# Overlay Networks and Tunneling

## Reading: 4.5, 9.4

COS 461: Computer Networks

Spring 2009 (MW 1:30-2:50 in COS 105)

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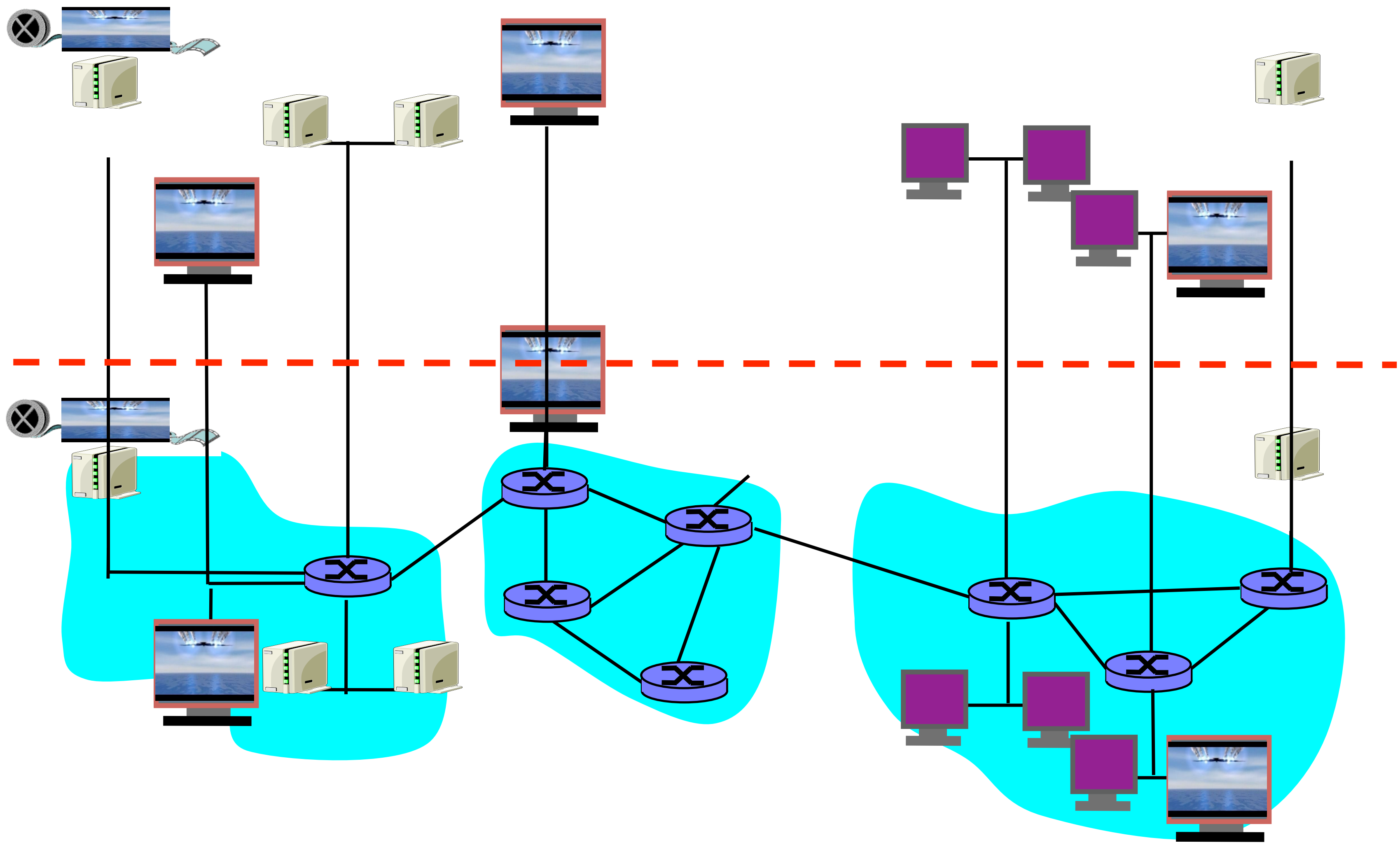
http://www.cs.princeton.edu/courses/archive/spring09/cos461/

# Goals of Today's Lecture

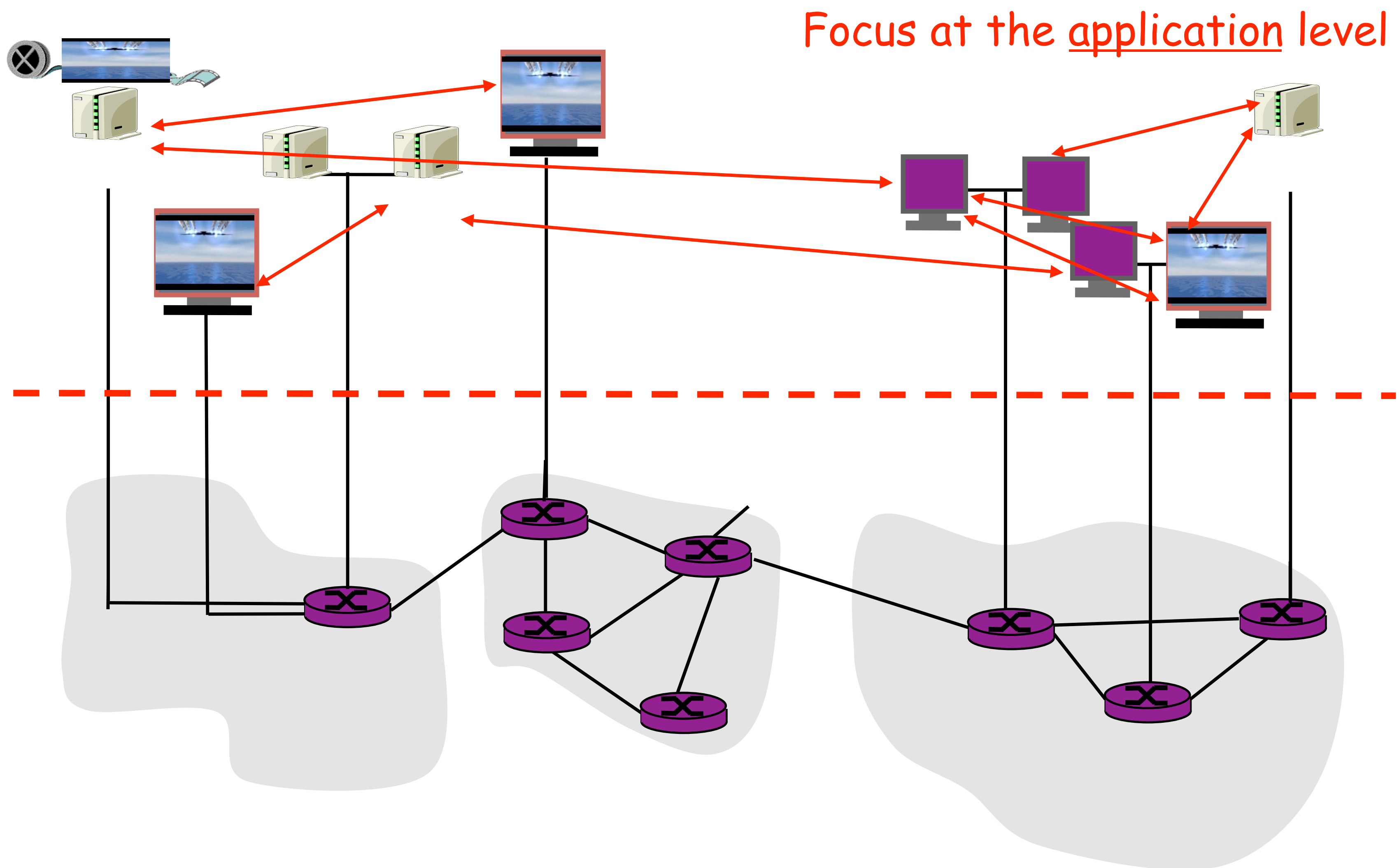
- Motivations for overlay networks
  - Incremental deployment of new protocols
  - Customized routing and forwarding solutions
- Overlays for partial deployments
  - 6Bone, Mbone, security, mobility, …
- Resilient Overlay Network (RON)
  - Adaptive routing through intermediate node
- Multi-protocol label switching (MPLS)
  - Tunneling at L2.5

