OVERLAY NETWORKS AND VPNS

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UC San Diego

ATTRIBUTION

- These slides incorporate material from:
  - Christo Wilson, NEU (used with permission)
  - Yashar Ganjali, Toronto (used with permission)

What are capes?

- **Only** source of feedback to UCSD about Professor & TA teaching
- **Anonymous**
- **Optional**
- **Extremely important**
  - Determines whether faculty get promoted, get tenure, keep their jobs
  - Determines whether TAs become TAs in the future

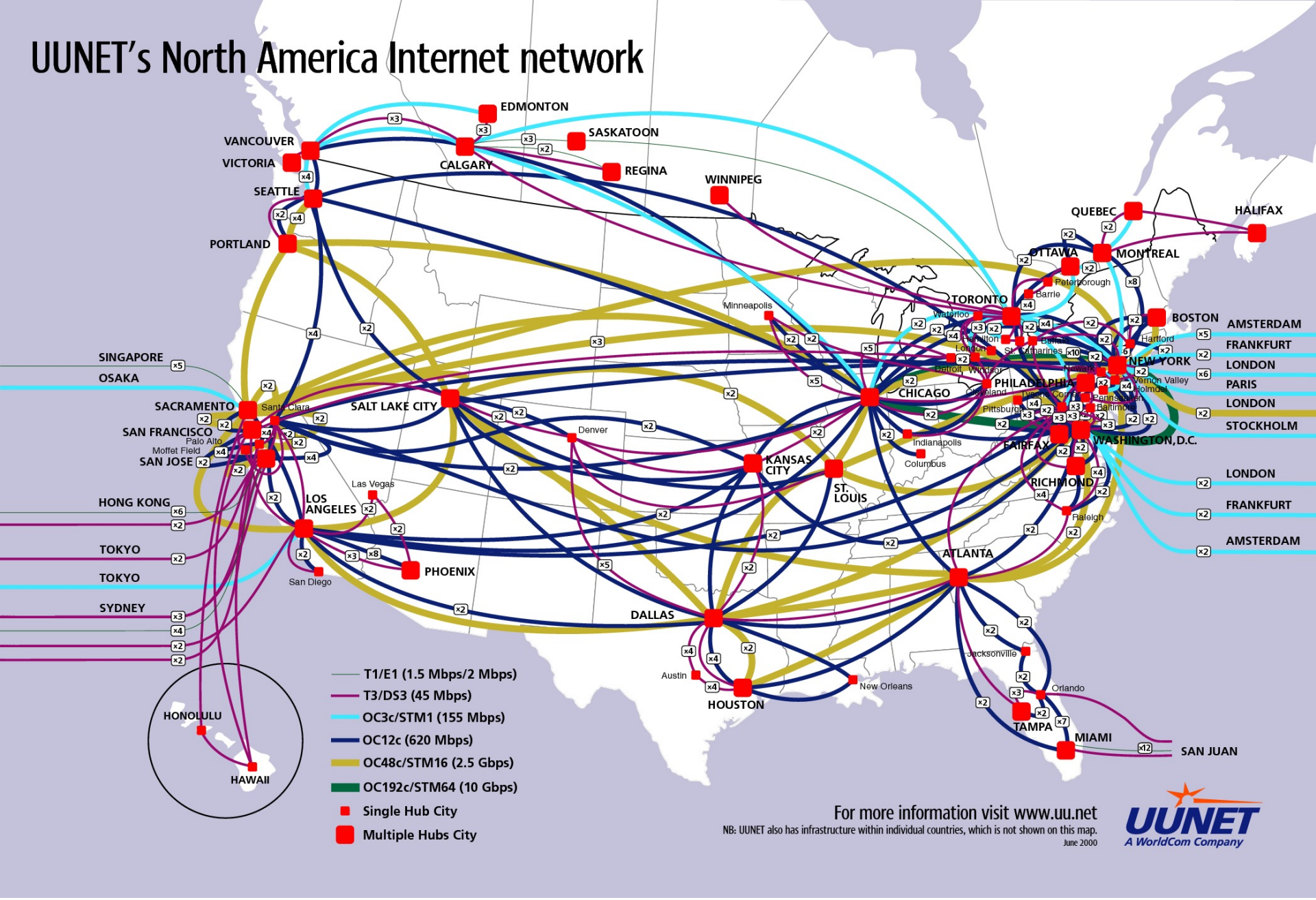
- **Please make your voice heard!**
  - Usually only students who ***love*** or ***hate*** the class fill them out
  - We appreciate the few minutes it takes to make your opinions/voice heard

Thanks!

Abstract View of the Internet

- A bunch of servers/virtual machines connected by point-to-point physical links
- Point-to-point links between routers are physically as direct as possible

UUNET's North America Internet network



For more information visit www.uu.net

NB: UUNET also has infrastructure within individual countries, which is not shown on this map.

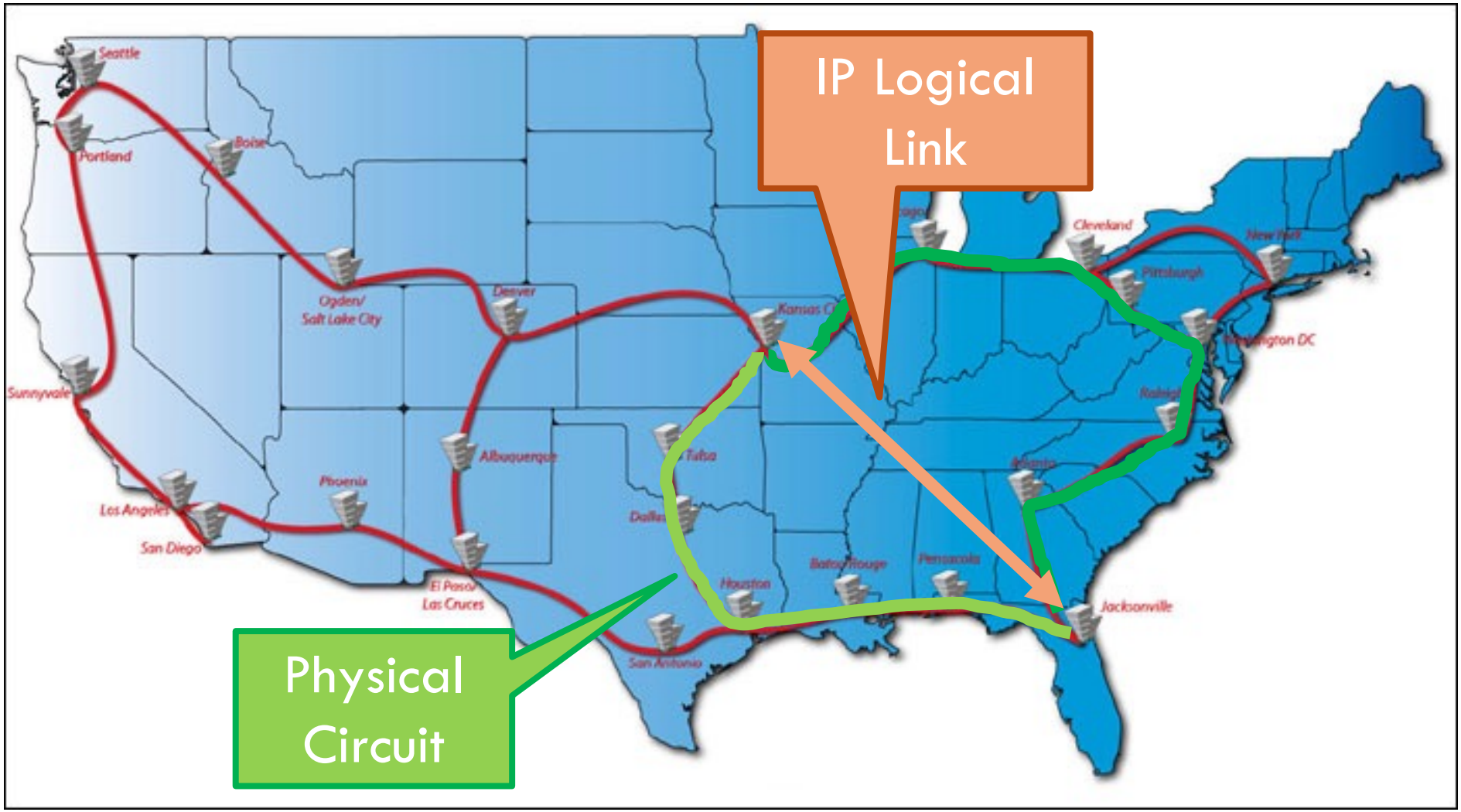
June 2000

UUNET
A WorldCom Company

Reality Check

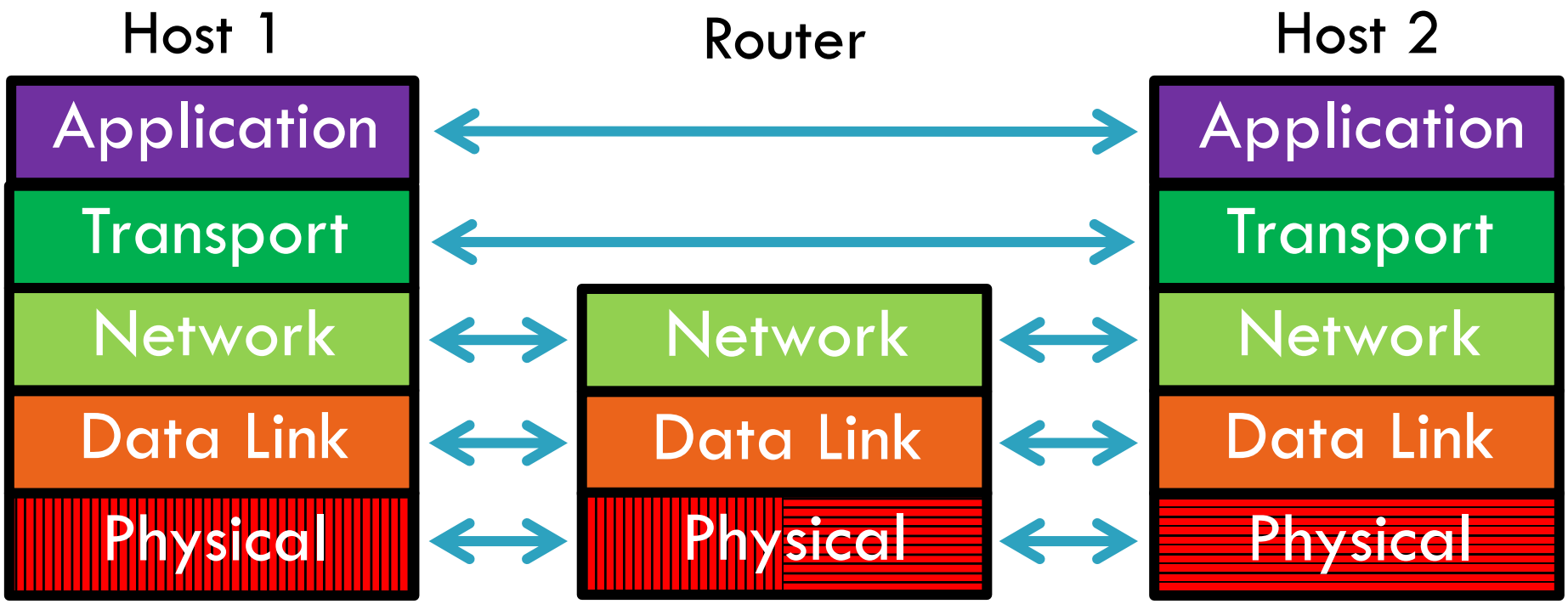
- Fibers and wires limited by physical constraints
  - You can't just dig up the ground everywhere
  - Most fiber laid along railroad tracks
- Physical fiber topology often far from ideal
- IP Internet is overlaid on top of the physical fiber topology
  - IP Internet topology is only logical
- Key concept: IP Internet is an overlay network

