Communication-R

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Previously…

- Add questions here
- Previous lecture:
  - Shared memory allows multiple programs to communicate

- Today's lecture:
  - What if we don
  - How to implement an alternative co edium, like message channel?

Outline

- Layered Protocols
- Routing
  - Distance-vector
  - Link-state
- Message-Orient Communication
  - Socket
- Stream-Oriented Communication

Computer Networking: A Top Down Approach

7th edition
Jim Kurose, Keith Ross
Pearson/Addison Wesley
April 2016

Note: Some slides are adapted from J.F Kurose and K.W. Ross

Layered Protocols

Communication-Routing

Week 3, COMP3221

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Communication problem

Communicating is about transmitting encoded information

- Problem: two computers must agree on the code (language) they use
- Open standards give rules for everyone to communicate with each other
  - International Sta
  The Open Systems In del names communication levels, and assigns roles to each level
  - Internet Engineering Task Force (IETF)

  The Request For Comments (RFC) are a public description of internet communication protocols (e.g., TCP->RFC793, UDP->RFC768, SMTP->RFC2821, ICMP->RFC792)
- Private "closed" protocols exist
  - Skype: people did reverse engineering to discover the protocol, find security issues, or to implement IM clients

Two modes of communication

Connection oriented vs. Connectionless

- Connection oriented
  - Establish explicitly a connection with a partner before exchanging data
  - Protocol example: Transmission Control Protocol (TCP)
  - Application usage: email
- Connectionless
  - No setup in advance is needed
  - Protocol example: User Datagram Packet (UDP, IP)
  - Application usage: VoIP (Skype), IPTV

Layers

OSI *layers*

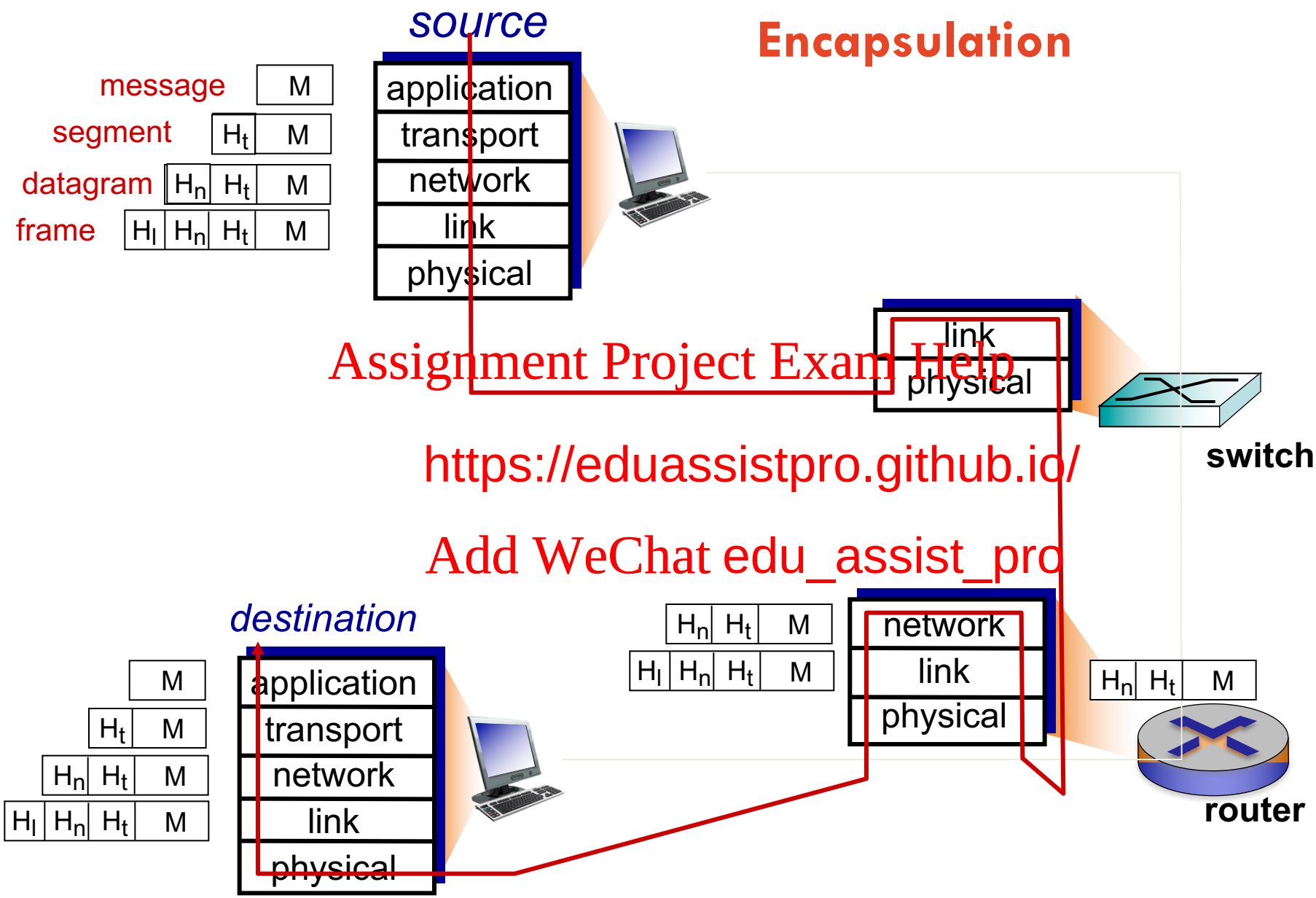
- Each layer deals with one specific aspect of the communication
- The problem is divided into sub-parts that can be implemented individually

Layers

Message structure

- As the message go through lower layers before being sent, each layer adds its header to the message.
- Upon reception, the message is unmarshalled by the successive layers from bott

Encapsulation



Network communication

Low-level layers

- **Physical layer**
  - send bits (0 and 1)
- **Data link layer**
  - groups bits into f
  - assigns sequence ecial bits at the beginning and end
  - adds a checksum (the result of some frame content)
  - If receiver disagree about the checksum, then it asks the sender to resend
  - Example: Ethernet for *Local Area Network (LAN)* or PPTP in *Virtual private network (VPN)*
- **Network layer**
  - Routing of datagrams from source to destination
  - Example: *Internet Protocol* (IP) for *Wide Area Network* (WAN)