# Overlay Networks

# Overlay Networks

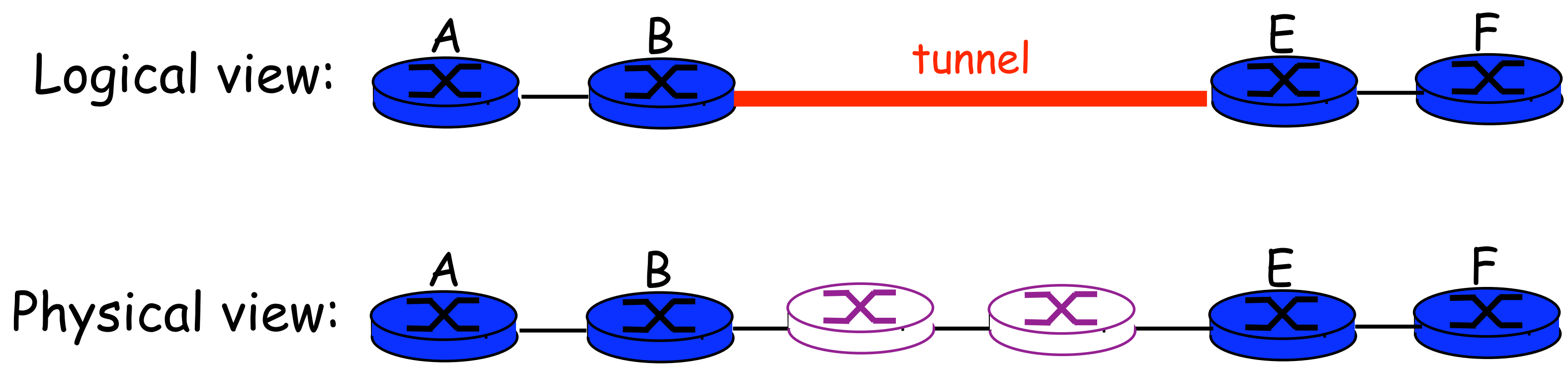


# Overlay Networks



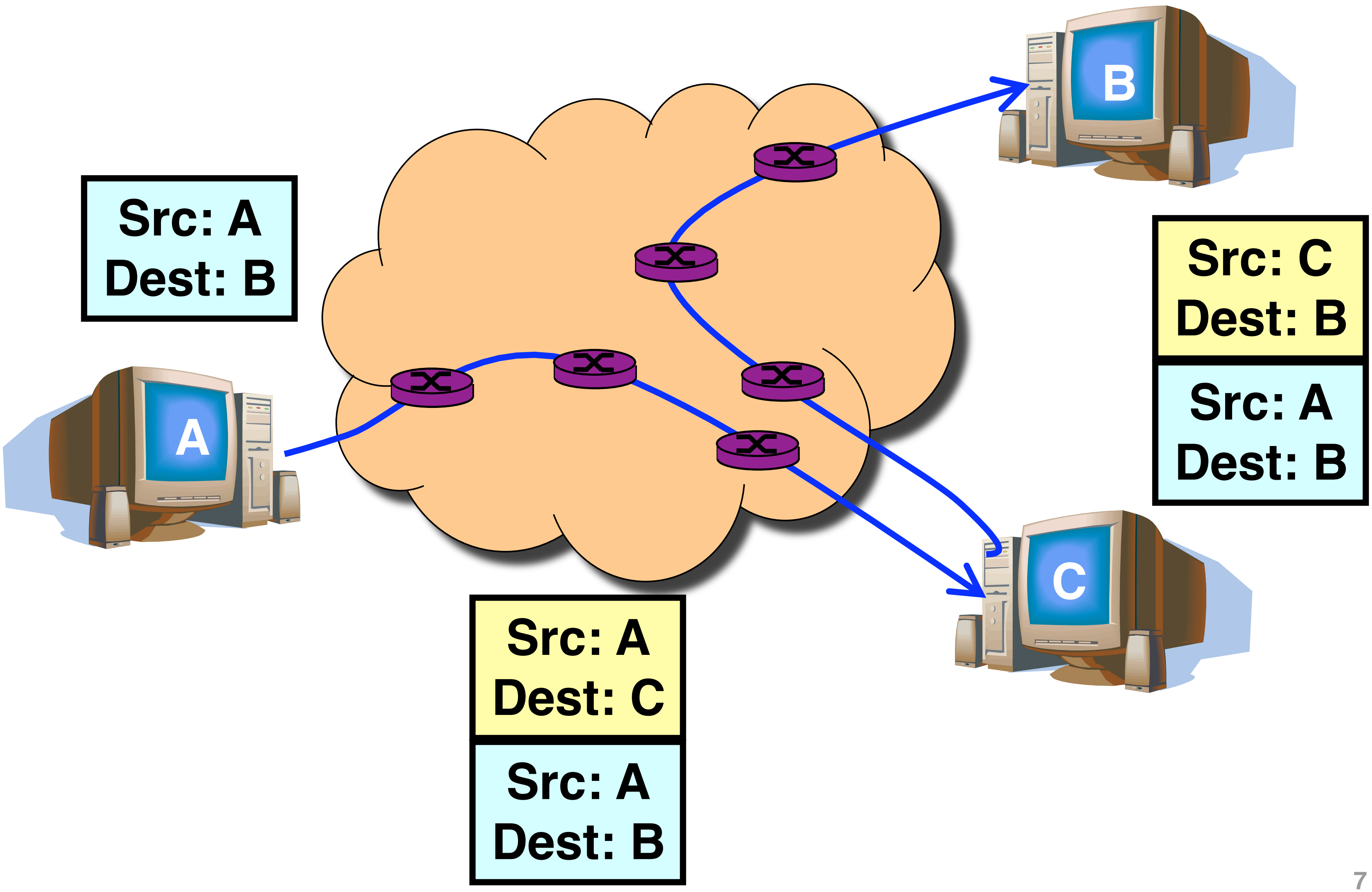
# IP Tunneling to Build Overlay Links

- 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

# Tunnels Between End Hosts



# Overlay Networks

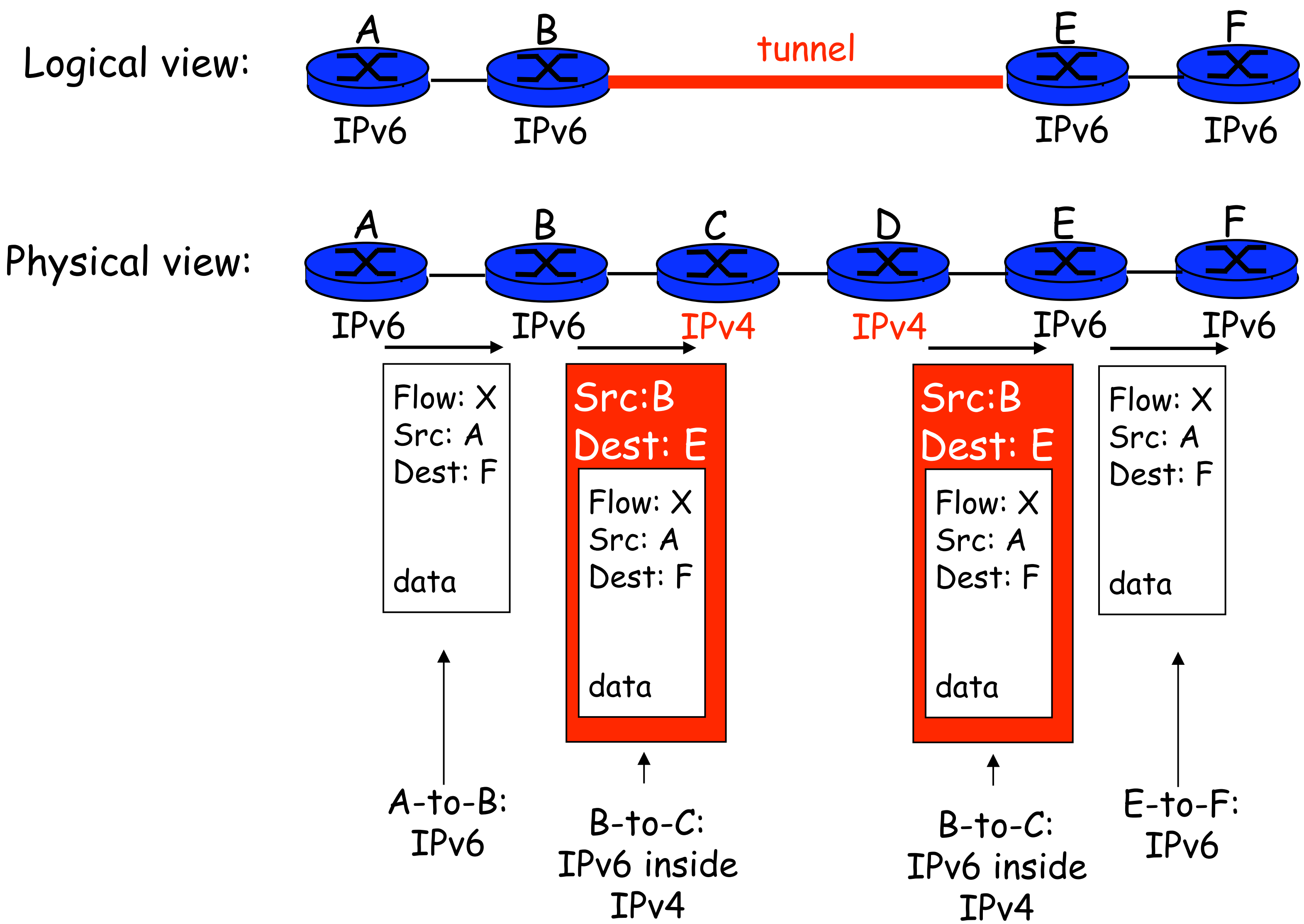
- A logical network built on top of a physical network
  - Overlay links are tunnels through the underlying network
- Many logical networks may coexist at once
  - Over the same underlying network
  - And providing its own particular service
- Nodes are often end hosts
  - Acting as intermediate nodes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

# Overlays for Incremental Deployment

# Using Overlays to Evolve the Internet

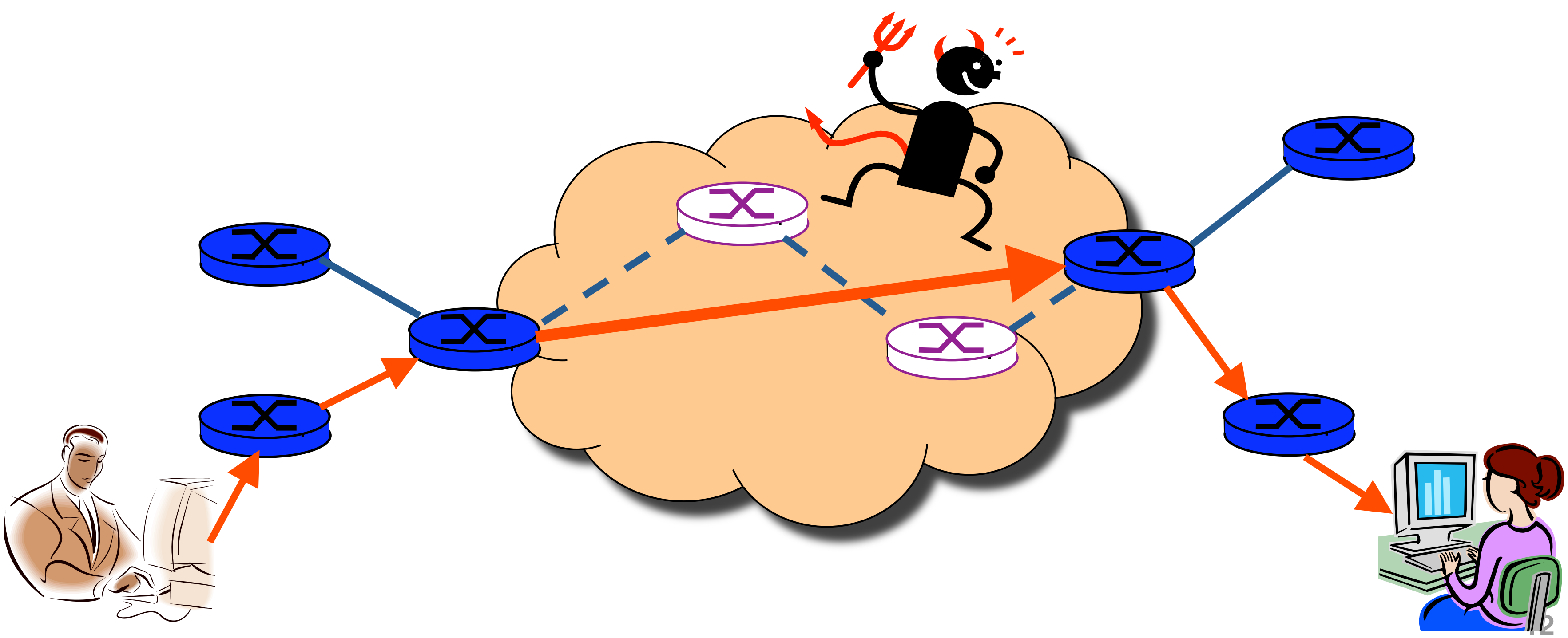
- Internet needs to evolve
  - IPv6
  - Security
  - Mobility
  - Multicast
- But, global change is hard
  - Coordination with many ASes
  - "Flag day" to deploy and enable the technology
- Instead, better to incrementally deploy
  - And find ways to bridge deployment gaps

