Internet Protocols

Internet Protocols

- Internet Protocols
  - Small set of functions that form basis of all protocols
  - Not all protocols have all functions
    - Reduce duplication of effort
    - May have same type of function in protocols at different levels
  - Encapsulation
  - Fragmentation and reassembly
  - Connection control
  - Ordered delivery
  - Flow control
  - Error control
  - Addressing
  - Multiplexing
  - Transmission services

Encapsulation

- Data usually transferred in blocks
  - Protocol data units (PDUs)
  - Each PDU contains data and control information
  - Some PDUs only control
- Three categories of control
  - Address
    - Of sender and/or receiver
  - Error-detecting code
    - E.g. frame check sequence
  - Protocol control
    - Additional information to implement protocol functions
- Addition of control information to data is encapsulation
- Data accepted or generated by entity and encapsulated into PDU
  - Containing data plus control information
  - e.g. TFTP, HDLC, frame relay, ATM, AAL5, LLC, IEEE 802.3, IEEE 802.11

Fragmentation and Reassembly (Segmentation – OSI)

- Exchange data between two entities
- Characterized as sequence of PDUs of some bounded size
  - Application level message
- Lower-level protocols may need to break data up into smaller blocks. This is called ***fragmentation***
- Many reasons for fragmentation
  - Communications network may only accept blocks of up to a certain size
    - ATM 53 octets
    - Ethernet 1526 octets
  - More efficient error control
    - Smaller retransmission
  - Fairer
    - Prevent station monopolizing medium
  - Smaller buffers
  - Provision of checkpoint and restart/recovery operations

Disadvantages of Fragmentation

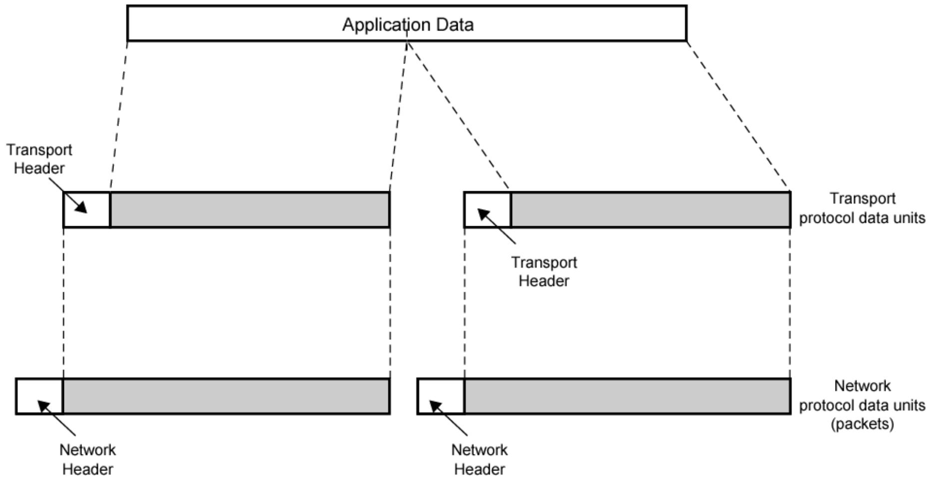
- Make PDUs as large as possible because
  - PDU contains some control information
  - Smaller block, larger overhead
- PDU arrival generates interrupt
  - Smaller blocks, more interrupts
- More time required to process many smaller PDUs

Reassembly

- Segmented data must be reassembled into messages
- More complex if PDUs have arrived out of order

PDUS and Fragmentation

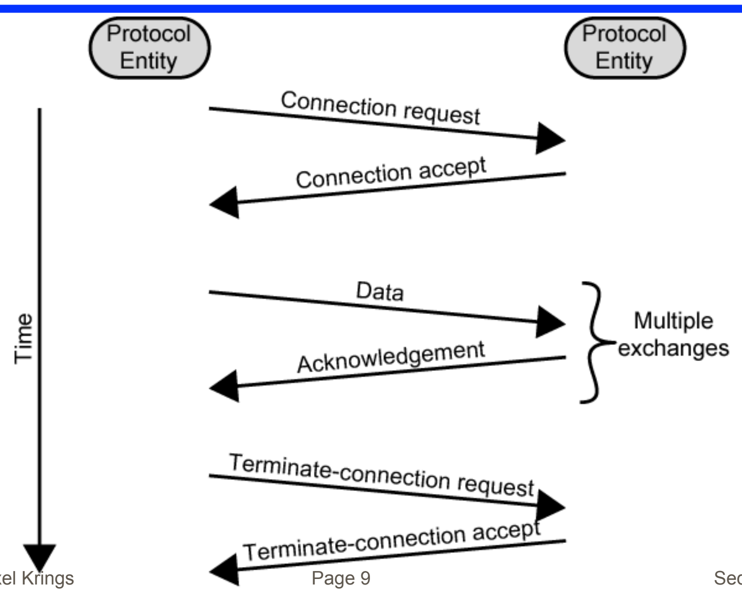
(Copied from chapter 2 fig 2.4)



