The Network Layer

Michael Brodskiy
Professor: E. Bernal Mor

October 26, 2023

- 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 hoe 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 architecyres
    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