# 6Bone: Deploying IPv6 over IP4



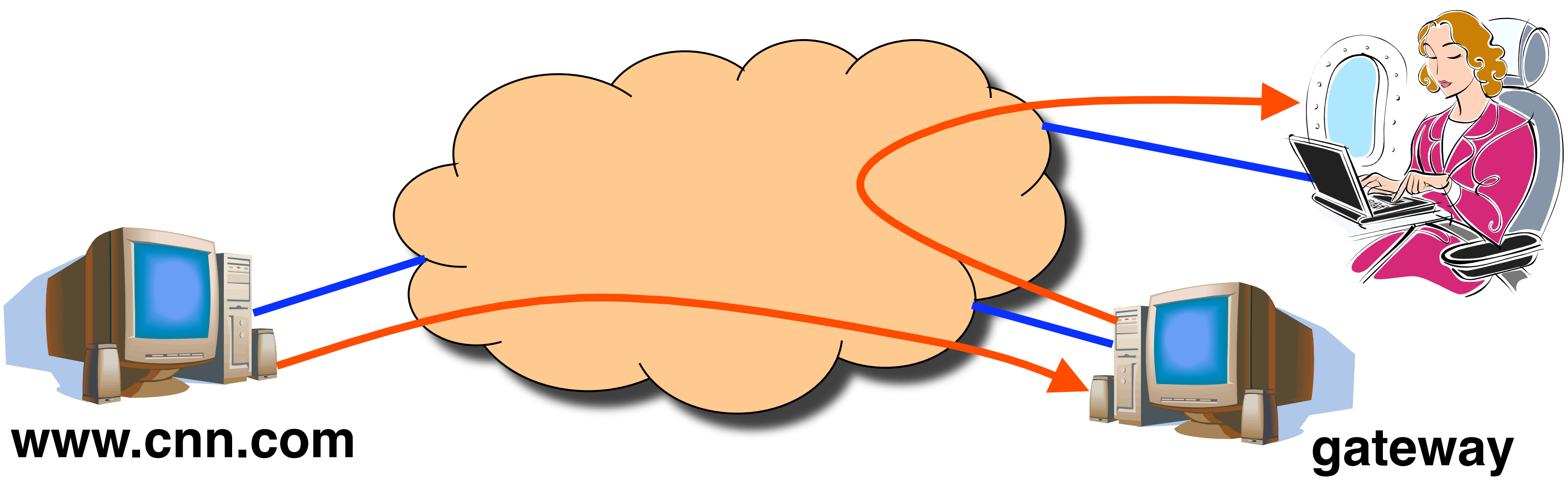
# Secure Communication Over Insecure Links

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



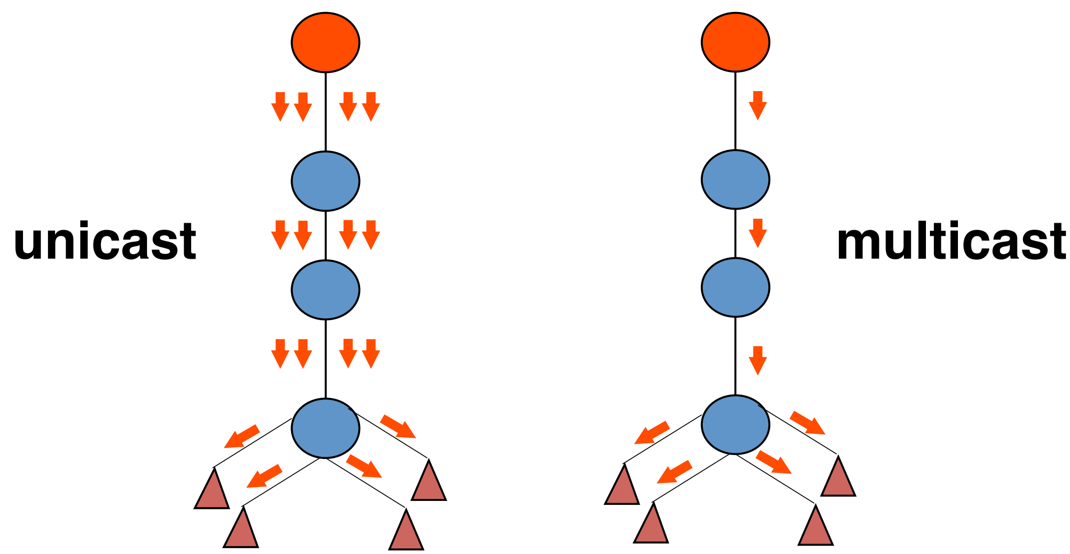
# Communicating With Mobile Users

- 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



# IP Multicast

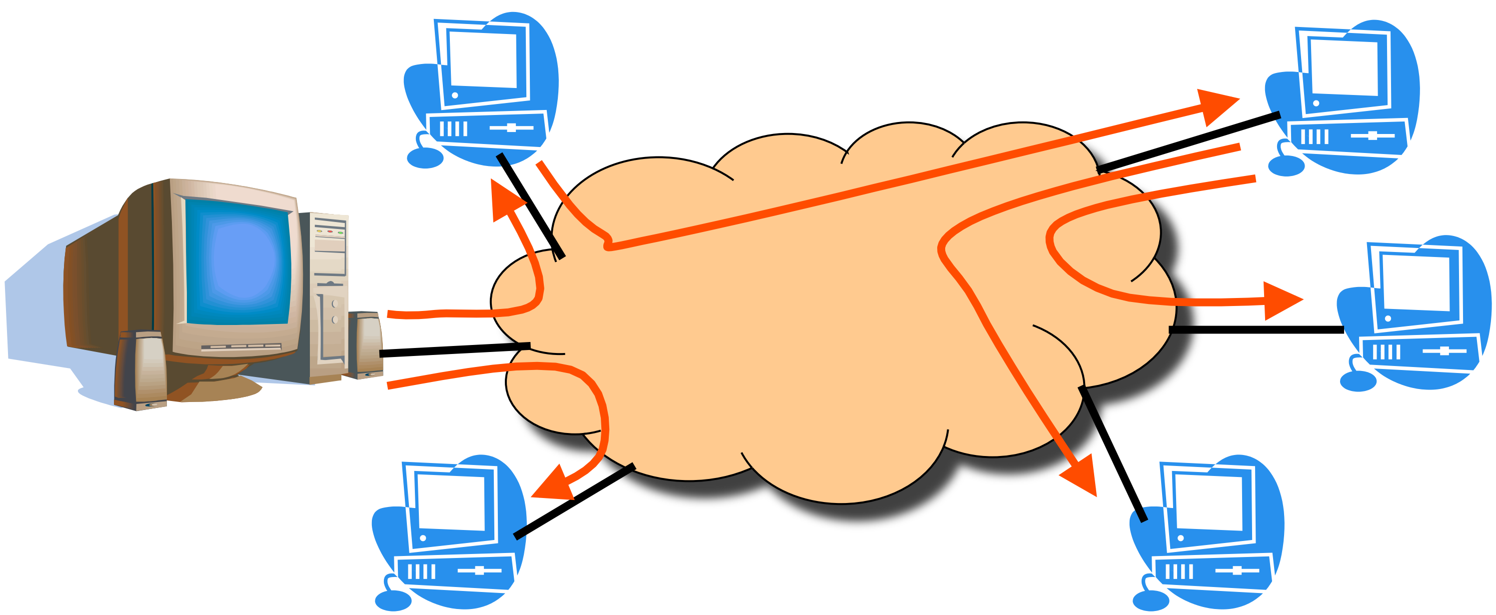
- Multicast
  - Delivering the same data to many receivers
  - Avoiding sending the same data many times




- IP multicast
  - Special addressing, forwarding, and routing schemes

# MBone: Multicast Backbone

- A catch-22 for deploying multicast
  - Router vendors wouldn't support IP multicast
  - … since they weren't sure anyone would use it
  - And, since it didn't exist, nobody was using it
- Idea: software implementing multicast protocols
  - And unicast tunnels to traverse non-participants



