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Advanced Networking Concepts
Network layer part 1

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1. Introduction Network Layer
1.1 Forwarding and Routing
1.2 Data and Control Plane

2. Network Service Model

3. Inside a Router

4. Queuing
4.1 Buffering
4.2 Scheduling

5. Middleboxes

Reading instructions

This lecture and its figures are based on and adapted from:

- [1, Chapter 4]

It should be regarded as a complement to the assigned reading in the chapter above.

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Introduction

Network layer

- Ensures that a package can reach a host in a different logical network.
- Below transport layer and above link layer.
- Hop-by-hop inspection

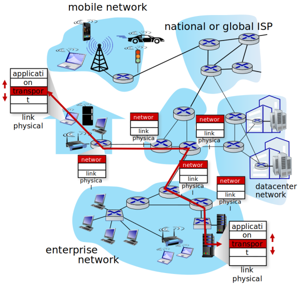

Figure: Network layer [1, figure 4.1]

Key functions

Forwarding

- Move a packet from an input port to an appropriate output port
- Multiple input and output ports
- Lots of packets

Routing

- Determine which output port a package should be sent out of
- $2^{32} - 1$ or $2^{128} - 1$ possible destinations
- Global network, multiple organisations, technologies, politics and economy to take into account.

Data plane

Data plane

- Handles forwarding
- High bandwidth, low overhead
- Operates at short timescales (e.g., nanoseconds).
- Buffers and queues

Control plane

Control plane

- Handles routing
- Network-wide logic
- Where to forward a package.
- Two approaches
  - Traditional
  - SDN

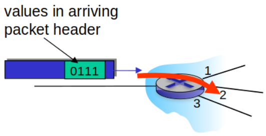

Figure: Routing algorithms [1, figure 4.2]

Routing — Traditional

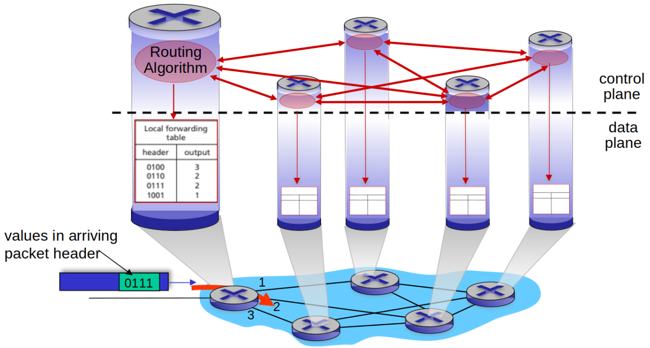

Figure: Routing algorithms [1, figure 4.2]

Routing — SDN

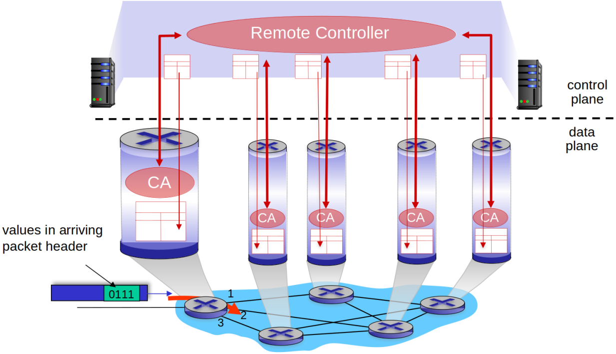

Figure: Remote controller [1, figure 4.3]

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What services *can* the network layer guarantee?

Individual packets

- Guaranteed delivery
- Guaranteed delivery with a bounded delay
- Security

Flows

- In-order packet delivery
- Guaranteed minimal bandwidth
- Security

What services *does* the network layer guarantee?

Network Architecture	Service Model	Bandwidth	Loss	Order	Timing
Internet	best effort	none	no	no	no
Internet	IntServ Guaranteed	yes	yes	yes	yes
Internet	DiffServ	possible	possibly	possibly	no

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Inside a router

Why is this interesting?

