Link layer, LANs: roadmap

- introduction
- multiple access protocols
  - Channel partitioning
  - Random Access protocols
    - Slotted ALOHA, CSMA/CD, CSMA/CA
- LANs
  - Ethernet
  - MAC addresses, ARP
  - Switches
  - Routing between subnets
  - VLANs
  - Datacenter networks

Router vs Switch

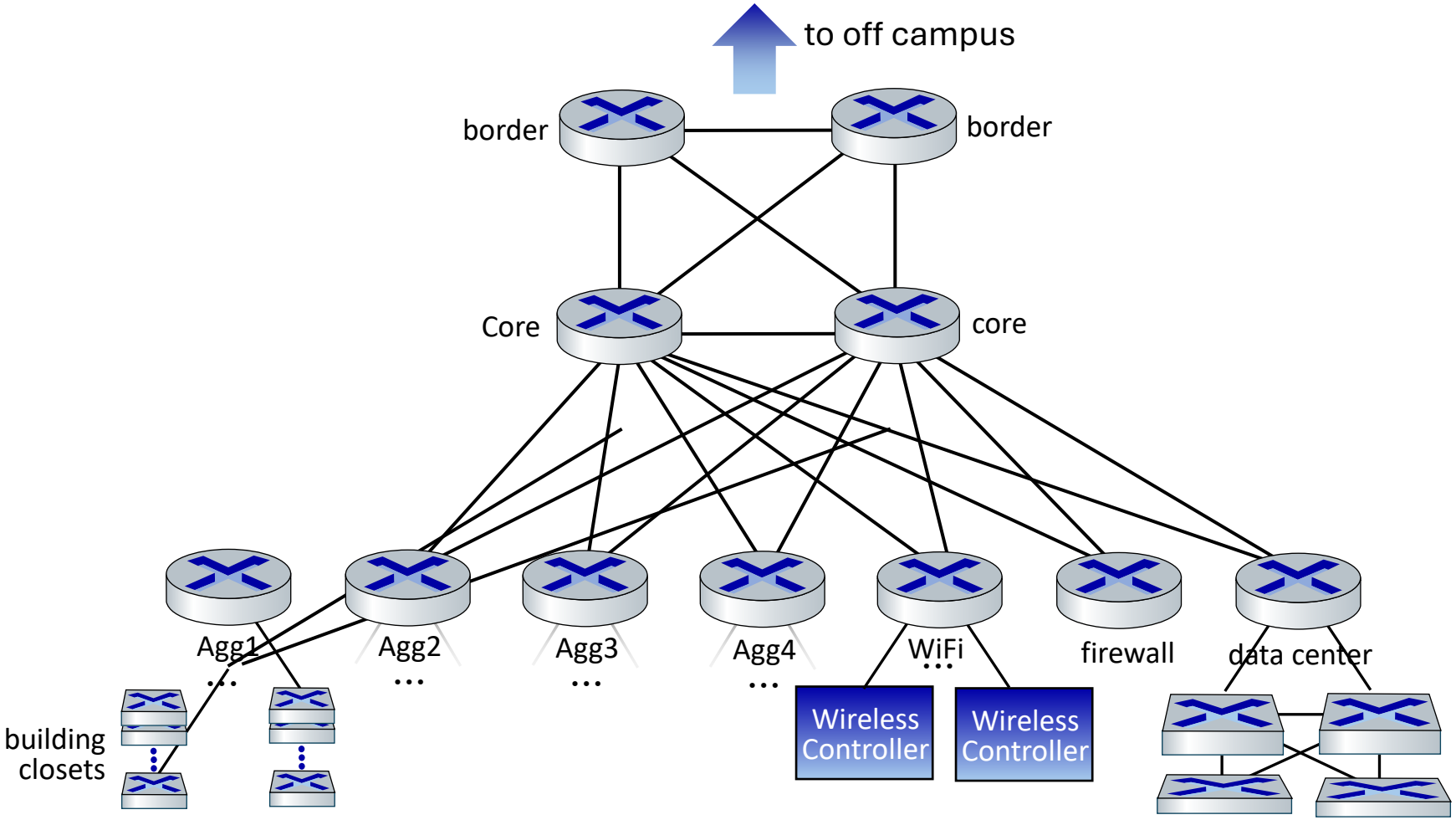
Router

- **Function**: Connects different networks (e.g., LAN to WAN).
- **Layer**: Operates at the Network Layer (Layer 3).
- **Purpose**: Routes data between networks using IP addresses.
- **Routing**: Uses routing tables to determine the best path for data.
- **Example**: Connects your home network to the internet.

Switch

- **Function**: Connects devices within the same network (e.g., PCs, printers).
- **Layer**: Operates at the Data Link Layer (Layer 2).
- **Purpose**: Forwards data to specific devices using MAC addresses.
- **Forwarding**: Self learning (plug-and-play)
- **Example**: Connects multiple computers in an office LAN.

UMass Campus Network - Detail



UMass network:

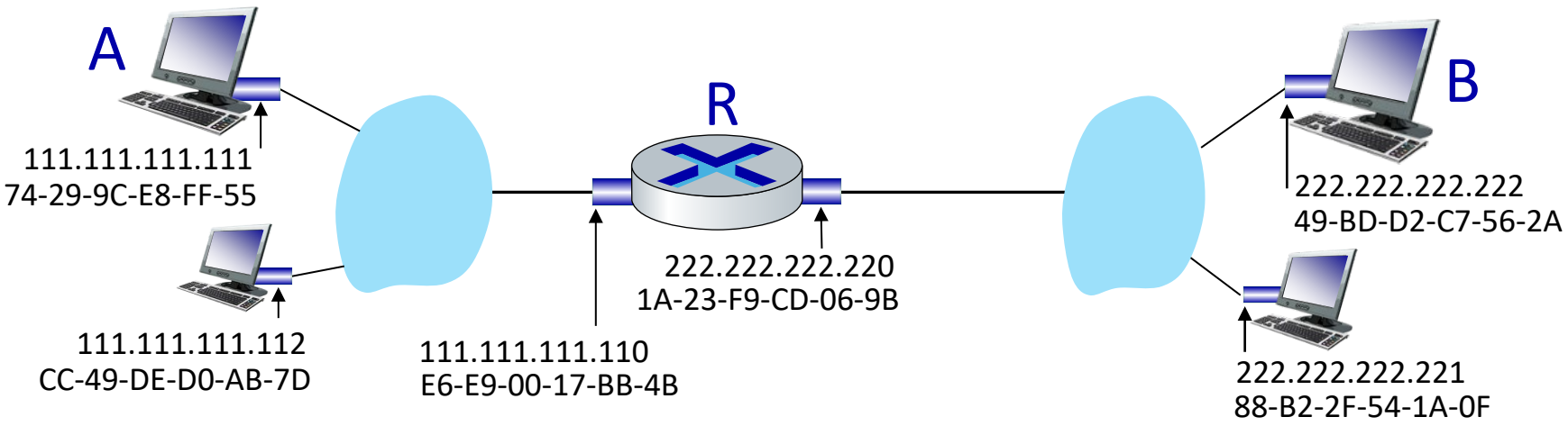
- 4 firewalls
- 10 routers
- 2000+ network switches
- 6000 wireless access points
- 30000 active wired network jacks
- 55000 active end-user wireless devices