National Lambda Rail Project



Made Possible By Layering

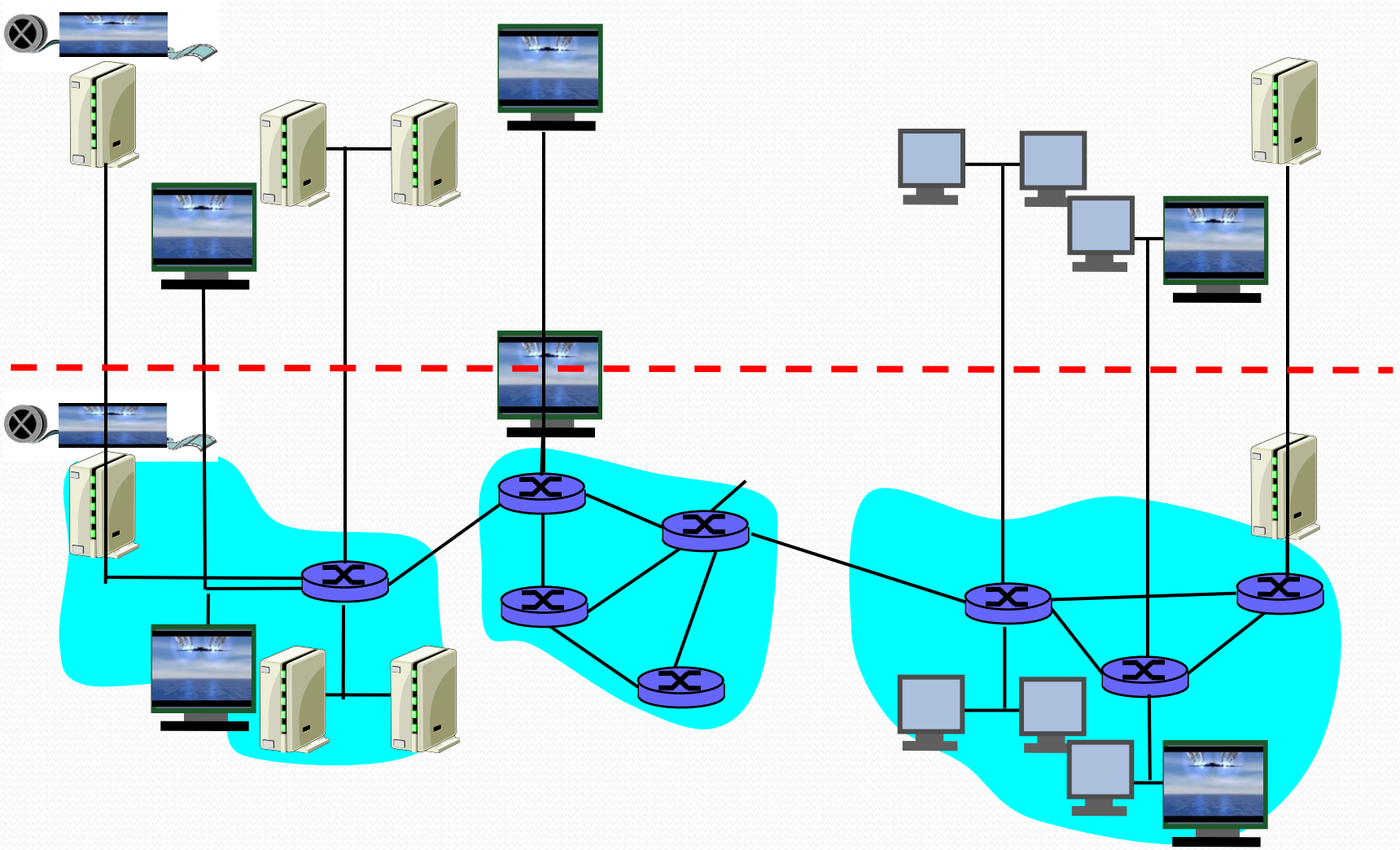
- Layering hides low level details from higher layers
  - IP is a logical, point-to-point overlay
  - ATM/SONET circuits on fibers



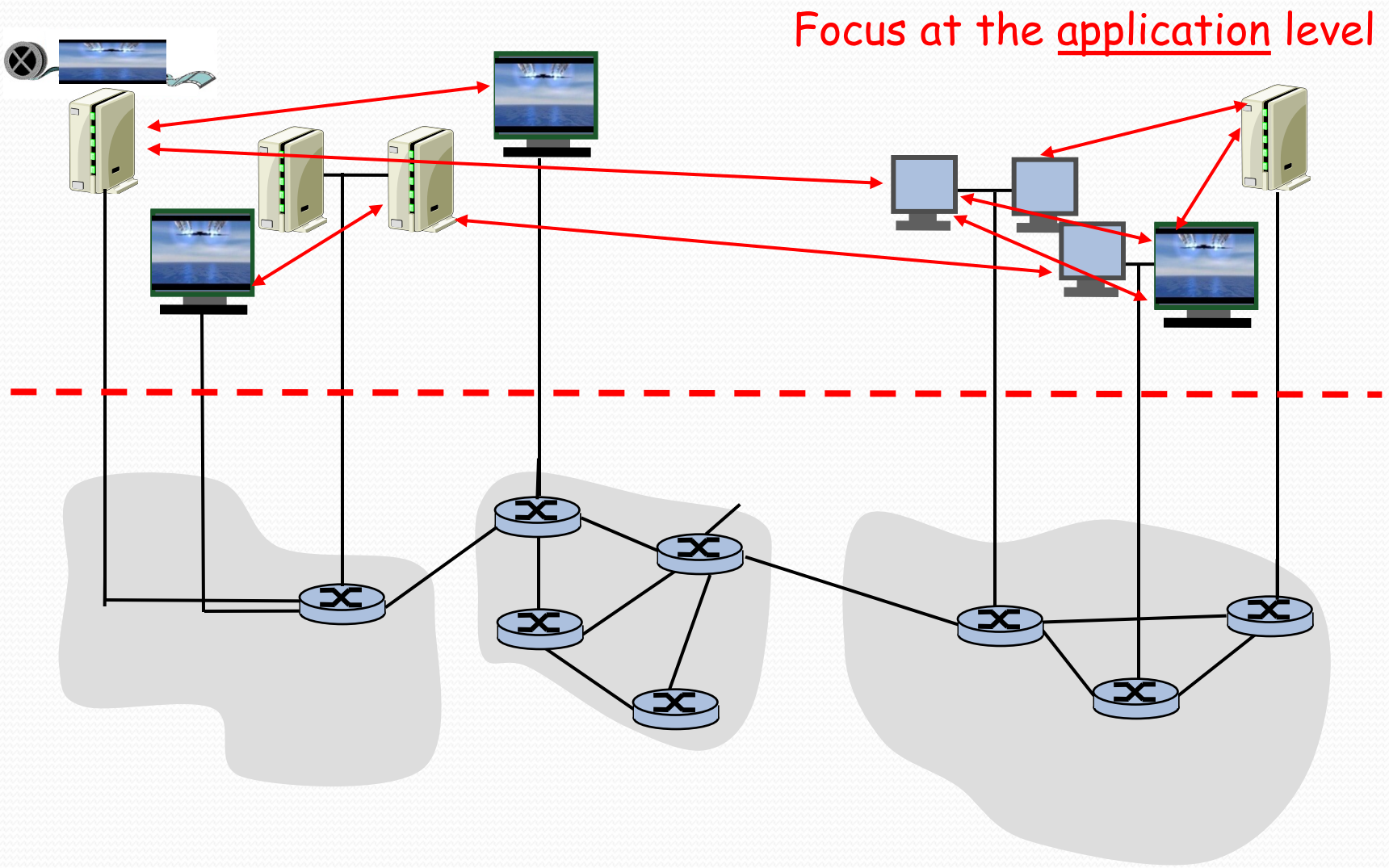
Overlays

- Overlay is a general concept
  - Networks are just about routing messages between named entities
- IP Internet overlays on top of physical topology
  - We assume that IP and IP addresses are the only names…
- Why stop there?
  - Overlay another network on top of IP

Overlay Networks



Overlay Networks



Overlay Networks

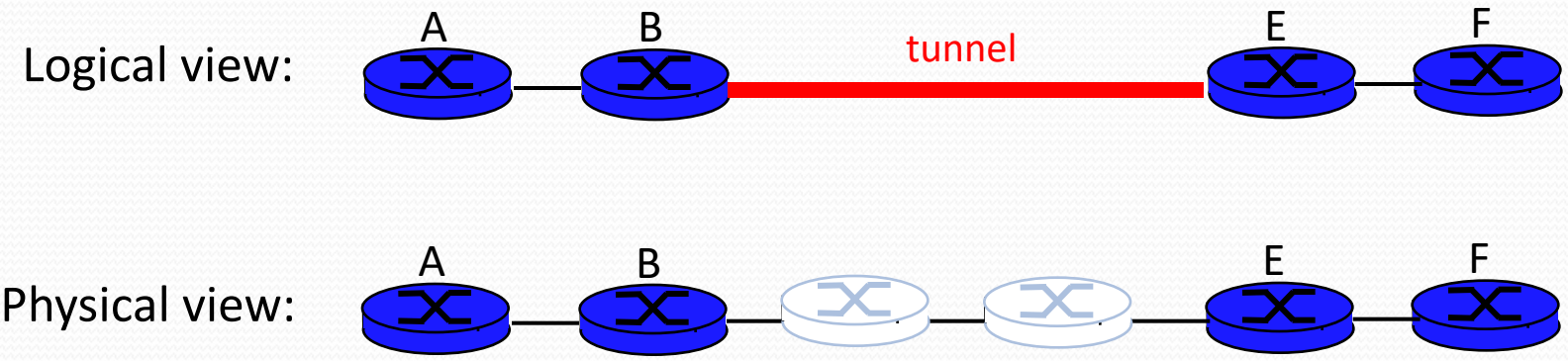
- A logical network built on top of a physical network
  - Overlay links are tunnels through the underlying network
- Many logical networks may coexist at once
  - Over the same underlying network
  - And providing its own particular service
- Nodes are often end hosts
  - Acting as intermediate nodes that forward traffic
  - Providing a service, such as access to files
- Who controls the nodes providing service?
  - The party providing the service (e.g., Akamai)
  - Distributed collection of end users (e.g., peer-to-peer)

Routing Overlays

- Alternative routing strategies
  - No application-level processing at the overlay nodes
  - Packet-delivery service with new routing strategies
- Incremental enhancements to IP
  - IPv6
  - Multicast
  - Mobility
  - Security
- Revisiting where a function belongs
  - End-system multicast: multicast distribution by end hosts
- Customized path selection
  - Resilient Overlay Networks: robust packet delivery