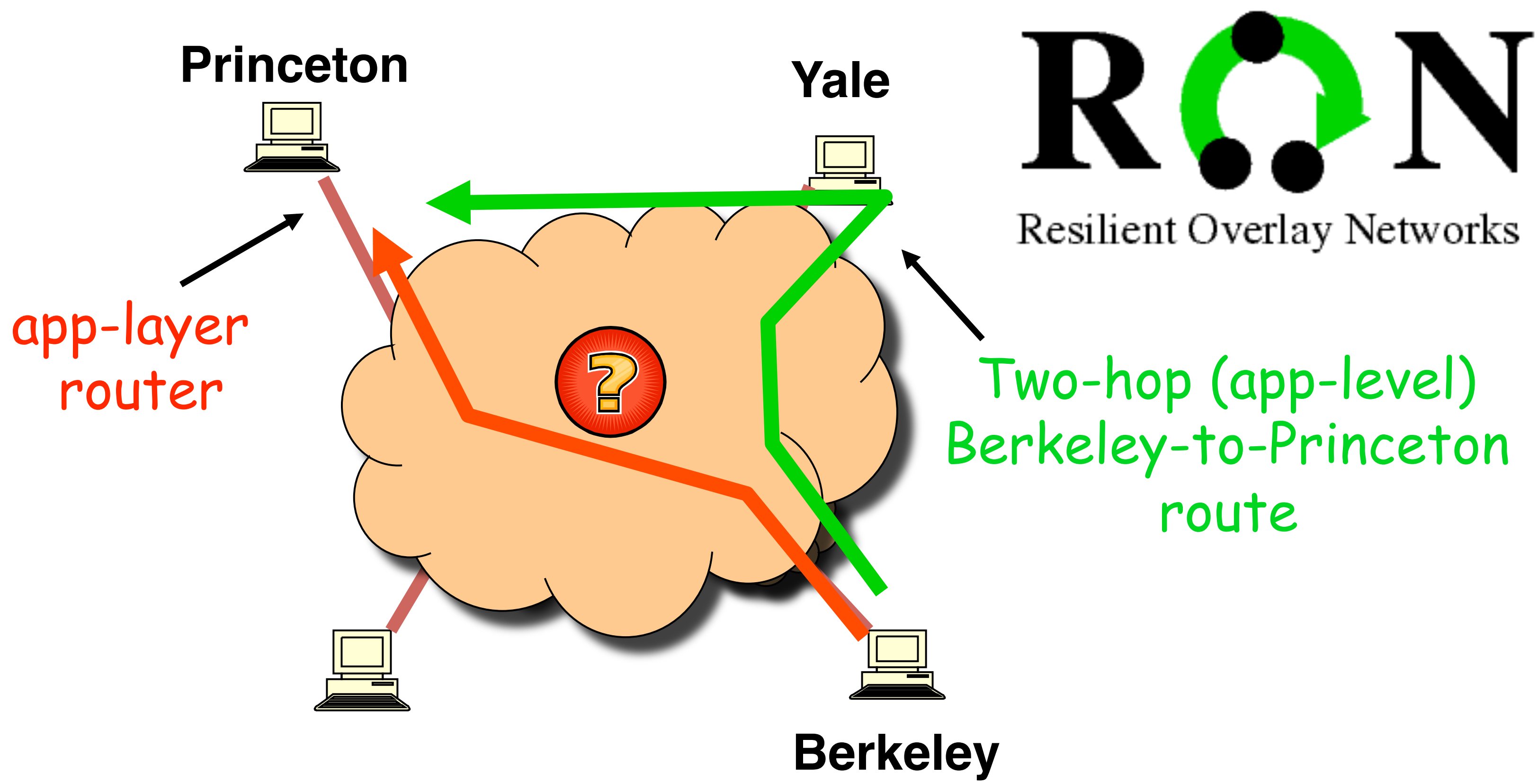
# Multicast Today

- Mbone applications starting in early 1990s
  - Primarily video conferencing, but no longer operational
- Still many challenges to deploying IP multicast
  - Security vulnerabilities, business models, …
- Application-layer multicast is more prevalent
  - Tree of servers delivering the content
  - Collection of end hosts cooperating to delivery video
- Some multicast within individual ASes
  - Financial sector: stock tickers
  - Within campuses or broadband networks: TV shows
  - Backbone networks: IPTV

# Case Study: Resilient Overlay Networks

# RON: Resilient Overlay Networks

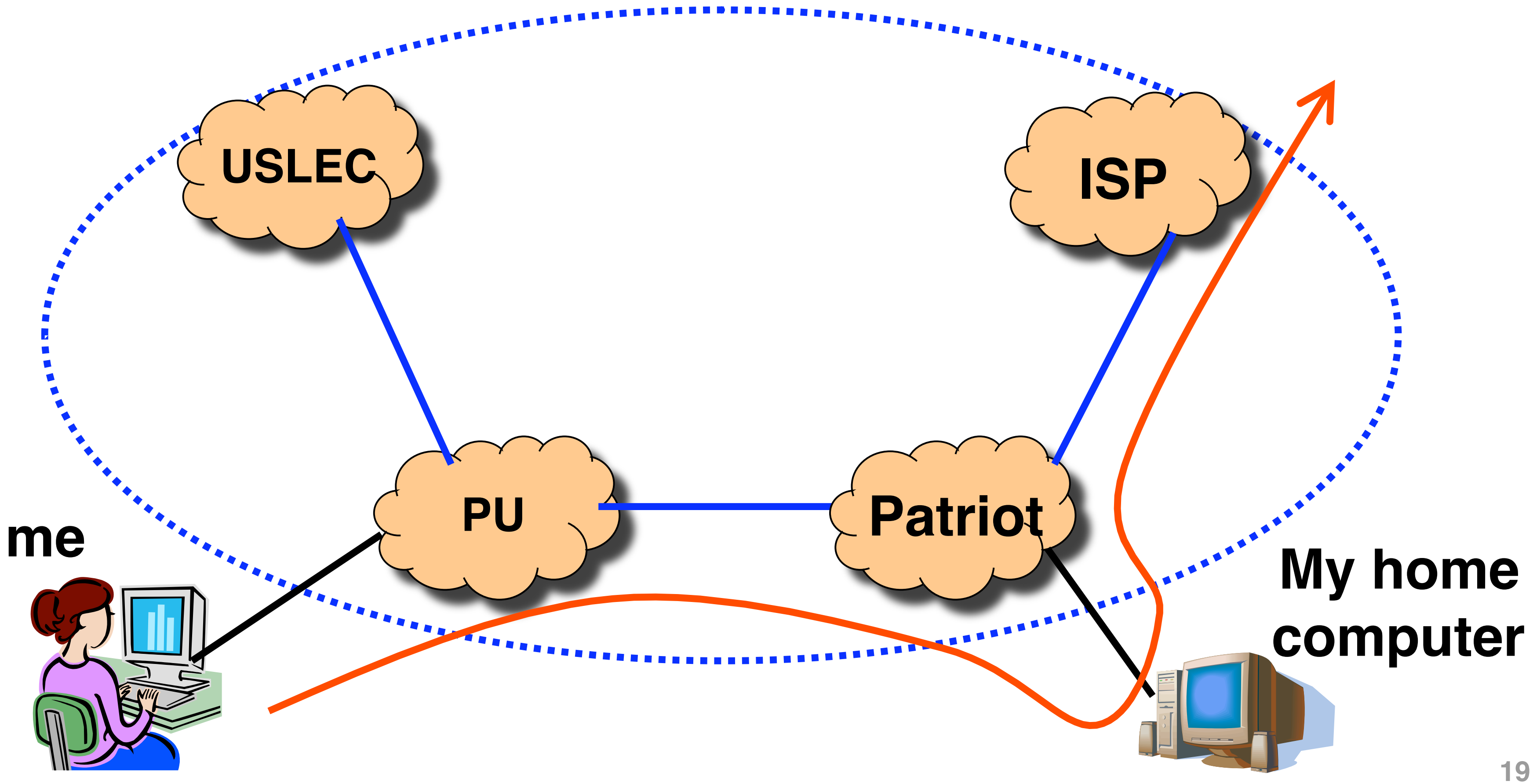
Premise: by building application overlay network, can increase performance and reliability of routing



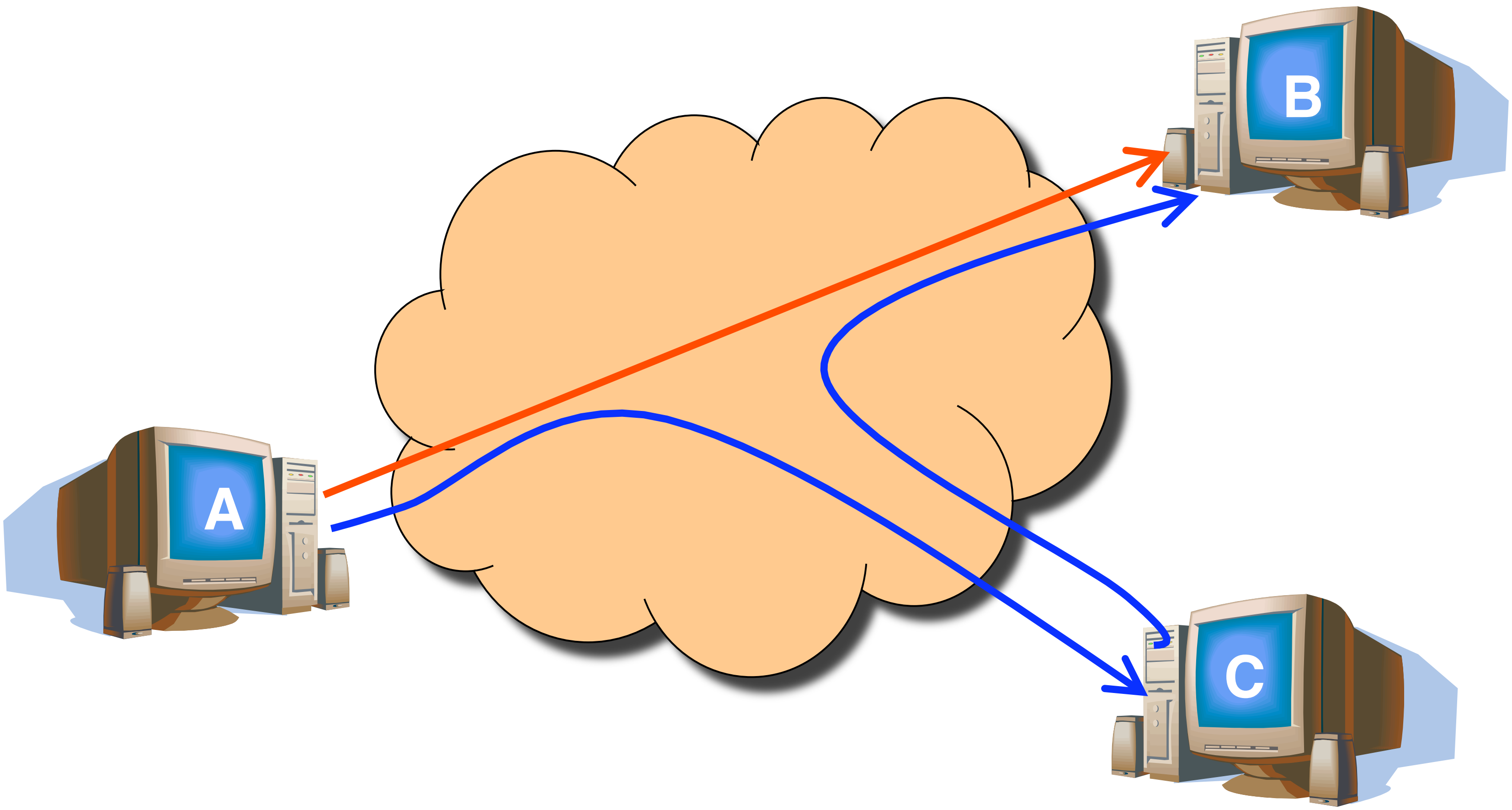

**http://nms.csail.mit.edu/ron/**

# RON Circumvents Policy Restrictions

- IP routing depends on AS routing policies
  - But hosts may pick paths that circumvent policies