... all built, operated, maintained by ~15 people

Routing to another subnet: addressing

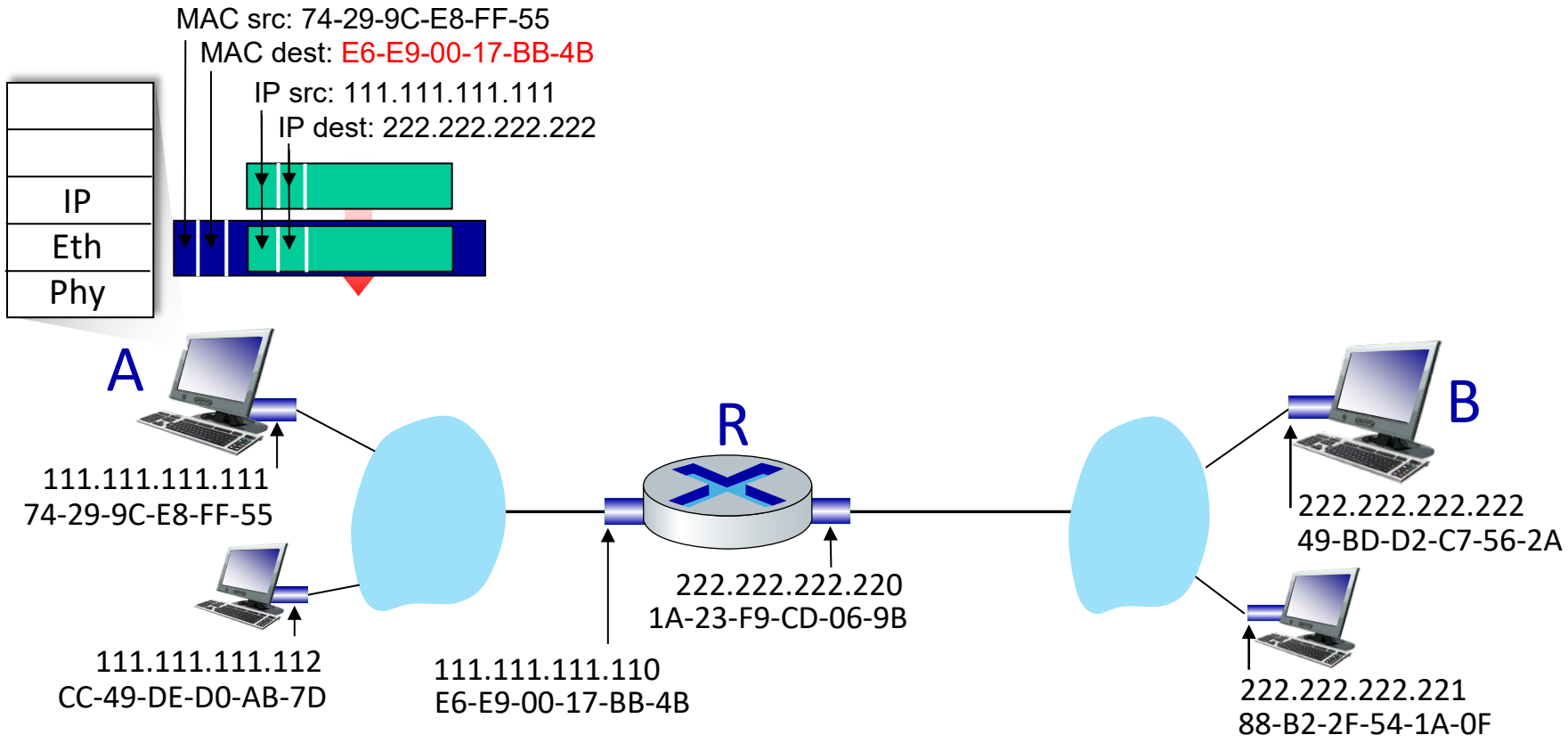
walkthrough: sending a datagram from *A* to *B* via *R*

- focus on addressing – at IP (datagram) and MAC layer (frame) levels
- assume that:
  - A knows B's IP address
  - A knows IP address of first hop router, R (how?)
  - A knows R's MAC address (how?)



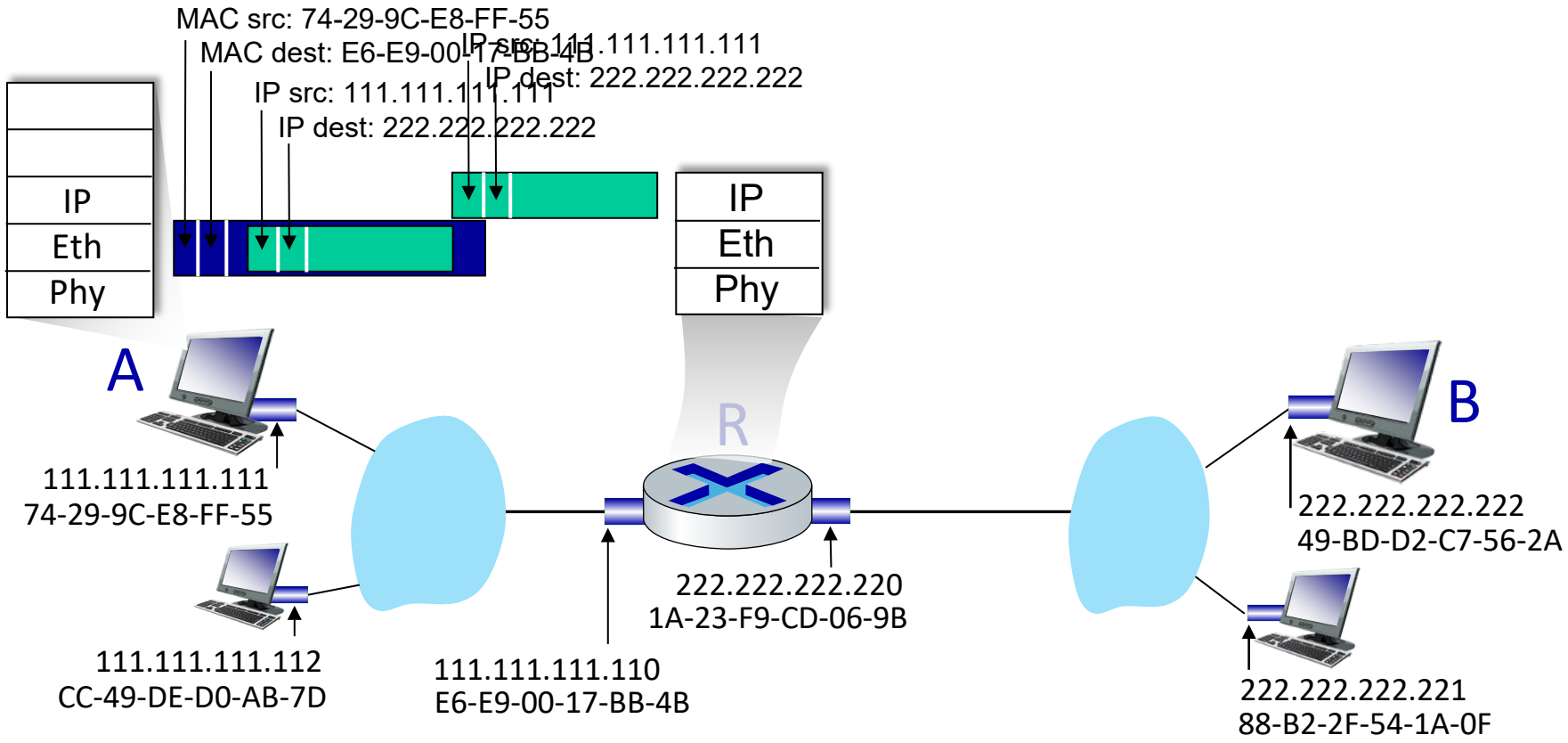
Routing to another subnet: addressing

- A creates IP datagram with IP source A, destination B
- A creates link-layer frame containing A-to-B IP datagram
  - R's MAC address is frame's destination