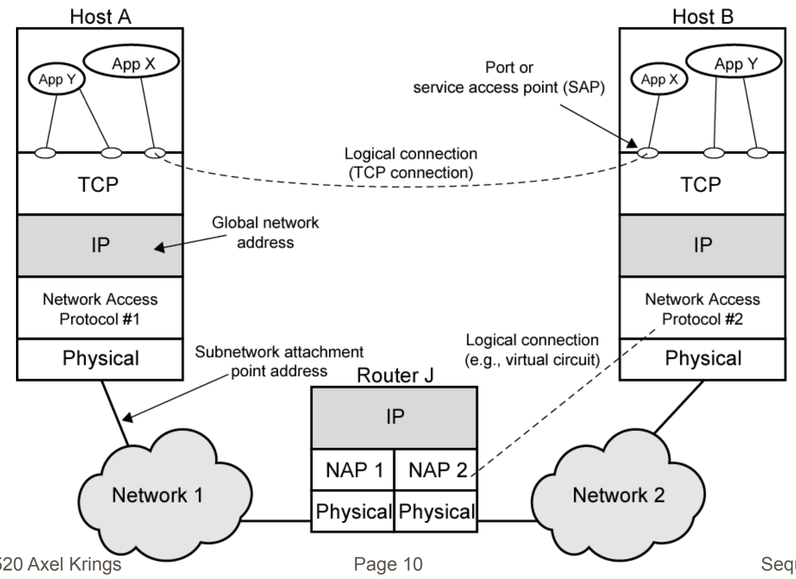
Connection Control

- Connectionless data transfer
  - Each PDU treated independently
  - E.g. datagram
- Connection-oriented data transfer
  - E.g. virtual circuit
- Connection-oriented preferred (even required) for lengthy exchange of data
- Or if protocol details must be worked out dynamically
- Logical association, or connection, established between entities
- Three phases occur
  - Connection establishment
  - Data transfer
  - Connection termination
  - May be interrupt and recovery phases to handle errors

Phases of Connection Oriented Transfer



TCP/IP Concepts



Internetworking Terms

- Communications Network
  - — Facility that provides data transfer service
- An internet
  - — Collection of communications networks interconnected by bridges and/ or routers
- The Internet - note upper case I
  - — The global collection of thousands of individual machines and networks
- Intranet
  - — Corporate internet operating within the organization
  - — Uses Internet (TCP/IP and http)technology to deliver documents and resources

Internetworking Terms (2)

- End System (ES)
  - —Device attached to one of the networks of an internet
  - —Supports end-user applications or services
- Intermediate System (IS)
  - —Device used to connect two networks
  - —Permits communication between end systems attached to different networks

Network Architecture Features

- Addressing
- Packet size
- Access mechanism
- Timeouts
- Error recovery
- Status reporting
- Routing
- User access control
- Connection based or connectionless

Architectural Approaches

- Connection oriented
- Connectionless

Connection Oriented

- Assume that each network is connection oriented
- IS connect two or more networks
  - —IS appear as ES to each network
  - —Logical connection set up between ESs
    - Concatenation of logical connections across networks
  - —Individual network virtual circuits joined by IS
- May require enhancement of local network services
  - —802, FDDI are datagram services

Connection Oriented IS Functions

- Relaying
- Routing

- e.g. X.75 used to interconnect X.25 packet switched networks

- Connection oriented not often used
  - —(IP dominant)

