Chapter 4
Network Layer

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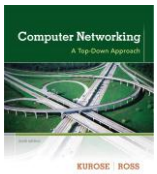


Computer Networking: A Top Down Approach
6th edition
Jim Kurose, Keith Ross
Addison-Wesley
March 2012

The course notes are adapted for Bucknell's CSCI 363
Xiannong Meng
Spring 2016

Chapter 4: outline

4.1 introduction
4.2 virtual circuit and datagram networks
4.3 what's inside a router
4.4 IP: Internet Protocol
- datagram format
- IPv4 addressing
- ICMP
- IPv6

4.5 routing algorithms
- link state
- distance vector
- hierarchical routing

4.6 routing in the Internet
- RIP
- OSPF
- BGP

4.7 broadcast and multicast routing

Some examples of switchers, routers, and bridge

Linksys 48 port switch
(Wikipedia)

Back of a typical home router
(Wikipedia)

Cisco CRS-1 Core Router
(Wikipedia)

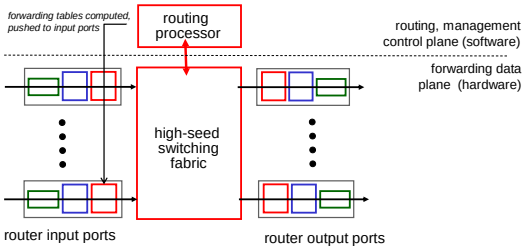
Avaya ERS 2550T-PWR 50-port network switch
(Wikipedia)

HP Procurve rack-mounted switches mounted in a standard Telco Rack 19-inch rack with network cables
(Wikipedia)

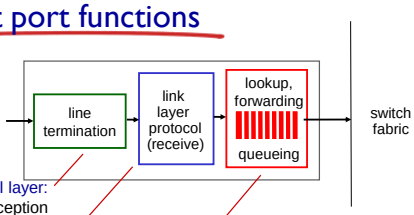
Rack-mounted 24-port 3Com switch
(Wikipedia)

Router architecture overview

two key router functions:
- run routing algorithms/protocol (RIP, OSPF, BGP)
- *forwarding* datagrams from incoming to outgoing link



Input port functions



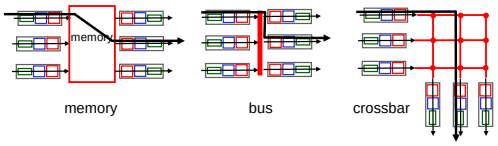
physical layer:
bit-level reception

data link layer:
e.g., Ethernet
see chapter 5

decentralized switching:
- given datagram dest., lookup output port using forwarding table in input port memory *("match plus action")*
- goal: complete input port processing at 'line speed'
- queuing: if datagrams arrive faster than forwarding rate into switch fabric

Switching fabrics

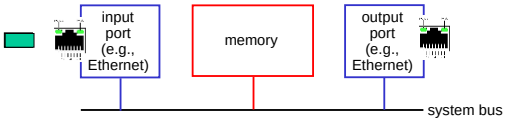
- transfer packet from input buffer to appropriate output buffer
- switching rate: rate at which packets can be transfer from inputs to outputs
  - often measured as multiple of input/output line rate
  - N inputs: switching rate N times line rate desirable
- three types of switching fabrics



Switching via memory

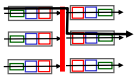
first generation routers:

- traditional computers with switching under direct control of CPU
- packet copied to system's memory
- speed limited by memory bandwidth (2 bus crossings per datagram)



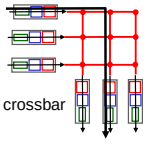
Switching via a bus

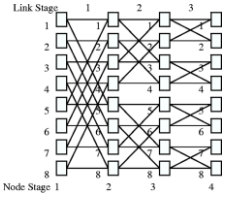
- datagram from input port memory to output port memory via a shared bus
- *bus contention:* switching speed limited by bus bandwidth
- 32 Gbps bus, Cisco 5600: sufficient speed for access and enterprise routers



Switching via interconnection network

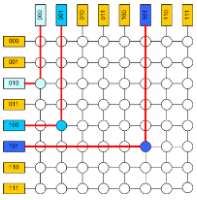
- overcome bus bandwidth limitations
- banyan networks, crossbar, other interconnection nets initially developed to connect processors in multiprocessor
- advanced design: fragmenting datagram into fixed length cells, switch cells through the fabric.
- Cisco 12000: switches 60 Gbps through the interconnection network





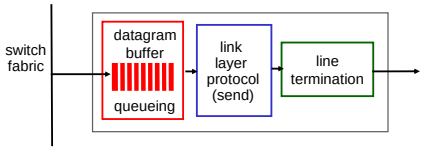
A 3-stage Banyan network switch logic (n/2 log n) switching elements. In the diagram, each node is a 2x2 switch. This is a 16x16 switch (16 inputs and 16 outputs, 8 nodes, each with 2 inputs and 2 outputs.)

Images from Google



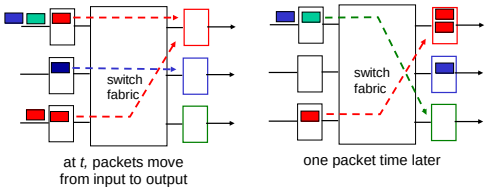
A cross-bar network switch logic (nxn switching elements)

Output ports



- *buffering* required when datagrams arrive from fabric faster than the transmission rate
- *scheduling discipline* chooses among queued datagrams for transmission

Output port queueing



- buffering when arrival rate via switch exceeds output line speed
- *queueing (delay) and loss due to output port buffer overflow!*

How much buffering?

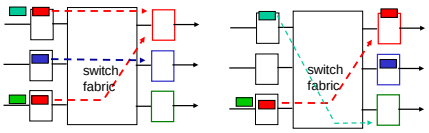
- RFC 3439 (December 2002) rule of thumb: average buffering equal to "typical" RTT (say 250 msec) times link capacity C (RTT * C)
  - e.g., C = 10 Gpbs link: 2.5 Gbit buffer
- more recent (2004) recommendation: with *N* flows, buffering equal to

$$\frac{RTT \cdot C}{\sqrt{N}}$$

http://yuba.stanford.edu/~nickm/papers/guido_buffer.pdf

Input port queuing

- fabric slower than input ports combined -> queueing may occur at input queues
  - *queueing delay and loss due to input buffer overflow!*
- Head-of-the-Line (HOL) blocking: queued datagram at front of queue prevents others in queue from moving forward



output port contention: only one red datagram can be transferred. *lower red packet is blocked*

one packet time later: green packet experiences HOL blocking

Queues, queues, and queues

- The theory of queuing has significant applications and impact on the internet.
- One of the pioneers of the internet, Leonard Kleinrock, is also known for his queuing systems book
  - Kleinrock is a computer science professor at UCLA
  - http://www.lk.cs.ucla.edu/index.html
  - Queuing systems books
  - http://www.amazon.com/Queueing-Systems-Volume-1-Theory/dp/0471491101

Names, names, names

- The naming of switchers, routers, and bridges can be confusing. In general, a *switch* implies that some or all ports have dedicated circuits; a *router* can forward traffic from input to output following certain algorithms (similar to switch) where ports may share circuits; a *bridge* interconnects different networks, some of which may run different protocols.
- A device can be called a switch, a router, a routing switch, a bridge, or the like

Devices with different protocol layers

- Switches can run at different protocol layers
  - Layer 2 switches use data link layer protocol (e.g., Ethernet)
  - Layer 3 switches run network protocols (e.g., IPv4)
- Routers typically run at data link layer (layer 2)
- More specifics to come