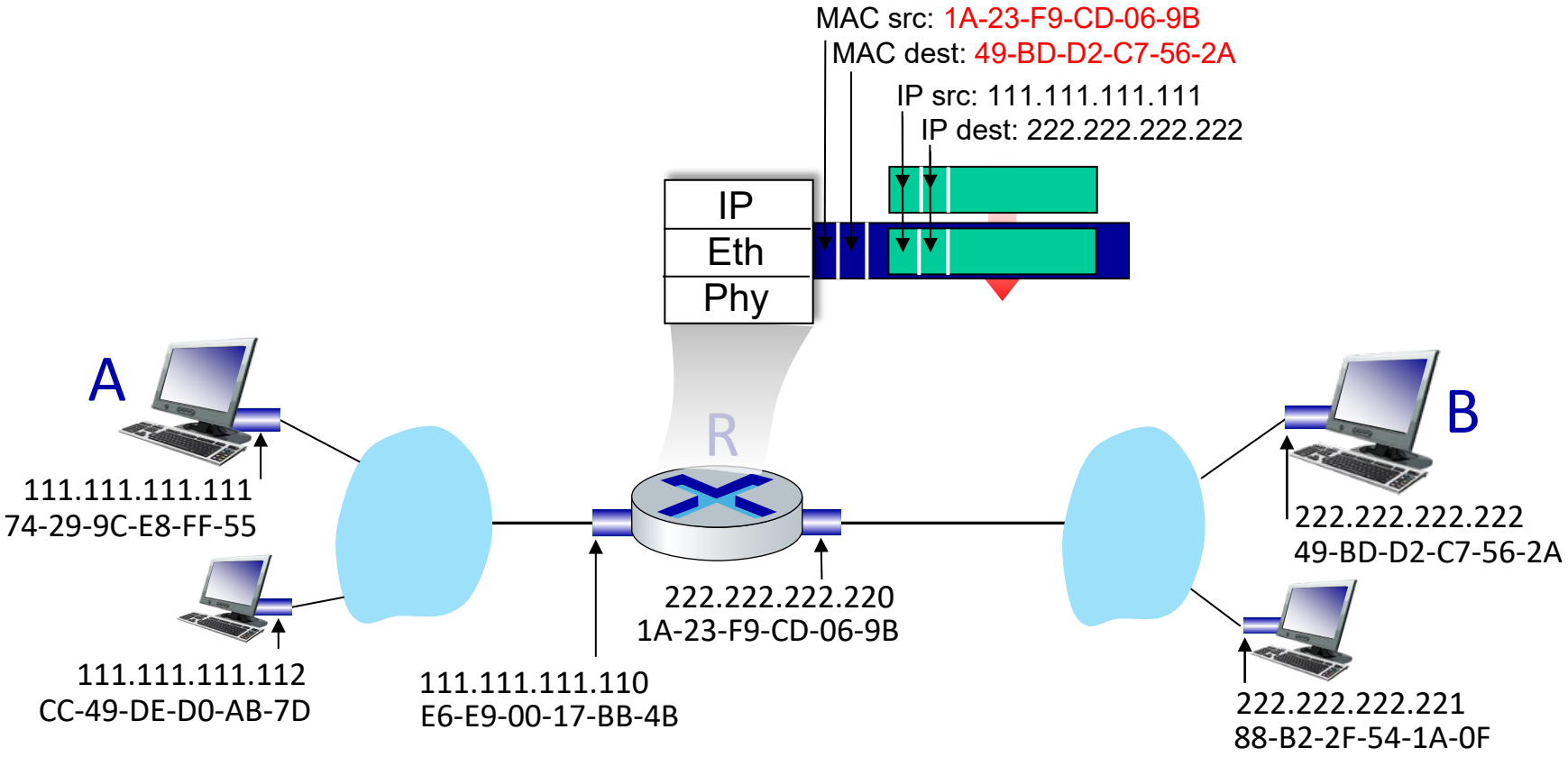
Routing to another subnet: addressing

- frame sent from A to R
- frame received at R, datagram removed, passed up to IP



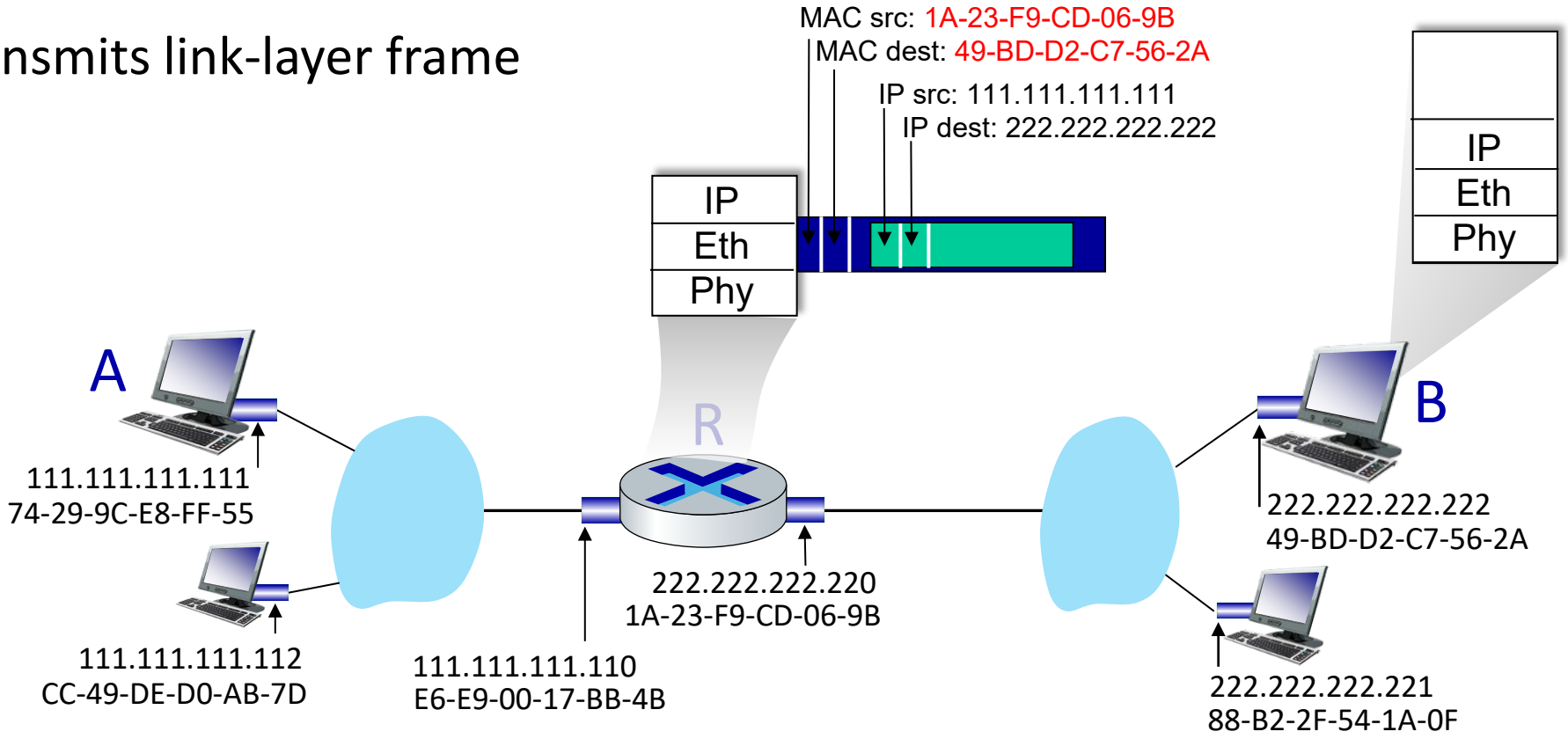
Routing to another subnet: addressing

- R determines outgoing interface, passes datagram with IP source A, destination B to link layer
- R creates link-layer frame containing A-to-B IP datagram. Frame destination address: B's MAC address