Network communication

Transport Layer

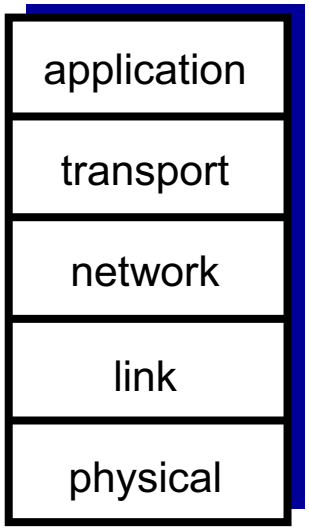
- Transport layer:
  - split the message from the application layer
  - number them
  - add the amounts
- Reliable transport layer can be buil
  - Connection-oriented protocol: packet red
  - Connectionless protocol: packet could be reordered
- Example of transport layer protocol: Transmission Control Protocol (TCP)
- Example of transport layer and network layer combination: TCP/IP

Network communication

High level layers

- OSI specifies three higher level layers:
- **Session**
  - synchronization, checkpointing, recovery of data exchange, dialog control
  - Example:
    - Domain Name Se
    - Lightweight Direc
- **Presentation layer**
  - allow applications to interpret meaning of dat , compression, machine-specific conventions
  - Sometimes the session and presentations layers are omitted: Internet protocol suite.
- **Application**
  - Hypertext Transfer Protocol (HTTP)
  - File Transfer Protocol (FTP)
  - TCP/IP Terminal Emulation Protocol (Telnet)
  - X-Window

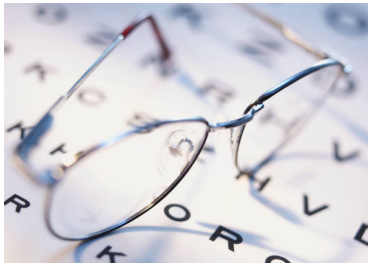
Internet protocol stack



Network communication

Analogy: Mail service vs. Web service

- Application (no clue of intermediary steps):
  - You post a letter with some address, the receiver reads it
  - HTTP: A user types a URL in a browser, a server sends back the web page
- Transport (error control):
  - Upon writing a ter will be sent back to you
  - TCP initialized a rrors and may retransmit
- Internet (recipient is unknown):
  - An airplane moves letters between ci wing the recipients
  - IP brings packets over the WAN potentially from one LAN to another
- Data link:
  - Trucks move letters within a city
  - Ethernet handles transmission within the LAN
- Physical layer:
  - Use pen to write and glasses to read letters
  - Specifying fiber, wire, radio to transmit the one and zero encoding the message



Routing

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Routing Problem

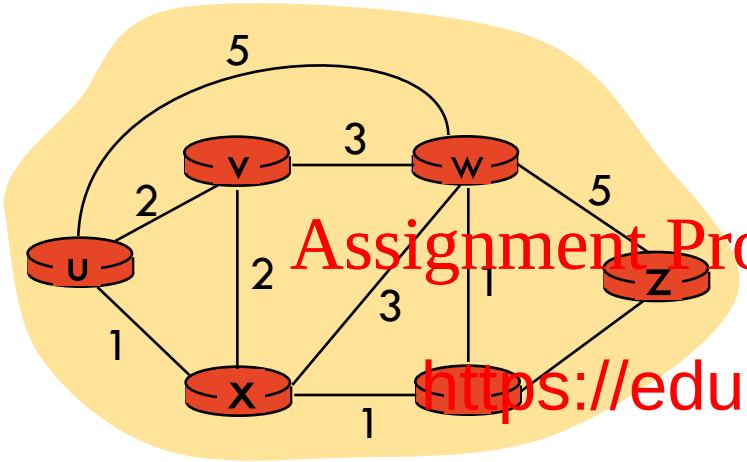
What are routing protocols used for?

- Dijkstra thought about the shortest path algorithm in Amsterdam when trying to find his way [Frana&Misa, CACM'10]
- Related to path find
- Graph nodes represent internet routers edges are communication links

- its use shortest path algorithms

- Routing is necessary in all networks except Local Area Networks (LANs) where Ethernet provides direct communication between all pairs of attached hosts
- The routing protocol is implemented in the network layer of each router to determine the route for the transmission of packets to their destination

Graph abstraction: costs



c(x,x') = cost of link (x,x')
e.g., c(w,z) = 5

cost could always be 1, or
y related to bandwidth,
sely related to
ion

cost of path $(x_1, x_2, x_3, \ldots, x_p) = c(x_1,x_2) + c(x_2,x_3) + \ldots + c(x_{p-1},x_p)$

key question: what is the least-cost path between u and z ?
routing algorithm: algorithm that finds that least cost path

Routing algorithm classification

Q: global or decentralized information?

Global:

- all routers have complete topology, link cos
- "**link state**" algo

Decentralized:

- router knows physically-connected neighbors, link costs to neighbors
- iterative process of computation, exchange of info with neighbors
- "**distance vector**" algorithms

Q: static or dynamic?

Static:

- routes change slowly over
- ange more
  - periodic update
  - in response to link cost changes

Distance vector algorithm

Bellman-Ford equation (dynamic programming)