- Identifies challenges
- Visualize what is happening
- Helps understand mechanisms used

Inside a router

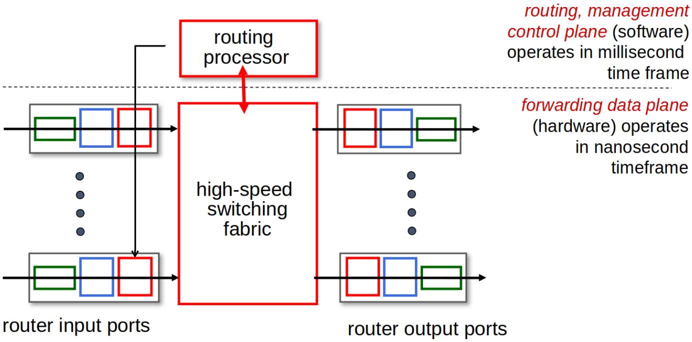

Figure: Inside a router [1, figure 4.4]

Input ports

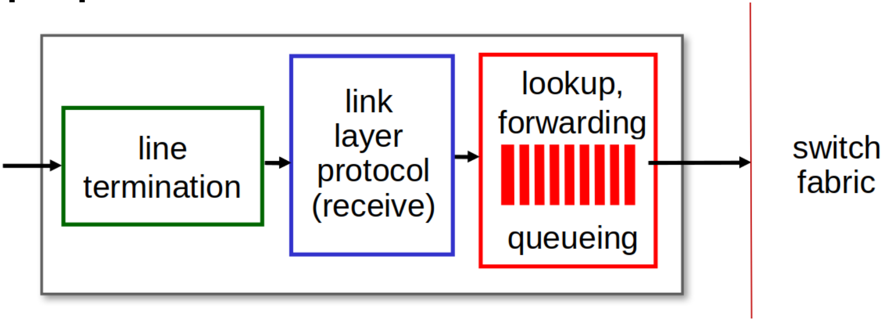

Figure: Input port processing [1, figure 4.5]

Routing Processor

Routing processor

Can be done either using *“Destination Based Forwarding”* or *“Generalized Forwarding”*.

Routing processor

Destination based forwarding

- Decision on outgoing interface based on destination address
- Each router decides independently how to forward packets.
- Decision based on the IP-protocol.
  - Routing table with known destinations
  - Decision based on the IP-address prefix
  - If multiple possible entries, longest match decides.

Routing processor

Generalized forwarding

- Use a central controller to decide how to forward packet
- Forwarding decision can be based on any header fields
- Forwarding unit is not considered to be a router.

Switching fabrics

Switching fabrics

- Transfers packet from incoming port to outgoing port.
- Ideal rate: $N \times R$ where N = ports, R = port speed.
- Memory, bus and interconnection network.

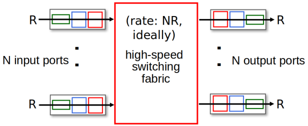

Figure: [1]

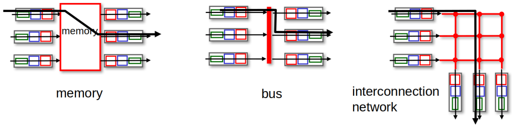

Figure: Three switching techniques [1, figure 4.6]

Switching via memory

- Switching is done directly by CPU
- Packet is copied into system´s memory
- Speed limited by memory bandwidth
  - 2 bus crossings per packet

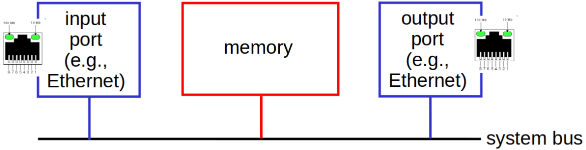

Figure: Memory Switching [1, figure 4.6]

Switching via bus

- Switching is done by shared bus
- Speed limited by bus bandwidth
    - Often very high (32 Gbps)

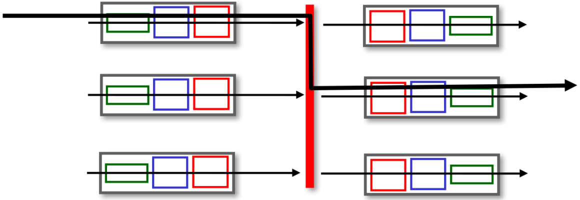

Figure: Bus Switching [1, figure 4.6]

Switching via interconnection network

- Crossbar, Clos networks, other interconnection nets developed to connect processors in multiprocessor environments.
- Fragment a packet into fixed length cells on entry
- reassemble packet at exit.