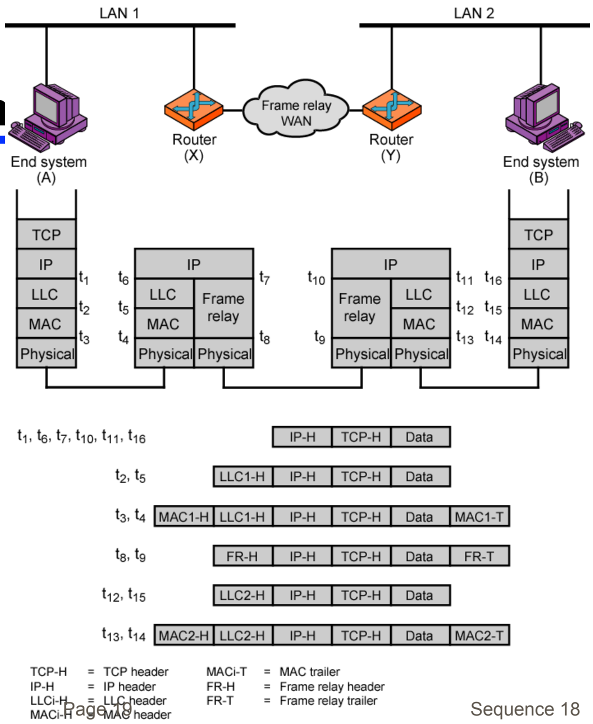
Connectionless Operation

- Corresponds to datagram mechanism in packet switched network
- Each NPDU treated separately
- Network layer protocol common to all DTEs and routers
  - Known generically as the internet protocol
- Internet Protocol
  - One such internet protocol developed for ARPANET
  - RFC 791 (Get it and study it)
- Lower layer protocol needed to access particular network

Connectionless Internetworking

- Advantages
  - Flexibility
  - Robust
  - No unnecessary overhead
- Unreliable
  - Not guaranteed delivery
  - Not guaranteed order of delivery
    - Packets can take different routes
  - Reliability is responsibility of next layer up (e.g. TCP)

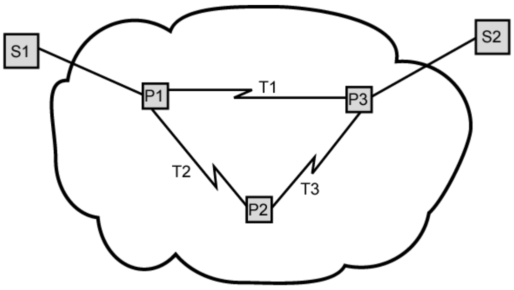
IP Operation



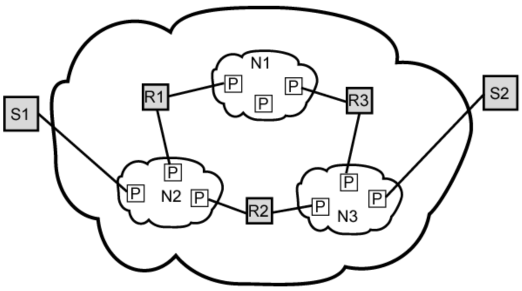
Design Issues

- Routing
- Datagram lifetime
- Fragmentation and re-assembly
- Error control
- Flow control

The Internet as a Network



(a) Packet-switching network architecture



(b) Internetwork architecture

Routing

- End systems and routers maintain routing tables
  - — Indicate next router to which datagram should be sent
  - — Static
    - May contain alternative routes
  - — Dynamic
    - Flexible response to congestion and errors
- Source routing
  - — Source specifies route as sequential list of routers to be followed
  - — Security
  - — Priority
- Route recording

Datagram Lifetime

- Datagrams could loop indefinitely
  - Consumes resources
  - Transport protocol may need upper bound on datagram life
- Datagram marked with lifetime
  - Time To Live field in IP
  - Once lifetime expires, datagram discarded (not forwarded)
  - Hop count
    - Decrement time to live on passing through a each router
  - Time count
    - Need to know how long since last router

Fragmentation and Re-assembly

- Different packet sizes
- When to re-assemble
  - At destination
    - Results in packets getting smaller as data traverses internet
  - Intermediate re-assembly
    - Need large buffers at routers
    - Buffers may fill with fragments
    - All fragments must go through same router
      - Inhibits dynamic routing

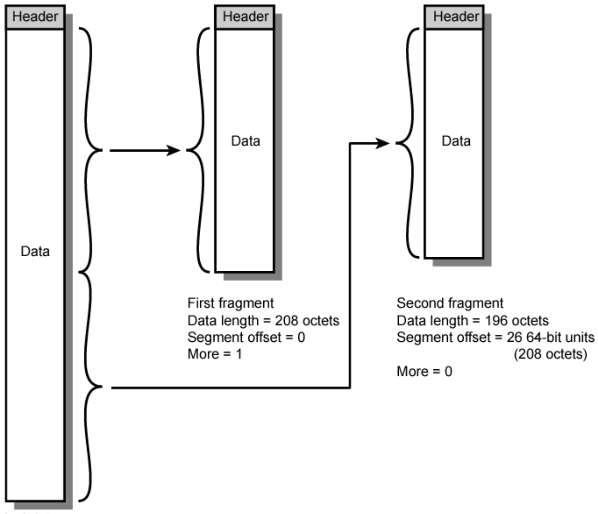
IP Fragmentation (1)

