

EN.601.414/614

Computer Networks

Final Review

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Fall 2020 (TuTh 1:30-2:45pm on Zoom)



<https://github.com/xinjin/course-net>

Final Exam

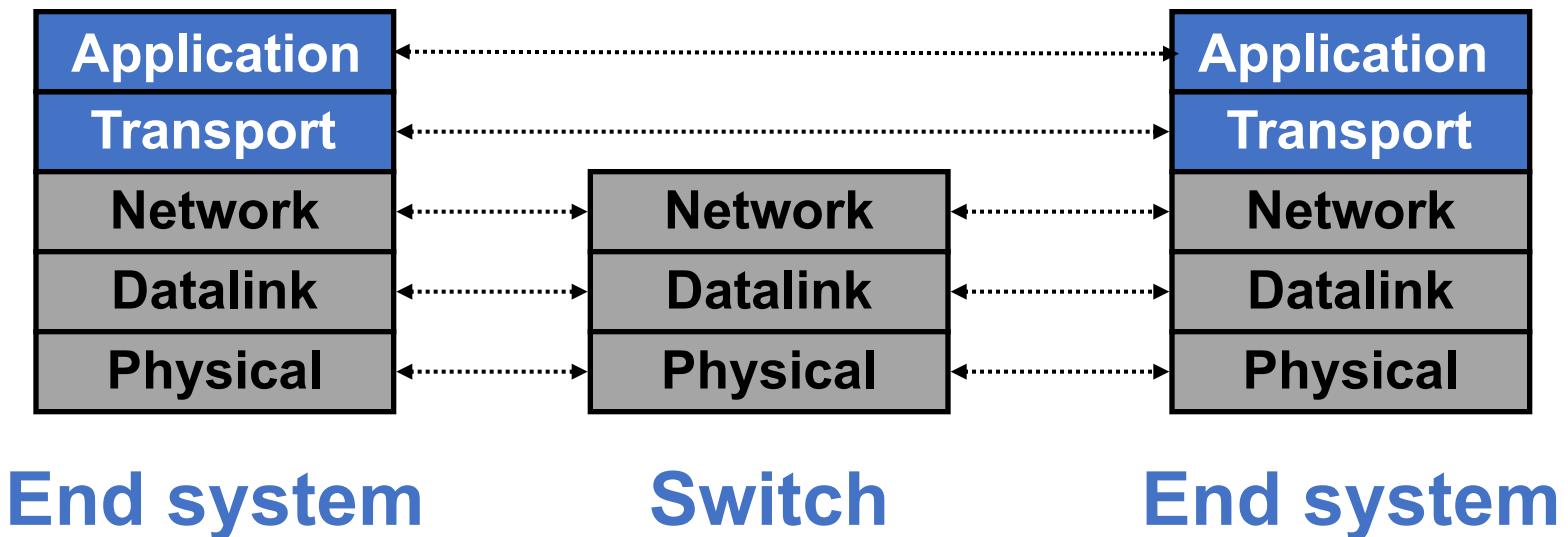
- **Time: 7pm-9pm, Wednesday, December 16**
- **Location: online**
- **Form: open-book**
 - Can use slides for reference
 - Can use a calculator
 - Anything else is prohibited
- **Focus on materials after midterm**
 - Materials before midterm will be tested, but not a focus
- **Senior option**
 - Your final exam score will be the same as your midterm score
- **Contact the course staff on piazza before December 11 (this Friday) if you want to use the senior option or if you need any special accommodation**
- **Check the post on Piazza for details**

This review

- **Walk through what you're expected to know at this point: key topics, important aspects of each**
- **Not covered in review does NOT imply you don't need to know it**
 - But if it's covered today, you should know it
- **Summarize, not explain**
 - Stop me when you want to discuss something further!

The networking stack

- Lower three layers implemented everywhere
- Top two layers implemented only at hosts

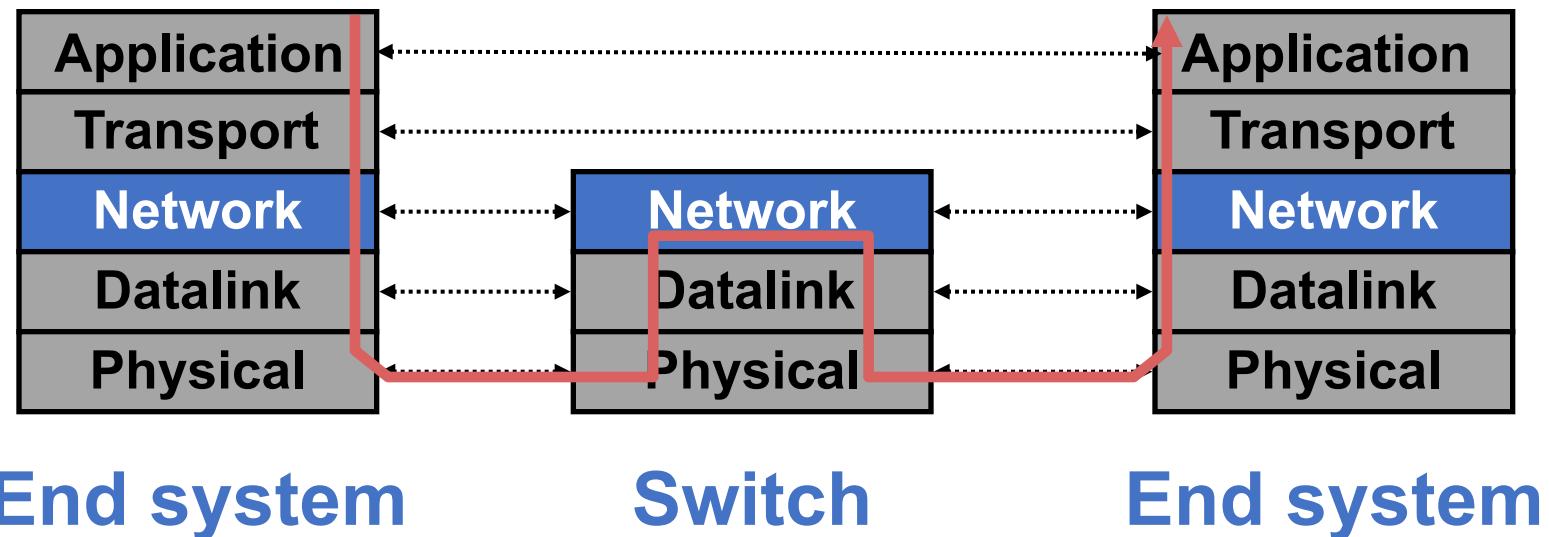


Topics

- **Network layer (lectures 12–15)**
 - Intra-domain routing
 - Inter-domain routing
- **Link layer (lectures 17–18)**
 - Ethernet
- **Topics in networking (lectures 16, 19–21)**
 - Programmable networks
 - Wireless
 - Security
 - Misc