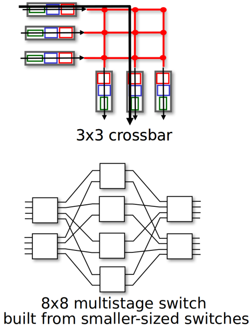

Figure: Crossbar Switching [1, figure 4.6]

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Input port queuing

- If switching fabric is slower than the rate of incoming packets
- Head-of-the-Line blocking
    - Packet in outgoing port queue is blocking incoming packets to be forwarded
- Queueing delay and packet losses.

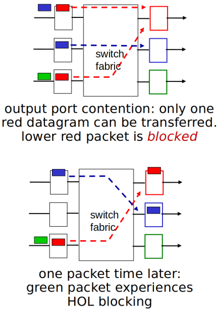

Figure: Input queued switch [1, figure 4.8]

Output port queuing

- If packets arrive faster from fabric than link transmission rate
- Output port buffer overflow causes high delay and packet losses.
- Drop policy if buffers are full:
  - Which packets to drop?
  - Drop everything that arrives, AQM
- Scheduling discipline
  - Which packet to send?
  - FIFO, Priority based?

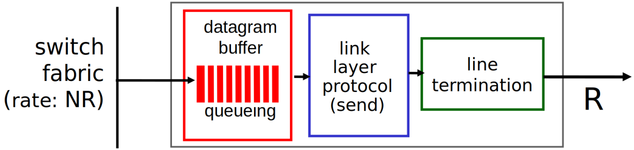

Figure: Output port processing [1, figure 4.7]

How much buffering?

Recommendation

$$\frac{RTT \times C}{\sqrt{N}}$$ *Where C = Capacity, N = Number of flows.*

- Based on TCPs sawtooth principle
- Only valid on many long-lived independent flows
- Assumes TCP-flows are not synchronising.

Too much buffering?

- Increase delay
- generate more packets
- bufferbloat

Buffer management

- Drop:
  - Tail drop
  - Priority
- Marking:
  - Which packets should be dropped
  - ECN, AQM (RED, CODEL)

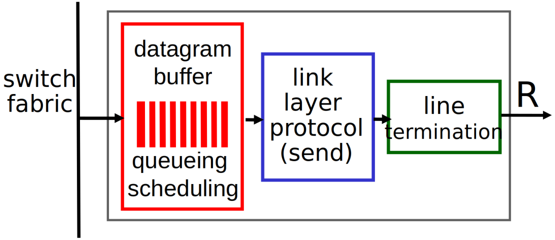

Figure: Output port processing [1, figure 4.7]

Packet Scheduling

Which packet to send next?

- FCFS
- Priority
- Round Robin
- WFQ

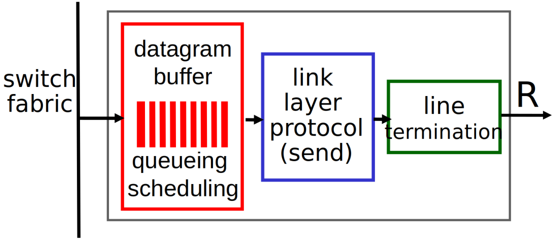

Figure: Output port processing [1, figure 4.7]

Packet Scheduling — Priority

Priority scheduling

- Arriving packets are classified and queued by class.
- Highest class sent first
  - FCFS within a class
  - Starvation

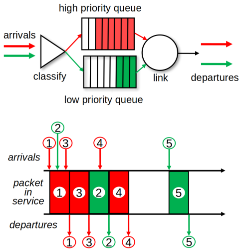

Figure: The priority queueing model [1, figure 4.13]

Packet Scheduling — Round Robin

Priority scheduling

- Arriving packets are classified and queued by class.
- Cyclically sending packets from each class
    - FCFS within a class
    - Solves starvation
    - No true prioritization