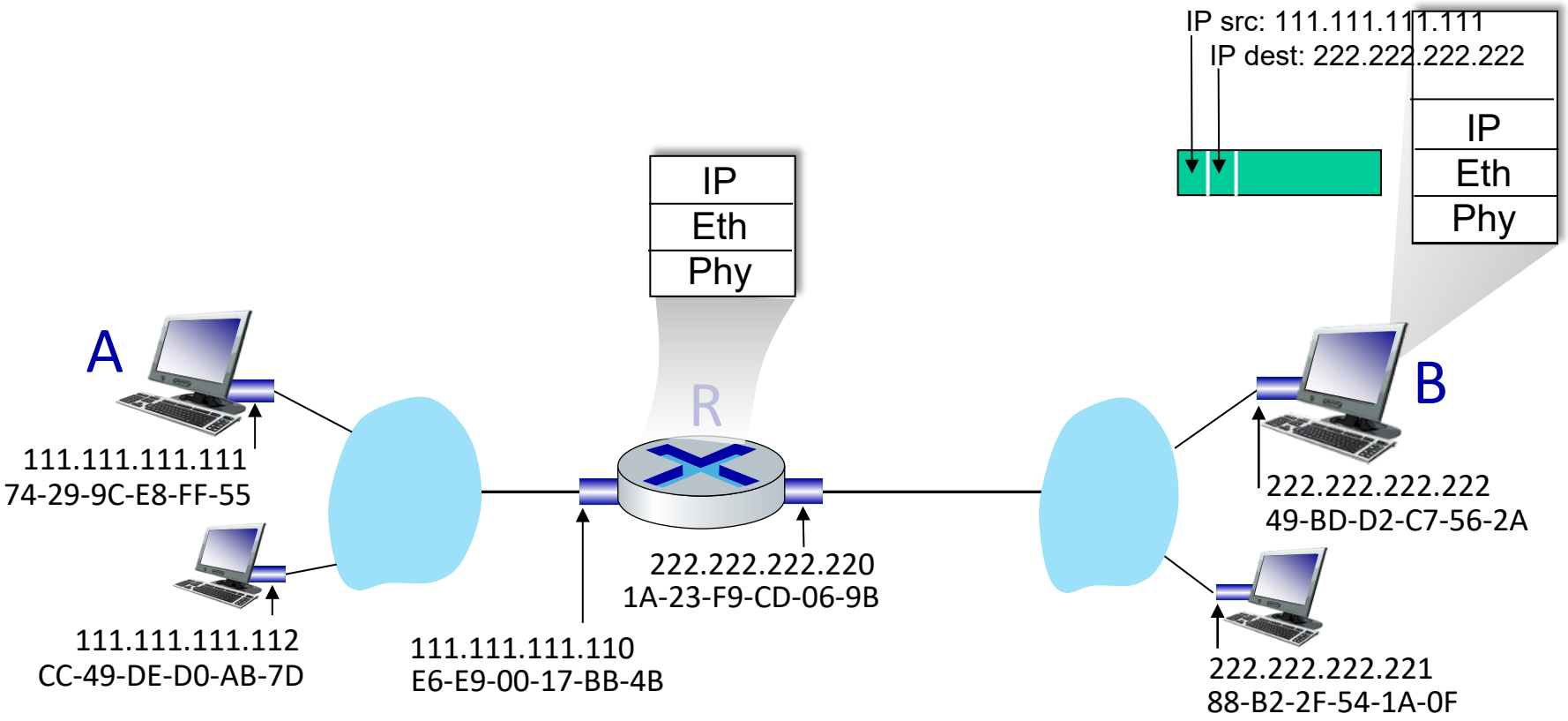
Routing to another subnet: addressing

- R determines outgoing interface, passes datagram with IP source A, destination B to link layer
- R creates link-layer frame containing A-to-B IP datagram. Frame destination address: B's MAC address
- transmits link-layer frame

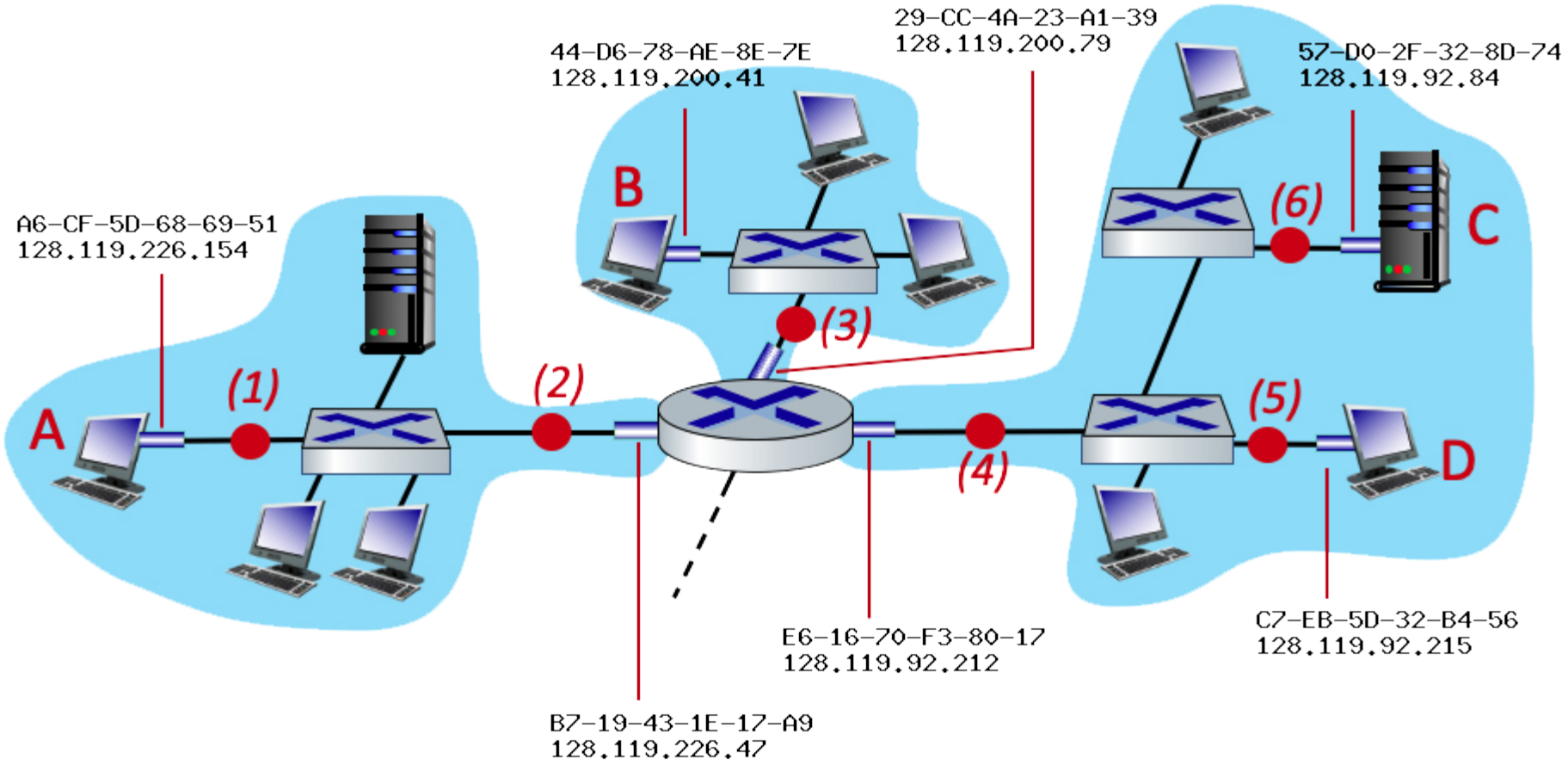


Routing to another subnet: addressing

- B receives frame, extracts IP datagram destination B
- B passes datagram up protocol stack to IP