Network layer

- Present everywhere
- Performs **addressing, forwarding, and routing**, among other tasks



Forwarding vs. routing

- **Forwarding:** “**data plane**”
 - Directing one data packet
 - Each router using local routing state
- **Routing:** “**control plane**”
 - Computing the forwarding tables that guide packets
 - Jointly computed by routers using a distributed algorithm
- **Very different timescales!**

Routing: Local vs. global view

- ***Local* routing state is the forwarding table in a single router**
 - By itself, the state in a single router cannot be evaluated
 - It must be evaluated in terms of the global context
- ***Global* state refers to the collection of forwarding tables in each of the routers**
 - Global state determines which paths packets take

“Valid” routing state

- **Global state is “valid” if it produces forwarding decisions that always deliver packets to their destinations**
- **Goal of routing protocols: compute valid state**
 - How can we tell if routing state is valid?

Necessary and sufficient condition

- **Global routing state is valid *if and only if*:**
 - There are no dead ends (other than destination)
 - There are no loops
- **A *dead end* is when there is no outgoing link (next-hop)**
 - A packet arrives, but the forwarding decision does not yield any outgoing link
- **A *loop* is when a packet cycles around the same set of nodes forever**

Least-cost routes

- **Least-cost routes provide an easy way to avoid loops**
 - No reasonable cost metric is minimized by traversing a loop
- **Least-cost paths form a spanning tree for each destination rooted at that destination**

Intra-domain routing

- **Link-state (LS) routing protocol**
 - Dijkstra's algorithm
 - Broadcast neighbors' info to everyone
- **Distance vector (DV) routing protocol**
 - Bellman-Ford algorithm
 - Gossip to neighbors about everyone

Similarities between LS and DV routing

- **Both are shortest-path based routing**
 - Minimizing cost metric (link weights) a common optimization goal
 - Routers share a common view as to what makes a path “good” and how to measure the “goodness” of a path
- **Due to shared goal, commonly used inside an organization**
 - RIP and OSPF are mostly used for **intra**-domain routing

Comparison of LS and DV routing

Messaging complexity

- LS: with N nodes, E links, O(NE) messages sent
- DV: exchange between neighbors only

Speed of convergence

- LS: relatively fast
- DV: convergence time varies
 - Count-to-infinity problem

Robustness: what happens if router malfunctions?

- LS:
 - Node can advertise incorrect link cost
 - Each node computes its own table
- DV:
 - Node can advertise incorrect path cost
 - Each node's table used by others (error propagates)

Addressing is key to scalable inter-domain routing

- Ability to aggregate addresses is crucial for
 - State: Small forwarding tables at routers
 - Much less than the number of hosts
 - Churn: Limited rate of change in routing tables

Classful addressing

- **Three classes**
 - 8-bit network prefix (Class A),
 - 16-bit network prefix (Class B), or
 - 24-bit network prefix (Class C)
- **Example: an organization needs 500 addresses.**
 - A single class C address is not enough (<500 hosts)
 - Instead, a class B address is allocated (~65K hosts)
 - Huge waste!

CIDR: Classless inter-domain routing

- **Flexible division between network and host addresses**
- **Offers a better tradeoff between size of the routing table and efficient use of the IP address space**

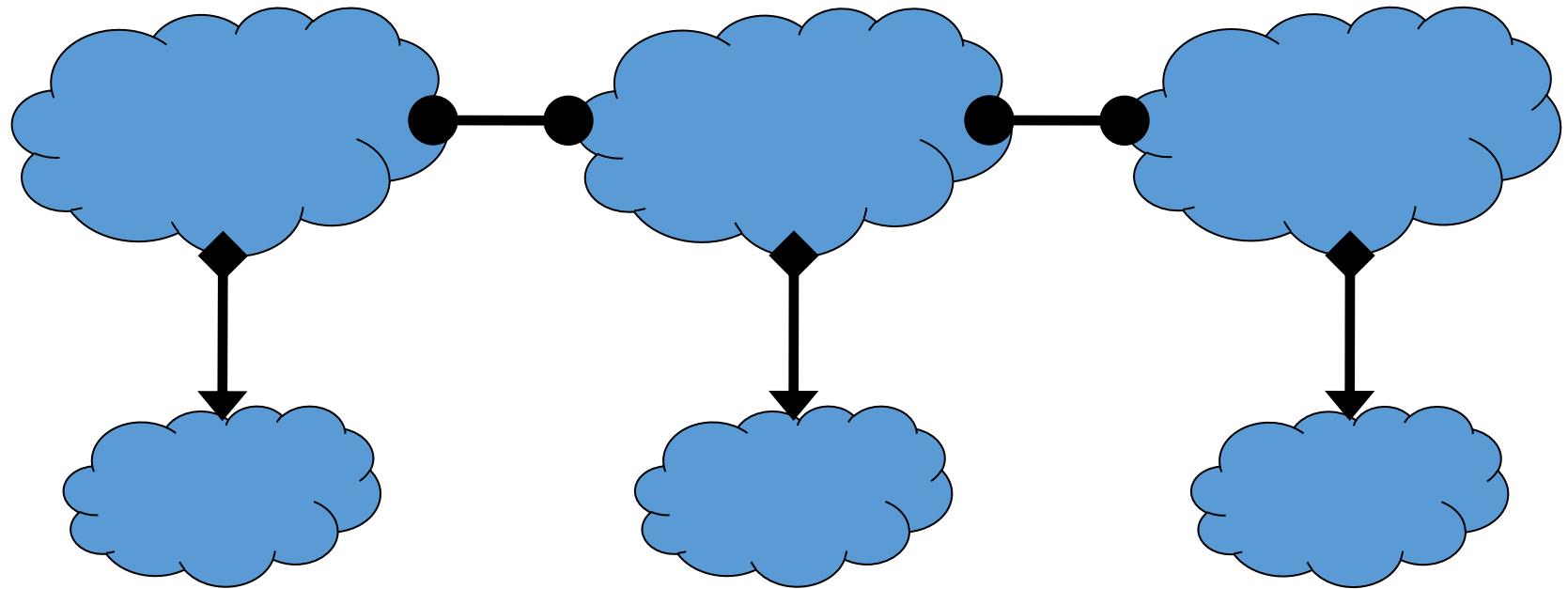
Administrative structure shapes Inter-domain routing