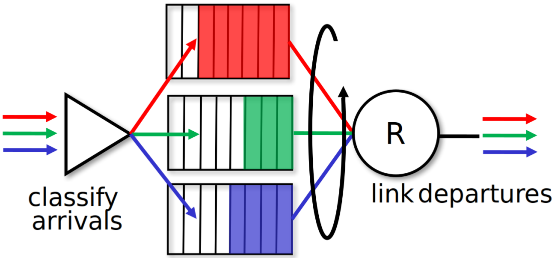

Figure: Weighted queueing [1]

Packet Scheduling — Weighted Fair Queuing

WFQ

- Arriving packets are classified and queued by class.
- Generalized round robin
    - Each class has weight, W_i
    - FCFS within a class
    - Solves starvation
    - Allows prioritization
    - $\frac{W_i}{\sum W_j}$

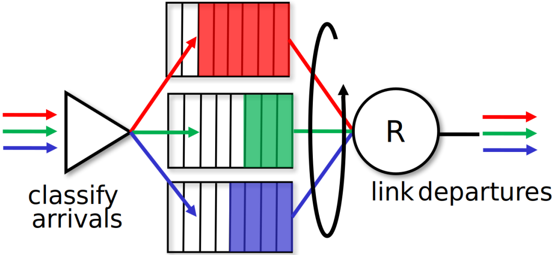

Figure: Weighted queueing [1]

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IP Hourglass “Narrow waist”

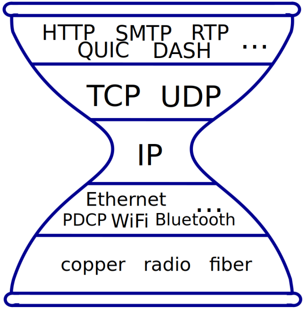

Figure: IP Hourglass [1, figure 4.31]

Middleboxes

Middlebox RFC 3234

"any intermediary box performing functions apart from normal, standard functions of an IP router on the data path between a source host and destination host"

Middleboxes functions

- NAT
- Security
- Performance enhancement

Examples of Middleboxes

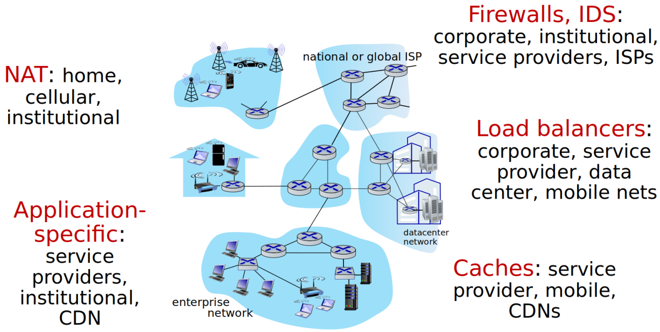

Figure: Middleboxes [1]

Middleboxes Services

NAT

- Allows multiple hosts with private addresses to share public addresses
- Middlebox keeps a record of which src ip+port is connecting to which dst ip+port
- Rewrites the source address to a public address the middlebox responds to.

Middleboxes cont.

Security

- Firewalls
- Intrusion Detection
- Application level filtering services
- VPN

Middleboxes cont.

Performance enhancement

- Compression
- Caching
- Load balancing

Middleboxes cont.

- Initially proprietary hardware solutions
- Becoming more common with open software based solutions
- Software solutions allows us to deploy these functions dynamically and at scale
- Software Defined Networking architecture
- Network Function Virtualisation (NFV)

IP Hourglass “The love handles”

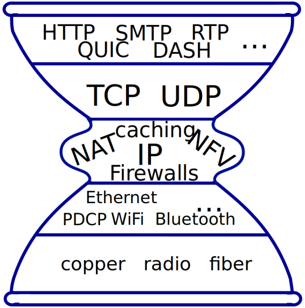

Figure: Middleage IP Hourglass [1]

Architectural Principles of the Internet

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Three cornerstone beliefs

- Goal: Simple connectivity
- Tool: IP protocol
- Intelligence and complexity at network edge

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