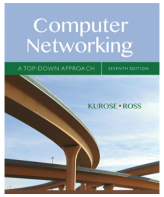
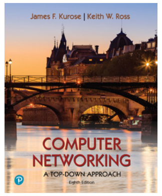
Chapter 4
Network Layer: Data Plane

Courtesy to the textbooks' authors and Pearson Addison-Wesley because many slides are adapted from the following textbooks and their associated slides.



Jim Kurose, Keith Ross, "Computer Networking: A Top Down Approach", 7th Edition, Pearson, 2016.



Jim Kurose, Keith Ross, "Computer Networking: A Top Down Approach", 8th Edition, Pearson, 2020.

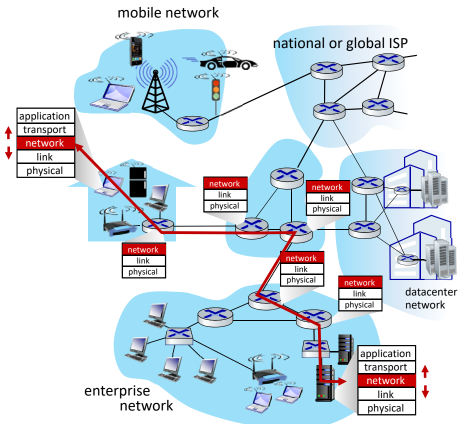
Network layer: "data plane" roadmap

- Network layer: overview
  - forwarding
  - routing
- What's inside a router
  - input ports, switching, output ports
  - buffer management, scheduling
- IP: the Internet Protocol
  - datagram format
  - addressing
  - network address translation
  - IPv6

- Generalized forwarding, SDN
  - match+action
  - OpenFlow: match+action in action
- Middleboxes

Network-layer services and protocols

- network layer protocols in *many Internet device*, including
  - hosts, routers
    - unlike transport layer protocols (not on routers)
- routers:
  - examines header fields in all IP datagrams passing through it
  - moves datagrams from input ports to output ports to transfer datagrams along end-to-end path



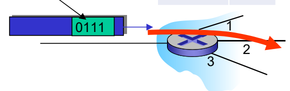
Two key network-layer functions

network-layer functions:

- *forwarding:* move packets from a input port/link to appropriate output port/link

header	port
0111	2
0010	1

values in arriving packet header



- *routing:* determine route/path taken by packets from source to destination
  - *routing algorithms*

analogy: taking a trip

- *forwarding:* process of getting through single interchange
- *routing:* process of planning trip from source to destination

forwarding

routing

Network service model

Q: What *service model* for "channel" transporting datagrams from sender to receiver?

example services for *individual* datagrams:

- guaranteed delivery (or not)
- guaranteed delivery with less than 40 msec delay (or not)

example services for a *flow* of datagrams:

- in-order datagram delivery (or not)
- guaranteed minimum bandwidth to a flow (or not)
- restrictions on changes in inter-packet spacing (or not)

Network-layer service model

Network Architecture	Service Model	Quality of Service (QoS) Guarantees ?			
		Bandwidth	Loss	Order	Timing
Internet	best effort	none	no	no	no

Internet "best effort" service model

No guarantees on:

i. successful datagram delivery to destination
ii. timing or order of delivery
iii. bandwidth available to end-to-end flow

Network-layer service model

Network Architecture	Service Model	Quality of Service (QoS) Guarantees ?			
		Bandwidth	Loss	Order	Timing
Internet	best effort	none	no	no	no
ATM	Constant Bit Rate	Constant rate	yes	yes	yes
ATM	Available Bit Rate	Guaranteed min	no	yes	no
Internet	Intserv Guaranteed (RFC 1633)	yes	yes	yes	yes
Internet	Diffserv (RFC 2475)	possible	possibly	possibly	no

Reflections on best-effort service:

- simplicity of mechanism has allowed Internet to be widely deployed and adopted
- sufficient provisioning of bandwidth allows performance of real-time applications (e.g., interactive voice, video) to be "good enough" for "most of the time"
- Internet's basic best-effort service model combined with adequate bandwidth provisioning have arguably proven to be more than "good enough"
  - to enable an amazing range of applications including
    - streaming video services such as Netflix and
    - video-over-IP, real-time conferencing applications such as Skype and Google Meet