- ASes want freedom to pick routes based on policy
- ASes want autonomy
- ASes want privacy

Topology & policy shaped by inter-AS business relationship

- **Three basic kinds of relationships between ASes**
 - AS A can be AS B's customer
 - AS A can be AS B's provider
 - AS A can be AS B's peer
- **Business implications**
 - Customer pays provider
 - Peers don't pay each other
 - Exchange roughly equal traffic

Business relationships



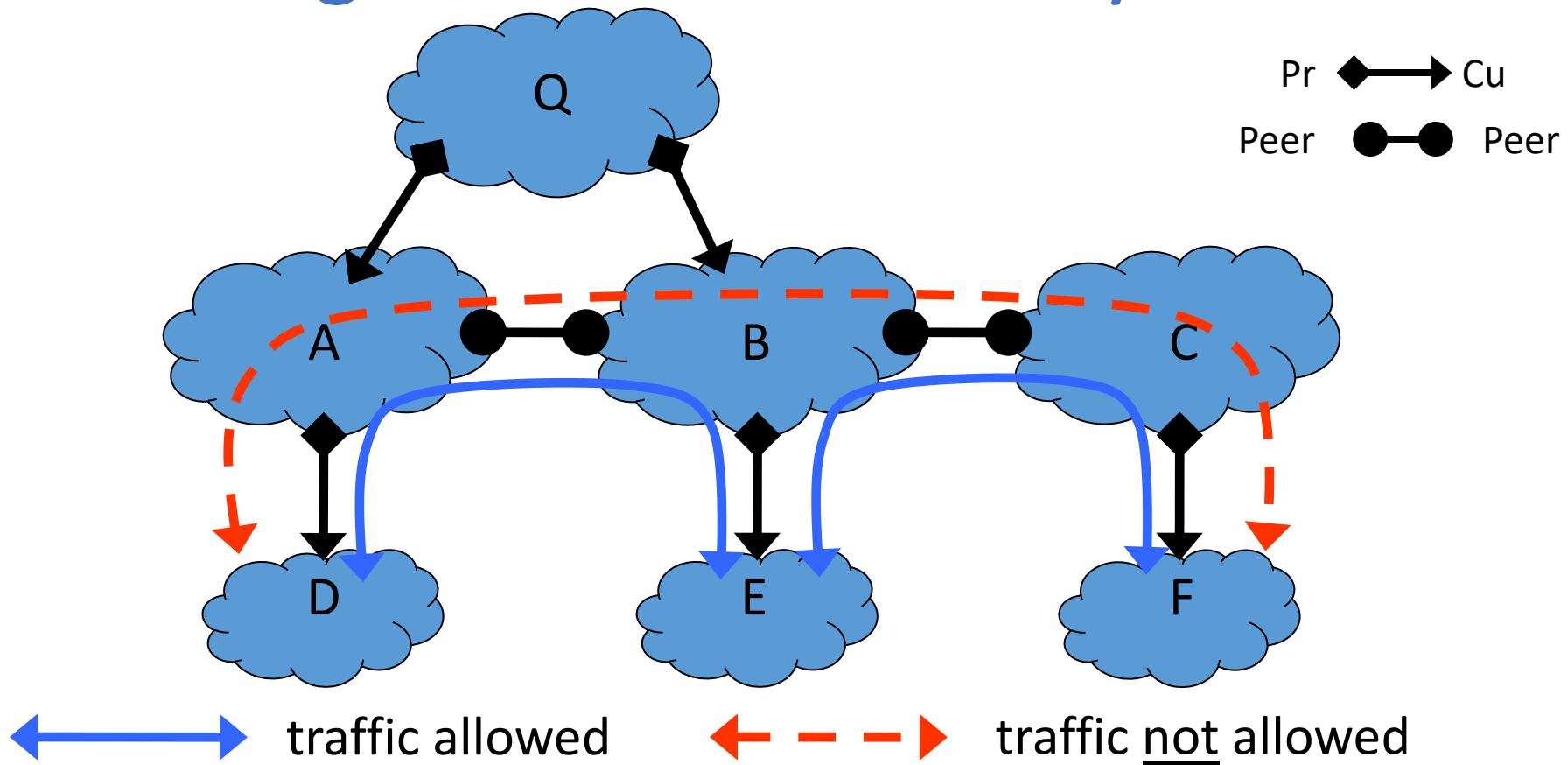
Relations between ASes

provider customer
peer peer

Business implications

- Customers pay provider
- Peers don't pay each other

Routing follows the money!