Identify Src/Dst MAC addresses for A to C



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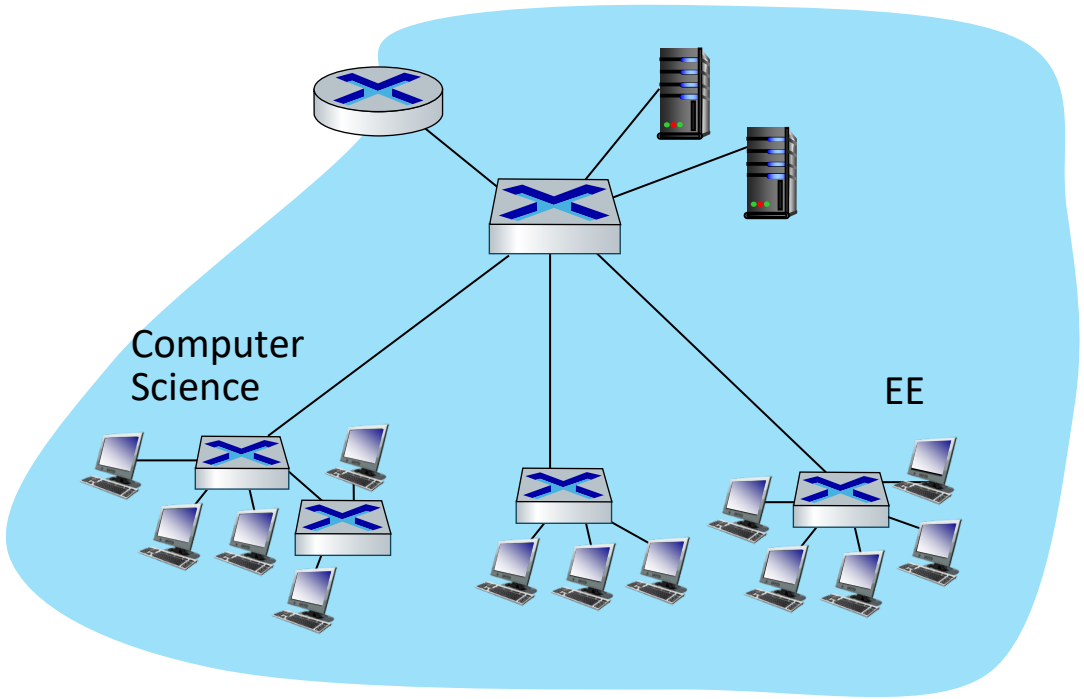
Virtual LANs (VLANs): motivation

Q: what happens as LAN sizes scale, users change point of attachment?



single broadcast domain:

- *scaling:* all layer-2 broadcast traffic (ARP, DHCP, unknown MAC) must cross entire LAN
- efficiency, security, privacy issues

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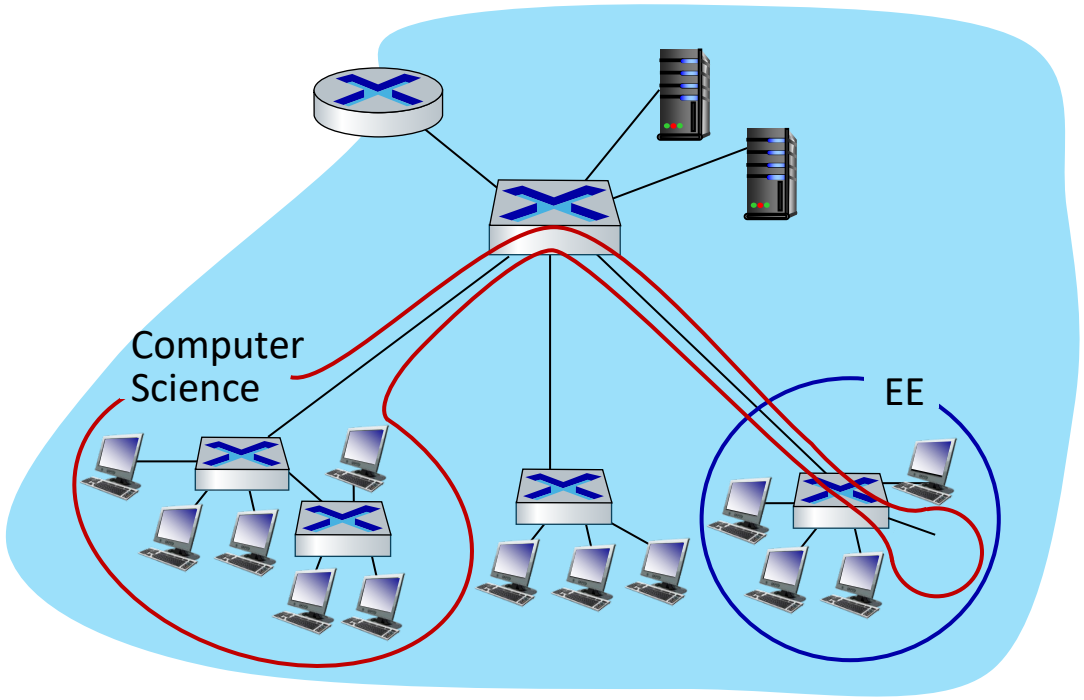


single broadcast domain:

- *scaling:* all layer-2 broadcast traffic (ARP, DHCP, unknown MAC) must cross entire LAN
- security, privacy, efficiency issues

administrative issues:

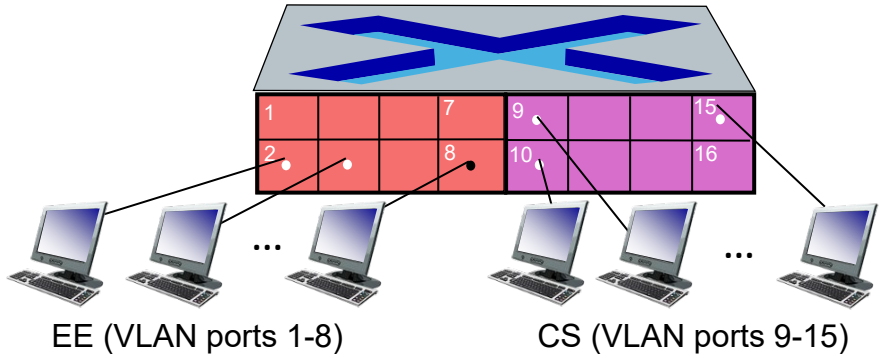
- CS user moves office to EE - *physically* attached to EE switch, but wants to remain *logically* attached to CS switch