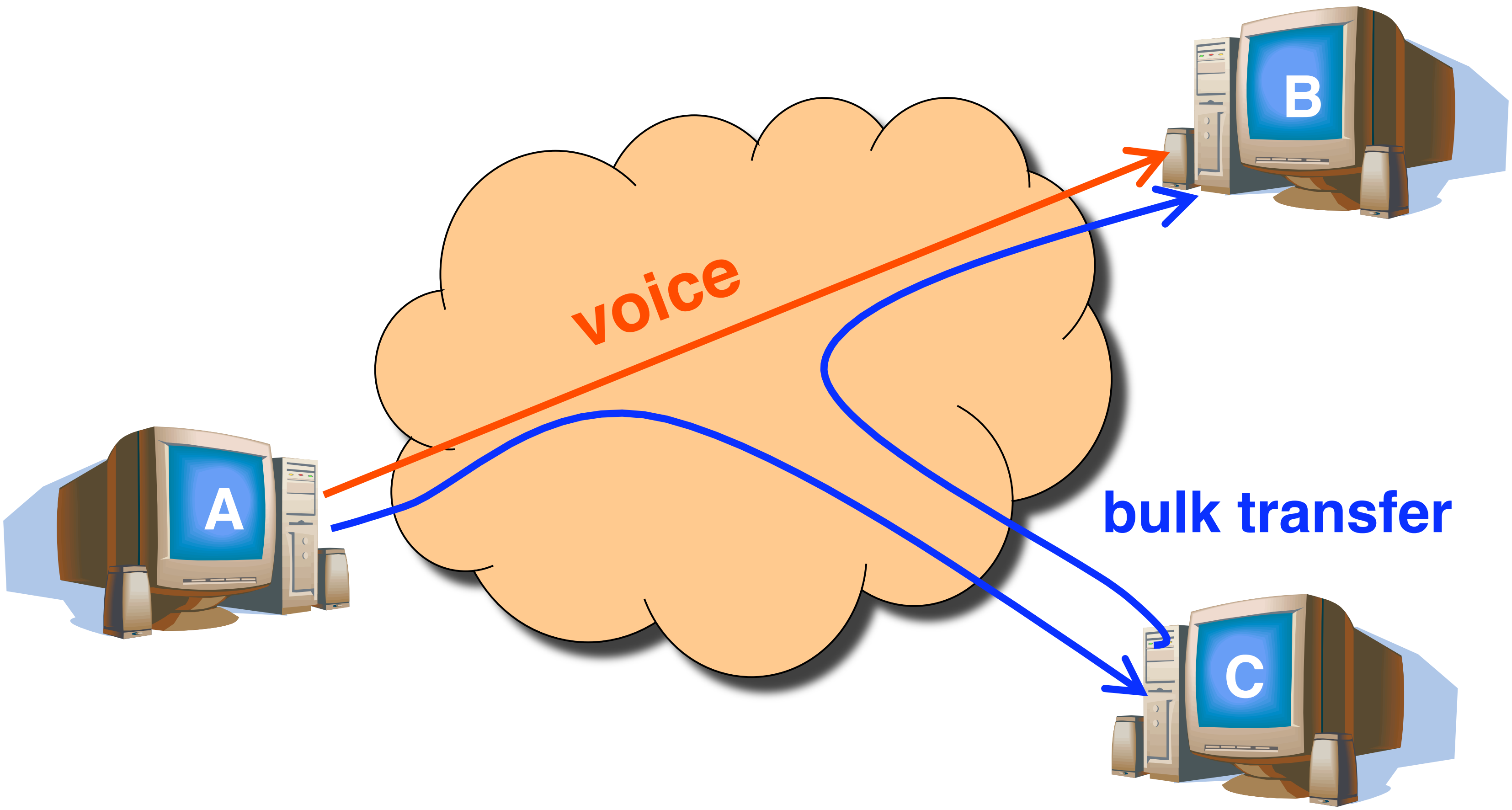


# RON Adapts to Network Conditions




- Start experiencing bad performance
  - Then, start forwarding through intermediate host

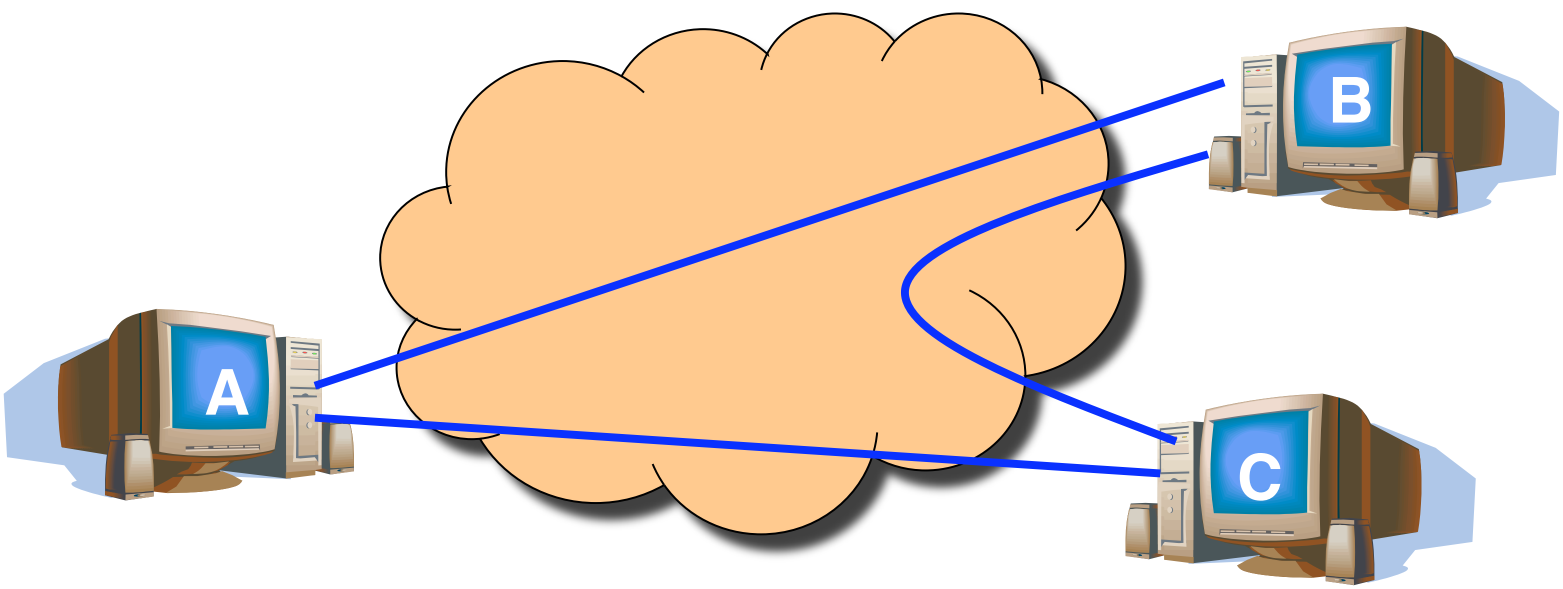
# RON Customizes to Applications




- VoIP traffic: low-latency path
- Bulk transfer: high-bandwidth path

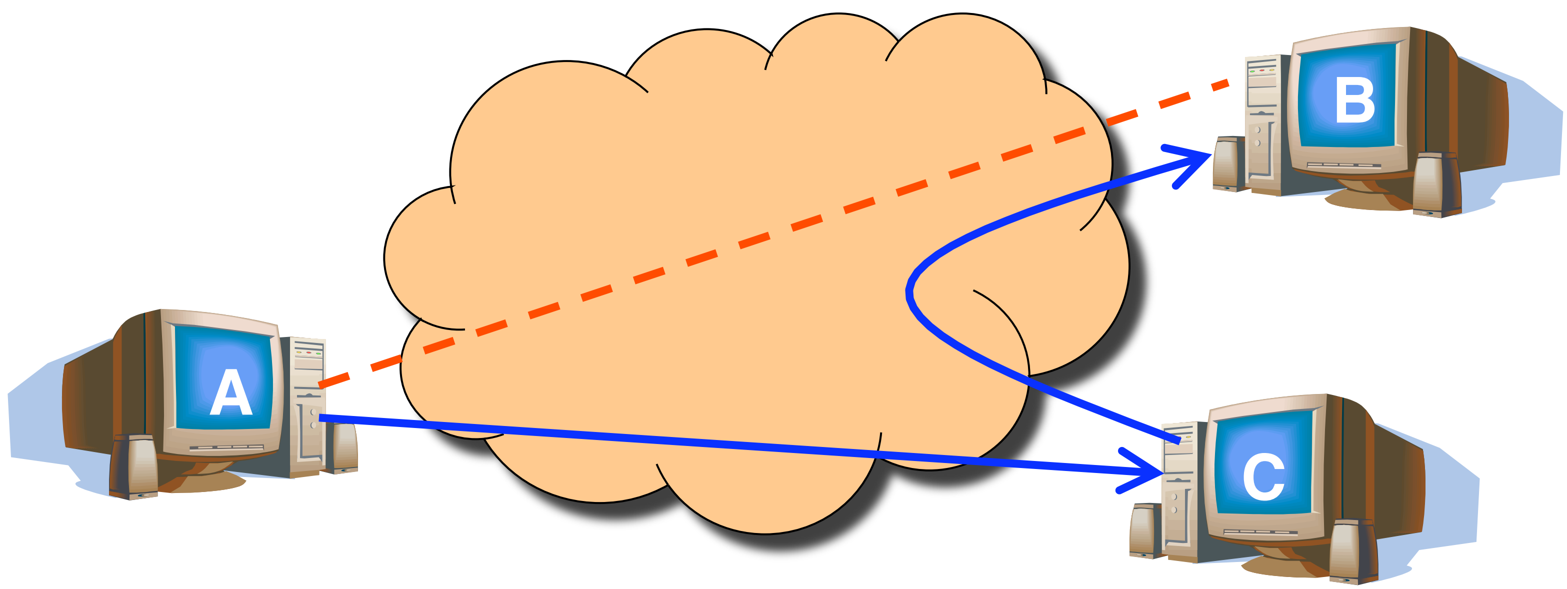
# How Does RON Work?

- Keeping it small to avoid scaling problems
  - A few friends who want better service
  - Just for their communication with each other
  - E.g., VoIP, gaming, collaborative work, etc.
- Send probes between each pair of hosts



# How Does RON Work?

- Exchange the results of the probes
  - Each host shares results with every other host
  - Essentially running a link-state protocol!
  - So, every host knows the performance properties
- Forward through intermediate host when needed



# RON Works in Practice

- Faster reaction to failure
  – RON reacts in a few seconds
  – BGP sometimes takes a few minutes
- Single-hop indirect routing
  – No need to go through many intermediate hosts
  – One extra hop circumvents the problems
- Better end-to-end paths
  – Circumventing routing policy restrictions
  – Sometimes the RON paths are actually shorter

# RON Limited to Small Deployments

- Extra latency through intermediate hops
  - Software delays for packet forwarding
  - Propagation delay across the access link
- Overhead on the intermediate node
  - Imposing CPU and I/O load on the host
  - Consuming bandwidth on the access link
- Overhead for probing the virtual links
  - Bandwidth consumed by frequent probes
  - Trade-off between probe overhead and detection speed
- Possibility of causing instability
  - Moving traffic in response to poor performance
  - May lead to congestion on the new paths

We saw tunneling “on top of” IP.
What about tunneling “below” IP?