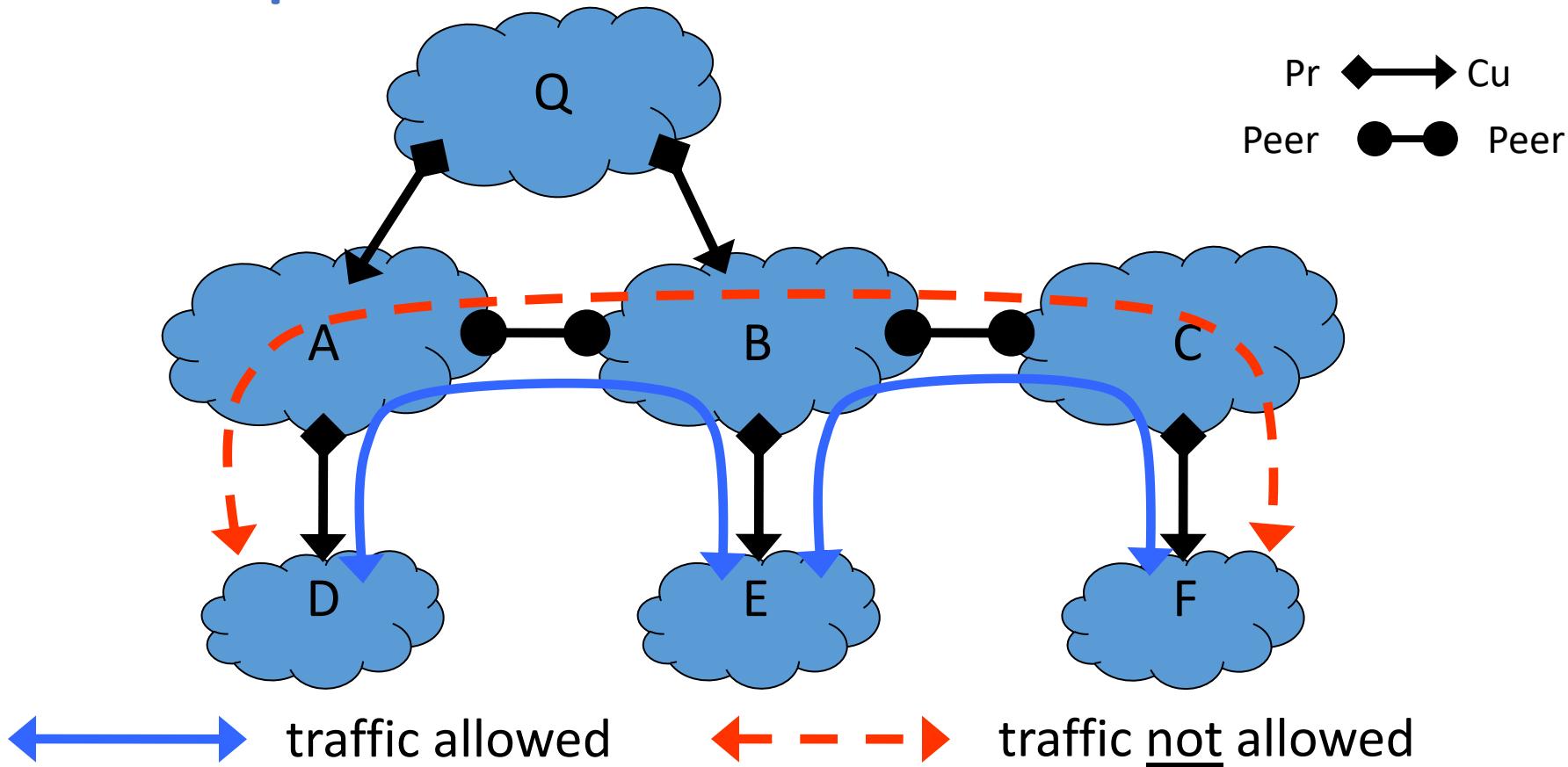


- ASes provide “transit” between their customers
- Peers do not provide transit between other peers

Valley-Free Routing

- Number links as $(+1, 0, -1)$ for customer-to-provider, peer and provider-to-customer
- In any path should only see sequence of +1, followed by at most one 0, followed by sequence of -1
- Example question: show why the traffic is allowed or not allowed in the previous slide with valley-free routing

Example Question

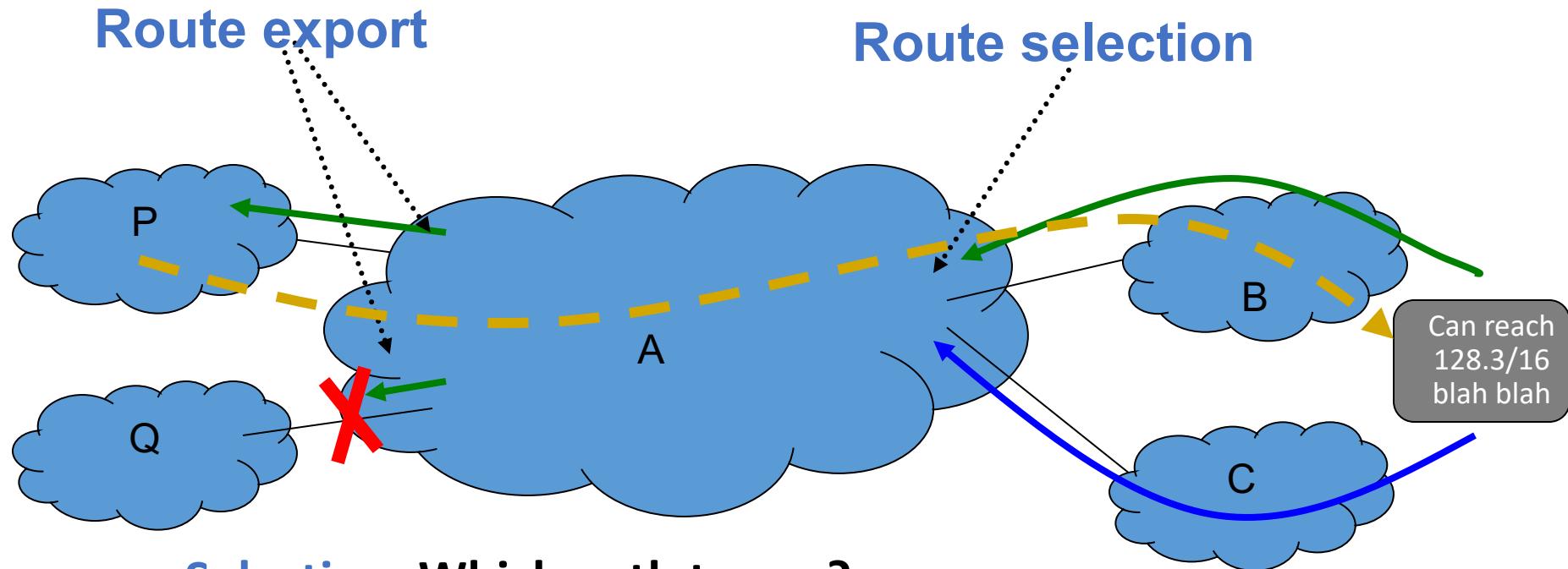


- Show why the traffic is allowed or not allowed with valley-free routing

BGP inspired by Distance-Vector with four differences

- **Shortest-path routes may not be picked to enforce policy**
- **Path-Vector routing to avoid loops**
- **Selective route advertisement may affect reachability**
- **Routes may be aggregated for scalability**