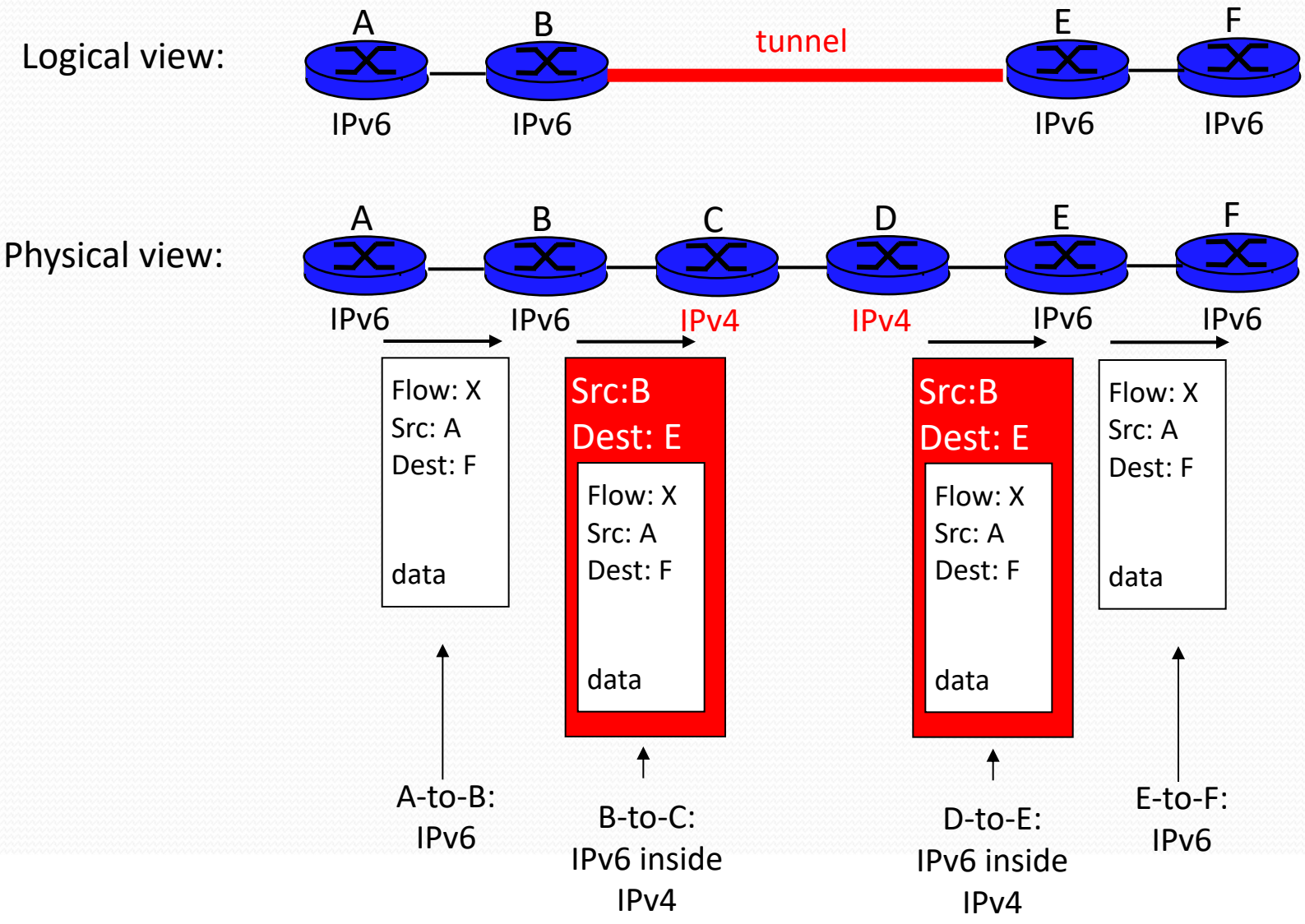
IP Tunneling

- IP tunnel is a virtual point-to-point link
  - Illusion of a direct link between two separated nodes



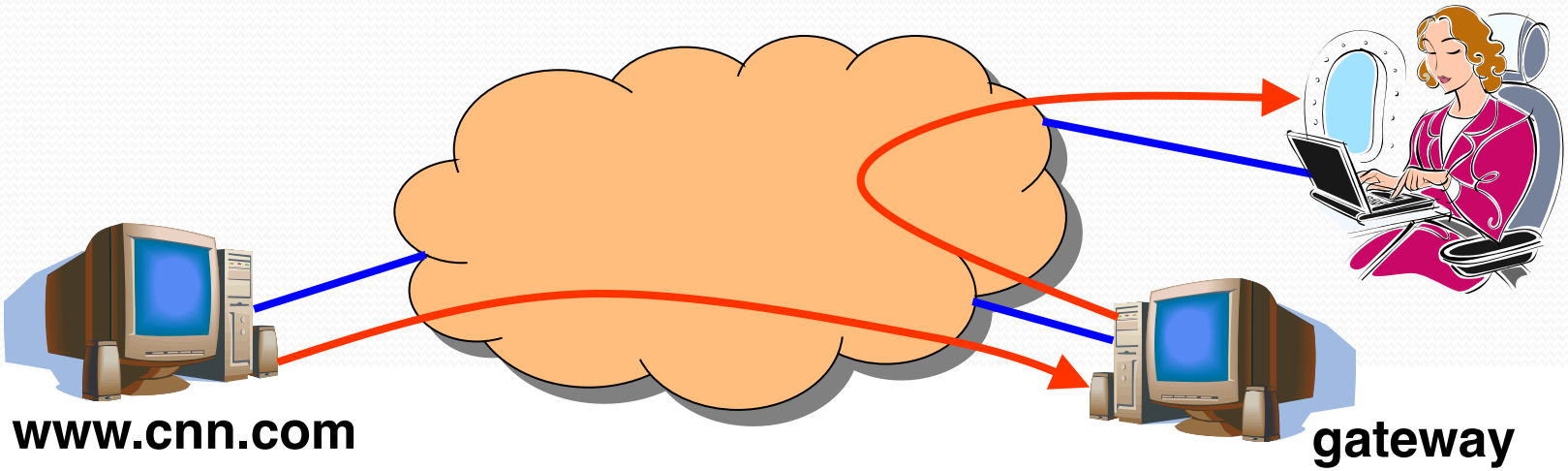
- Encapsulation of the packet inside an IP datagram
  - Node B sends a packet to node E
  - … containing another packet as the payload

6Bone: Deploying IPv6 over IP4



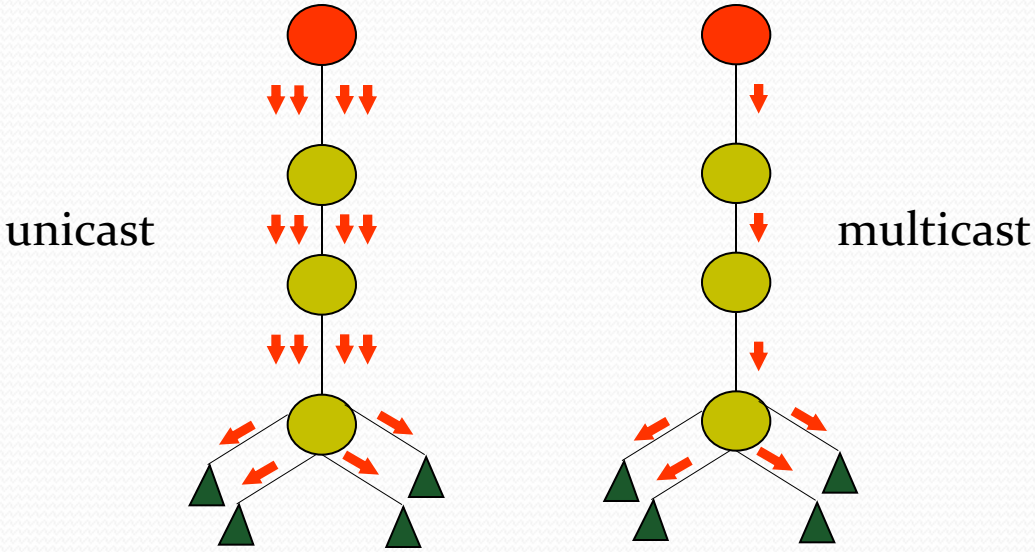
Communicating With Mobile Users

- A mobile user changes locations frequently
  - So, the IP address of the machine changes often
- The user wants applications to continue running
  - So, the change in IP address needs to be hidden
- Solution: fixed gateway forwards packets
  - Gateway has a fixed IP address
  - … and keeps track of the mobile's address changes



MBone: IP Multicast

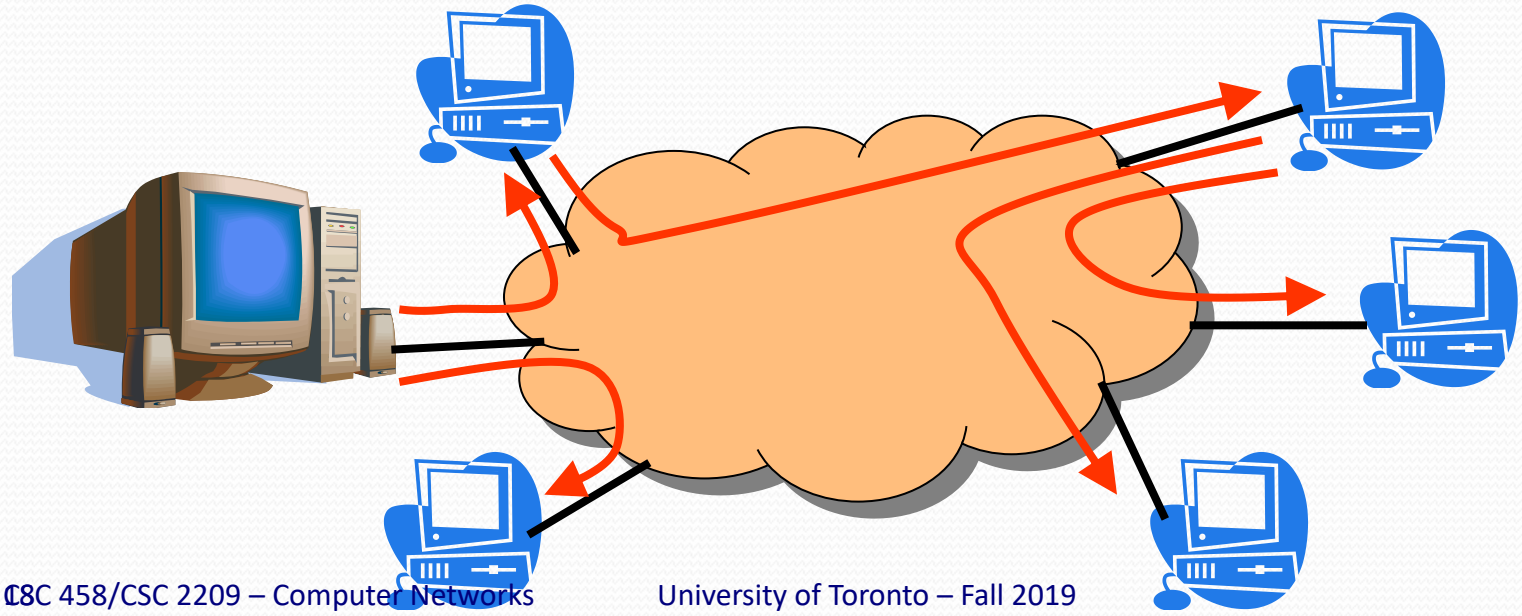
- Multicast
  - Delivering the same data to many receivers
  - Avoiding sending the same data many times



