Network Layer Services

Chapter 7

Chapter 7: Network Layer Services

Chapter goals:

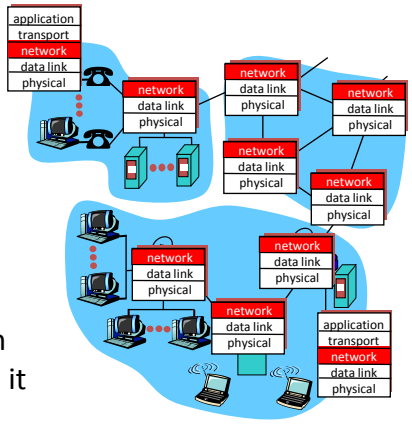
- understand principles behind network layer services:
  - routing (path selection)
  - dealing with scale
  - how a router works
- instantiation and implementation in the Internet

Outlines

1. Introduction
2. Virtual circuit and datagram networks
3. IP: Internet Protocol
   - Datagram format
   - IPv4 addressing

Network layer

- transport segment from sending to receiving host
- on sending side encapsulates segments into datagrams
- on receiving side, delivers segments to transport layer
- network layer protocols in *every* host, router
- Router examines header fields in all IP datagrams passing through it



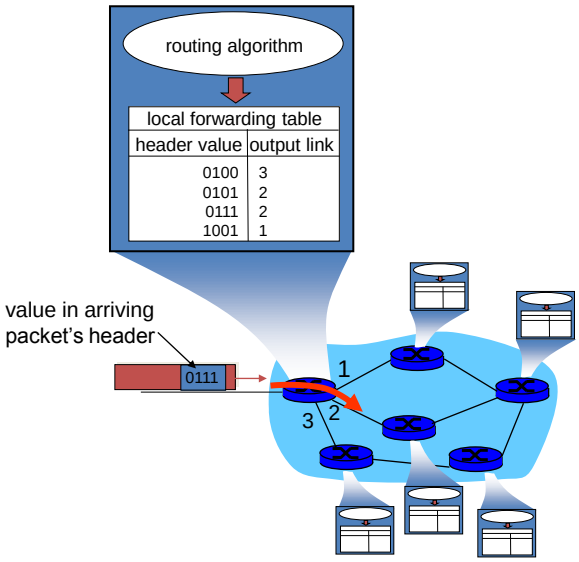
Key Network-Layer Functions

- *forwarding:* move packets from router's input to appropriate router output
- *routing:* determine route taken by packets from source to dest.
  - *Routing algorithms*

analogy:

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

Interplay between routing and forwarding



Connection setup

- 3rd important function in *some* network architectures:
  - ATM, frame relay, X.25
- Before datagrams flow, two hosts and intervening routers establish virtual connection
  - Routers get involved

Connection-Oriented and Connectionless Service

- Network layers can offer two types of service to the transport layer:
  - Connection-oriented service
    - Network layer provides the Transport layer with a reliable service: all packets will be delivered (flow control), in-sequence delivery.
    - Connection setup required before communication begins.
  - Connectionless service
    - No guarantee (latency, bandwidth …)
    - No prior connection setup required; packets are stored and forwarded one at a time by IMPs.
    - Provides flexibility in the routing and handling of individual packets and is robust in the face of IMP crashes.

1.2. Services provided by IP

- Connectionless Delivery (each datagram is treated individually).
- Unreliable (delivery is not guaranteed).
- Fragmentation / Reassembly (based on hardware MTU).
- Routing.
- Error detection.

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Network layer connection and connection-less service

- **Datagram network** provides network-layer connectionless service
- **VC network** provides network-layer connection service
- Analogous to the transport-layer services, but:
  - Service: host-to-host
  - No choice: network provides one or the other
  - Implementation: in the core

Virtual circuits

"source-to-dest path behaves much like telephone circuit"
- performance-wise
- network actions along source-to-dest path

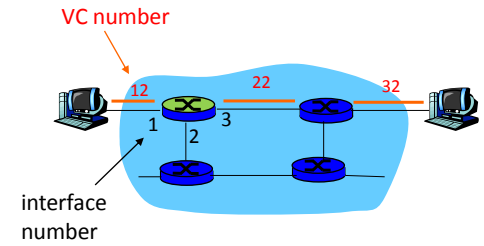
- call setup, teardown for each call *before* data can flow
- each packet carries VC identifier (not destination host address)
- *every* router on source-dest path maintains "state" for each passing connection
- link, router resources (bandwidth, buffers) may be *allocated* to VC

VC implementation

A VC consists of:

1. Path from source to destination
2. VC numbers, one number for each link along path
3. Entries in forwarding tables in routers along path
   - Packet belonging to VC carries a VC number.
   - VC number must be changed on each link.
     - New VC number comes from forwarding table