Policy dictates how routes are “selected” and “exported”



- **Selection: Which path to use?**
 - Controls whether/how traffic leaves the network
- **Export: Which path to advertise?**
 - Controls whether/how traffic enters the network

eBGP, iBGP, and IGP

- **eBGP: BGP sessions between border routers in different ASes**
 - Learn routes to external destinations
- **iBGP: BGP sessions between border routers and other routers within the same AS**
 - Distribute externally learned routes internally
- **IGP: “Interior Gateway Protocol” = Intra-domain routing protocol**
 - Provide internal reachability
 - E.g., OSPF, RIP

eBGP, iBGP, and IGP together

- Learn routes to external destination using eBGP
- Distribute externally learned routes internally using iBGP
- Travel shortest path to egress using IGP

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Data link layer

- **Provides four primary services**

- **Framing**

- Encapsulates network layer data

- **Link access**

- Medium access control (MAC) protocol defines when to transmit frames

- **Reliable delivery**

- Primarily for mediums with high error rates (e.g., wireless)

- **Error detection and correction**

Point-to-point vs. broadcast medium

- **Point-to-point: dedicated pairwise communication**
 - E.g., long-distance fiber link
 - E.g., Point-to-point link b/n Ethernet switch and host
- **Broadcast: shared wire or medium**
 - Traditional Ethernet (pre ~2000)
 - 802.11 wireless LAN

Random access MAC protocols

- **When node has packet to send**
 - Transmit at full channel data rate **w/o** coordination
- **Two or more transmitting nodes** ⇒ **collision**
 - Data lost
- **Random access MAC protocol specifies**
 - How to **detect** and **recover** from collisions
- **Examples**
 - ALOHA and Slotted ALOHA
 - CSMA, **CSMA/CD**, CSMA/CA (wireless)

CSMA (Carrier Sense Multiple Access)

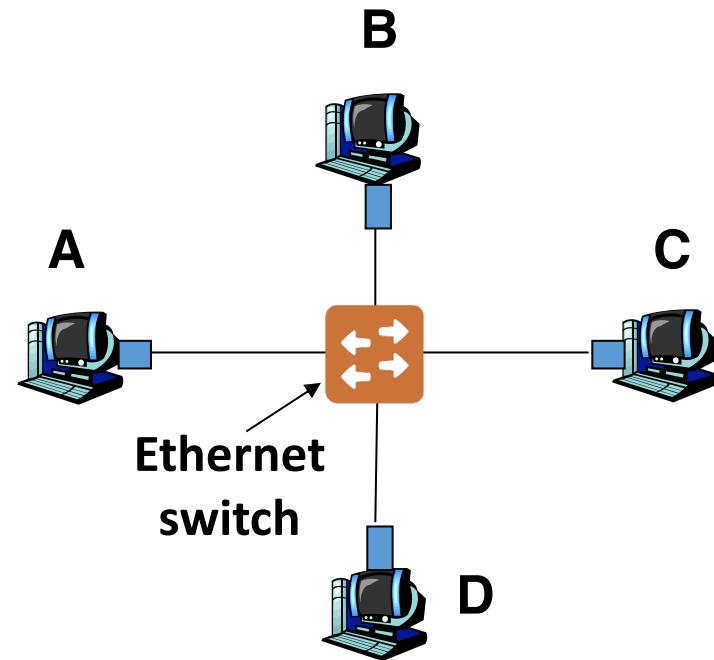
- **CSMA: listen before transmit**
 - If channel sensed idle: transmit entire frame
 - If channel sensed busy, defer transmission
- **Human analogy: don't interrupt others!**
- **Does not eliminate all collisions**
 - Why?

CSMA/CD (Collision Detection)

- **CSMA/CD: carrier sensing, deferral as in CSMA**
 - Collisions detected within short time
 - Colliding transmissions aborted, reducing wastage
- **Collision detection easy in wired (broadcast) LANs**
 - Compare transmitted, received signals
- **Collision detection difficult in wireless LANs**

Why switched Ethernet?

- **Enables concurrent communication**
 - Host A can talk to C, while B talks to D
 - No collisions and no need for CSMA/CD
 - No constraints on link lengths, etc.

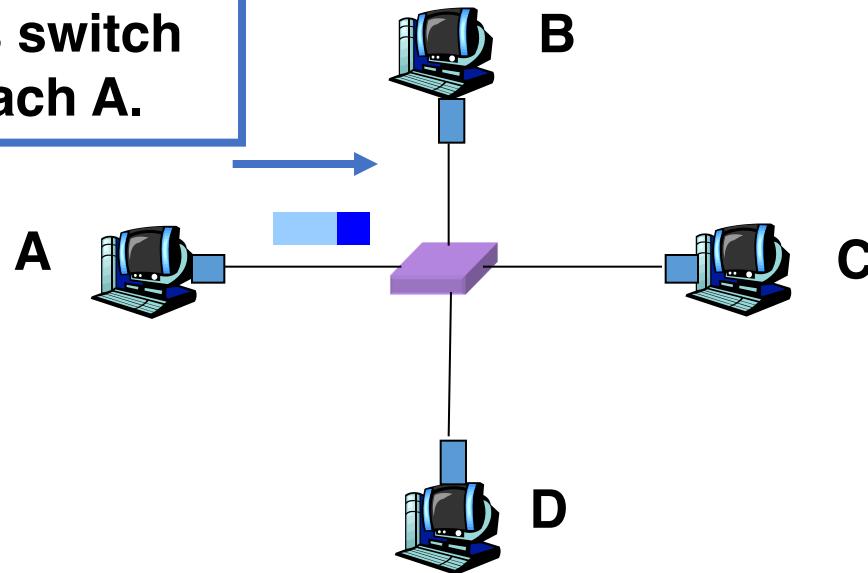


Ethernet switches are “self learning”

- When a packet arrives:

- Inspect source MAC address, associate with incoming port
- Store mapping in the switch table
- Use **time-to-live** field to eventually forget mapping

Packet tells switch how to reach A.



