a router both cost $100 and have similar specs and achieve similar performance in packet switching/routing. As a rational buyer, I would buy the router. [True/False]

- Answer: True, the router (why?)

Life of Packet



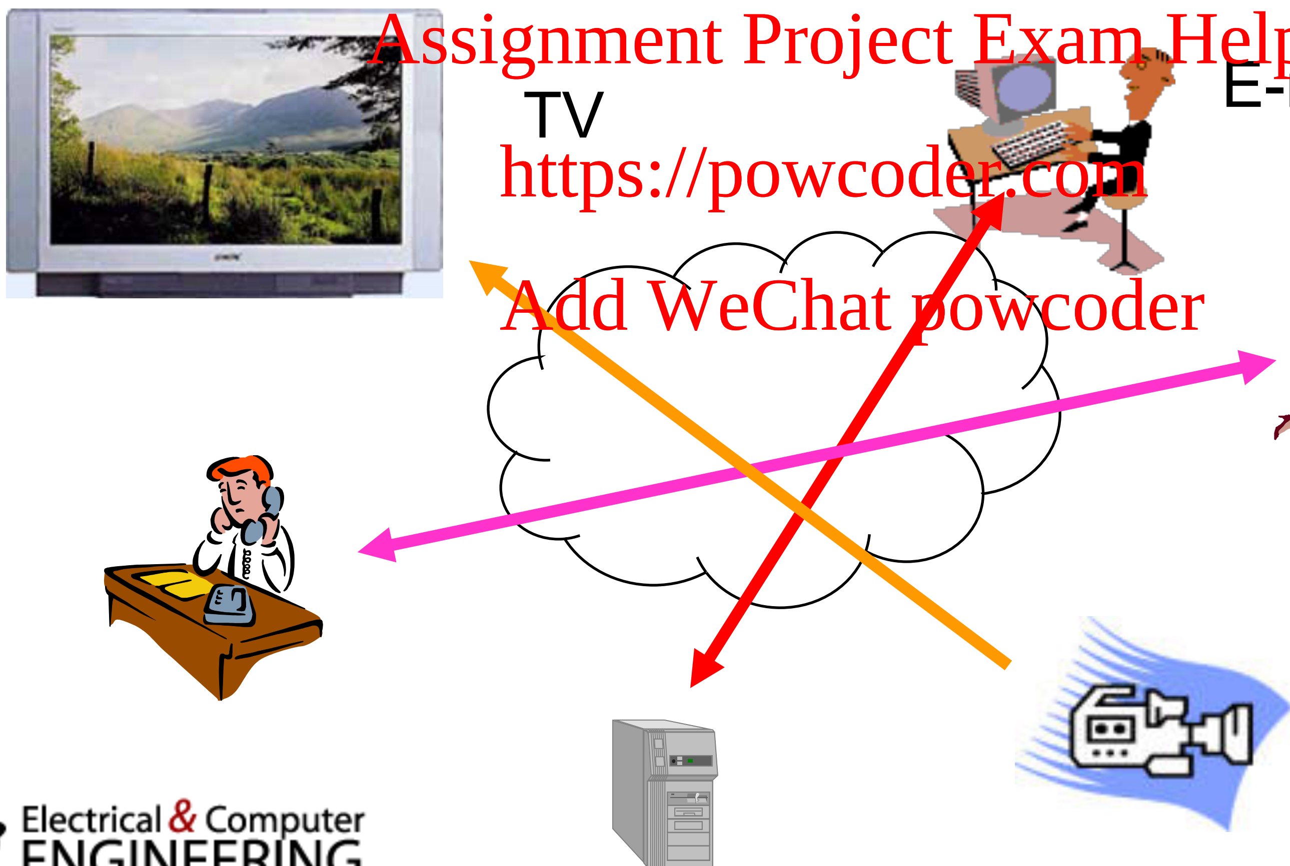
Physical Layer (PHY) - I

Physical Layer: Outline

- Digital networking
- Modulation
- Characterization of Communication Channels
- Fundamental Limits in Digital Transmission
- Modems and Digital Modulation
- Line Coding
- Properties of Media and Digital Transmission Systems
- Error Detection and Correction