- IP re-assembles at destination only
- Uses fields in header
  - Data Unit Identifier (ID)
    - Identifies end system originated datagram
      - Source and destination address
      - Protocol layer generating data (e.g. TCP)
      - Identification supplied by that layer
  - Data length
    - Length of user data in octets

IP Fragmentation (2)

- Offset
  - Position of fragment of user data in original datagram
  - In multiples of 64 bits (8 octets)
- *More* flag
  - Indicates that this is not the last fragment

Fragmentation Example



Original datagram
Data length = 404 octets
Segment offset = 0
More = 0

Dealing with Failure

- Re-assembly may fail if some fragments get lost
- Need to detect failure
- Re-assembly time out
  - —Assigned to first fragment to arrive
  - —If timeout expires before all fragments arrive, discard partial data
- Use packet lifetime (time to live in IP)
  - —If time to live runs out, kill partial data

Error Control

- Not guaranteed delivery
- Router should attempt to inform source if packet discarded
  - —e.g. for time to live expiring
- Source may modify transmission strategy
- May inform high layer protocol
- Datagram identification needed
- (Look up ICMP)

Flow Control

- Allows routers and/or stations to limit rate of incoming data
- Limited in connectionless systems
- Send flow control packets
  - —Requesting reduced flow
- e.g. ICMP

Internet Protocol (IP) Version 4

- Part of TCP/IP
  - —Used by the Internet
- Specifies interface with higher layer
  - —e.g. TCP
- Specifies protocol format and mechanisms
- RFC 791
  - —Get it and study it!
  - —www.rfc-editor.org
- Will (eventually) be replaced by IPv6 (see later)

IP Services

- Primitives
  - —Functions to be performed
  - —Form of primitive implementation dependent
    - e.g. subroutine call
  - —Send
    - Request transmission of data unit
  - —Deliver
    - Notify user of arrival of data unit
- Parameters
  - —Used to pass data and control info

Parameters (1)

- Source address
- Destination address
- Protocol
  - —Recipient e.g. TCP
- Type of Service
  - —Specify treatment of data unit during transmission through networks
- Identification
  - —Source, destination address and user protocol
  - —Uniquely identifies PDU
  - —Needed for re-assembly and error reporting
  - —Send only

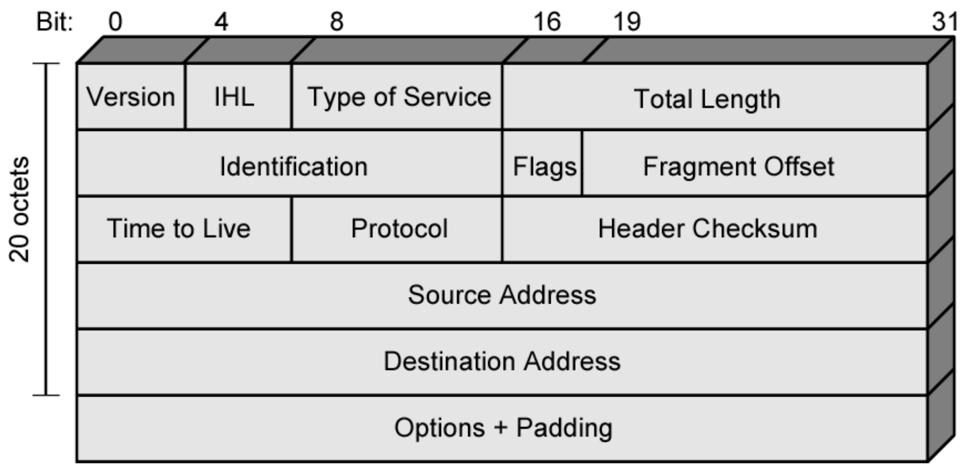
Parameters (2)

- Don't fragment indicator
  - —Can IP fragment data
  - —If not, may not be possible to deliver
  - —Send only
- Time to live
  - —Send only
- Data length
- Option data
- User data

Options

- Security
- Source routing
- Route recording
- Stream identification
- Timestamping

IPv4 Header



Header Fields (1)

- Version
  - —Currently 4
  - —IP v6 - see later
- Internet header length
  - —In 32 bit words
  - —Including options
- Type of service
- Total length
  - —Of datagram, in octets

