

# The Network Layer

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- Network Layer Overview
  - Transport segment from sending to receiving host
    - \* Sender: encapsulates segments into packets, passes to link layer
    - \* Receiver: extracts segments from packets and delivers segments to transport layer protocol
- Network Layer Functions
  - Forwarding: move packets from router's input link to appropriate router's output link
  - Routing: determine route taken by packets from source to destination
    - \* Routing Algorithms
  - Analogy: Taking a Trip
    - \* Forwarding: process of getting through single intersection
    - \* Routing: process of planning trip from source to destination
- Data Plane
  - Local, per-router function
  - Determines how packet arriving on router input port is forwarded to router output port
- Control Plane
  - Network-wide logic
  - Determines how packet is routed among routers along end-end path from source host to destination host
  - Two control-plane approaches

- \* Traditional routing algorithms: implemented in routers
  - \* Software-Defined Networking (SDN): implemented in (remote) servers
- Traditional Control Plane Algorithms
  - Individual routing algorithm components in each and every router interact in the control plane
- SDN Control Plane
  - Remote controller interacts with local Control Agents (CAs) to compute, install forwarding tables in routers
- Network Layer Service Model
  - A network layer service model defines the characteristics of end-to-end transport of packets between sending and receiving hosts
  - Examples of possible services (this is only a partial list, there are countless variants):
    - \* Guaranteed delivery
    - \* Guaranteed delivery with bounded delay
    - \* In-order packet delivery
    - \* Guaranteed minimum transmission rate
    - \* Security
  - Services provided by the network layer: two main options
    1. Connection-oriented service
      - \* A path from source all the way to destination must be established before any data packets can be sent
        - This connection is called a Virtual Circuit (VC)
        - The network is called a virtual-circuit network
        - Each VC requires router table space and reservation of resources
      - \* Designed to provide some quality of service (QoS) (*i.e.* maximum delay guarantees, minimum losses, minimum throughput guarantees, etc.)
      - \* Example: Asynchronous Transfer Mode (ATM) → popular in the 90s early 200, being replaced by all-IP architectures
    2. Connectionless service
      - \* Best-effort service
      - \* Packets are injected into the network individually and routed independently of each other
      - \* No advance setup is needed
      - \* No error or flow service functionalities provided

- The transport layer might do something end-to-end
  - The link layer might do something at the link level
  - \* For example, IP (internet protocol)
- Reflections on Best-Effort Service
  - Simplicity of mechanism has allowed Internet to be widely deployed and adopted
  - Sufficient provisioning of capacity allows performance of real-time applications (*e.g.* interactive voice, video) to be “good enough” for “most of the time”
  - Replicated, application-layer distributed services (data centers, content distribution networks) connecting close to clients’ networks, allow services to be provided from multiple locations
  - Congestion control at the transport layer of “elastic” services helps
- Input Ports
  - Decentralized Switching:
    - \* Using header field values, lookup output port using forwarding table in input port memory (“match plus action”)
      - Destination-based forwarding: forward based only on destination IP address (traditional)
      - Generalized forwarding: forward based on any set of header field values
      - Input port queueing: if packets arrive faster than forwarding rate into switch fabric
- Input Port Queueing
  - If switch 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 packet at front of queue prevents others in queue from moving forward
- Output Ports
  - Buffering required when packets arrive from fabric faster than link transmission rate
  - Drop policy: which packets to drop if no free buffers?
  - Scheduling discipline chooses among queued packets for next transmission
    - \* FCFS (First Come, First Served), priority, ...
- The Internet Protocol

- The glue that holds the whole Internet together (data plane)
  - \* Designed with internetworking in mind
- Provides a best-effort (no guarantee) way to transport IP packets (aka datagrams) from source to destination
  - \* Without regard to whether these machines are on the same network or whether there are other networks between them
- There are two versions of IP in use today
  - \* IPv4 (IP version 4)
    - The first “major version” of IP and currently the dominant protocol of the Internet
  - \* IPv6