Port-based VLANs

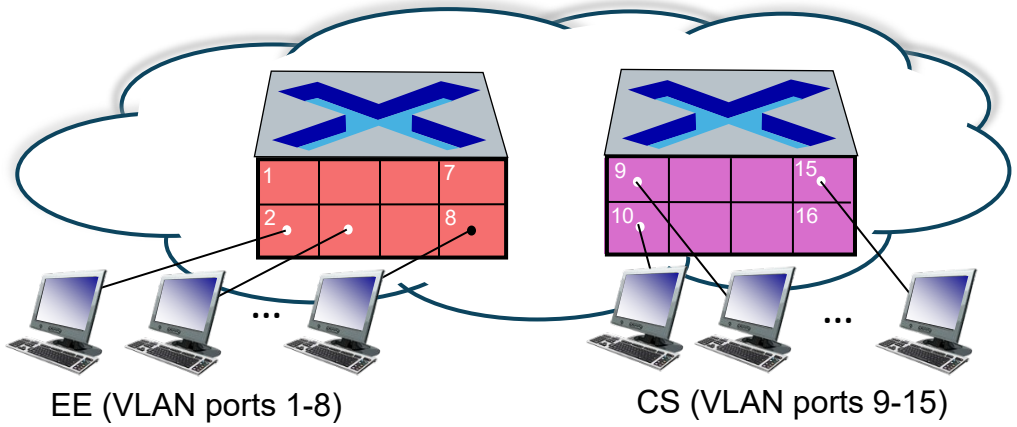
Virtual Local Area Network (VLAN)

switch(es) supporting VLAN capabilities can be configured to define multiple *virtual* LANS over single physical LAN infrastructure.

port-based VLAN: switch ports grouped (by switch management software) so that *single* physical switch ……

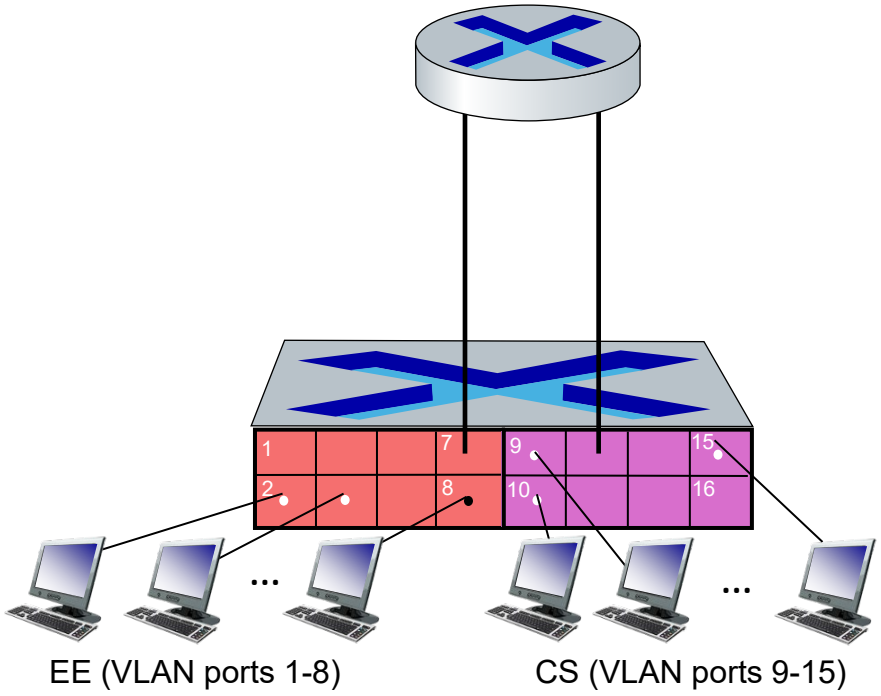


… operates as multiple virtual switches

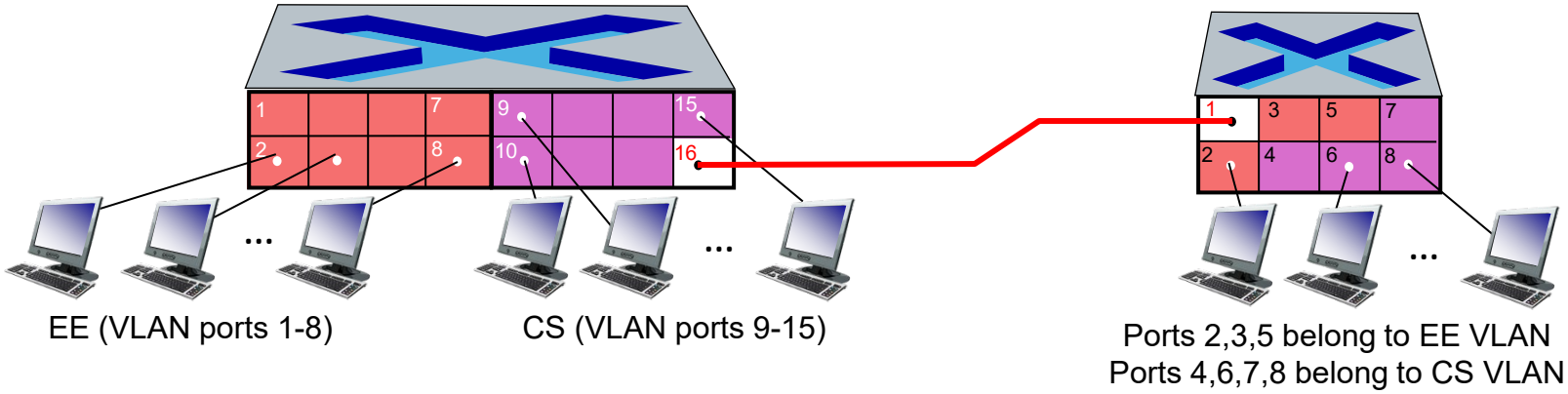


Port-based VLANs

- traffic isolation: frames to/from ports 1-8 can *only* reach ports 1-8
  - can also define VLAN based on MAC addresses of endpoints, rather than switch port
- dynamic membership: ports can be dynamically assigned among VLANs
- forwarding between VLANS: done via routing (just as with separate switches)
  - in practice vendors sell combined switches plus routers



VLANS spanning multiple switches



trunk port: carries frames between VLANS defined over multiple physical switches

- frames forwarded within VLAN between switches can't be vanilla 802.1 frames (must carry VLAN ID info)
- 802.1q protocol adds/removed additional header fields for frames forwarded between trunk ports

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Datacenter networks

10’s to 100’s of thousands of hosts, often closely coupled, in close proximity:

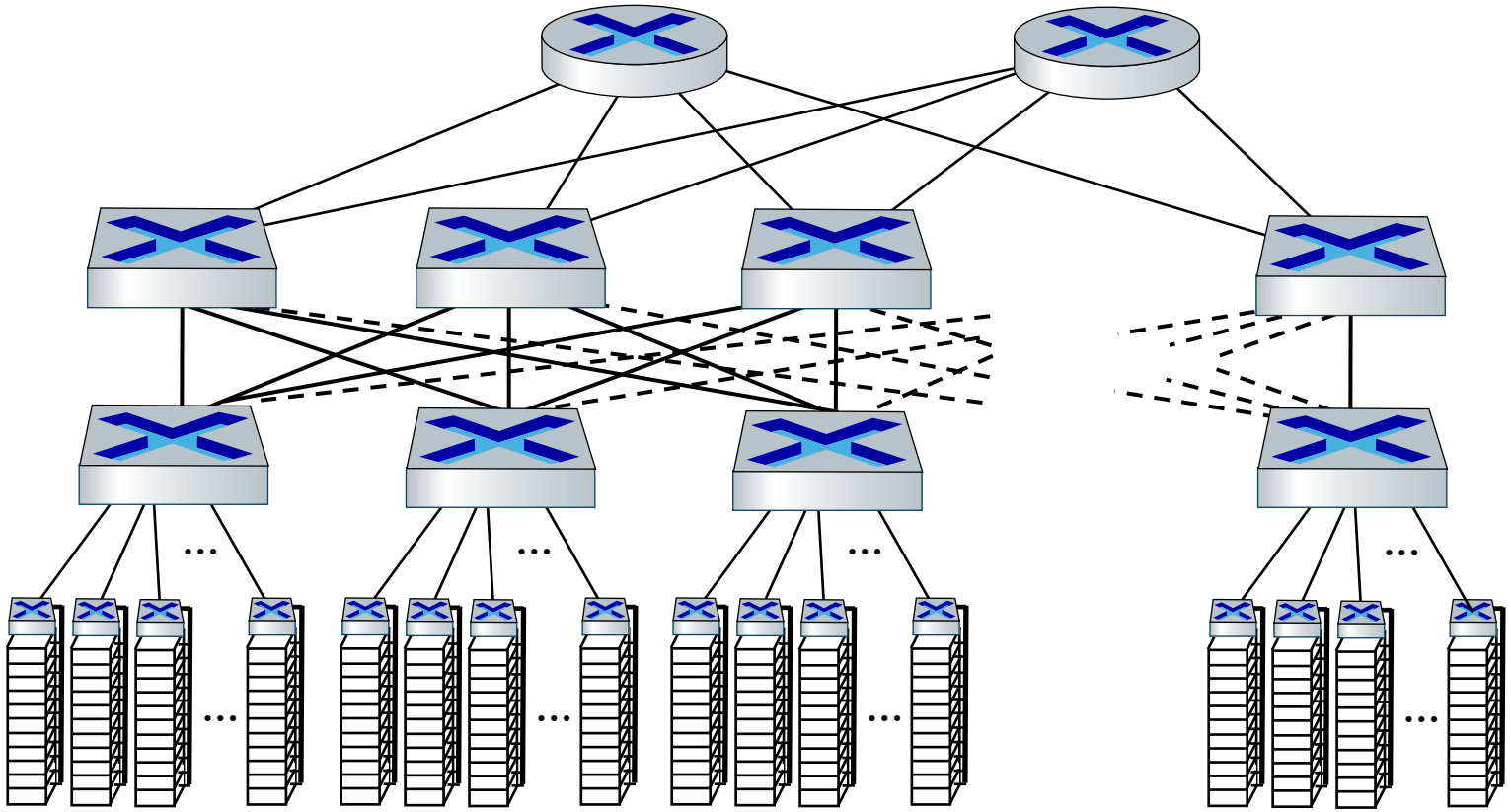
- e-business (e.g. Amazon)
- content-servers (e.g., YouTube, Akamai, Apple, Microsoft)
- search engines, data mining (e.g., Google)

challenges:

- multiple applications, each serving massive numbers of clients
- reliability
- managing/balancing load, avoiding processing, networking, data bottlenecks

Inside a 40-ft Microsoft container, Chicago data center

Datacenter networks: network elements



Border routers

- connections outside datacenter

Tier-1 switches

- connecting to ~16 T-2s below

Tier-2 switches

- connecting to ~16 TORs below

Top of Rack (TOR) switch

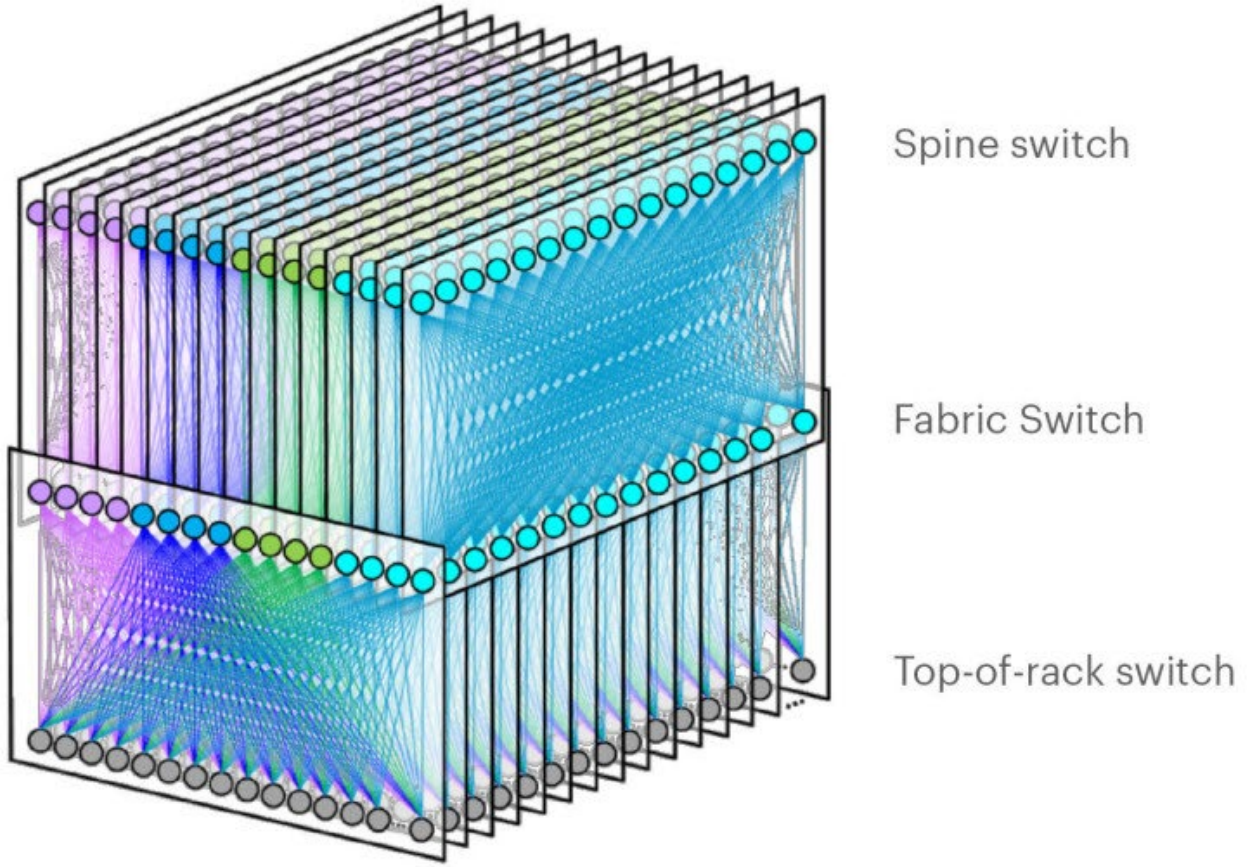
- one per rack
- 100G-400G Ethernet to blades