Header Fields (2)

- Identification
  - — Sequence number
  - — Used with addresses and user protocol to identify datagram uniquely
- Flags
  - — More bit
  - — Don't fragment
- Fragmentation offset
- Time to live
- Protocol
  - — Next higher layer to receive data field at destination

Header Fields (3)

- Header checksum
  - —Reverified and recomputed at each router
  - —16 bit ones complement sum of all 16 bit words in header
  - —Set to zero during calculation
- Source address
- Destination address
- Options
- Padding
  - —To fill to multiple of 32 bits long

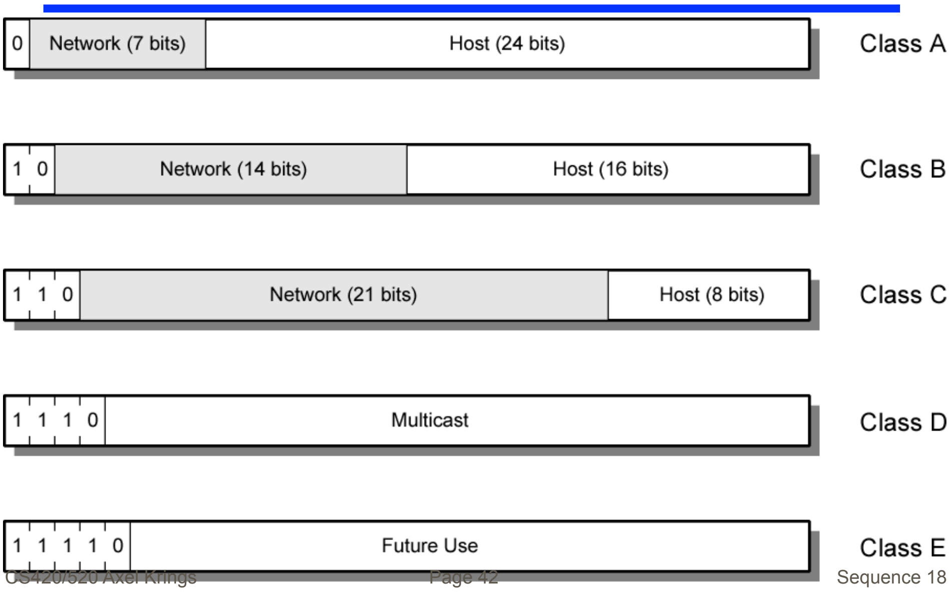
Data Field

- Carries user data from next layer up
- Integer multiple of 8 bits long (octet)
- Max length of datagram (header plus data) 65,535 octets

Inter-domain Routing

- Classful network design
- Classless Inter-Domain Routing - CIDR
  - —Introduced in 1993 by the Internet Engineering Task Force
  - —Goal was to slow the growth of routing tables on routers across the Internet, and to help slow the rapid exhaustion of IPv4 addresses
  - —CIDR appends a "/" character to the address and the decimal number of leading bits of the routing prefix
  - —Example:
    - 192.168.1.0/24 for IPv4,
    - 2001:db8::/32 for IPv6

IPv4 Address Formats



IP Addresses - Class A

- 32 bit global internet address
- Two parts
  - —Network part
  - —Host part
- Class A
  - —Start with binary 0
  - —All 0 reserved
  - —01111111 (127) reserved for loopback
  - —Range 1.x.x.x to 126.x.x.x
  - —All allocated

IP Addresses - Class B

- Start with binary 10
- Range 128.x.x.x to 191.x.x.x
- Second Octet also included in network address
- 2^{14} = 16,384 class B addresses
- All allocated

