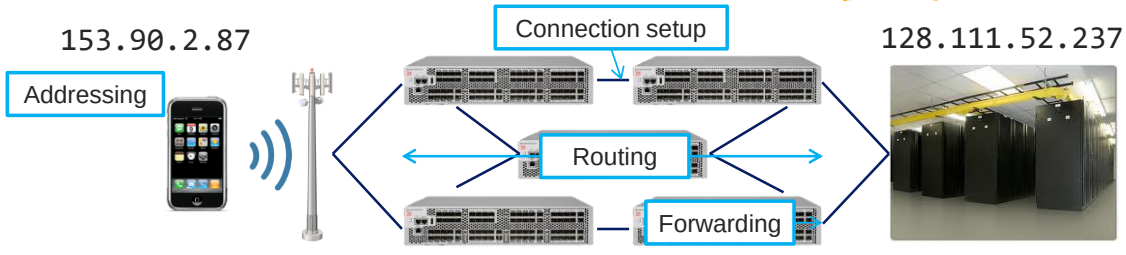
MONTANA STATE UNIVERSITY

Chapter 4: Network Layer – Data Plane

Data Forwarding Methods

Network layer functionality

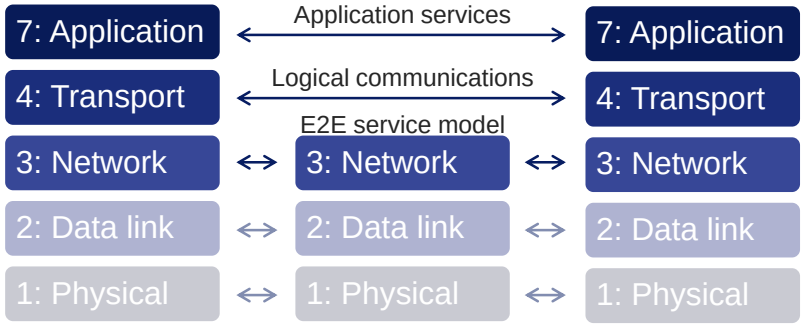
MONTANA STATE UNIVERSITY



Logic on every node in the network – no longer E2E

Forwarding decisions based on packet headers and routing tables

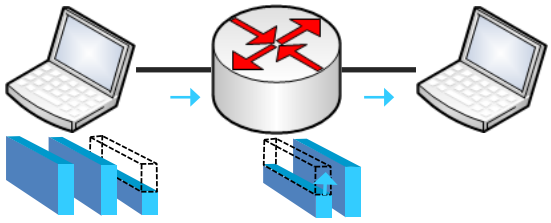
How can packets arrive out of order at a receiver?



Forwarding methods

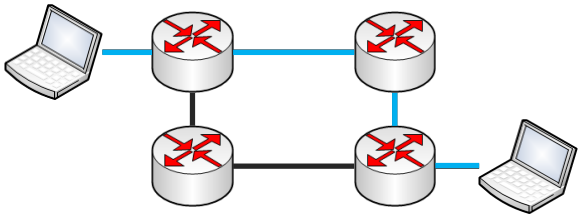
MONTANA STATE UNIVERSITY

Packet switching

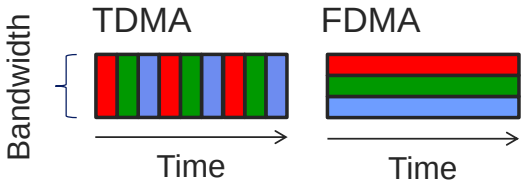


- *Store and forward*: entire packet must arrive at router before it can be transmitted on next link
- Assuming packet has l bits and link capacity r, what is the end-to-end delay over two hops?
  (assume only serialization delay)

Circuit switching



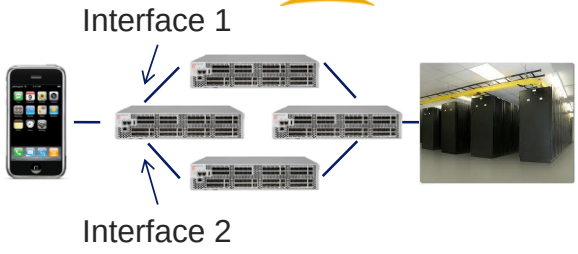
- End-to-end resources reserved for the duration of transmission



Datagram networks

MONTANA STATE UNIVERSITY

- Datagram network provides network-layer *connectionless* service
  - No call setup at network layer
  - Routers: no state about end-to-end connections
- Packets forwarded to *ranges* of destination addresses