Digital Networks

- Digital transmission enables networks to support many services



Analog versus Digital Information

- Analog information takes on continuous values
  - Sound, images, etc.
- Digital information takes on discrete values
  - Text, banking data, etc.
- Can convert between the two representations of information
  - Sampling and interpolation

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Block vs. Stream Information

Block

- Information that occurs in a single block
  - Text message
  - Data file
  - JPEG image
  - MPEG file
- Size = bits / block

  or Bytes/block
  - 1 KByte (KB) = 2^{10} bytes
  - 1 MByte (MB) = 2^{20} bytes
  - 1 GByte (GB) = 2^{30} bytes

Stream

- Information that is produced & transmitted *continuously*
  - Real-time voice
  - Streaming video
- Bit rate = bits / second
  - 1 Kbps = 10^3 bps
  - 1 Mbps = 10^6 bps
  - 1 Gbps = 10^9 bps

Many Types of Information

	Analog	Digital
Stream	Voice, video	Stock market
Block	Images, radar map, …	Spreadsheets, text file, …

Traditional Communication Options

- Send analog information over analog networks
  - Voice over the telephone network
  - Video using broadcast TV
  - Pictures using the USPS
- Send digital information over digital networks
  - Messages via telegraph: beacons … electrical
  - Internet: many applications, e.g., http, (text) email, ssh, social networks, …

But Can Mix and Match

- Analog information can be digitized and sent over digital network
  - Video becomes MPEG
  - Image becomes JPEG
- Digital networks use analog channels
  - Bits are encoded on analog waveforms
  - But switching is done based on the bits

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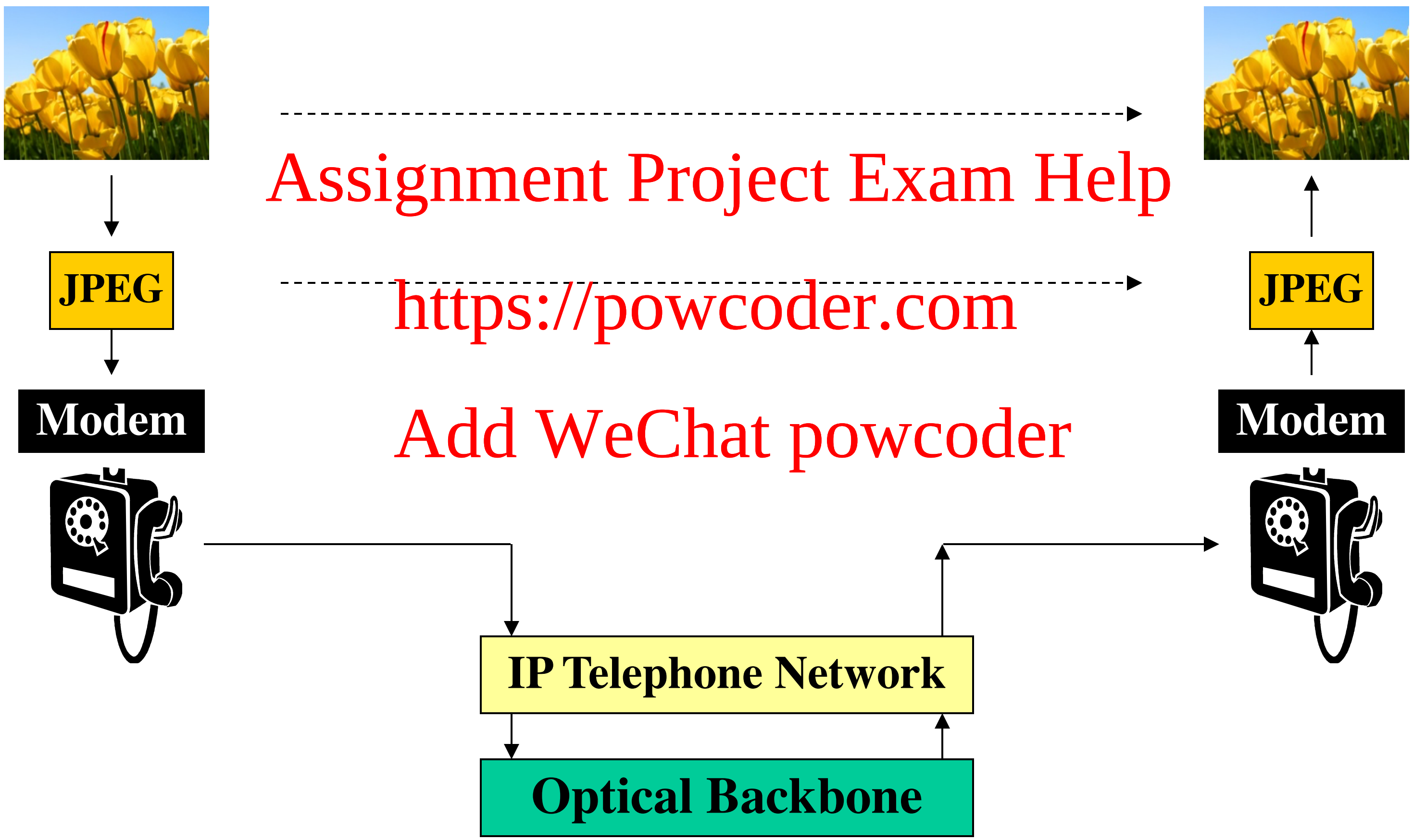
Example