let

$d_x(y)$:= cost of l

then

$$d_x(y) = \min_v \{c(x,v) + d_v(y)\}$$

cost from neighbor v to destination y

cost to neighbor v

min taken over all neighbors v of x

Distance vector algorithm

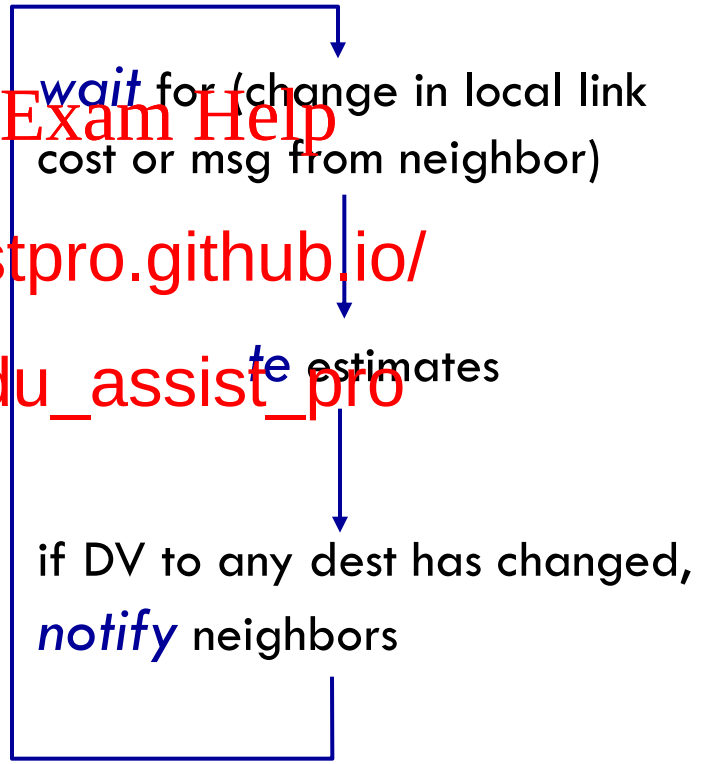
iterative, asynchronous: each local iteration caused by:

- local link cost change
- DV update message from neighbor

distributed:

- each node notifies neighbors *only* when its DV changes
  - neighbors then notify their neighbors if necessary

each node:



$D_x(y) = \min\{c(x,y) + D_y(y), c(x,z) + D_z(y)\}$
$= \min\{2+0 , 7+1\} = 2$

$D_x(z) = \min\{c(x,y) + D_y(z), c(x,z) + D_z(z)\}$
$= \min\{2+1 , 7+0\} = 3$

node x table

from \ cost to	x	y	z
x	0	2	7
y	∞	∞	∞
z	∞	∞	∞

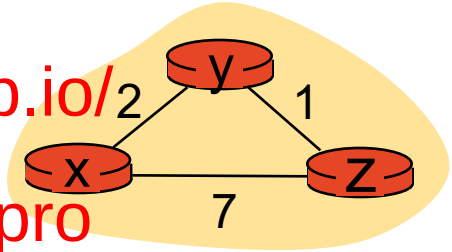
from \ cost to	x	y	z
x	0	2	3
y	2	0	1
z	7	1	0

node y table

from \ cost to	x	y	z
x	∞	∞	∞
y	2	0	1
z	∞	∞	∞

node z table

from \ cost to	x	y	z
x	∞	∞	∞
y	∞	∞	∞
z	7	1	0



time

$D_x(y) = \min\{c(x,y) + D_y(y), c(x,z) + D_z(y)\}$
$= \min\{2+0 , 7+1\} = 2$

$D_x(z) = \min\{c(x,y) + D_y(z), c(x,z) + D_z(z)\}$
$= \min\{2+1 , 7+0\} = 3$

node x table

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y	∞	∞	∞
z	∞	∞	∞

from \ cost to	x	y	z
x	0	2	3
y	2	0	1
z	7	1	0

from \ cost to	x	y	z
x	0	2	3
y	2	0	1
z	3	1	0

node y table

from \ cost to	x	y	z
x	∞	∞	∞
y	2	0	1
z	∞	∞	∞

from \ cost to	x	y	z
x	0	2	3
y	2	0	1
z	7	1	0

from \ cost to	x	y	z
x	0	2	3
y	2	0	1
z	3	1	0

node z table

from \ cost to	x	y	z
x	∞	∞	∞
y	∞	∞	∞
z	7	1	0

from \ cost to	x	y	z
x	0	2	7
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x	0	2	3
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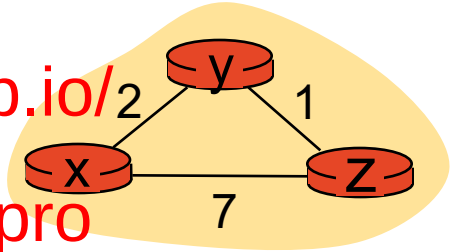
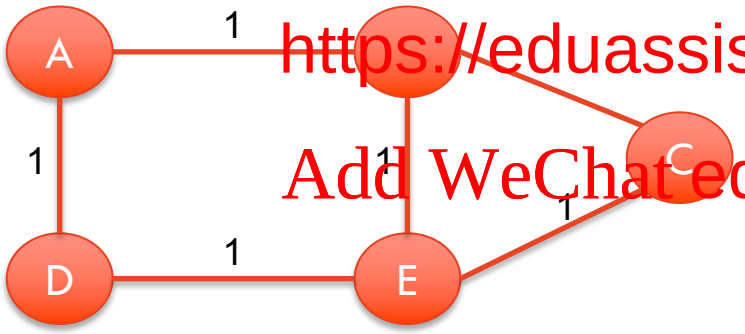


time

Distance-vector routing algorithm

Router Information Protocol (RIP)

- Mainly used in internet up to 1979
- Relies on Bellman-Ford algorithm: Bellman algorithm [1957] distributed by Ford and Fulkerson [1972]
- Link cost = 1



g table of router A

	Dir	Cost
	ocal	0
		1
		2
D	D	1
E	B	2

- If a node detects a link failure, it sets ∞ as the associated cost of such a link and sends its local table to neighbours
- *Eventually (when failures stop) each router gets for each destination the direction leading to the minimal cost*

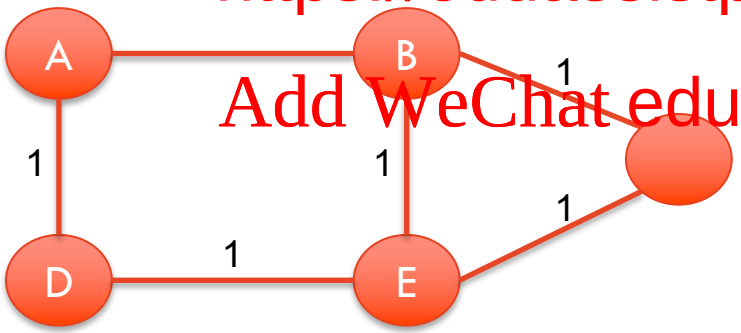
Distance-vector routing algorithm

RIP (con't)