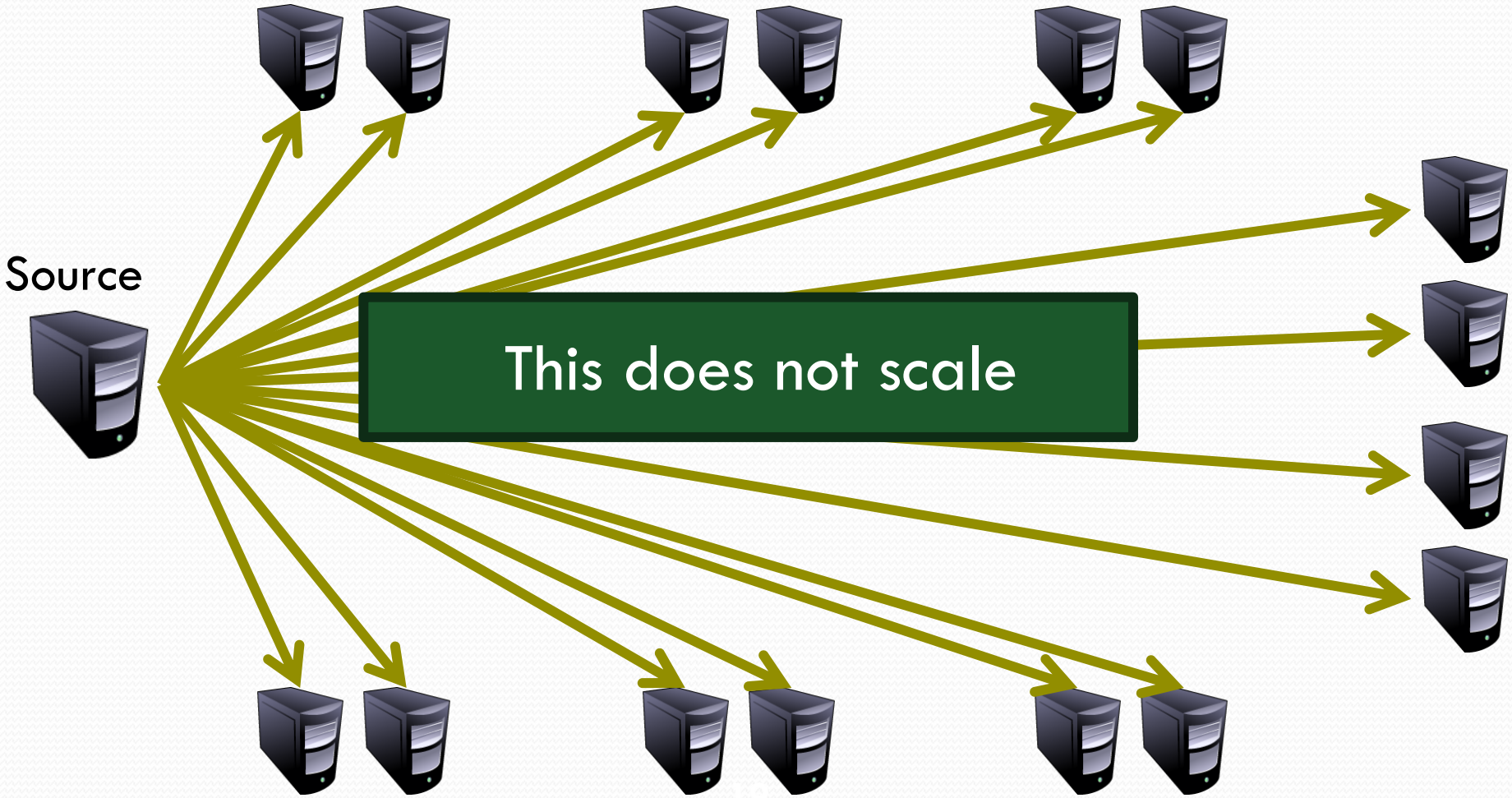
- IP multicast
  - Special addressing, forwarding, and routing schemes
  - Not widely deployed, so MBone tunneled between nodes

End-System Multicast

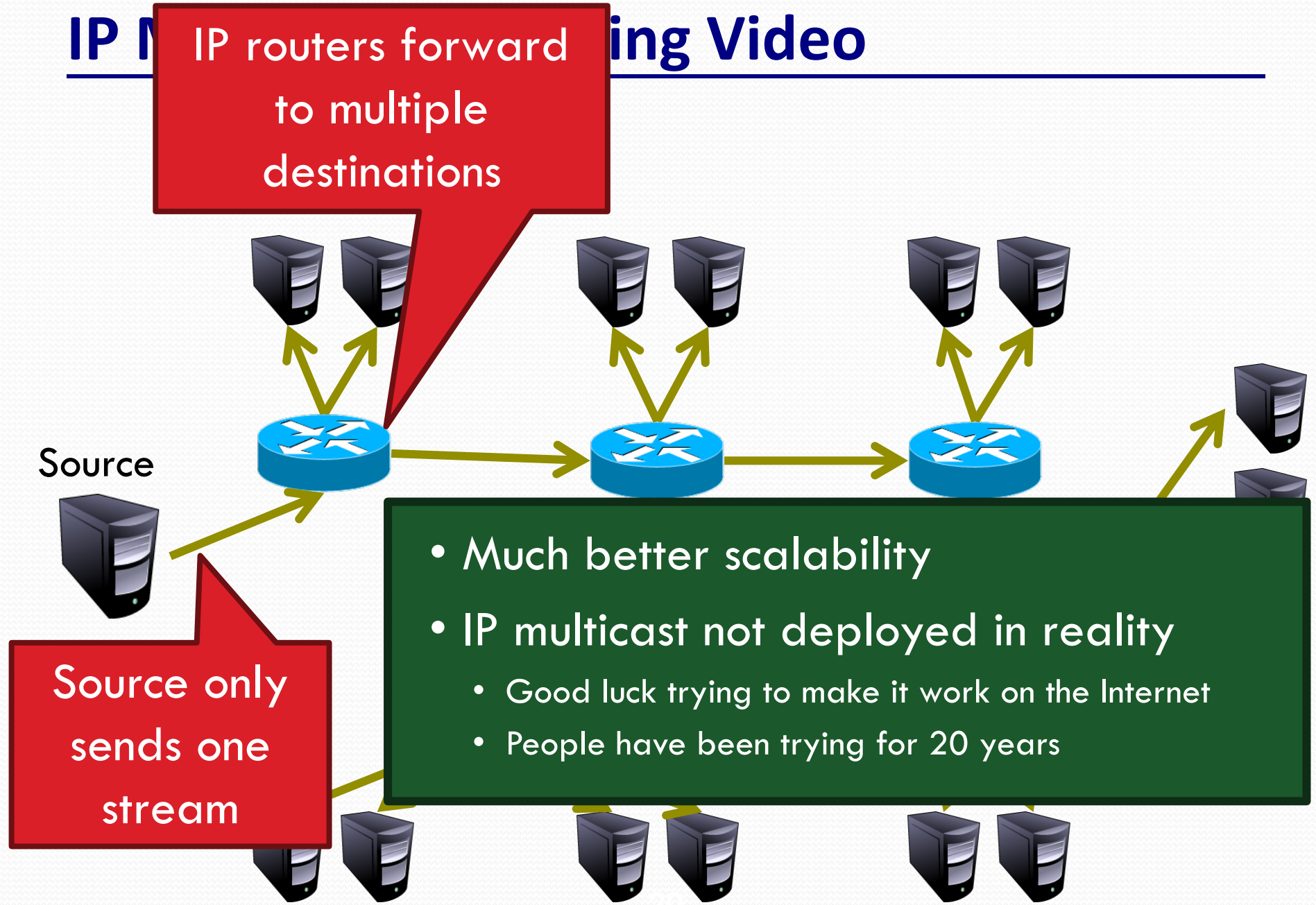
- IP multicast still is not widely deployed
  - Technical and business challenges
  - Should multicast be a network-layer service?
- Multicast tree of end hosts
  - Allow end hosts to form their own multicast tree
  - Hosts receiving the data help forward to others