ARP and DHCP

- **Link layer discovery protocols**
 - ARP → Address Resolution Protocol
 - DHCP → Dynamic Host Configuration Protocol
 - Confined to a single local-area network (LAN)
 - Rely on broadcast capability

Key ideas in both ARP and DHCP

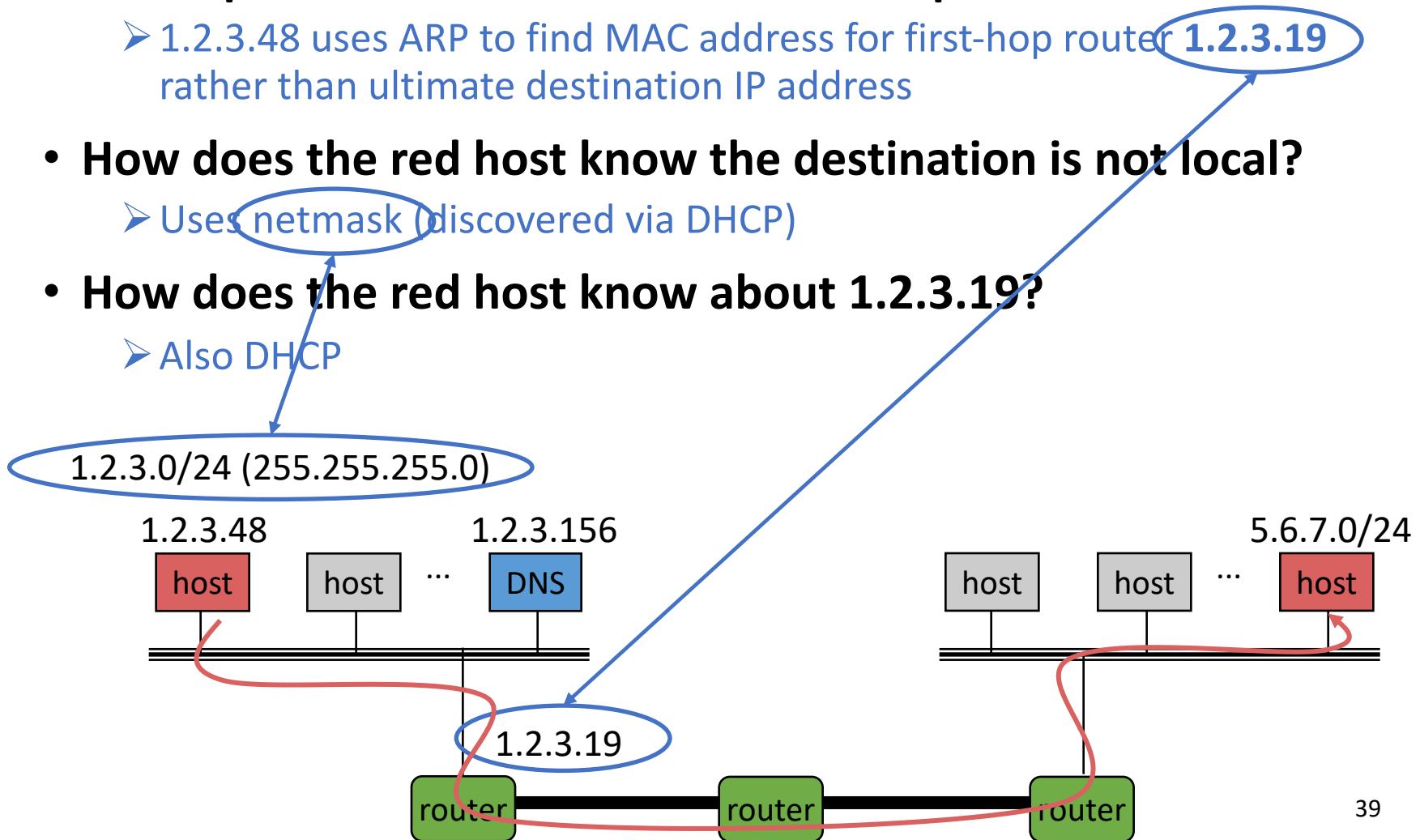
- **Broadcasting:** Can use broadcast to make contact
 - Scalable because of limited size
- **Caching:** remember the past for a while
 - Store the information you learn to reduce overhead
- **Soft state:** eventually forget the past
 - Associate a time-to-live field with the information
 - ... and either refresh or discard the information
 - Key for robustness in the face of unpredictable change

ARP: Address Resolution Protocol

- **Every host maintains an ARP table**
 - List of (IP address → MAC address) pairs
- **Consult the table when sending a packet**
 - Map dest. IP address to dest. MAC address
 - Encapsulate (IP) data packet with MAC header; xmit
- **What if IP address not in the table?**
 - Sender broadcasts: Who has IP address 1.2.3.156?
 - Receiver replies: MAC address 58-23-D7-FA-20-B0
 - Sender caches result in its ARP table

What if the destination is remote?

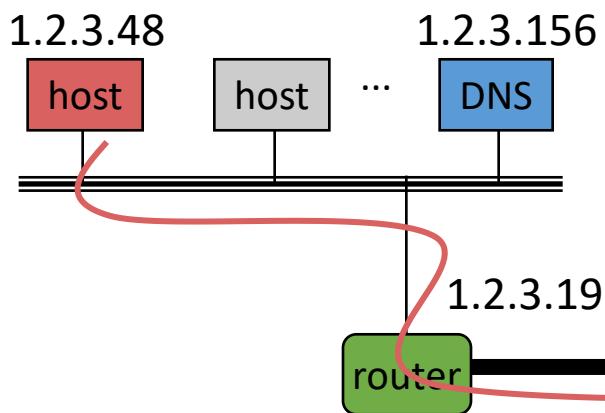
- Look up the MAC address of the first hop router
 - 1.2.3.48 uses ARP to find MAC address for first-hop router **1.2.3.19** rather than ultimate destination IP address
- How does the red host know the destination is not local?
 - Uses netmask (discovered via DHCP)
- How does the red host know about 1.2.3.19?
 - Also DHCP