Let's re-start the algorithm from scratch: all routing tables are empty

Routing table of router A		
Dest.	**Dir**	**Cost**
A	local	0

Routing table of router B		



Routing table of router C		
Dest.	**Dir**	**Cost**
C	local	0

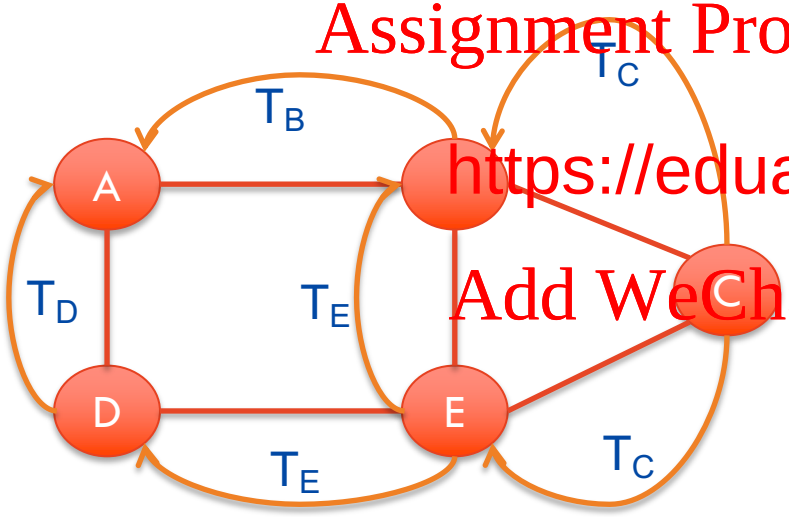
Routing table of router D		
Dest.	**Dir**	**Cost**
D	local	0

Routing table of router E		
Dest.	**Dir**	**Cost**
E	local	0

Distance-vector routing algorithm

RIP (con't)

- Example: How is routing table A built from scratch?

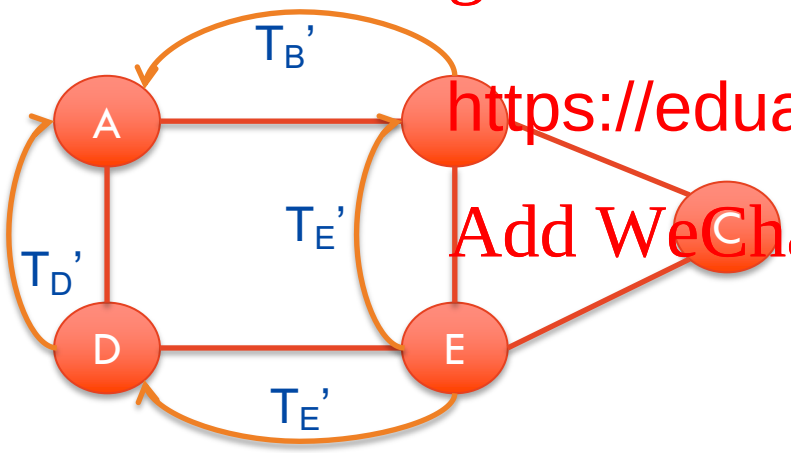


ting table of router A		
t.	Dir	Cost
A	local	0
B	1	
D	1	

Distance-vector routing algorithm

RIP (con't)

- Example: How is routing table A built from scratch?

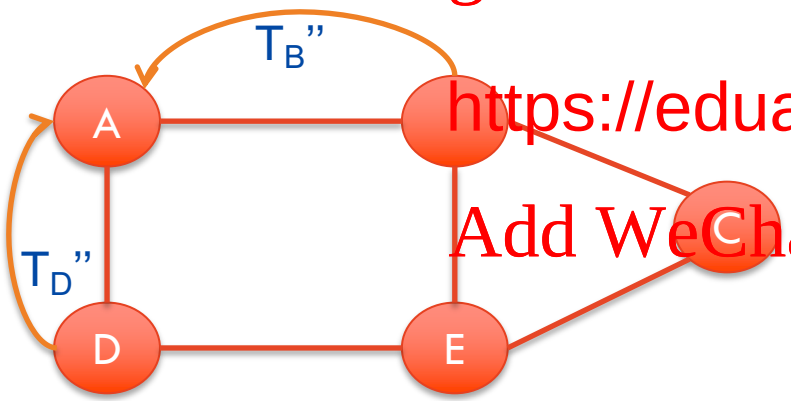


ting table of router A		
t.	Dir	Cost
A	local	0
	B	1
	B	2
D	D	1
E	B	2

Distance-vector routing algorithm

RIP (con't)

- Example: How is routing table A built from scratch?



ting table of router A		
t.	Dir	Cost
A	local	0
	B	1
	B	2
D	D	1
E	B	2

RIP algorithm

- Advantages:
  - Simple
  - Efficient in small networks
- Limitations:
  - Costs based on the number of hops (not bandwidth of links counts)
  - No big deal: this is just a matter of defining link weights (support negative values)
  - Inefficient in large networks as loops may occur before the convergence state is reached

A link-state routing algorithm

***Dijkstra's algorithm** (1956):* find the shortest path from a node i to other nodes

- net topology, link costs known to all nodes
  - accomplishe ”
  - all nodes ha
- computes least cost paths from source ”) to all other nodes
  - gives *forwarding table* for that node
- iterative: after k iterations, know least cost path to k dest.'s
- Used in IS-IS (IP) and OSPF protocols

Dijsktra's algorithm

1 ***Initialization:***
2 N' = {u}
3 for all nodes v
4 if v adjacent to u
5 then D(v) = c(u,v)
6 else D(v) = ∞
7
8 ***Loop***
9 find w not in N' such that D(w) is a
10 add w to N'
11 update D(v) for all v adjacent to w and not in N' :
12 **D(v) = min(D(v), D(w) + c(w,v))**
13 /* new cost to v is either old cost to v or known
14 shortest path cost to w plus cost from w to v */
15 ***until all nodes in N'***

Notation:

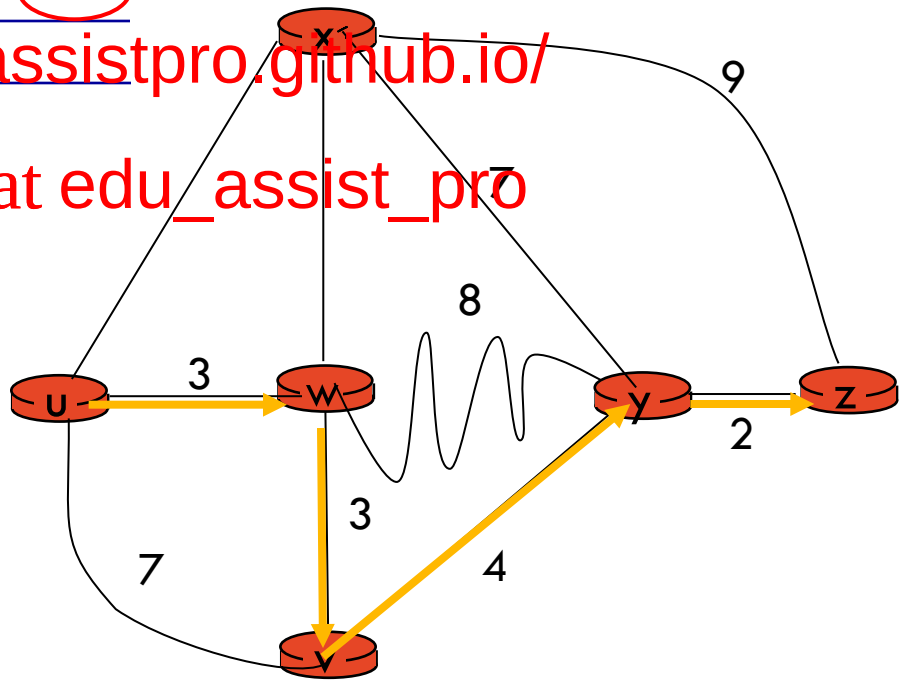
- c(x,y): link cost from node x to y; = ∞ if not direct neighbors
- D(v): current value of cost of path from source to dest. v
- p(v): predecessor node along path
  rce to v
  f nodes whose least cost
  initiv

Dijkstra's algorithm: example

Step	N'	D(v), p(v)	D(w), p(w)	D(x), p(x)	D(y), p(y)	D(z), p(z)
0	u	7,u	3,u	5,u	∞	∞
1	uw	6,w		5,u	11,w	∞
2	uwx	6,w			11,w	14,x
3	uwxv				10,v	14,x
4	uwxvy					
5	uwxvyz					

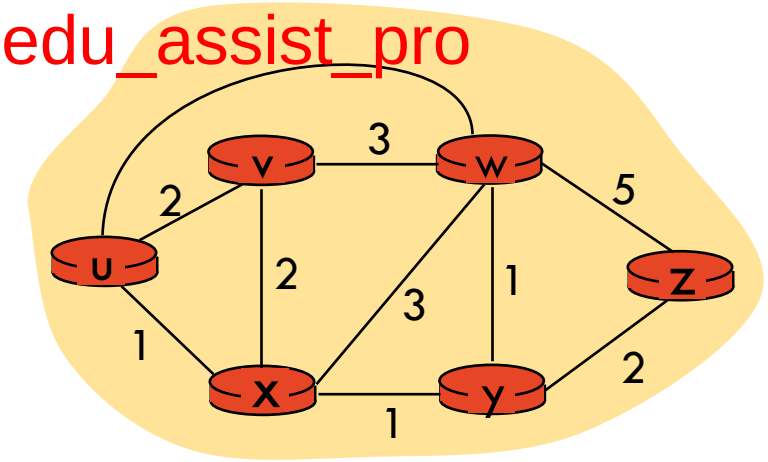
Notes:

- Construct shortest path tree by tracing predecessor nodes
- Ties can exist (can be broken arbitrarily)



Dijkstra's algorithm: another example

Step	N'	D(v),p(v)	D(w),p(w)	D(x),p(x)	D(y),p(y)	D(z),p(z)
0	u	2,u	5,u	1,u	∞	∞
1	ux	2,u	4,x		2,x	∞
2	uxy	2,u	3,y			4,y
3	uxyv		3,y			4,y
4	uxyvw					4,y
5	uxyvwz					

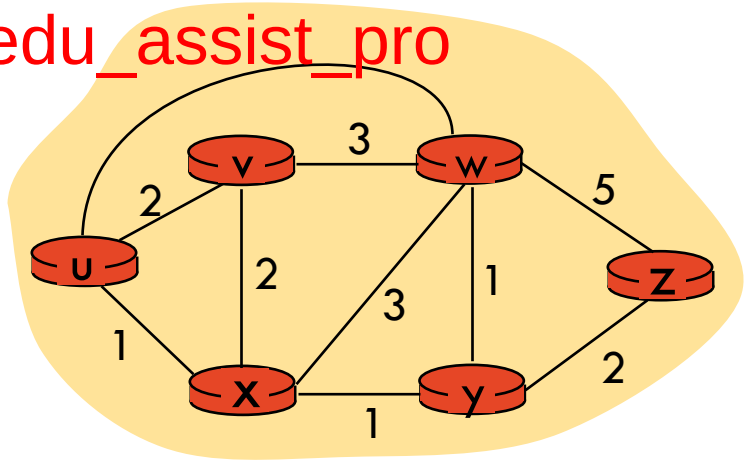


Dijkstra's algorithm: another example

Step	N'	D(v),p(v)	D(w),p(w)	D(x),p(x)	D(y),p(y)	D(z),p(z)
0	u	2,u	5,u	1,u	∞	∞
1	ux	2,u	4,x		2,x	∞
2	uxy	2,u	3,y			4,y
3	uxyv		3,y			4,y
4	uxyvw					4,y
5	uxyvwz					

Resulting shortest-path to w:

- w ← y ← x ←u



Dijkstra's algorithm, discussion

Algorithm complexity: n nodes

- each iteration: need to check all nodes, w, not in N
- n(n+1)/2 com
- more efficient O(nlogn)

Link-state routing algorithm

OSPF (Open Shortest Path First)

- "open": publicly available
- Uses link-state algorithm
  - link state packet dissemination
  - topology map at each node
  - **route computa**
- router floods O nfs to all other routers in *entire* AS
  - carried in OSPF messages directly r than TCP or UDP
  - link state: for each attached link
- multiple same-cost paths allowed (only one path in RIP)

Comparison of LS and DV algorithms

Message complexity

- ***LS:*** with n nodes, E links, O(nE) msgs sent
- ***DV:*** exchange between neighbors only
  - convergence ti

Speed of converge

- ***LS:*** $O(n^2)$ algorithm requires O(nE) msgs
  - may have oscillations
- ***DV:*** convergence time varies
  - may be routing loops
  - count-to-infinity problem

Robustness: what happens if router malfunctions?