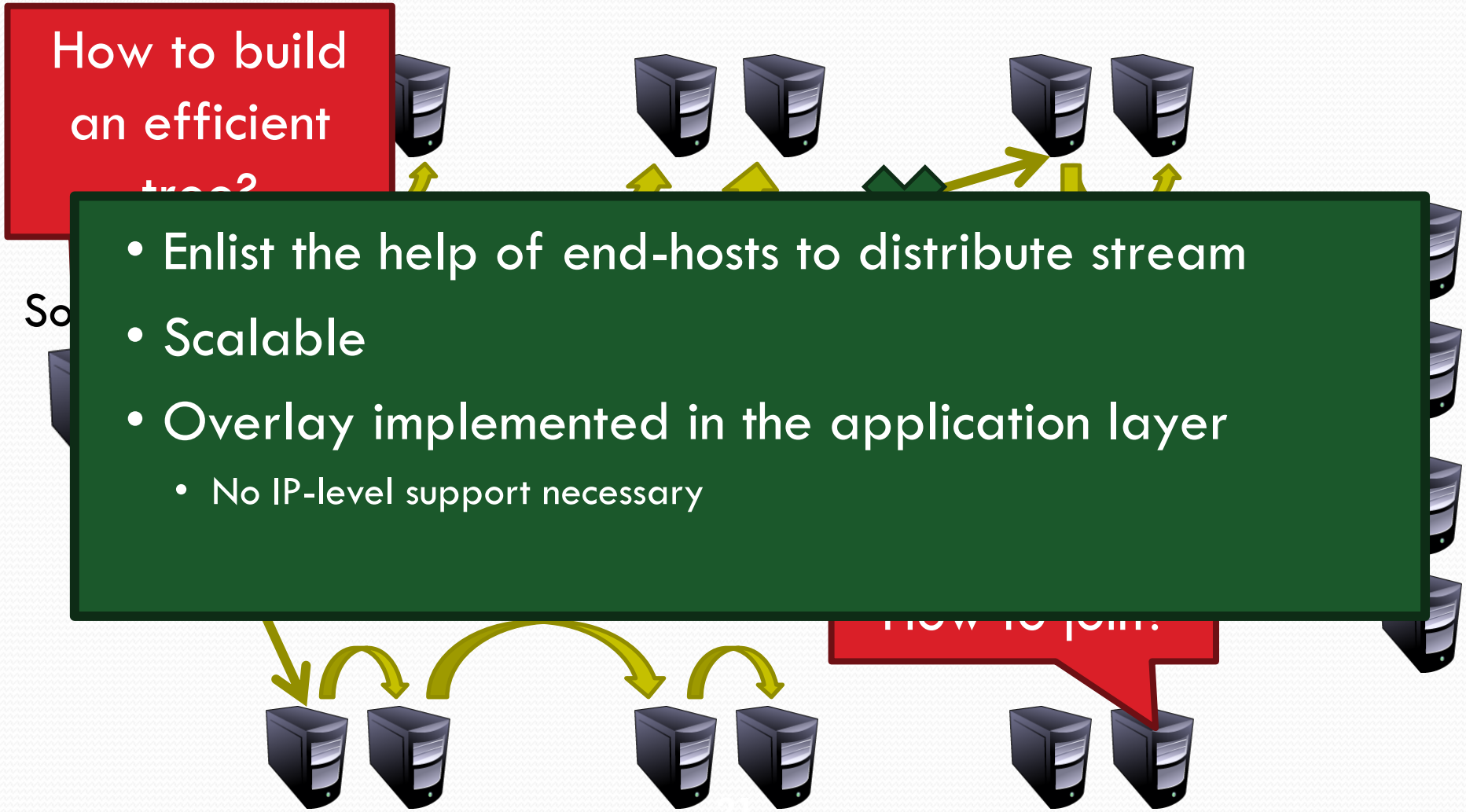
Unicast Streaming Video



IP M ing Video

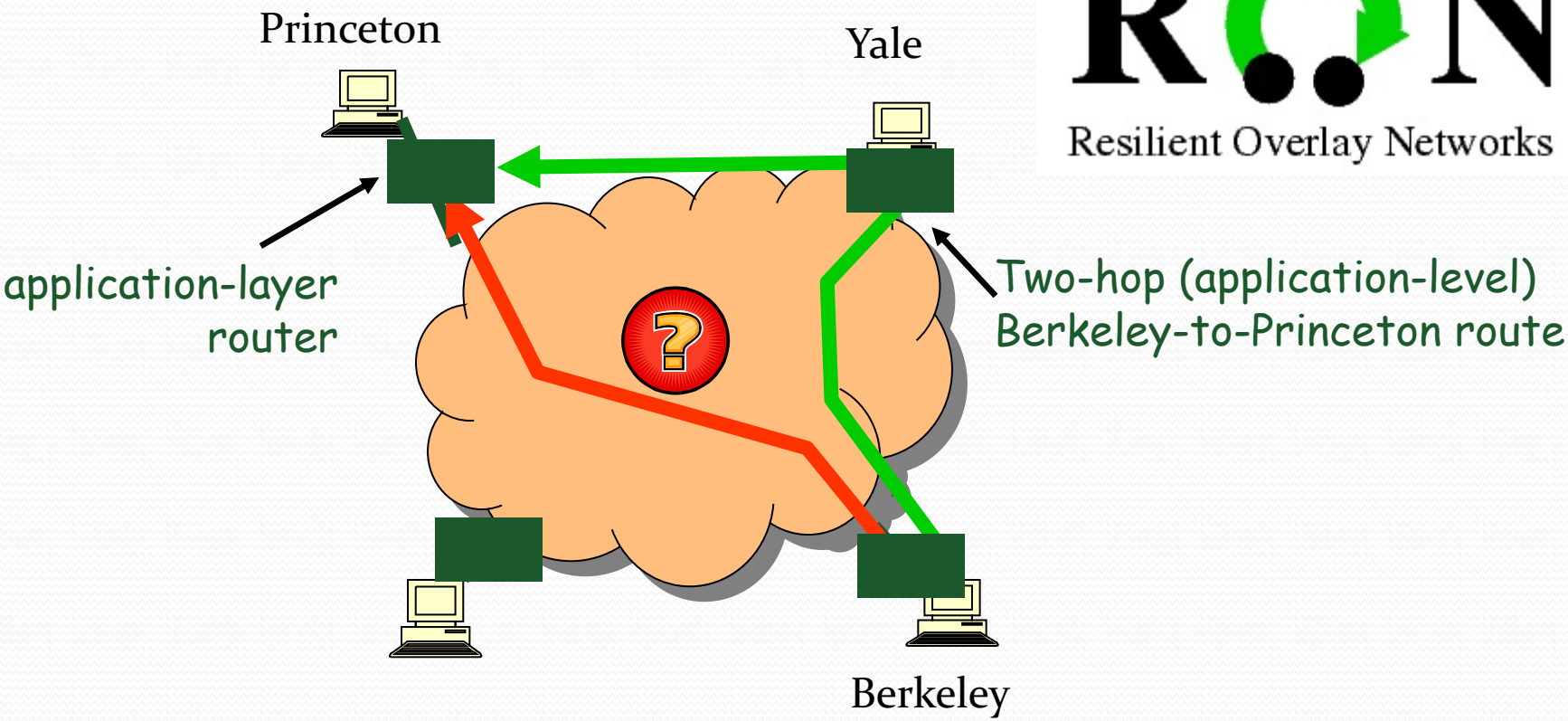


End System Multicast Overlay



RON: Resilient Overlay Networks

Premise: by building application overlay network, can increase performance and reliability of routing

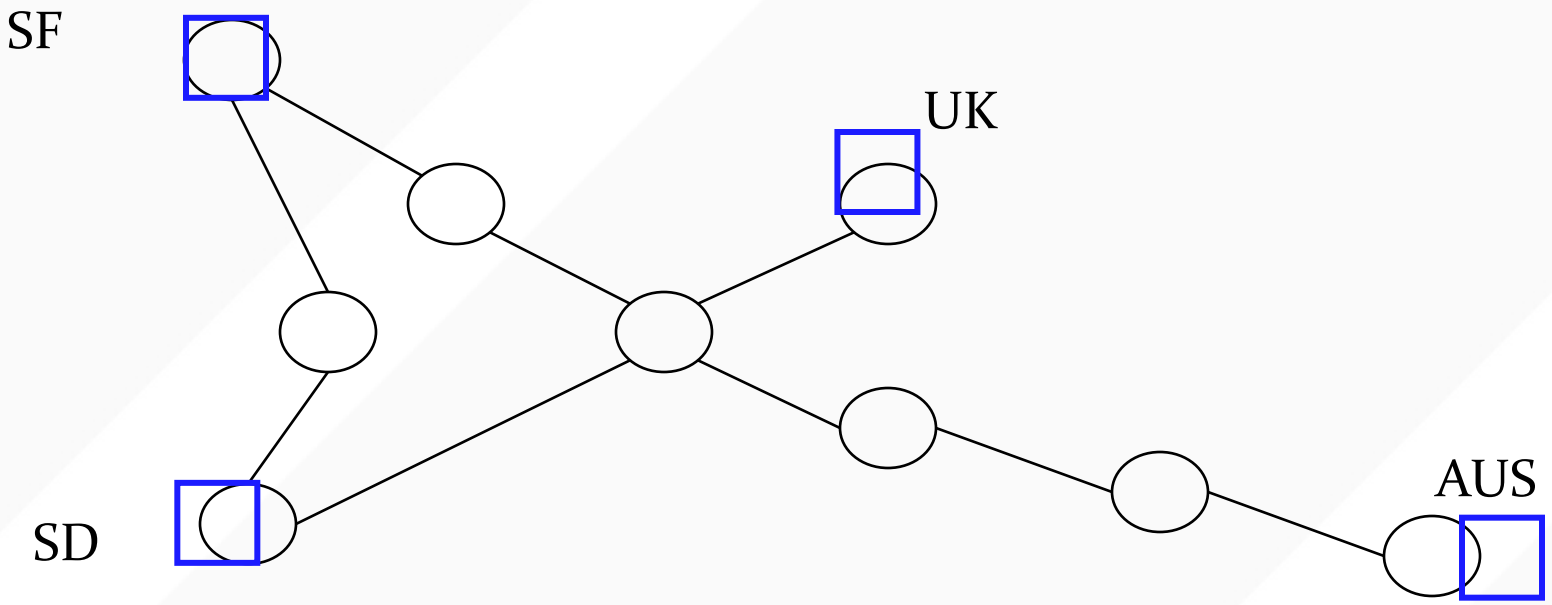


RON Can Outperform IP Routing

- IP routing does not adapt to congestion
  - But RON can reroute when the direct path is congested
- IP routing is sometimes slow to converge
  - But RON can quickly direct traffic through intermediary
- IP routing depends on AS routing policies
  - But RON may pick paths that circumvent policies

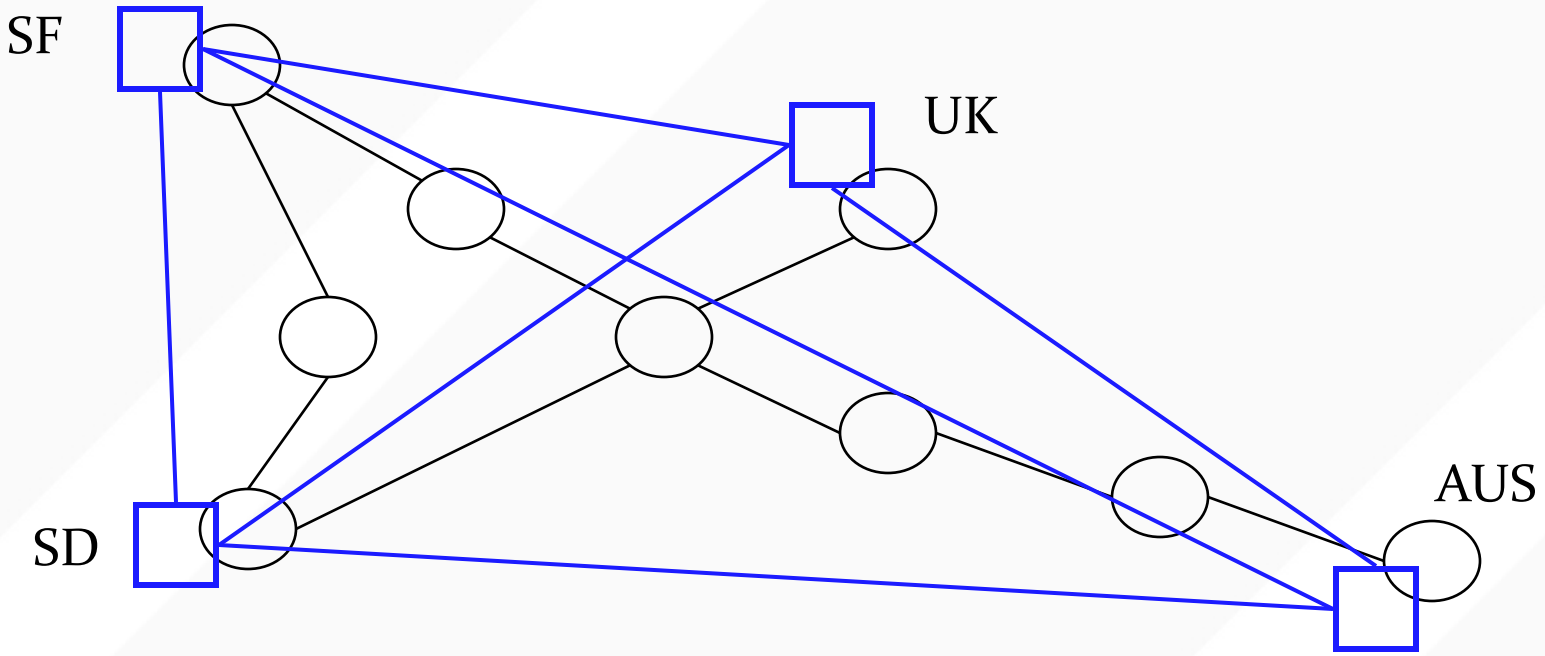
- Then again, RON has its own overheads
  - Packets go in and out at intermediate nodes
    - Performance degradation, load on hosts, and financial cost
  - Probing overhead to monitor the virtual links
    - Limits RON to deployments with a small number of nodes

OVERLAY NETWORKS FOR ROUTING



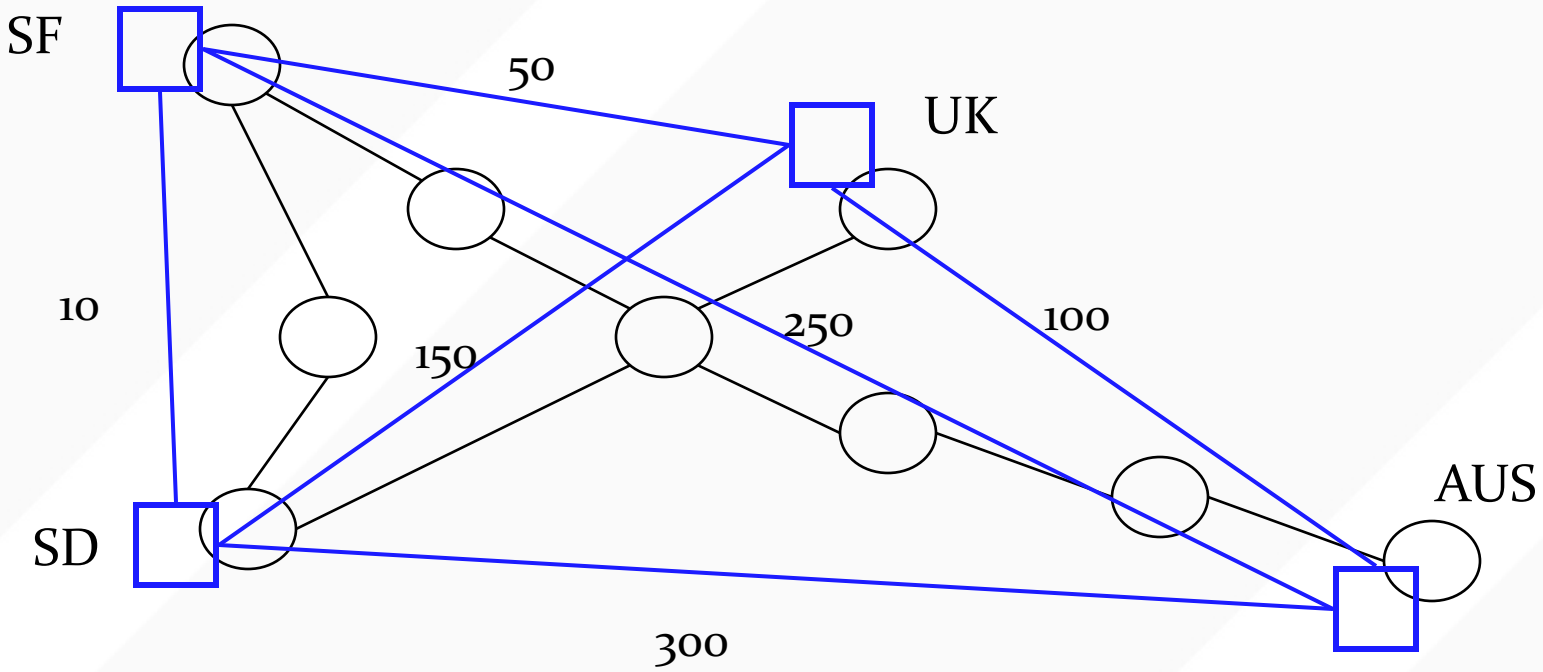
- Underlying network
  - Internet connectivity (IP Routing)