Forwarding table



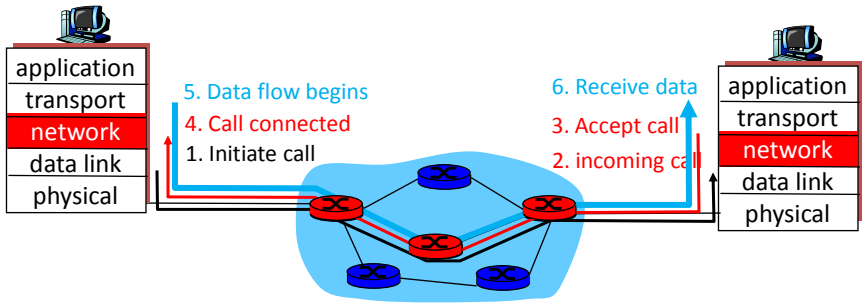
Forwarding table in northwest router:

Incoming interface	Incoming VC #	Outgoing interface	Outgoing VC #
1	12	3	22
2	63	1	18
3	7	2	17
1	97	2	87
…	…	…	…

Routers maintain connection state information!

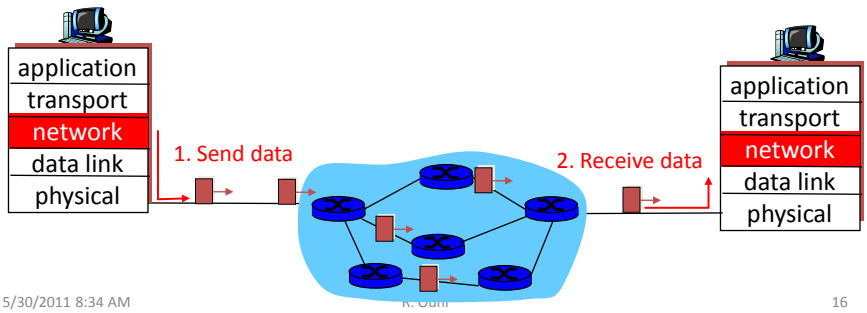
Virtual circuits: signaling protocols

- used to setup, maintain & teardown VC
- used in ATM, frame-relay, X.25
- not used in today's Internet



Datagram networks

- no call setup at network layer
- routers: no state about end-to-end connections
  - no network-level concept of "connection"
- packets forwarded using destination host address
  - packets between same source-dest pair may take different paths



Forwarding table

4 billion possible entries

Destination Address Range		Link Interface
11001000 00010111 00010000 00000000		
through	through	0
11001000 00010111 00010111 11111111		
11001000 00010111 00011000 00000000		
through	through	1
11001000 00010111 00011000 11111111		
11001000 00010111 00011001 00000000		
through	through	2
11001000 00010111 00011111 11111111		
otherwise	otherwise	3

Longest prefix matching

Prefix Match	Link Interface
11001000 00010111 00010	0
11001000 00010111 00011000	1
11001000 00010111 000111	2
otherwise	3

Examples

DA: 11001000 00010111 00010110 10100001 Which interface?

DA: 11001000 00010111 00011000 10101010 Which interface?

Datagram or VC network: why?

Internet

- data exchange among computers
  - "elastic" service, no strict timing requirement.
- "smart" end systems (computers)
  - can adapt, perform control, error recovery
  - simple inside network, complexity at "edge"
- many link types
  - different characteristics
  - uniform service difficult

ATM

- evolved from telephony
- human conversation:
  - strict timing, reliability requirements
  - need for guaranteed service
- "dumb" end systems
  - telephones
  - complexity inside network

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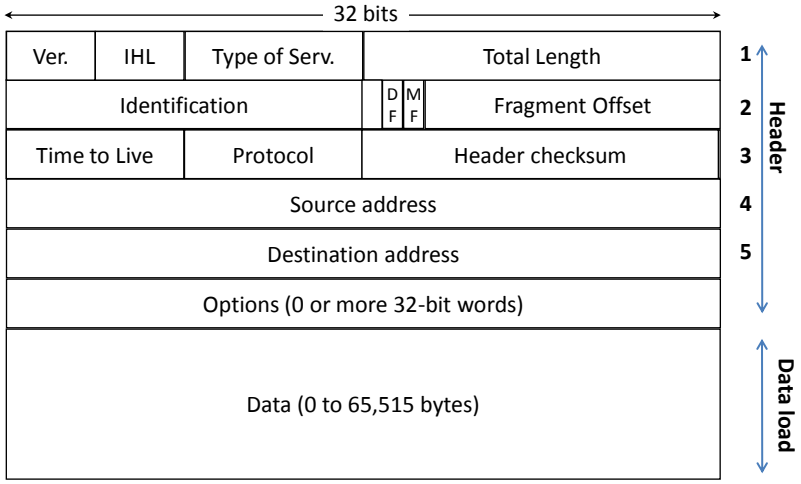
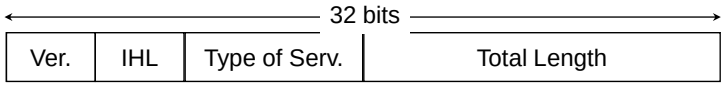
3. The Internet Protocol (IP)

- Provides delivery of packets from one host in the Internet to any other host in the Internet, even if the hosts are on different networks
- Internet packets are often called "datagrams" and may be up to 64 kilobytes in length (although they are typically much smaller)
- Internet IMPs are known as "routers" and they operate in a connectionless mode.
  - Router is a **store** and **forward** device. Treats packets **individually**.