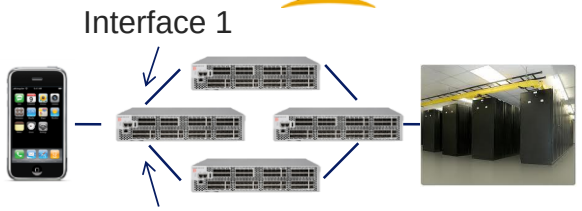


Address range	Interface
128.11.52.0 – 128.11.52.255	1
153.90.2.0 – 153.90.2.255	2
153.90.2.87 – 153.90.2.89	1

Virtual Circuit (VC) networks

MONTANA STATE UNIVERSITY

- Virtual-circuit network provides network-layer connection service
  - Call setup, teardown for each call before data can flow
  - Every router on source-dest path maintains "state" for each passing connection
  - Bandwidth and buffers allocated to VC (dedicated resources = predictable service)
- Packets forwarded using VC identifiers:
  - VC ids embedded in cells (packets)
  - Router looks up outgoing interface for VC id
- Can you think of advantages and disadvantages of VC-based forwarding?
  - \+ Smaller headers, instant forwarding
  - – Per-flow state at router



Are VC ids unique for the whole network?

In interface	In VC id	Out VC id	Out interface
1	6	22	1
1	7	13	2
1	13	5	1

Network layer service models

MONTANA STATE UNIVERSITY

Network architecture	Service model	Guarantees				Congestion feedback
		Bandwidth	Loss	Order	Timing	
Internet	Best effort	none	no	no	no	no (inferred from loss)
ATM	CBR	constant rate	yes	yes	yes	no
ATM	ABR	guaranteed minimum	no	yes	no	yes
ATM	UBR	none	no	yes	no	no

VC or Datagram network: why?

MONTANA STATE UNIVERSITY

ATM (VC)

- Evolved from telephony
- Human conversation:
  - Strict timing, reliability requirements
  - Need for guaranteed service
- "Dumb" end systems
  - Telephones
  - Complexity inside network

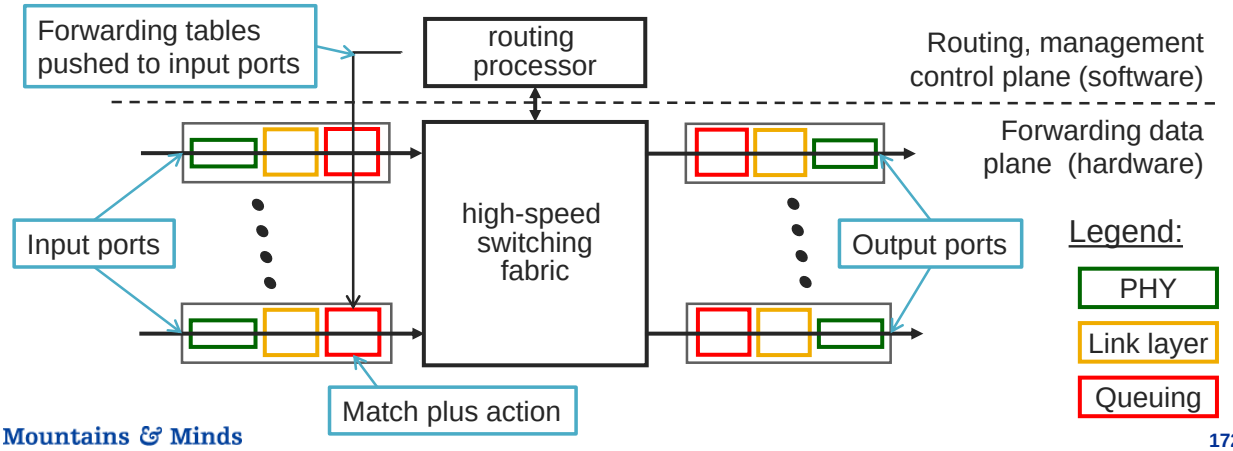
Internet (datagram)

- Data exchange among computers
  - "Elastic" service, no strict timing requirements
- Many link types
  - Different characteristics
  - Uniform service difficult
- "Smart" end systems (computers)
  - Can adapt, perform control, error recovery
  - Simple inside network, complexity at "edge"

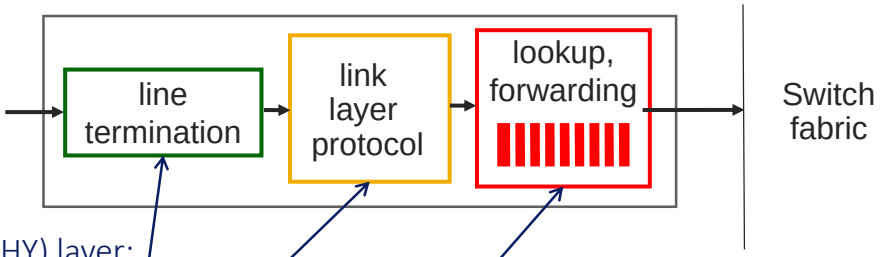
Router architecture overview

MONTANA STATE UNIVERSITY

- Two key router functions:
  - Run routing algorithms/protocol (RIP, OSPF, BGP), but also can be centrally configured
  - Forwarding datagrams from incoming to outgoing link