LS:

- node can advertise incorrect *link* cost
- node computes only its table

e can advertise incorrect *path* cost

- each node's table used by others
  - error propagate thru network

Path finding in large scale networks

- Many graph libraries are available
  - Python: NetworkX - https://networkx.github.io

- Efficient implementations for many commonly known graph algorithms are a
- Example: Dijkstra's shortest path

Message-Oriented Transient Communication

Socket

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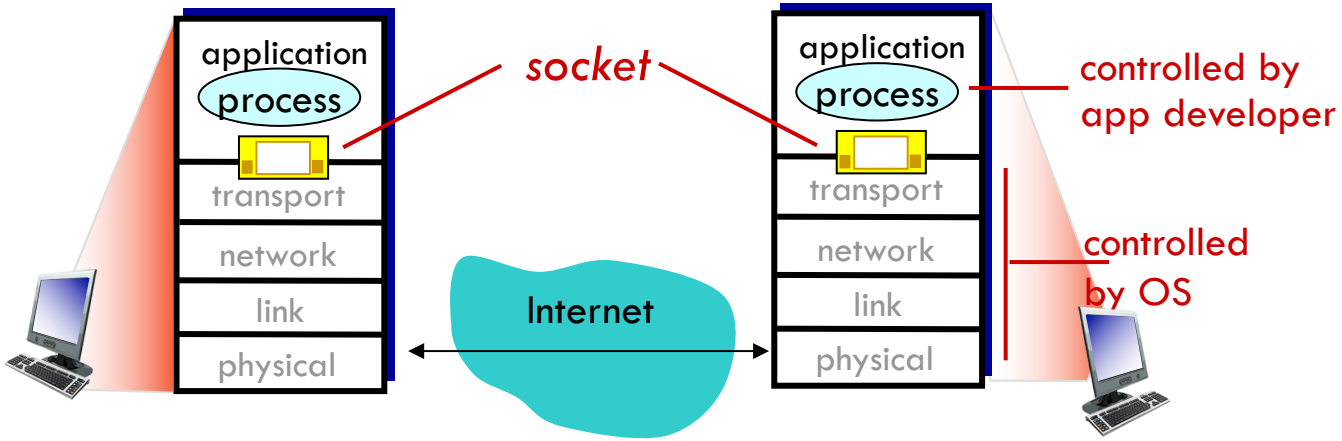
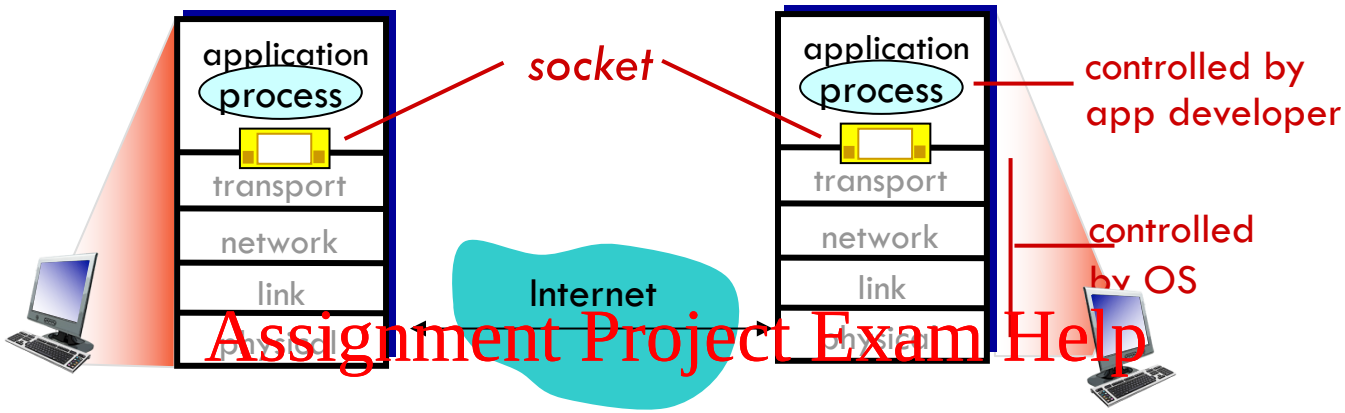
Socket



- *Socket*: interface b twork: communication end-points write d ork, and incoming data can be read
  - Application creates a socket
  - Socket type dictates the style of communications: connection less/oriented
- A socket is identified by an IP address concatenated with a port number
- In general, sockets use the client-server model:
  - The server waits for incoming client requests by listening to a specified port
  - Once a request is received, the server accepts a connection from the client

Address, Port, and Socket



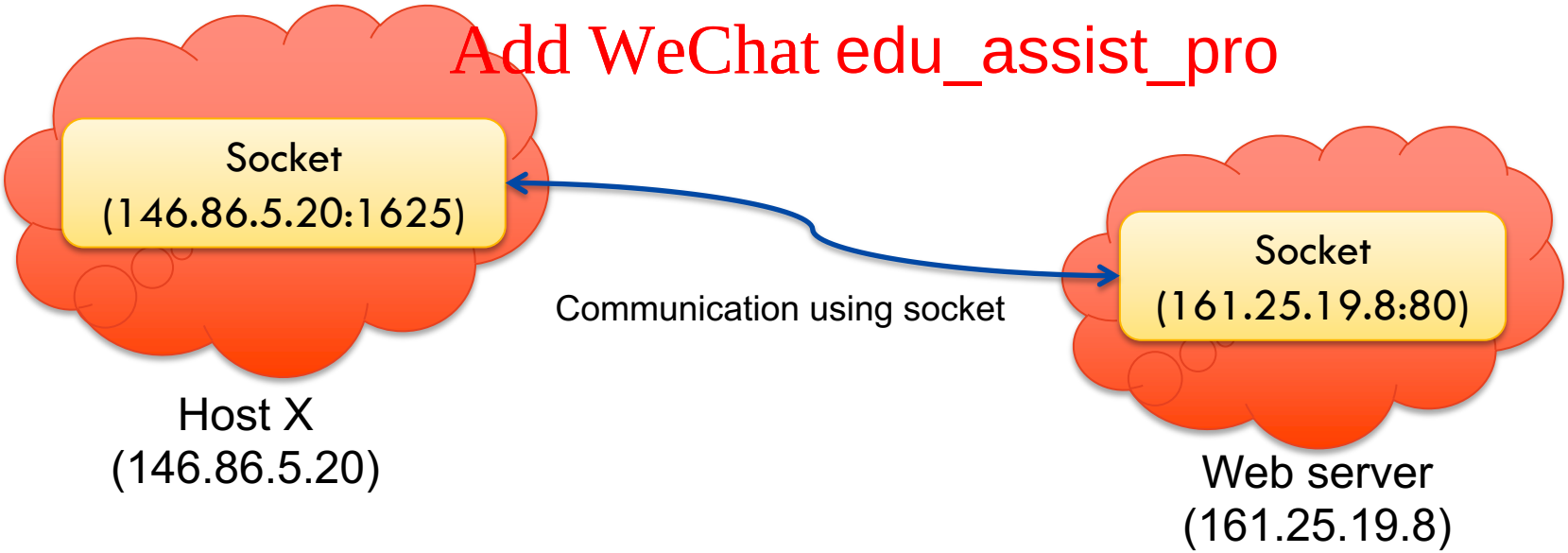
- *Like Apartment and Mailboxes*
  - You are the application
  - Your apartment building address is address
  - Your mailbox is the port
  - Socket is the key giving you access to the right mailbox