JPEG
Modem
JPEG
Modem
IP Telephone Network
Optical Backbone

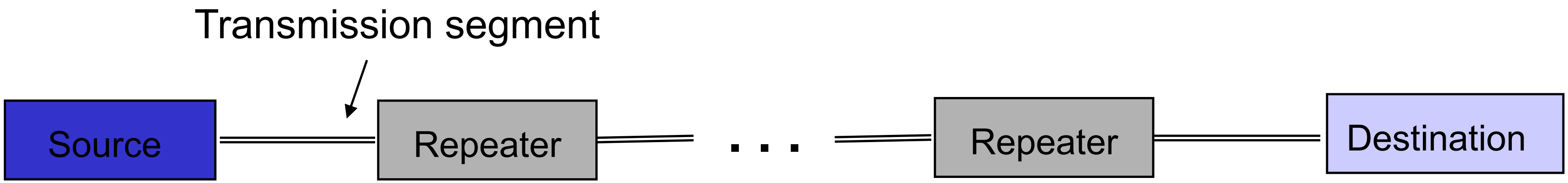
Why Use a Single Digital Network?

- Economically advantageous to have a single network
- Multimedia applications want to mix different types of data
  - More convenient if a single networks is used
- Computers operate only on digital data
- Digital transmission can recover from errors (e.g. noise, distortion)
  - Not possible when transmitting analog information over an analog network

Analog Transmission

All details must be reproduced accurately

Why digital? Problem with Analog Long-Distance Communications



- Each repeater attempts to restore analog signal to its original form
- Restoration is imperfect
  - Distortion is not completely eliminated
  - Noise & interference is only partially removed
- Signal quality decreases with # of repeaters
- Communications becomes distance-limited
- Still used in analog cable TV systems
- Analogy: Copy a song using a cassette recorder

Digital Transmission

Only discrete levels need to be reproduced

Simple Receiver: Was original pulse positive or negative?

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Digital Long-Distance Communications

- Regenerator recovers original data sequence and retransmits on next segment
- Can design so error probability is very small
- Then each regeneration is like the first time!
- Analogy: copy an MP3 file
- Communications is possible over very long distances
- Digital systems advantage over analog systems
  - Less power, longer distances, lower system cost
  - Monitoring, multiplexing, coding, encryption, protocols…

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