OVERLAY NETWORKS



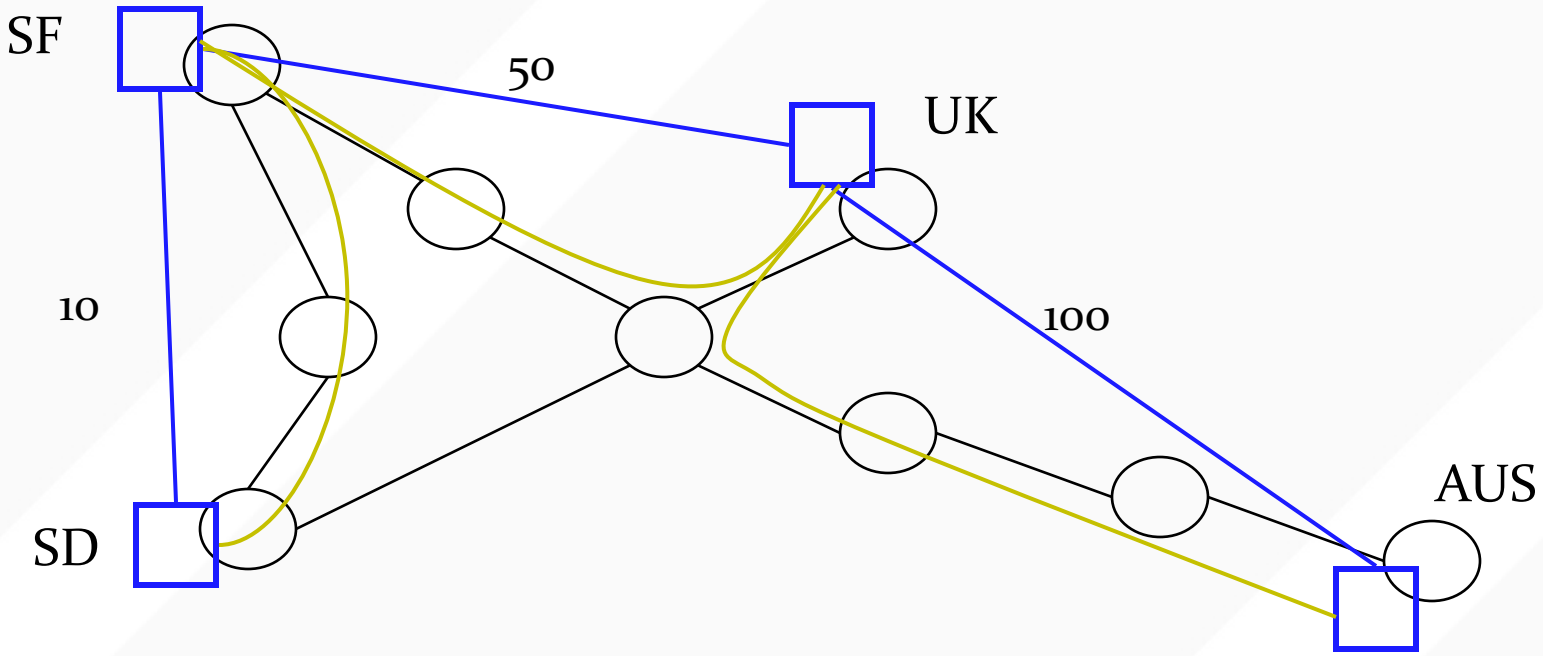
- Potential overlay connectivity
  - SF as root

OVERLAY NETWORKS



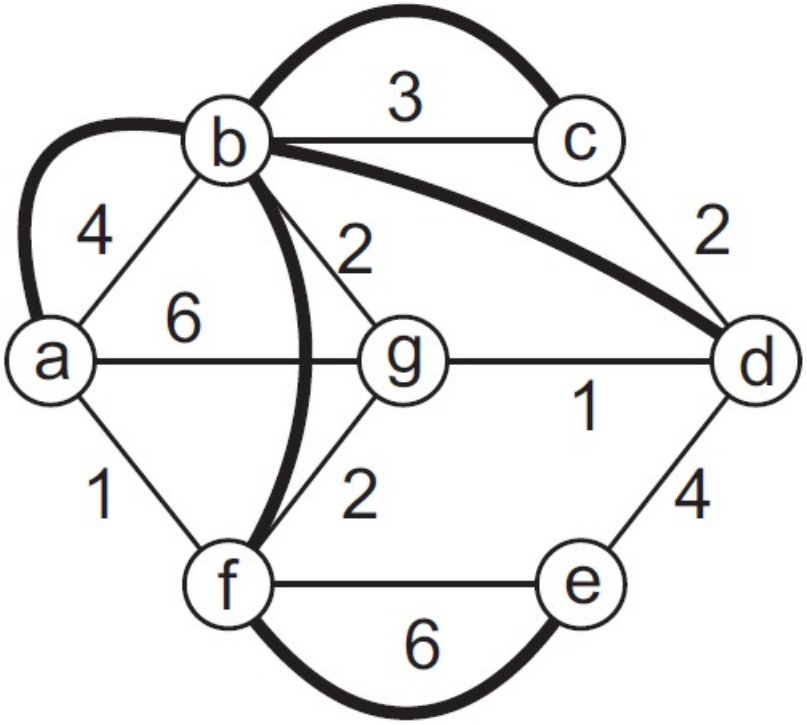
- Determine edge weights
  - E.g., bandwidth, latency

OVERLAY NETWORKS



- Build overlay connectivity
  - An application-layer distribution tree

APP-LAYER OVERLAY EXAMPLE

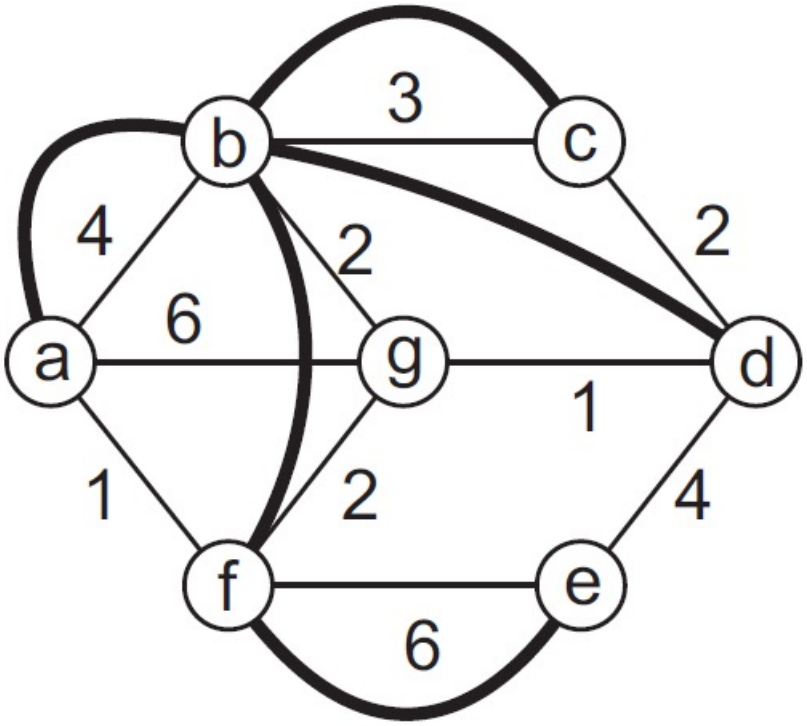


- "Tree" constructed using application-layer sockets
- Data flows along tree, not underlying network
- Why?
  - Can improve reliability
    - If link from B->G fails, can take few minutes for Internet to recover
      (meanwhile app can respond in milliseconds to create new path)
  - Disseminate data in a scalable way
  - Avoid censorship

KEY CONCEPTS

- Link stress
  - How often a packet transits a given link
- Relative delay penalty (aka “Stretch”)
  - Ratio of delay in overlay vs. underlying network

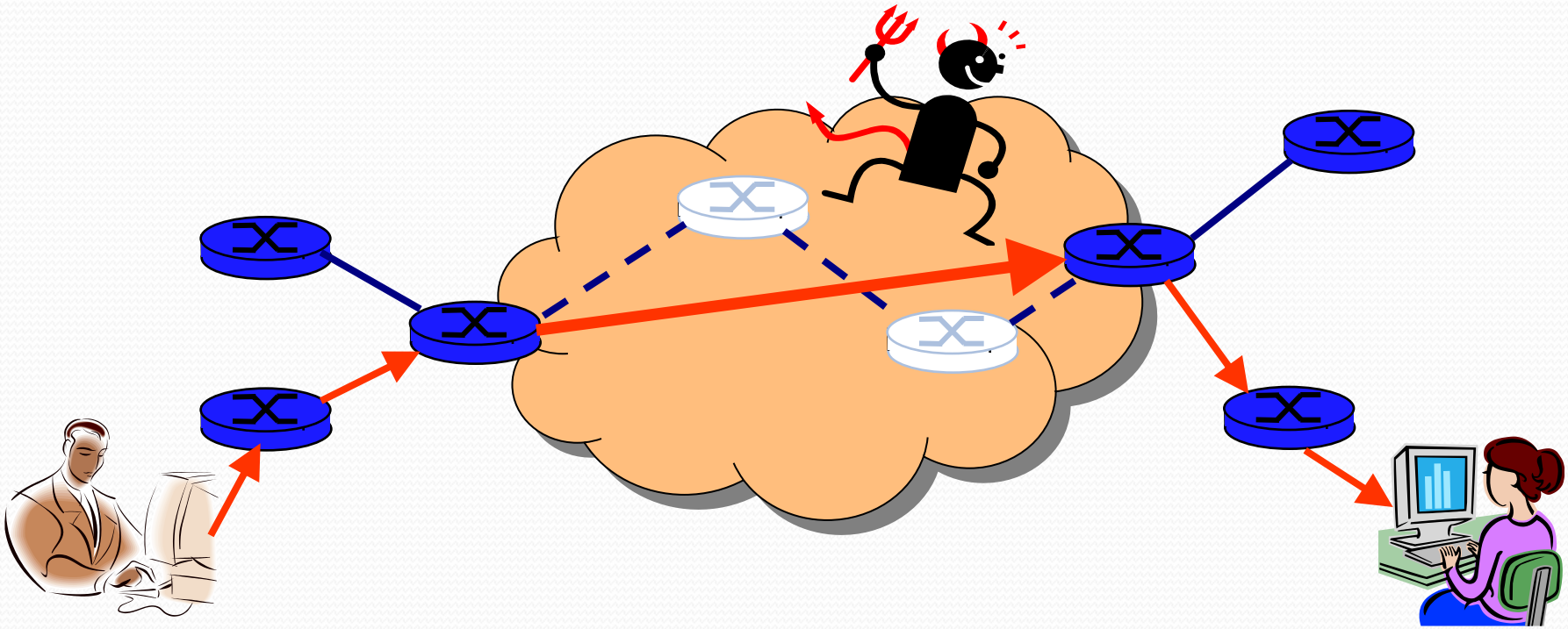
APP-LAYER OVERLAY EXAMPLE



- Network cost A -> F
  - 1
- Overlay cost A -> F
  - 4 + 2 + 2 = 8
- Relative delay penalty A -> F
  - 8/1