- Q: How to choose which port a socket connects to ?

Socket

Port

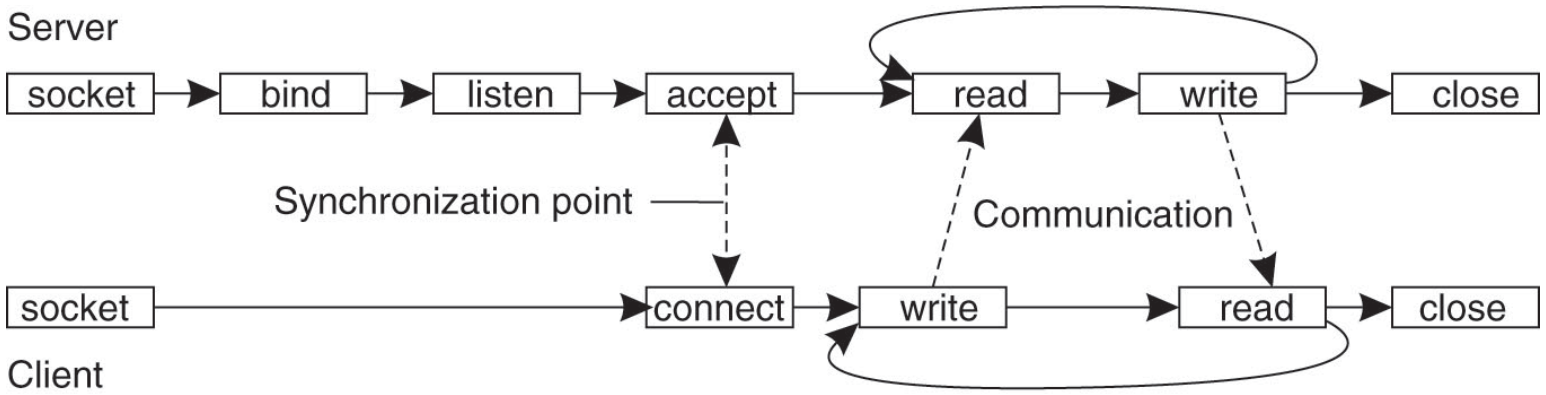
- Port numbers <1024 are for specific service protocols
  e.g., 80:HTTP, SSH:22, FTP:21, SMTP:25
- A client initiating a connection is assigned a free port number (>1024) by its h



Socket

Berkley Sockets: Socket interface as proposed in Berkley UNIX in the 70's

1. Servers generally execute the first 4 primitives on accept
2. Bind associates the newly created socket to a local address and a port; the client binds implicitly to any available port
3. The client connects to a s
4. Once the connection is ac the client and server can send and receive.



Stream-Oriented Communication

Communication
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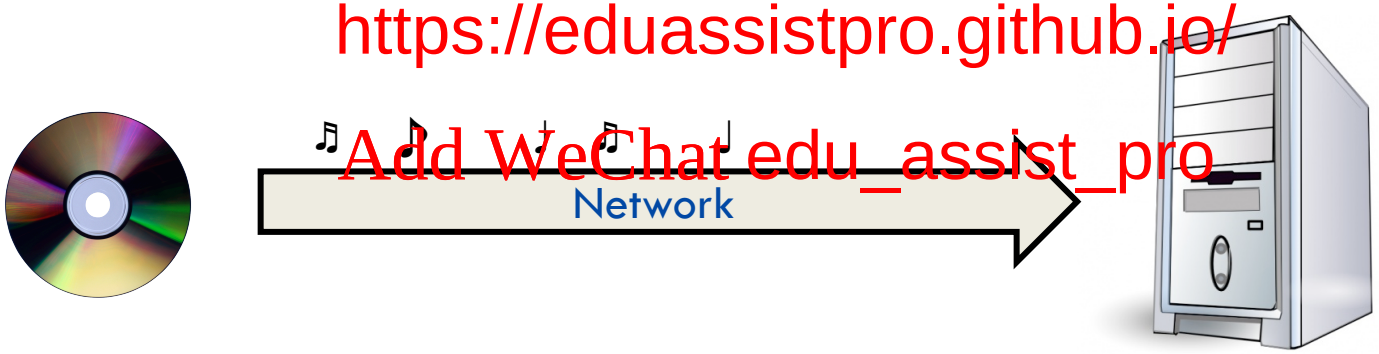
Stream-oriented communication

When timing is crucial

- Previous communication modes do not guarantee transmission rate
- In stream-oriented communication, the stream should not be interrupted, i.e., messages should keep being received at regular (typically small) time intervals



- Example: an *audio stream* in CD quality w/ sound wave at 44,100Hz
  - Destination starts reading before the entire information has been transmitted
  - Each piece of data should be read in order at fixed rate: every 1/44,100 seconds.