Server racks

- 20- 40 server blades: hosts

Datacenter networks: network elements

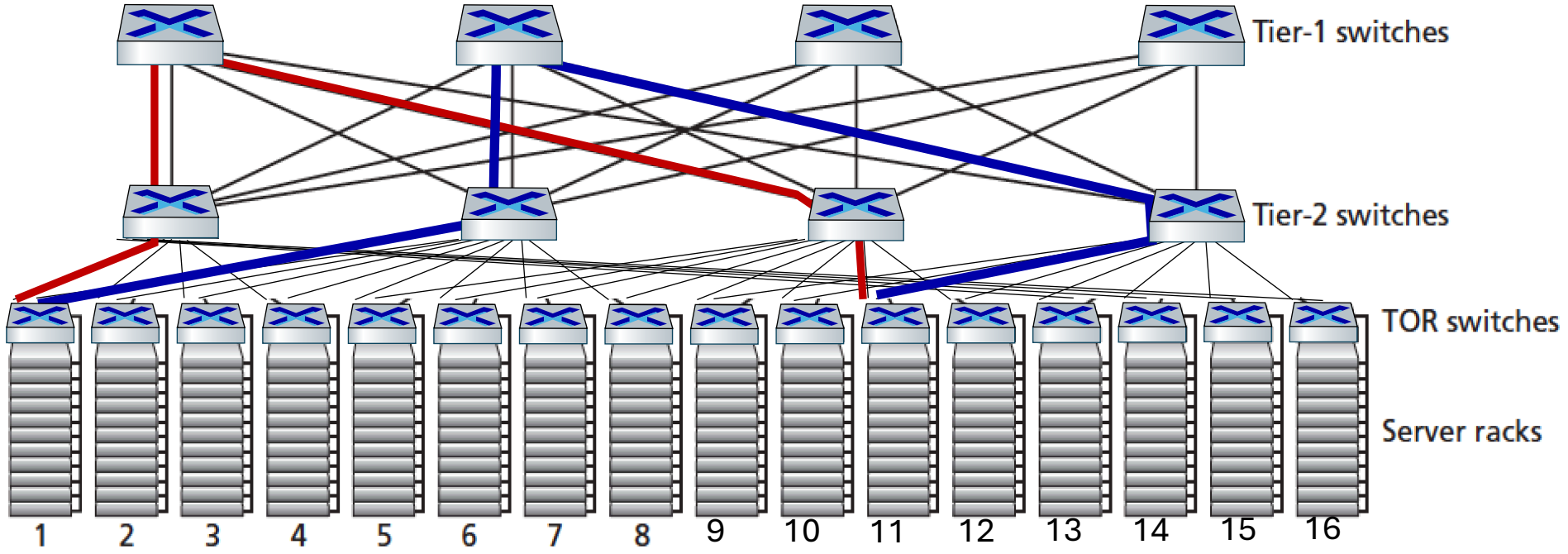
Facebook F16 data center network topology:



https://engineering.fb.com/data-center-engineering/f16-minipack/ (posted 3/2019)

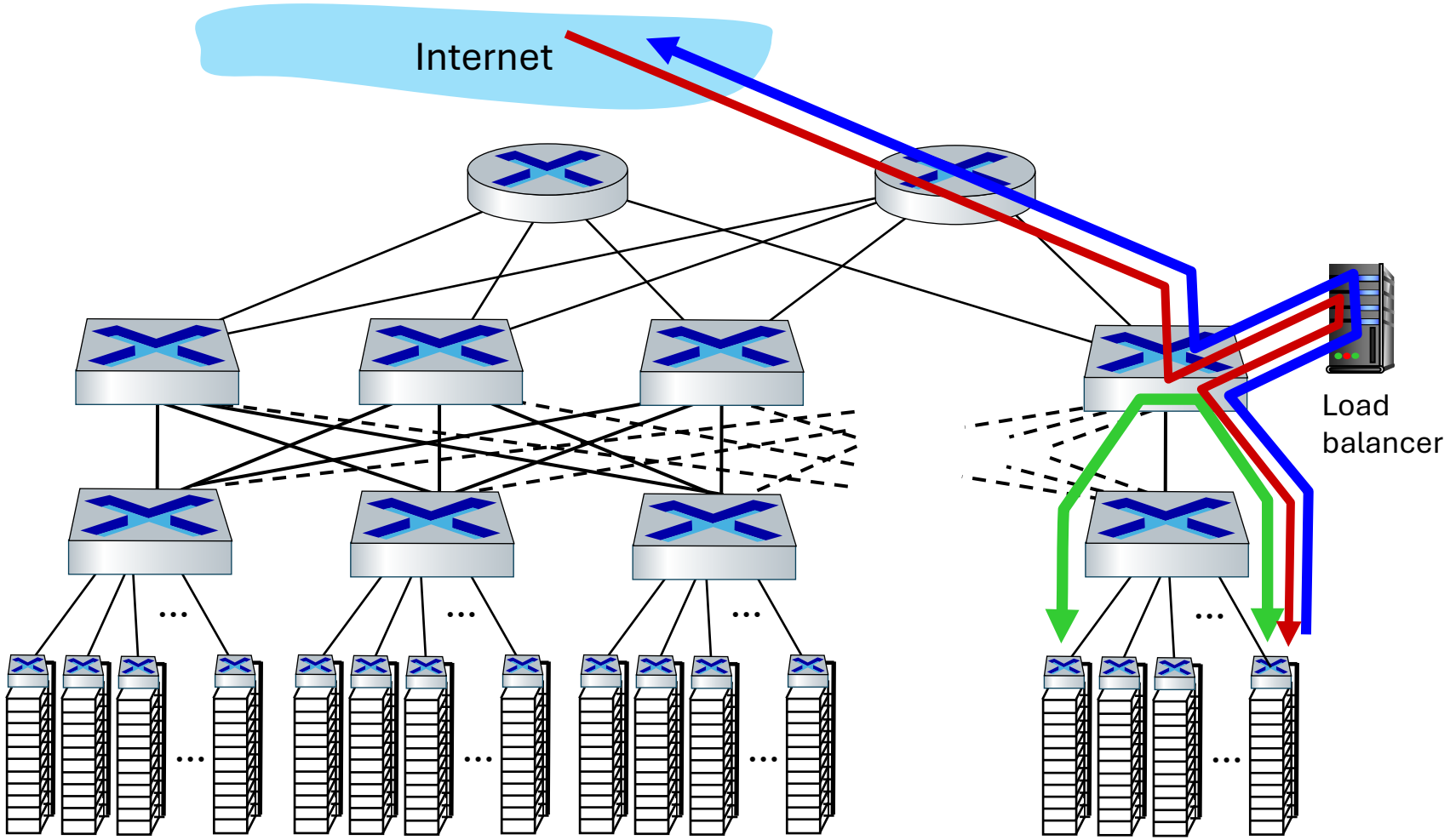
Datacenter networks: multipath

- rich interconnection among switches, racks:
  - increased throughput between racks (multiple routing paths possible)
  - increased reliability via redundancy



two disjoint paths highlighted between racks 1 and 11

Datacenter networks: application-layer routing



load balancer: application-layer routing

- receives external client requests
- directs workload within data center
- returns results to external client (hiding data center internals from client)

Datacenter networks: protocol innovations

- link layer:
  - RoCE: remote DMA (RDMA) over Converged Ethernet
- transport layer:
  - ECN (explicit congestion notification) used in transport-layer congestion control (DCTCP, DCQCN)
  - experimentation with hop-by-hop (backpressure) congestion control
- routing, management:
  - SDN widely used within/among organizations' datacenters
  - place related services, data as close as possible (e.g., in same rack or nearby rack) to minimize tier-2, tier-1 communication

Google Networking: Infrastructure and Selected Challenges (Slides: https://networkingchannel.eu/google-networking-infrastructure-and-selected-challenges/