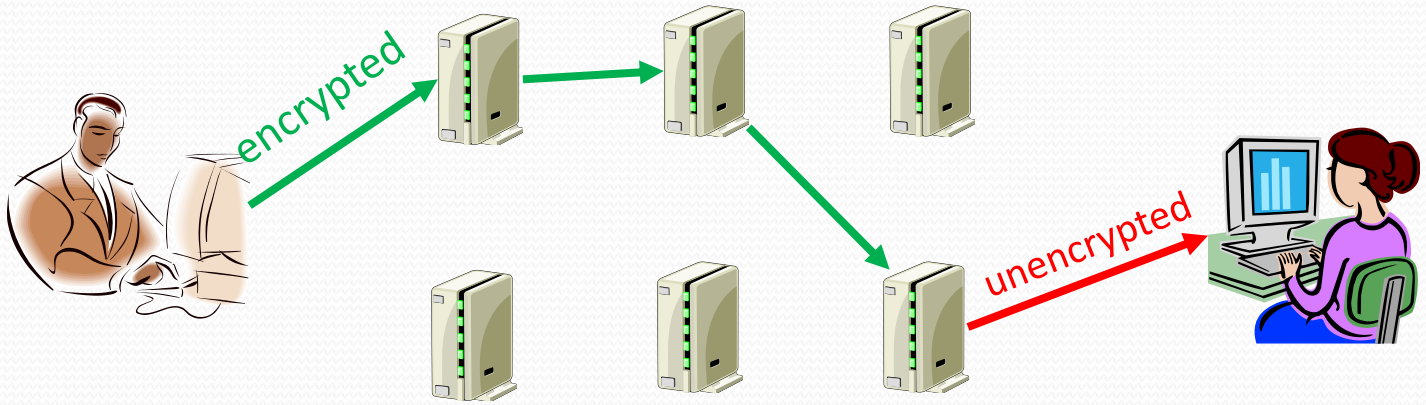
Secure Communication Over Insecure Links

- Encrypt packets at entry and decrypt at exit
- Eavesdropper cannot snoop the data
- … or determine the real source and destination



Tor Project

- An overlay to enhance anonymity and privacy
  - Volunteer operated servers (?)
- How Tor Works
  - Obtain a list of Tor nodes from a directory
  - Pick a random path to destination server
  - Select a different path for other servers



WHAT IS CRYPTOGRAPHY?

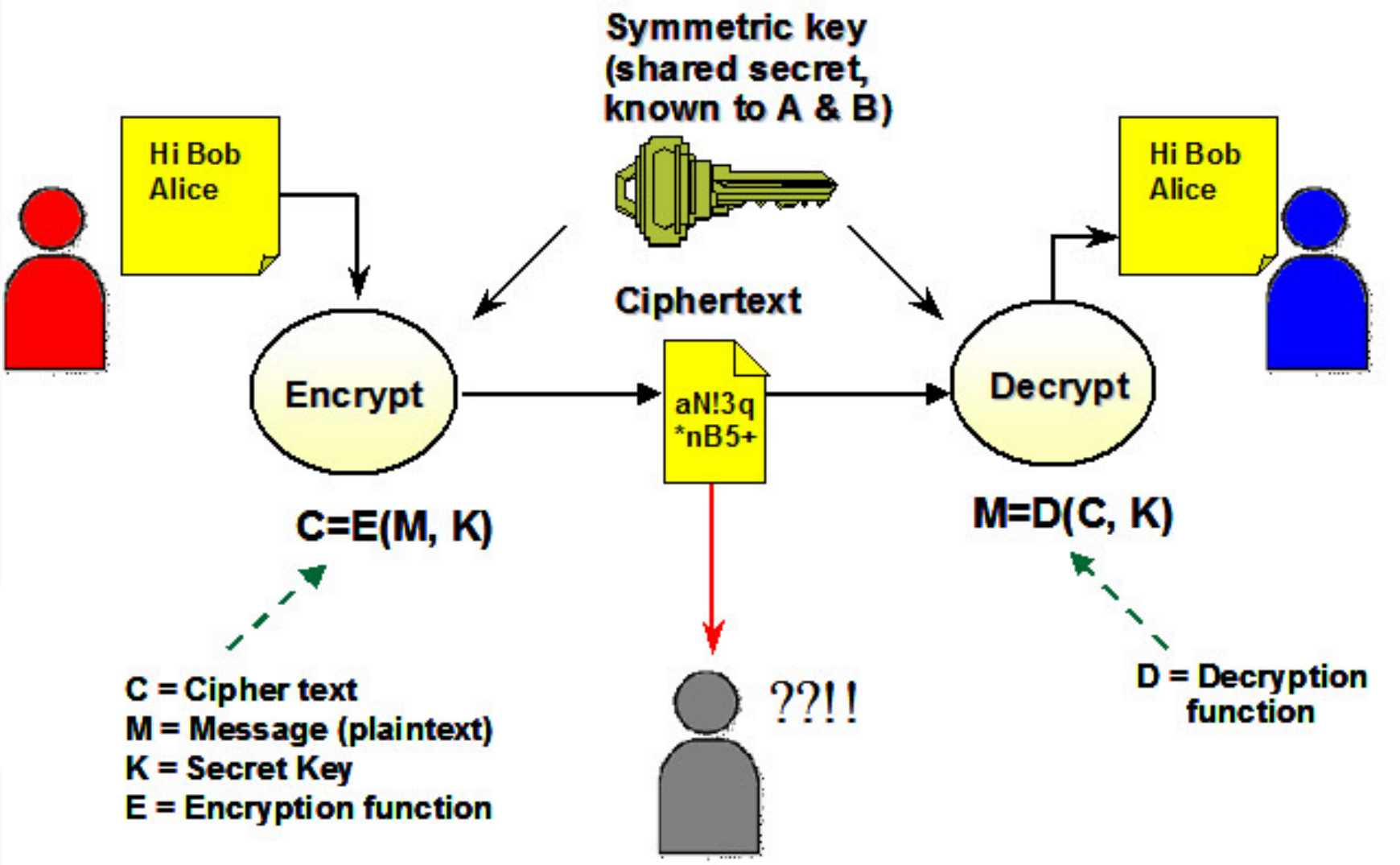
- From Greek, meaning “secret writing”
- Confidentiality: encrypt data to hide content
- Include “signature” or “message authentication code”
  - Integrity: Message has not been modified
  - Authentication: Identify source of message

- Modern encryption:
  - *Algorithm* public, *key* secret and provides security
  - Symmetric (shared secret) or asymmetric (public-private key)

SYMMETRIC (SECRET KEY) CRYPTO

- Sender and recipient share common key
  - **Main challenge: How to distribute the key?**
- Provides dual use:
  - Confidentiality (encryption)
  - Message authentication + integrity (MAC)
- 1000x more computationally efficient than asymmetric

SYMMETRIC CIPHER MODEL



PUBLIC-KEY CRYPTOGRAPHY

- **Each party has (public key, private key)**

- **Alice's public key PK**
  - Known by anybody
  - Bob uses PK to encrypt messages *to* Alice
  - Bob uses PK to verify signatures *from* Alice

- **Alice's private/secret key: sk**
  - Known only by Alice
  - Alice uses sk to decrypt ciphertexts sent to her
  - Alice uses sk to generate new signatures on messages

PUBLIC-KEY CRYPTOGRAPHY

- (PK, sk) = generateKey(keysize)

- **Encryption API**
  - ciphertext = encrypt (message, PK)
  - message = decrypt (ciphertext, sk)

- **Digital signatures API**
  - Signature = sign (message, sk)
  - isValid = verify (signature, message, PK)

(SIMPLE) RSA ALGORITHM

- Generating a key:
  - Generate composite **n = p * q**, where p and q are secret primes
  - Pick public exponent **e**
  - Solve for secret exponent **d** in $d \cdot e \equiv 1 \pmod{(p-1)(q-1)}$
  - Public key = (e, n), private key = d

- Encrypting message m: $c = m^e \bmod n$
- Decrypting ciphertext c: $m = c^d \bmod n$

- **Security** due to cost of factoring large numbers
  - Finding **(p,q)** given **n** takes $O(e^{\log n \log \log n})$ operations
  - n chosen to be 2048 or 4096 bits long

IPSec

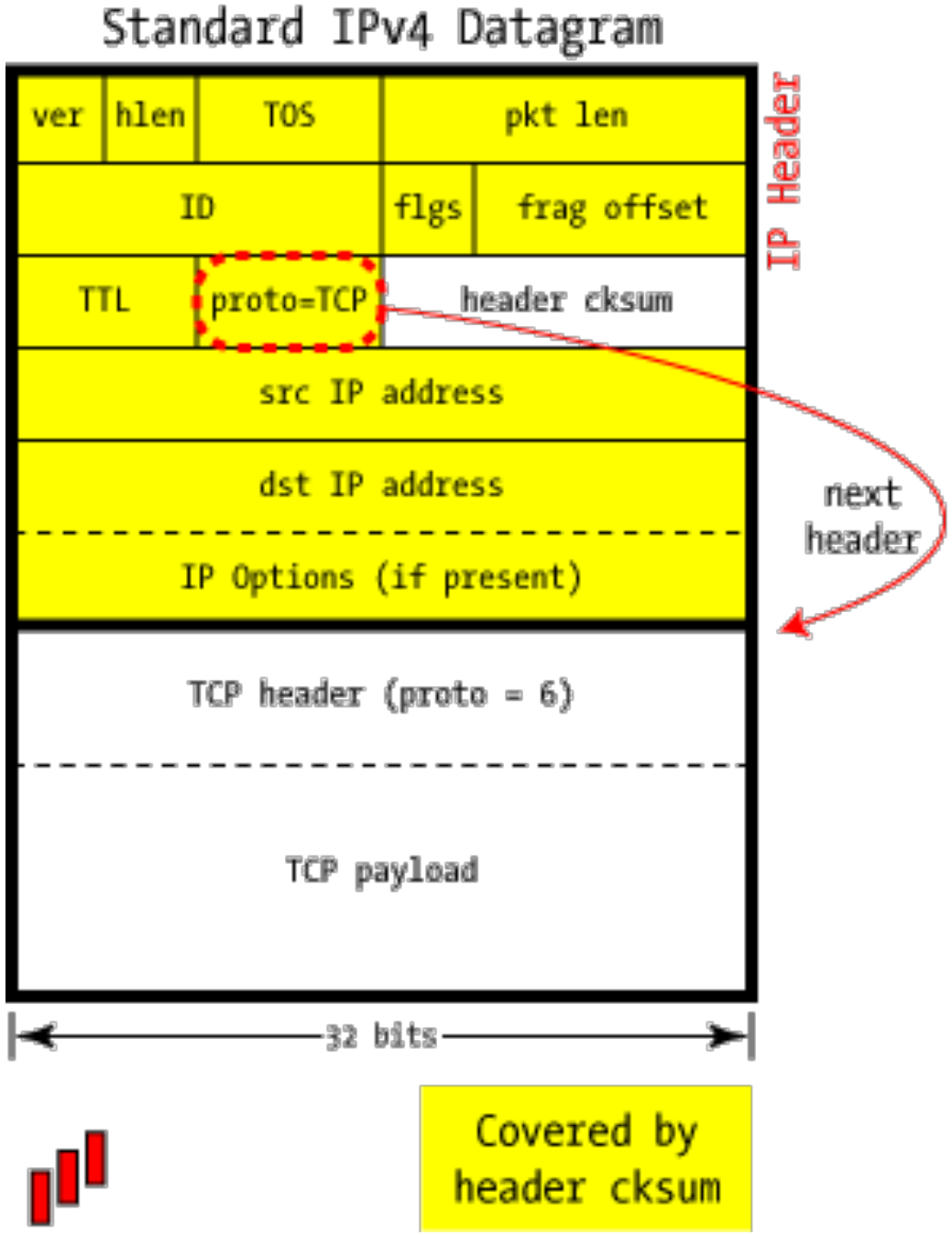
- Support for IPsec, as the architecture is called, is optional in IPv4 but mandatory in IPv6.
- IPsec is really a framework (as opposed to a single protocol or system) for providing all the security services discussed throughout this chapter.
- IPsec provides three degrees of freedom.
  - First, it is highly modular, allowing users (or more likely, system administrators) to select from a variety of cryptographic algorithms and specialized security protocols.
  - Second, IPsec allows users to select from a large menu of security properties, including access control, integrity, authentication, originality, and confidentiality.
  - Third, IPsec can be used to protect “narrow” streams (e.g., packets belonging to a particular TCP connection being sent between a pair of hosts) or “wide” streams (e.g., all packets flowing between a pair of routers).