Example Question

- Describe the process for 1.2.3.48 to access **www.foo.com** hosted on 5.6.7.10

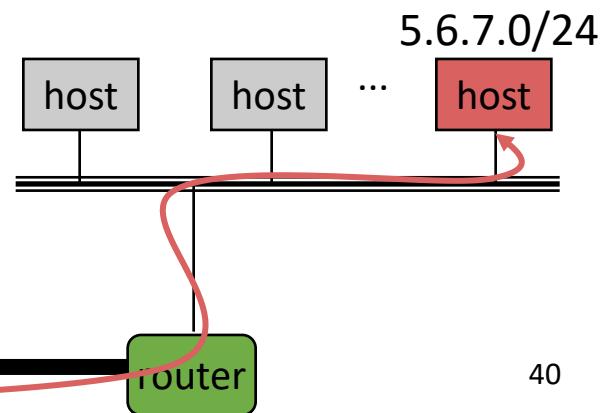
1.2.3.0/24 (255.255.255.0)



1.2.3.156

1.2.3.19

router

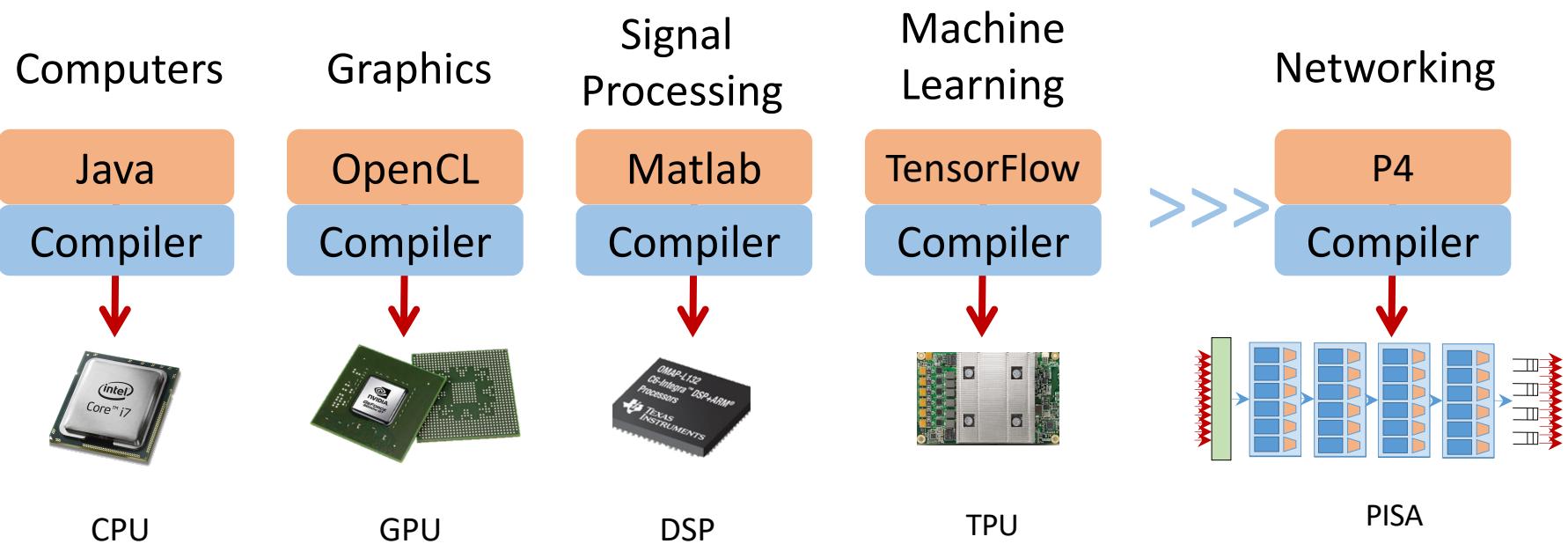


5.6.7.0/24

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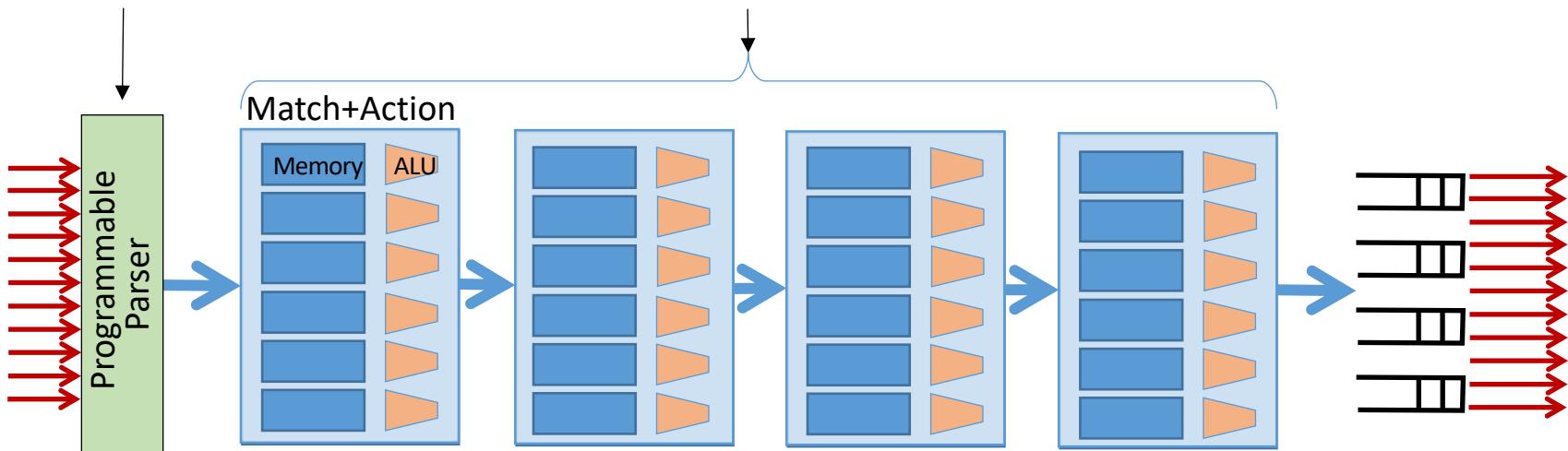
Domain Specific Processors



PISA: Protocol Independent Switch Architecture

Programmer declares which headers are recognized

Programmer declares what tables are needed and how packets are processed



All stages are identical – makes PISA a good “compiler target”