Stream-oriented communication

Quality of Service (QoS)

- Requirements to ensure that the temporal relationships in a stream can be preserved:
  - The required bit rate at which data should be transported
  - The maximum d t up (i.e., when an application can
  - The maximum end-to-end delay (i.e ill take until a data unit makes it to a recipient)
  - The maximum delay variance, or jitter
  - The maximum round-trip delay
- Problem: how to stream over internet?
  - Internet Protocol (IP) is best effort, it drops packet
  - IP rarely implements QoS

Stream-oriented communication

Buffer to cope with variable delays

- Use a buffer to store several data in advance at the receiver
- If packets are delayed with a certain variance but the average rate is sustainable
- The receiver can pass packets to the application at regular time intervals

- The size of the receiver buffer is 9 seconds of packets to pass, unfortunately packet #8 took 11 seconds to reach the receiver at which time the buffer was empty.

Stream-oriented communication

Error correction and interleaving to cope with message losses

- With best effort protocols, packets can be dropped
- TCP/IP retransmit drops packets, yet this is too heavy for streaming application
- Forward error correction: k out of n packets are enough to reconstruct k packets
- Interleaving circumvents dropped packet to contain multiple consecutive audio and video frame

- The effect of packet loss in (a) non-interleaved transmission and (b) interleaved transmission

Streaming multimedia: DASH

- *DASH: D*ynamic, *A*daptive *S*treaming over *H*TTP
- *server:*
  - divides video file into multiple chunks
  - each chunk stored, encoded at different rates
  - *manifest file* nt chunks
- *client:*
  - periodically measures server nd width
  - consulting manifest, requests one chunk at a time
    - chooses maximum coding rate sustainable given current bandwidth
    - can choose different coding rates at different points in time (depending on available bandwidth at time)

Streaming multimedia: DASH

- *DASH: Dynamic, Adaptive Streaming over HTTP*
- *"intelligence" at client:* client determines
  - *when* to request chunk (so that buffer starvation, or overflow does not occur)
  - *what encodi* quality when more bandwidth
  - *where* to request chunk (can URL server that is "close" to client or ha ble bandwidth)

Video Streaming and CDNs: context

- video traffic: major consumer of Internet bandwidth
  - Netflix, YouTube: 37%, 16% of downstream residential ISP traffic
  - ~1B YouTube users, ~75M Netflix users
- challenge: scale - how to reach ~1B users?
  - single mega-vid
- challenge: heter
  - different users have different capa wired versus mobile; bandwidth ric bandwidth poor)

Content distribution networks

- *challenge:* how to stream content (selected from millions of videos) to hundreds of thousands of *simultaneous* users?

- *option 1:* single, large "mega-server"
  - single point
  - point of net
  - long path to distant clients
  - multiple copies of video sent over outgoing link

….quite simply: this solution *doesn't scale*

Content distribution networks

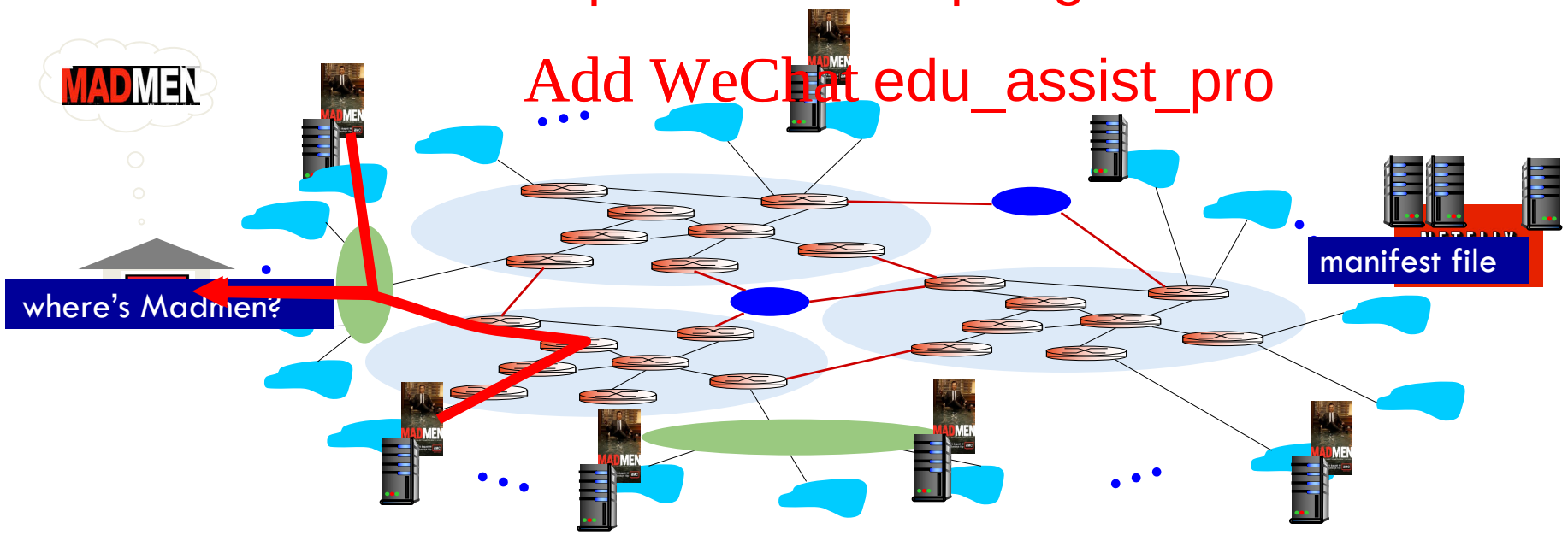
- *challenge:* how to stream content (selected from millions of videos) to hundreds of thousands of simultaneous users?

- *option 2:* store/serve multiple copies of videos at multiple geographically
  - *enter deep:* pu access networks
    - close to users
    - used by Akamai, 1700 locati
  - *bring home:* smaller number (10's) of larger clusters in POPs near (but not within) access networks
    - used by Limelight

- *solution:* distributed, application-level infrastructure

Content Distribution Networks (CDNs)

- CDN: stores copies of content at CDN nodes
  - e.g. Netflix stores copies of MadMen
- subscriber requests content from CDN
  - directed to nearby copy, retrieves content
  - may choos path congested



Conclusion

- Network protocols are divided into layers
- Routing protocols are
  - simple but not scalable (distance-vector) or
  - more complex but scalable (link-state)
- There are variou depending on the needs:
  - We covered: General-purpose com cket)
- Streaming-oriented Communication

What's Next ?

- **Tutorial on Wednesday.**

- Read Chapter 4 of the textbook

- Next week: mor distributed systems

- See you all next week !