Transport vs. tunnel mode

- Transport:
  - Host-to-host secure connection
  - Encrypted, authenticated, or both
- Tunnel
  - Host-to-network or network-to-network
  - Entire IP packet tunneled in secure IPSec “envelope” to recovered at destination

Security in IPSec

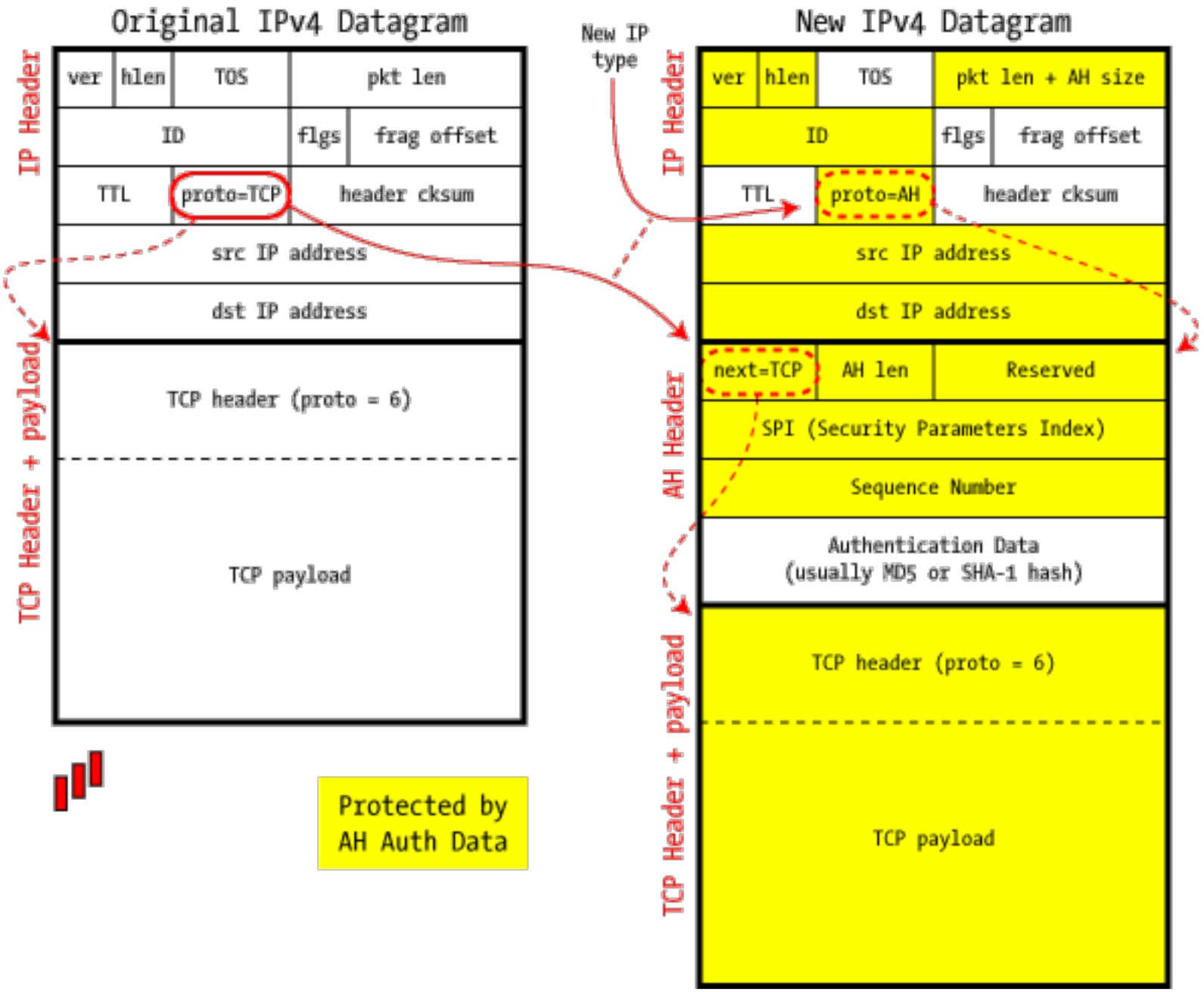
- AH: Authentication header
  - Access control, message integrity, authentication, and antireplay protection
- ESP: Encapsulating Security Payload
  - Like AH, but with encryption too
- SA: Security association
  - Selection of algorithms, crypto, hashes, etc
- SPI: Security Parameters Index (SPI)
  - Per-connection index into SA database
- ISAKMP: Internet Security Association and Key Management Protocol

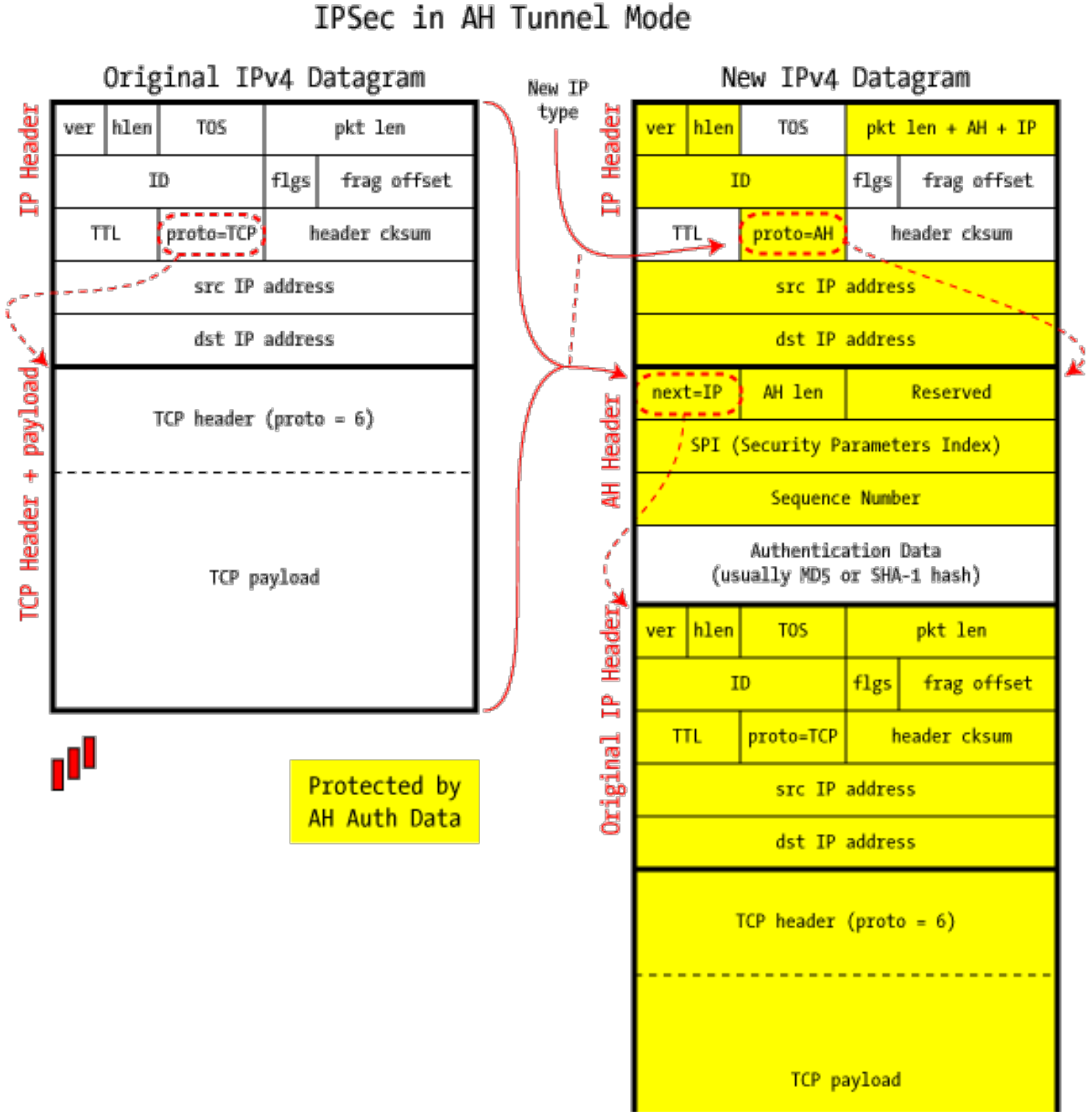


http://www.unixwiz.net/techtips/iguide-ipsec.html

IP “next” protocols

Protocol code	Protocol Description
1	ICMP — Internet Control Message Protocol
2	IGMP — Internet Group Management Protocol
4	IP within IP (a kind of encapsulation)
6	TCP — Transmission Control Protocol
17	UDP — User Datagram Protocol
41	IPv6 — next-generation TCP/IP
47	GRE — Generic Router Encapsulation (used by PPTP)
50	IPsec: ESP — Encapsulating Security Payload
51	IPsec: AH — Authentication Header


IPSec in AH Transport Mode
Original IPv4 Datagram
IP Header
ver
hlen
TOS
pkt len
ID
flgs
frag offset
TTL
proto=TCP
header cksum
src IP address
dst IP address
TCP Header + payload
TCP header (proto = 6)
TCP payload
Protected by
AH Auth Data
New IP
type
New IPv4 Datagram
IP Header
ver
hlen
TOS
pkt len + AH size
ID
flgs
frag offset
TTL
proto=AH
header cksum
src IP address
dst IP address
AH Header
next=TCP
AH len
Reserved
SPI (Security Parameters Index)
Sequence Number
Authentication Data
(usually MD5 or SHA-1 hash)
TCP Header + payload
TCP header (proto = 6)
TCP payload


IPSec in AH Tunnel Mode
Original IPv4 Datagram
New IPv4 Datagram
New IP type
IP Header
TCP Header + payload
AH Header
Original IP Header
ver
hlen
TOS
pkt len
pkt len + AH + IP
ID
flgs
frag offset
TTL
proto=TCP
proto=AH
header cksum
src IP address
dst IP address
TCP header (proto = 6)
TCP payload
next=IP
AH len
Reserved
SPI (Security Parameters Index)
Sequence Number
Authentication Data
(usually MD5 or SHA-1 hash)
Protected by
AH Auth Data

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