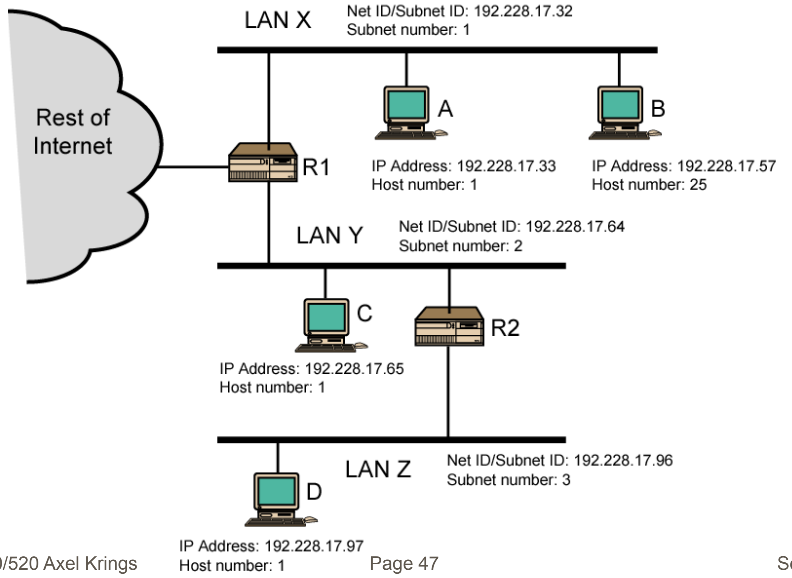
IP Addresses - Class C

- Start with 110
- Range 192.x.x.x to 223.x.x.x
- Second and third octet also part of network address
- 2^{21} = 2,097,152 addresses
- Nearly all allocated
  - See IPv6

Subnets and Subnet Masks

- Allow arbitrary complexity of internetworked LANs within organization
- Insulate overall internet from growth of network numbers and routing complexity
- Site looks to rest of internet like single network
- Each LAN assigned subnet number
- Host portion of address partitioned into subnet number and host number
- Local routers route within subnetted network
- Subnet mask indicates which bits are subnet number and which are host number

Routing Using Subnets



ICMP

- Internet Control Message Protocol
- RFC 792 (get it and study it)
- Transfer of (control) messages from routers and hosts to hosts
- Feedback about problems
  - e.g. time to live expired
- Encapsulated in IP datagram
  - Not reliable

ICMP Message Formats

0	8	16	31
Type	Code	Checksum	
Unused			
IP Header + 64 bits of original datagram			

(a) Destination Unreachable; Time Exceeded; Source Quench

0	8	16	31
Type	Code	Checksum	
Pointer	Unused		
IP Header + 64 bits of original datagram			

(b) Parameter Problem

0	8	16	31
Type	Code	Checksum	
Gateway Internet Address			
IP Header + 64 bits of original datagram			

(c) Redirect

0	8	16	31
Type	Code	Checksum	
Identifier		Sequence Number	
Optional data			

(d) Echo, Echo Reply

0	8	16	31
Type	Code	Checksum	
Identifier		Sequence Number	
Originate Timestamp			

(e) Timestamp

0	8	16	31
Type	Code	Checksum	
Identifier		Sequence Number	
Originate Timestamp			
Receive Timestamp			
Transmit Timestamp			

(f) Timestamp Reply

0	8	16	31
Type	Code	Checksum	
Identifier		Sequence Number	

(g) Address Mask Request

0	8	16	31
Type	Code	Checksum	
Identifier		Sequence Number	
Address Mask			

(h) Address Mask Reply

IP v6 - Version Number

- IP v 1-3 defined and replaced
- IP v4 - current version
- IP v5 - streams protocol
- IP v6 - replacement for IP v4
  - Next Generation

Why Change IP?

- Address space exhaustion
  - Two level addressing (network and host) wastes space
  - Network addresses used even if not connected to Internet
  - Growth of networks and the Internet
  - Extended use of TCP/IP
  - Single address per host
- Requirements for new types of service

IPv6 RFCs

- 1752 - Recommendations for the IP Next Generation Protocol
- 2460 - Overall specification
- 2373 - addressing structure
- others (find them)
- www.rfc-editor.org

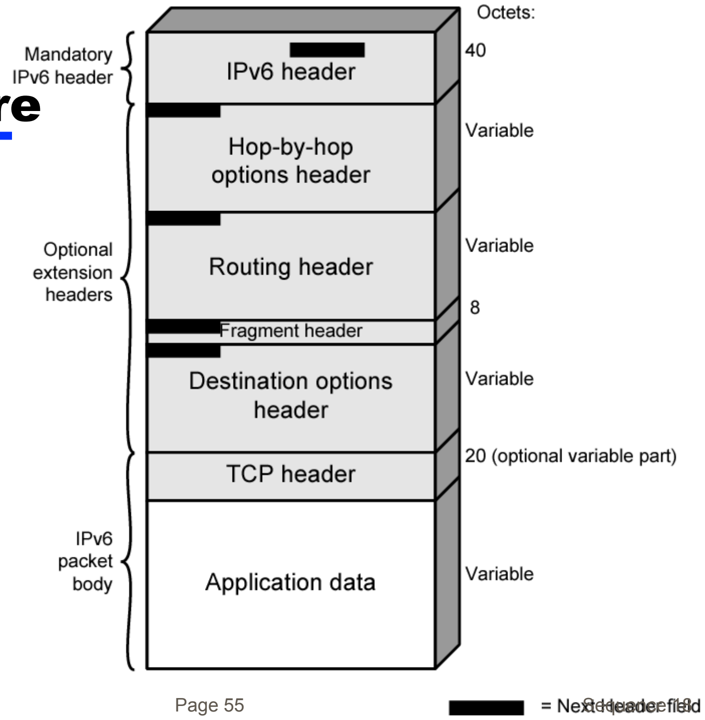
IPv6 Enhancements (1)