3.1. IP Packet Format



IP Packet Fields



- Version
  - The IP version number (currently 4)
- IHL
  - IP Header Length in 32-bit words
- Type of Service
  - Contains priority information, used for traffic classification
- Total Length
  - The total length of the datagram in bytes
  - Includes header

IP Packet Fields *(cont´d)*

- Identification
  - When an IP packet is segmented into multiple fragments, each fragment is given the same identification
  - This field is used to reassemble fragments
- DF
  - Don't Fragment
- MF
  - More Fragments
  - When a packet is fragmented, all fragments except the last one have this bit set
- Fragment offset
  - The fragment's position within the original packet

IP Packet Fields *(cont´d)*

Time to Live	Protocol	Header checksum

- Time to Live (TTL)
  - Hop count, decremented each time the packet reaches a new router
  - When hop count = 0, packet is discarded
- Protocol
  - Identifies which transport layer protocol is being used for this packet
- Header Checksum
  - Verifies the contents of the IP header
  - Not polynomial-based

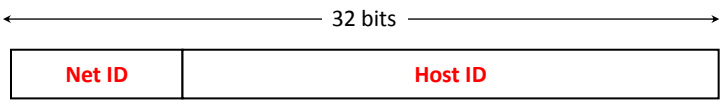
IP Packet Fields *(cont´d)*

Source address
Destination address
Options (0 or more 32-bit words)

- Source and Destination Addresses
  - Uniquely identify sender and receiver of the packet
- Options
  - Up to 40 bytes in length
  - Used to extend functionality of IP
  - Examples: source routing, security, record route

3.2. IP Addresses

- IP addresses are *logical* addresses (not physical)
- 32 bits (4 bytes) => IPv4
- Includes a network ID and a host ID.
- Every host must have a unique IP address.

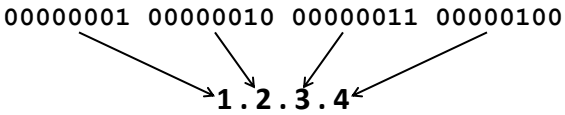


Network and Host IDs

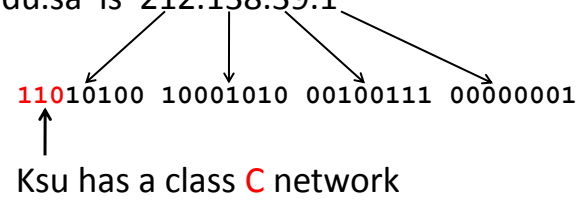
- A Network ID is assigned to an organization by a global authority.
- Host IDs are assigned locally by a system administrator.
- Both the Network ID and the Host ID are used for routing.

IP Addresses

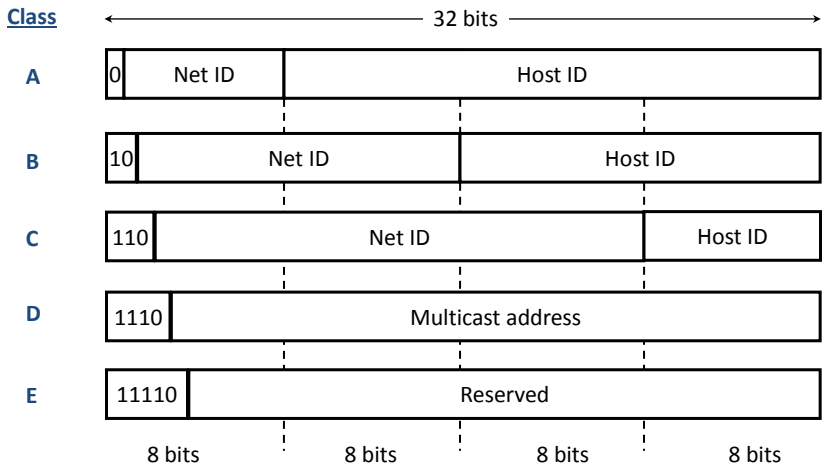
- IP Addresses are usually shown in *dotted decimal* notation:



- ksu.edu.sa is 212.138.39.1



IP Address Classes



Host and Network Addresses

- A single network interface is assigned a single IP address called the *host* address.
- A host may have multiple interfaces, and therefore multiple *host* addresses.
- Hosts that share a network all have the same IP *network* address (the network ID).

Routing steps based on routing table contents

Host or IMP gets the destination IP address:

1. **If** complete destination address found in routing table,
   then forward a packet to the destination.
2. **Else if** destination network ID found,
   then forward a packet to the next hop in the dest path.
3. **Else if** there is a default router,
   then deliver a packet toward the default hop.
4. **Otherwise**, an ICMP "host unreachable error" message is sent back to the sender.