Introducing

Multi-Protocol Label Switching

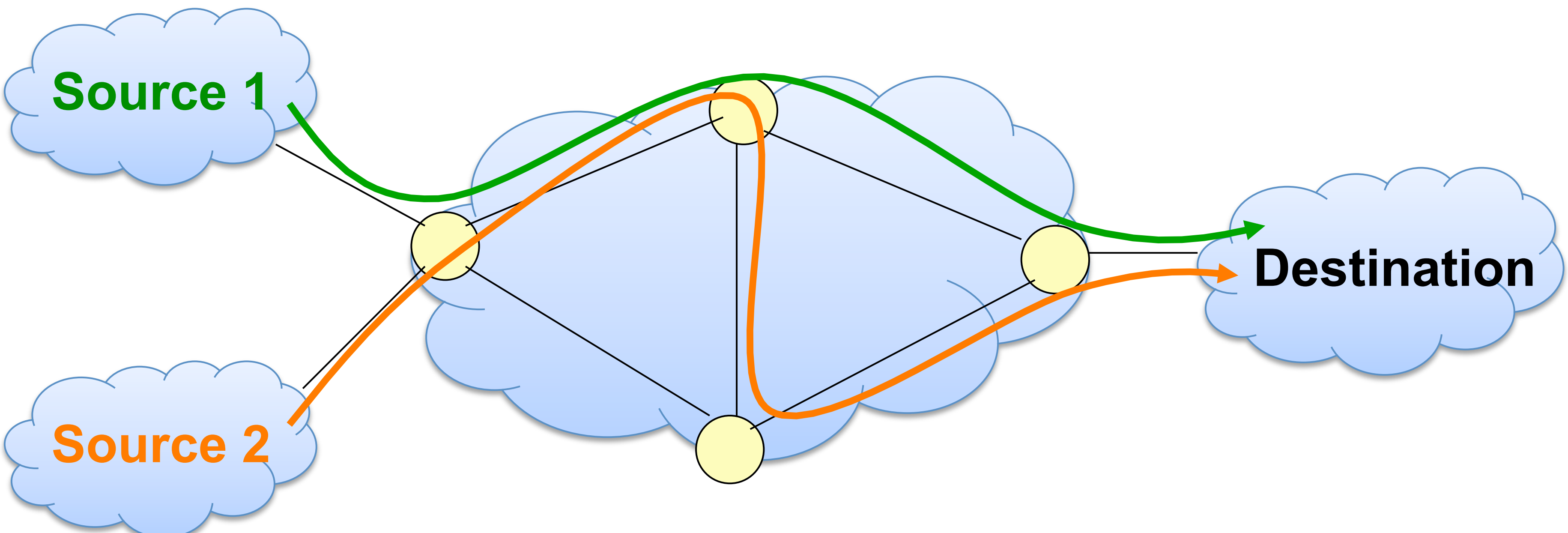
(MPLS)

# Why Tunnel?

- Reliability
  - Fast Reroute, Resilient Overlay Networks (Akamai SureRoute)
- Flexibility
  - Topology, protocol
- Stability ("path pinning")
  - E.g., for performance guarantees
- Security
  - E.g., Virtual Private Networks (VPNs)
- Bypassing local network engineers
  - Censoring regimes: China, Pakistan, …

# MPLS Overview

- **Main idea:** Virtual circuit
  - Packets forwarded based only on circuit identifier




**Router can forward traffic to the same destination on different interfaces/paths.**

# MPLS Overview

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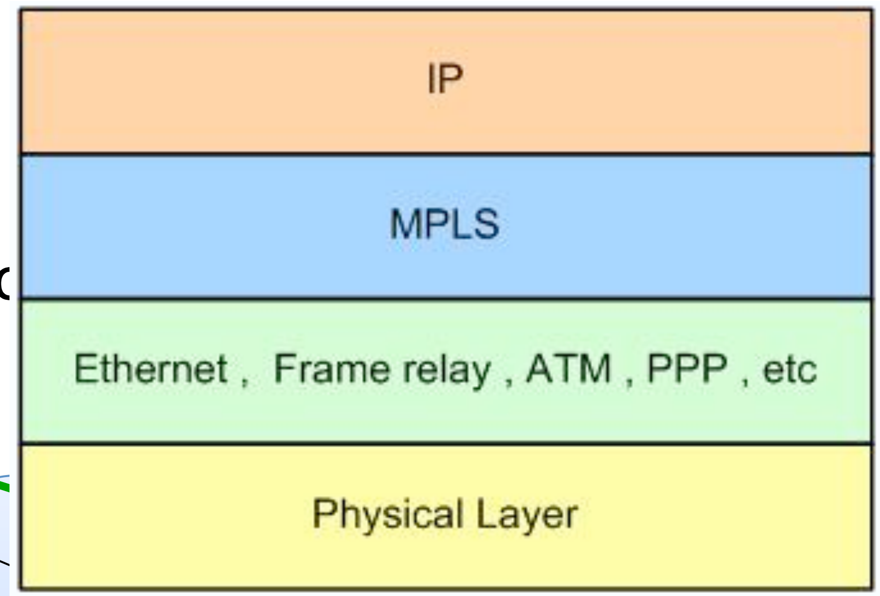
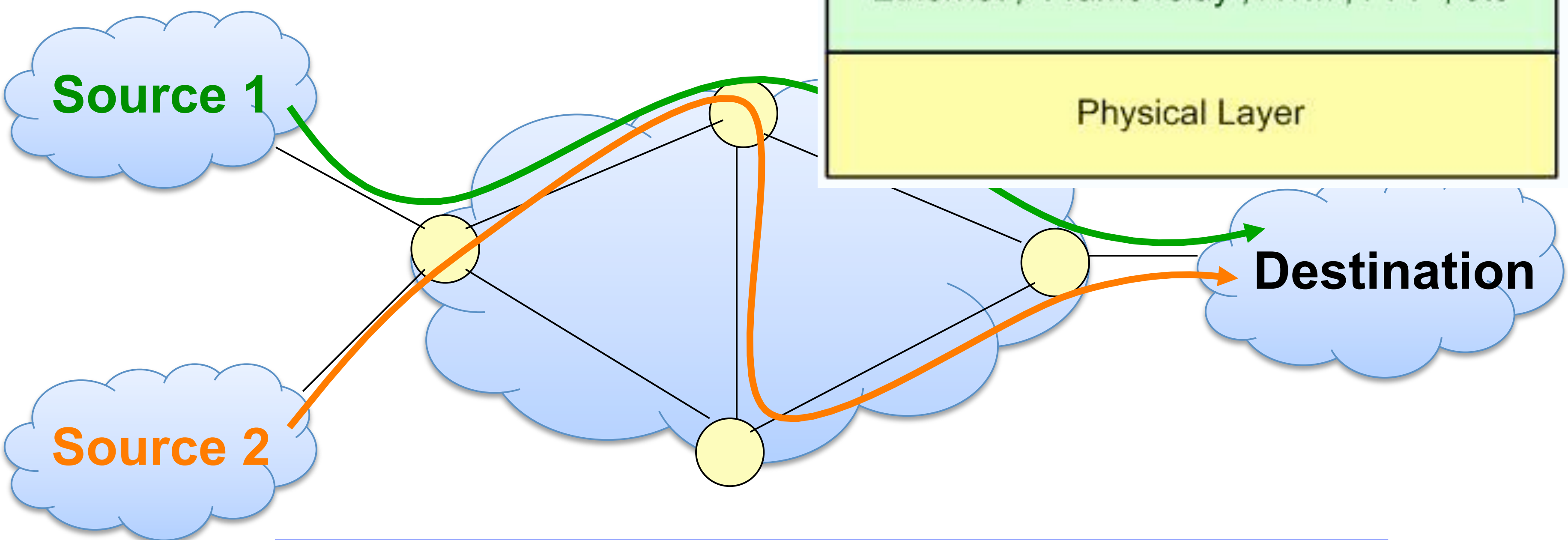
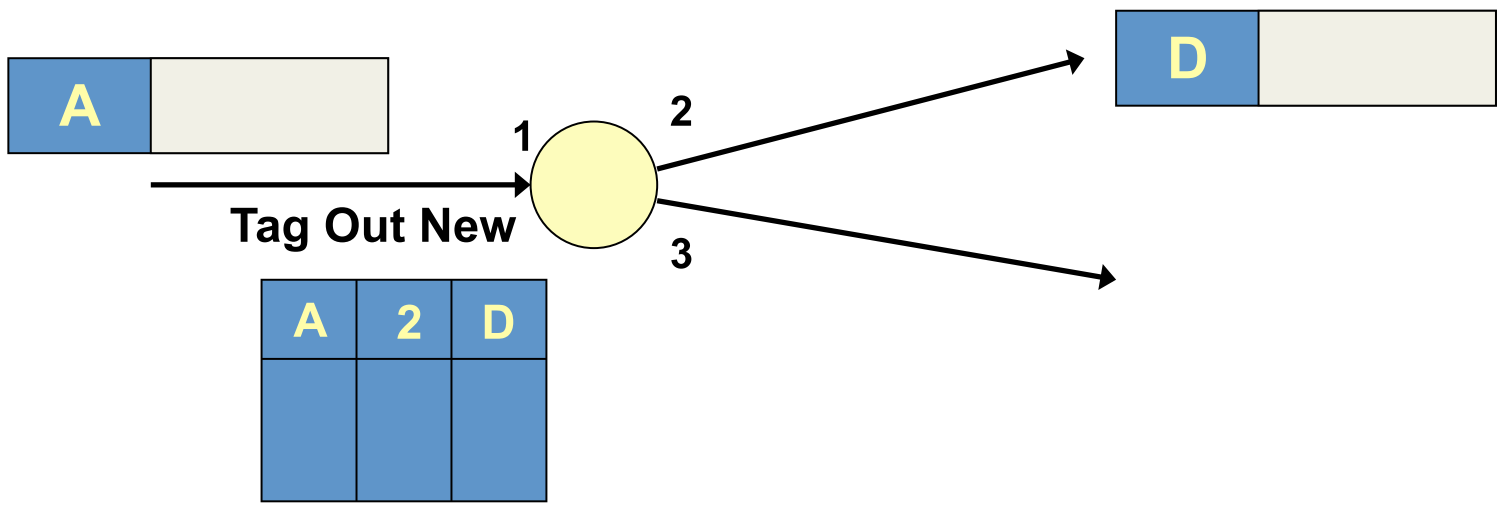