- Expanded address space
  - —128 bit
- Improved option mechanism
  - —Separate optional headers between IPv6 header and transport layer header
  - —Most are not examined by intermediate routes
    - Improved speed and simplified router processing
    - Easier to extend options
- Address autoconfiguration
  - —Dynamic assignment of addresses

IPv6 Enhancements (2)

- Increased addressing flexibility
  - —Anycast - delivered to one of a set of nodes
  - —Improved scalability of multicast addresses
- Support for resource allocation
  - —Replaces type of service
  - —Labeling of packets to particular traffic flow
  - —Allows special handling
  - —e.g. real time video

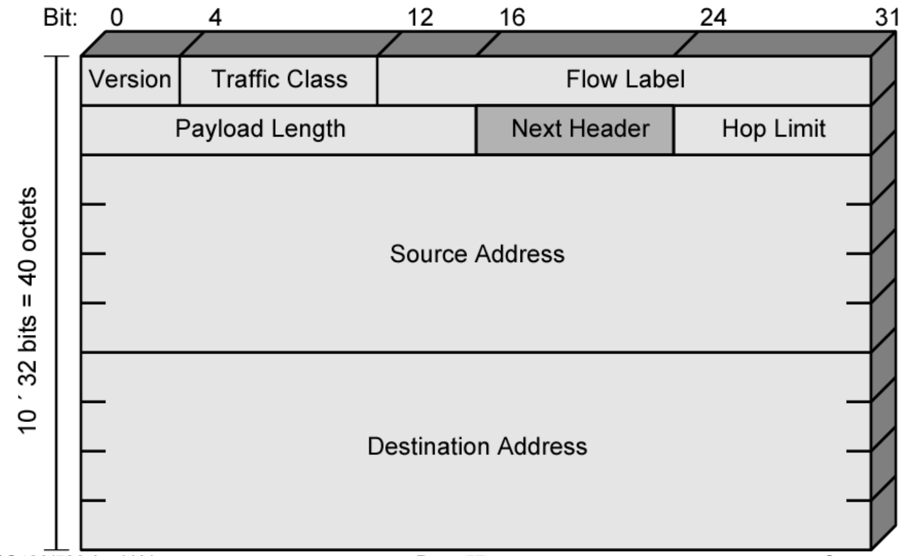
IPv6 Structure



Extension Headers

- Hop-by-Hop Options
  - Require processing at each router
- Routing
  - Similar to v4 source routing
- Fragment
- Authentication
- Encapsulating security payload
- Destination options
  - For destination node

IP v6 Header



IP v6 Header Fields (1)

- Version
  - —6
- Traffic Class
  - —Classes or priorities of packet
  - —Still under development
  - —See RFC 2460
- Flow Label
  - —Used by hosts requesting special handling
- Payload length
  - —Includes all extension headers plus user data

IP v6 Header Fields (2)

- Next Header
  - —Identifies type of header
    - Extension or next layer up
- Source Address
- Destination address