Summary of Programmable Networks

1. **Chip speed:** We can now make programmable switch chips as fast as fixed ones.
2. **Chip technology:** The difference in chip area and power between “programmable” and “fixed function” is going away.
3. **Chip complexity:** There are now too many protocols to correctly hard-code in silicon.
4. **New ideas:** Beautiful new ideas are owned by the programmer, not the chip designer.
5. **Level playing field:** Lets us create a solid platform, an abstraction layer, upon which more will be built

To learn more, visit P4.org

Wireless link characteristics

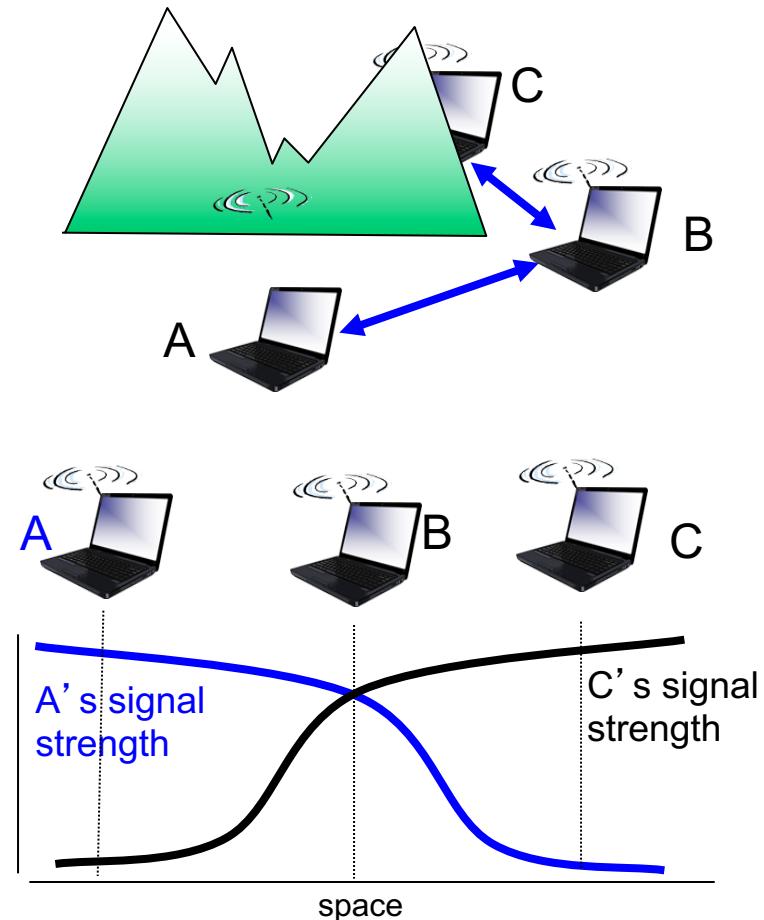
- **Three important differences from wired link ...**
 - **Decreased signal strength:** Radio signal attenuates as it propagates through matter (path loss)
 - **Multipath propagation:** Radio signal reflects off objects ground, arriving at destination at slightly different times
 - **Interference from other sources:** Standardized wireless network frequencies (e.g., 2.4 GHz) shared by other devices (e.g., phone); devices (motors) interfere as well
- **... make communication across (even a point-to-point) wireless link much more “difficult”**

Wireless network characteristics

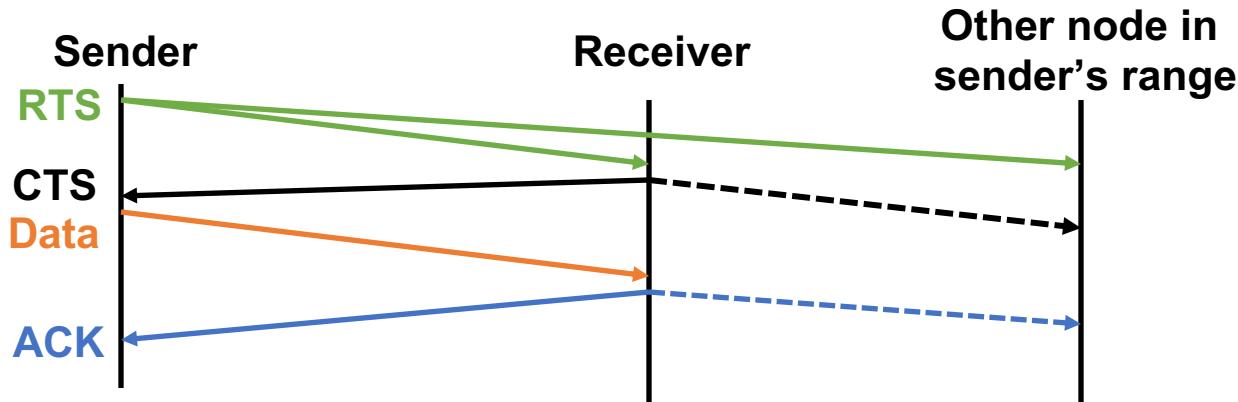
- **Multiple wireless senders and receivers create many problems**
 - Multiple access issues
 - Hidden terminal problem

Hidden terminal problem

- B, A hear each other
- B, C hear each other
- A, C can not hear each other
- Hence, A, C are unaware of their interference at B



CSMA/CA



- **Before every data transmission**
 - Sender sends a Request to Send (RTS) frame with the length of transmission and the destination
 - Receiver respond with a Clear to Send (CTS) frame
 - Sender sends data
 - Receiver sends an ACK
- **If sender doesn't get a CTS back, it assumes collision**

General goals for communication security: CIA

- **Confidentiality**
 - No one **read** our communication
 - Cryptography
- **Message Integrity**
 - No one can **modify** our communication w/o detection
 - Verification
- **Availability and Authentication**
 - Redundancy, DoS/DDoS prevention
 - Only we can **access** our data and communicate on our behalf

Computer networks is a fast growing area

- **Software-Defined Networking**
- **Cloud Computing**
- **Network Virtualization**
- **Network Testing and Verification**
- **Big Network Data Processing**
- **AI and Networking**
- **Internet of Things**
- **Bitcoin and Blockchain**

Summary

- **Final exam:**
 - Time: 7pm-9pm, Wednesday, December 16
 - Location: online
- **2021 Spring: EN.601.714 Advanced Computer Networks**
- **THANK YOU SO MUCH!!!**

Thanks!
Q&A