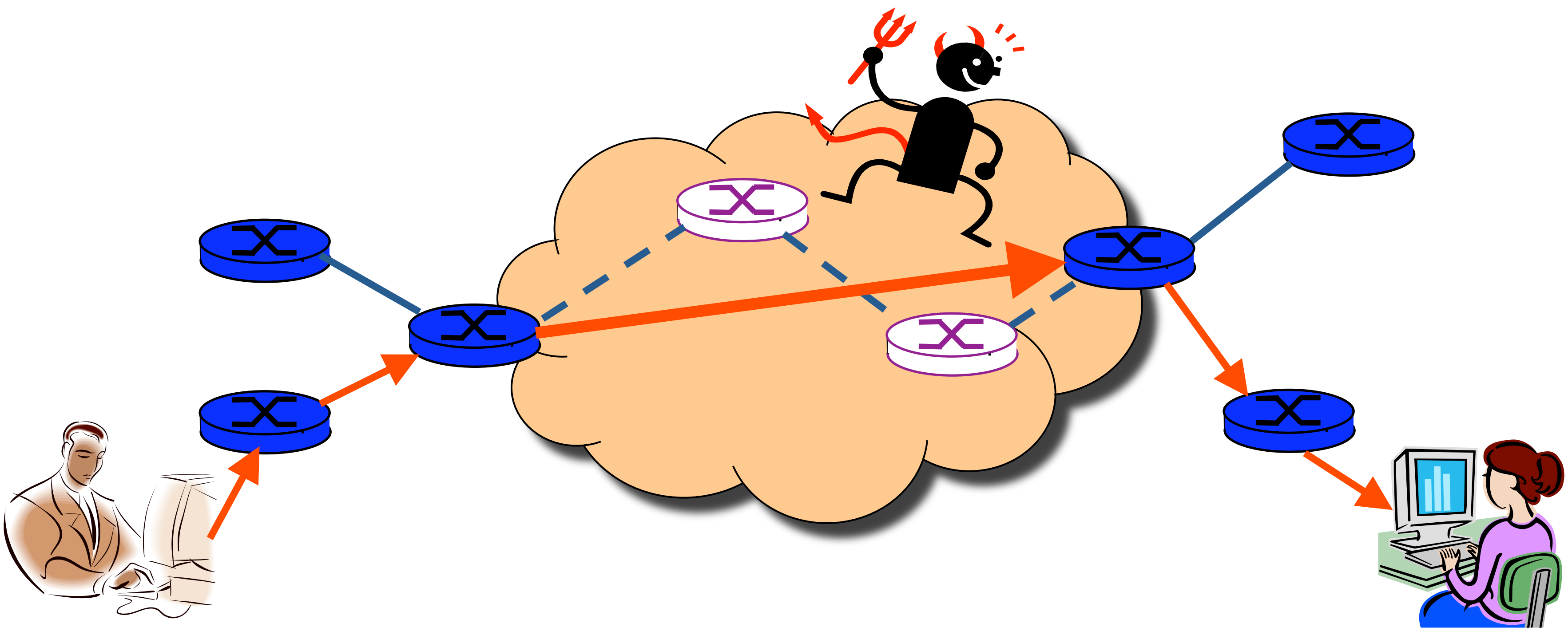

**Router can forward traffic to the same destination on different interfaces/paths.**

# Circuit Abstraction: Label Swapping




- **Label-switched paths (LSPs):** Paths are "named" by the label at the path's entry point
- At each hop, MPLS routers:
  - Use label to determine outgoing interface, new label
  - Thus, push/pop/swap MPLS headers that encapsulate IP
- **Label distribution protocol:** responsible for disseminating signalling information

# Reconsider security problem



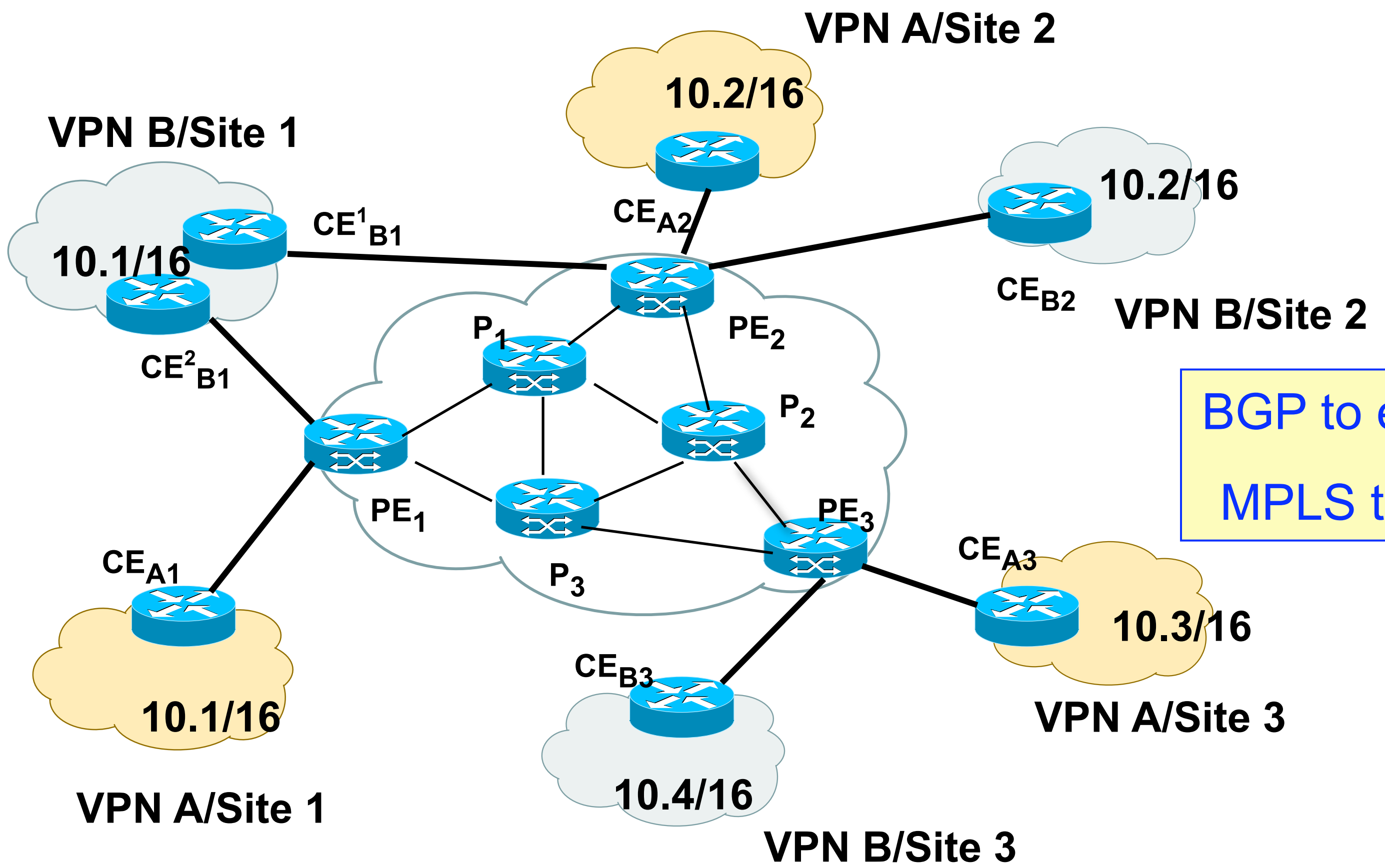
# Layer 3 Virtual Private Networks

- Private communications over a public network
- A set of sites that are allowed to communicate with each other
- Defined by a set of administrative policies
  - Determine both connectivity and QoS among sites
  - Established by VPN customers
  - One way to implement: BGP/MPLS VPN (RFC 2547)

# Layer 2 vs. Layer 3 VPNs

- Layer 2 VPNs can carry traffic for many different protocols, whereas Layer 3 is "IP only"
- More complicated to provision a Layer 2 VPN
- Layer 3 VPNs: potentially more flexibility, fewer configuration headaches

# Layer 3 BGP/MPLS VPNs

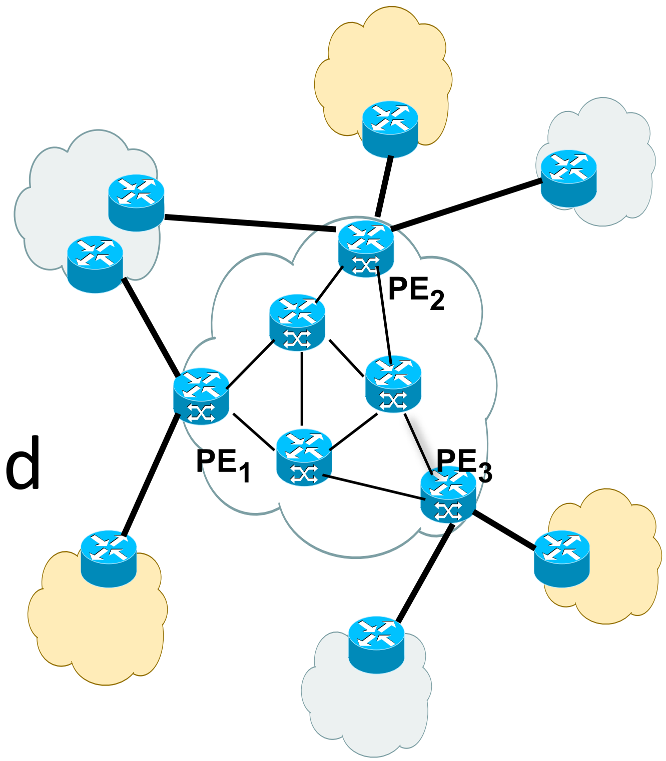



BGP to exchange routes

MPLS to forward traffic

- **Isolation:** Multiple logical networks over a single, shared physical infrastructure
- **Tunneling:** Keeping routes out of the core