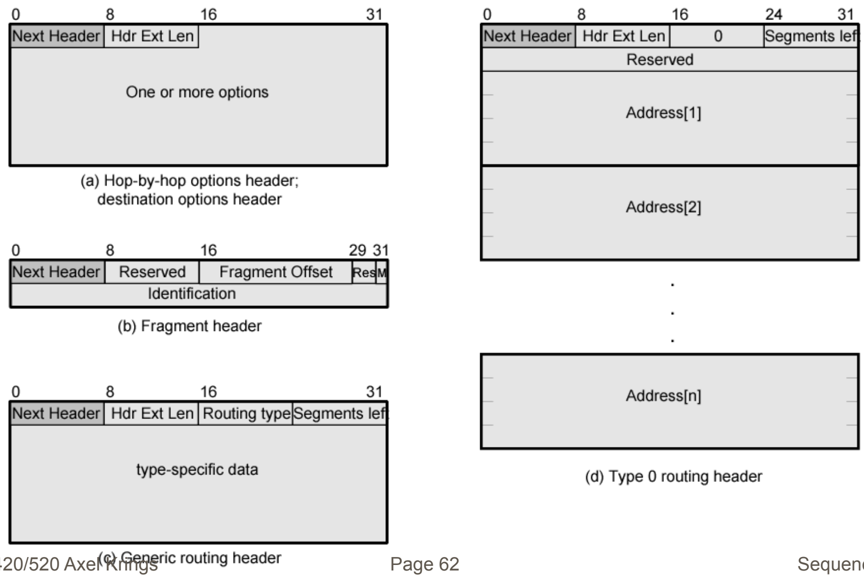
IPv6 Addresses

- 128 bits long
- Assigned to interface
- Single interface may have multiple unicast addresses
- Three types of address

Types of address

- Unicast
  - —Single interface
- Anycast
  - —Set of interfaces (typically different nodes)
  - —Delivered to any one interface
  - —the "nearest"
- Multicast
  - —Set of interfaces
  - —Delivered to all interfaces identified

IPv6 Extension Headers



Hop-by-Hop Options

- Next header
- Header extension length
- Options
  - Pad1
    - Insert one byte of padding into Options area of header
  - PadN
    - Insert *N* (≥2) bytes of padding into Options area of header
    - Ensure header is multiple of 8 bytes
  - Jumbo payload
    - Over 2^{16} = 65,535 octets
  - Router alert
    - Tells router that contents of packet is of interest to router
    - Provides support for RSPV (chapter 16)

Fragmentation Header

- Fragmentation only allowed at source
- No fragmentation at intermediate routers
- Node must perform path discovery to find smallest MTU of intermediate networks
- Source fragments to match MTU
- Otherwise limit to 1280 octets

Fragmentation Header Fields

- Next Header
- Reserved
- Fragmentation offset
- Reserved
- More flag
- Identification

Routing Header

- List of one or more intermediate nodes to be visited
- Next Header
- Header extension length
- Routing type
- Segments left
  - —i.e. number of nodes still to be visited

Destination Options Header

- carries optional info for destination node
- format same as hop-by-hop header

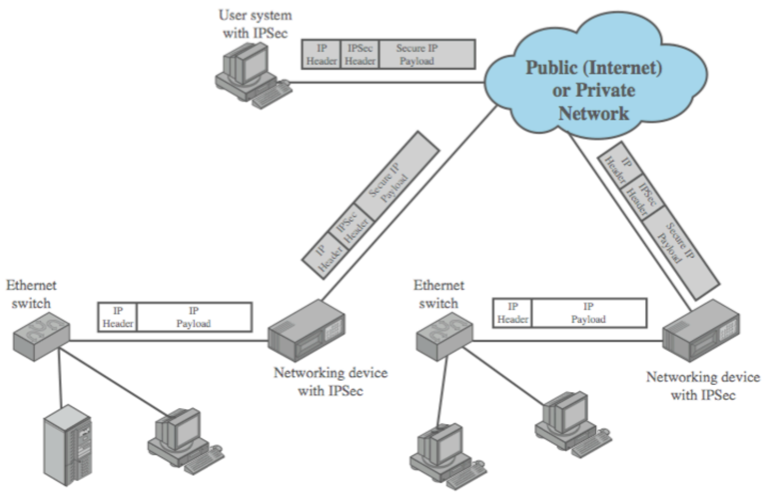
Virtual Private Networks

- set of computers interconnected using an insecure network
  - e.g. linking corporate LANs over Internet
- using encryption & special protocols to provide security
  - to stop eavesdropping & unauthorized users
- proprietary solutions are problematical
- hence development of IPSec standard

IPSec

- RFC 1636 (1994) identified security need
- encryption & authentication to be IPv6
- but designed also for use with current IPv4
- applications needing security include:
  - —branch office connectivity
  - —remote access over Internet
  - —extranet & intranet connectivity for partners
  - —electronic commerce security

IPSec Scenario



IPSec Benefits

- provides strong security for external traffic
- resistant to bypass
- below transport layer hence transparent to applications
- can be transparent to end users
- can provide security for individual users if needed

IPSec Functions

- Authentication Header
  - for authentication only
- Encapsulating Security Payload (ESP)
  - for combined authentication/encryption
- a key exchange function
  - manual or automated
- VPNs usually need combined function
- see chapter 21

Summary

- basic protocol functions
- internetworking principles
- connectionless internetworking
- IP
- IPv6
- IPSec