Input port functions



Physical (PHY) layer:
bit-level reception

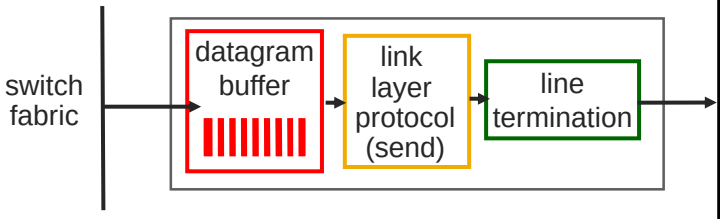
Data link layer:
e.g., Ethernet
see chapter 6

Decentralized switching:

- Given datagram destination, lookup output port using forwarding table in input port memory
- Goal: complete input port processing at 'line speed'
- Queuing: if datagrams arrive faster than forwarding rate into switch fabric

Output ports

- Buffering required when datagrams arrive from fabric faster than the transmission rat
- How much buffer space?
  - RTT * link capacity
  - RTT * link capacity / sqrt(num. flows.)
- Scheduling discipline chooses among queued datagrams for transmission
  - First come first serve (FCFS)
  - Weighted fair queuing (WFQ)
  - Other QoS mechanisms



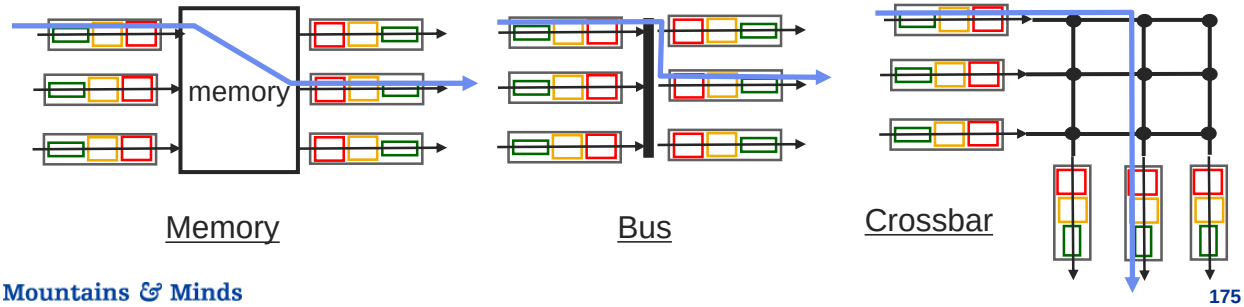
- Active queue management (AQM): Random Early Detection (RED)
  - Queue length < `min_th`?: enqueue packet
  - Queue length > `max_th`?: drop packet
  - Queue length in `[min_th, max_th]`: drop packet with probability tied to queue length
- Why would this be beneficial?
  - Think of a scenario with multiple TCP flows.

Switching fabrics

MONTANA STATE UNIVERSITY

- Transfer packet from input buffer to appropriate output buffer
- Switching rate: rate at which packets can be transferred from inputs to outputs
  - Often measured as multiple of input/output line rate
  - N inputs: switching rate N times line rate desirable
- Three types of switching fabrics

Which is best? Discuss relative advantages. Consider different forwarding patterns and describe performance bottlenecks.



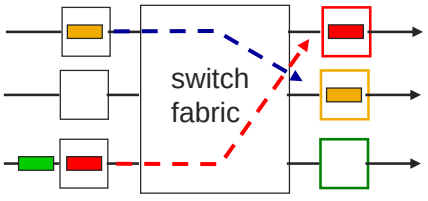
Memory Bus Crossbar

Queuing scenarios

MONTANA STATE UNIVERSITY

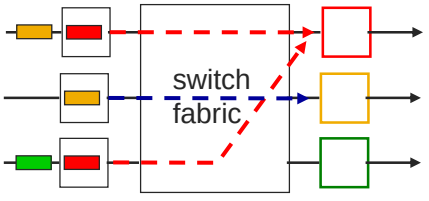
- Where are packets queued when:
  - Line speed in = switch fabric speed = line speed out?
  - Line speed in = switch fabric speed > line speed out?
  - Line speed in << switch fabric speed >> line speed out?

Head of line (HOL) blocking



Green packet experiences HOL blocking

Output port contention



Only one red datagram can be transferred. *Lower red packet is blocked*