# High-Level Overview of Operation



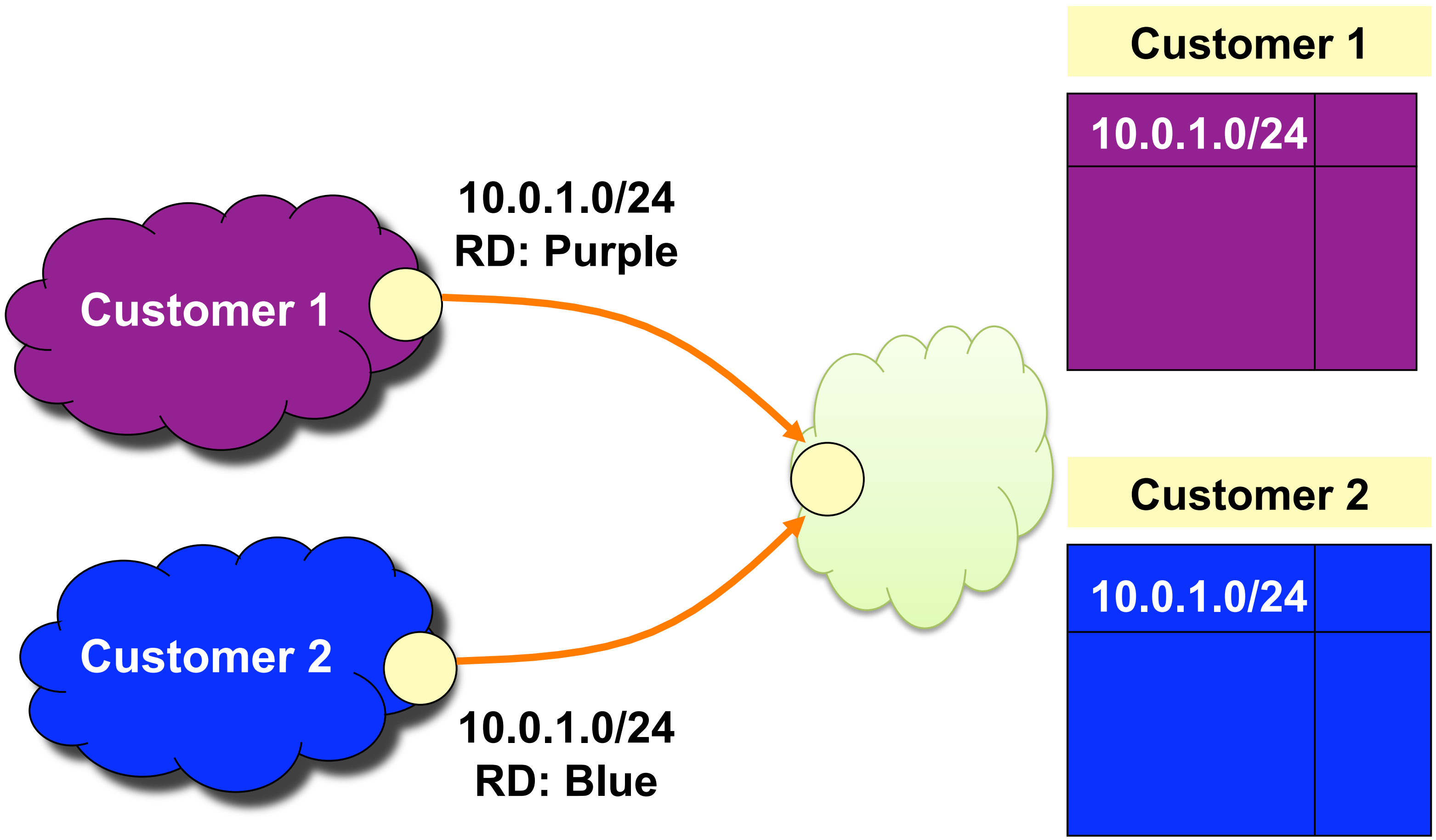

- IP packets arrive at PE
- Destination IP address is looked up in forwarding table
- Datagram sent to customer's network using tunneling (*i.e.*, an MPLS label-switched path)

# BGP/MPLS VPN key components

- Forwarding in the core:  MPLS
- Distributing routes between PEs:  BGP
- Isolation: Keeping different VPNs from routing traffic over one another
  - Constrained distribution of routing information
  - Multiple “virtual” forwarding tables
- Unique Addresses: VPN-IPv4 extensions
  - RFC 2547:  Route Distinguishers

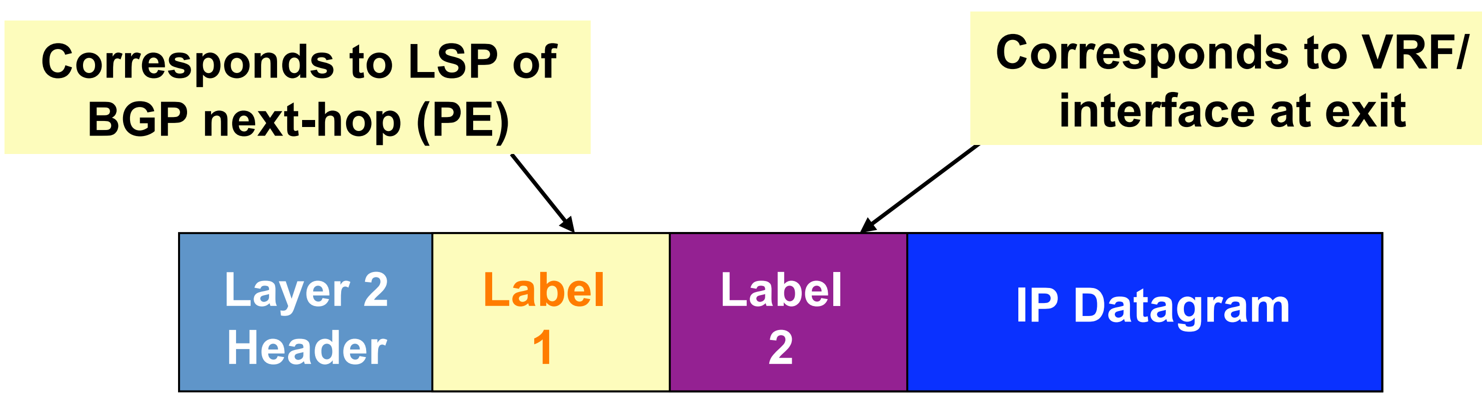
# Virtual Routing and Forwarding

- Separate tables per customer at each router



# Forwarding

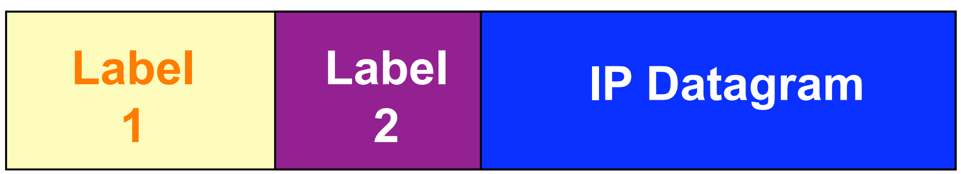
- PE and P routers have BGP next-hop reachability through the backbone IGP
- Labels are distributed through LDP (hop-by-hop) corresponding to BGP Next-Hops
- **Two-Label Stack** is used for packet forwarding
  - Top label indicates Next-Hop (interior label)
  - Second label indicates outgoing interface / VRF (exterior label)



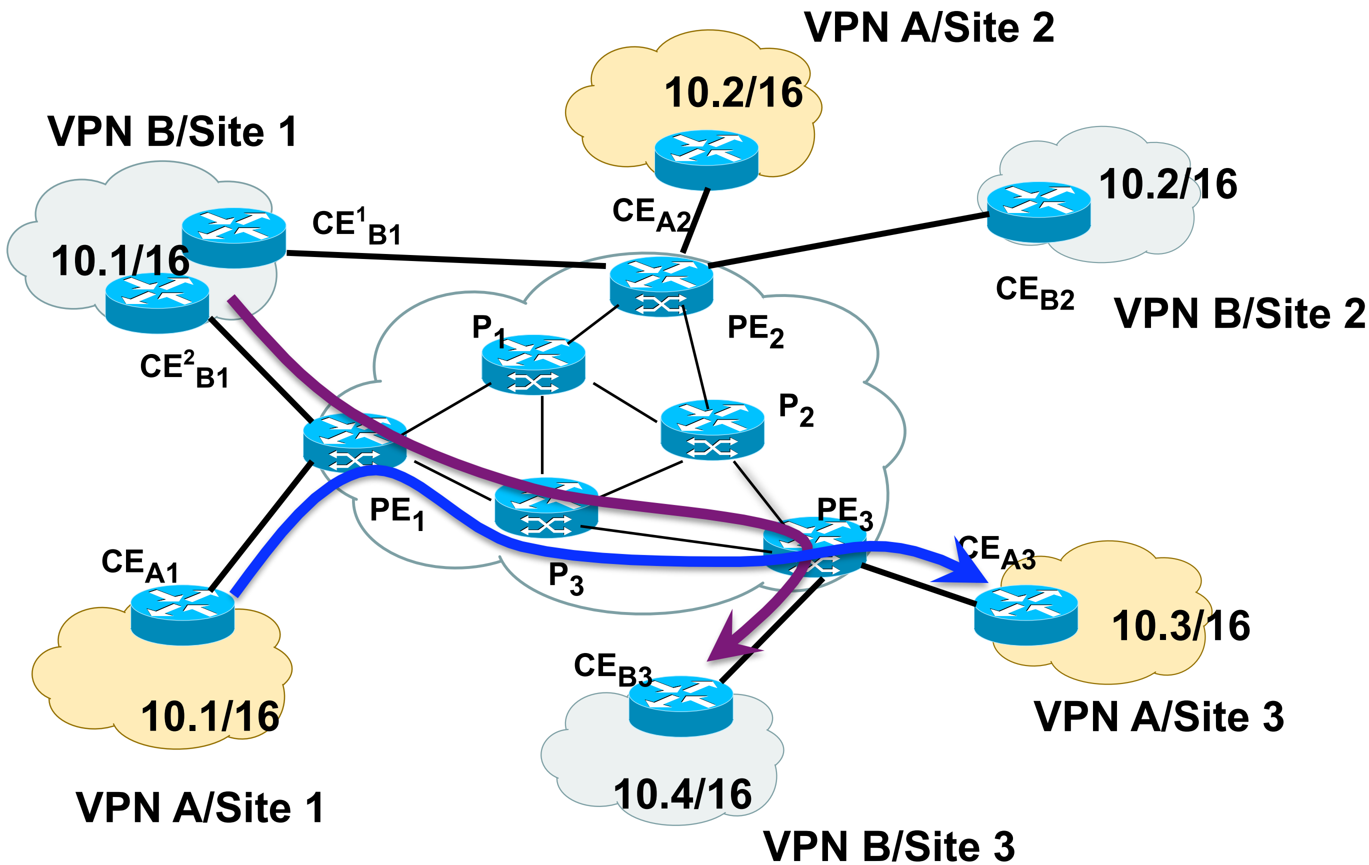
# Forwarding in BGP/MPLS VPNs

- **Step 1:** Packet arrives at incoming interface
  – Site VRF determines BGP next-hop and Label #2


- **Step 2:** BGP next-hop lookup, add corresponding LSP (also at site VRF)



# Layer 3 BGP/MPLS VPNs




BGP to exchange routes

MPLS to forward traffic

# Conclusions

- Overlay networks
  - Tunnels between host computers
  - Build networks "on top" of the Internet
  - Deploy new protocols and services
  - Provide better control, flexibility, QoS, isolation, …
- Underlay tunnels
  - Across routers within AS
  - Build networks "below" IP route
  - Provide better control, flexibility, QoS, isolation, …
- Next time
  - Peer-to-peer applications