Fundamentals of Computer Networks
ECE 478/578

Lecture #14: InternetWorking
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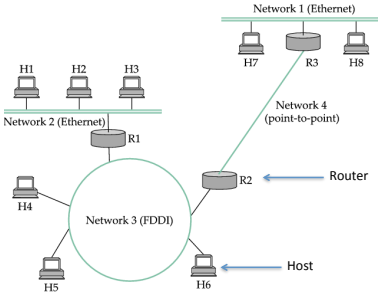
Intrernetworking

An arbitrary collection of networks interconnected to provide host-to-host packet delivery



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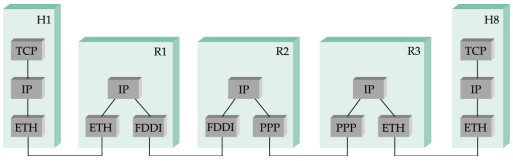
The Internet Protocol (IP)

A common protocol that bridges the heterogeneity between hosts of different types of networks.

E.g. Interconnection of hosts H1 and H8



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"Best Effort" Networking

IP is a datagram connectionless protocol

Does not provide any type of guarantee about packet delivery
Out of order packet deliveries, duplicate packets, no error correction

If packets are lost, IP does not try to recover or retransmit (though lower or higher layer functionalities may do so)

IPoAC (IP over Avian Carriers) RFC 1149. Use pigeons to carry IP packets

IPoAC has been implemented successfully carrying 9 packets with 55% packet loss, and delay from 3,000-6,000 sec.

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IPV4 Packet Format

<table>
<tr><td>4-bit Version</td><td>4-bit Header Length</td><td>8-bit Type of Service (TOS)</td><td colspan="2">16-bit Total Length (Bytes)</td></tr>
<tr><td colspan="3">16-bit Identification</td><td>3-bit Flags</td><td>13-bit Fragment Offset</td></tr>
<tr><td>8-bit Time to Live (TTL)</td><td>8-bit Protocol</td><td colspan="3">16-bit Header Checksum</td></tr>
<tr><td colspan="5">32-bit Source IP Address</td></tr>
<tr><td colspan="5">32-bit Destination IP Address</td></tr>
<tr><td colspan="5">Options (if any)</td></tr>
<tr><td colspan="5">Payload</td></tr>
</table>

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IP Packet Header Fields(1)

Version number (4 bits)
- Indicates the version of the IP protocol
- Necessary to know what other fields to expect
- Typically "4" (for IPv4), and sometimes "6" (for IPv6)

Header length (4 bits)
- Number of 32-bit words in the header
- Typically "5" (for a 20-byte IPv4 header)
- Can be more when "IP options" are used

Type-of-Service (8 bits)
- Allow packets to be treated differently based on needs
- E.g., low delay for audio, high bandwidth for bulk transfer

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IP Packet Header Fields(2)

Total length (16 bits)
- Number of bytes in the packet
- Maximum size is 63,535 bytes (2^{16} -1)
- … though underlying links may impose harder limits

Fragmentation information (32 bits)
- Packet identifier, flags, and fragment offset
- Supports dividing a large IP packet into fragments
- … in case a link cannot handle a large IP packet

Time-To-Live (8 bits)
- Used to identify packets stuck in forwarding loops
- … and eventually discard them from the network

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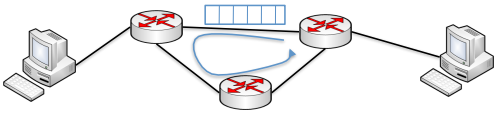
Time To Live (TTL) Field

Potential robustness problem
- Forwarding loops can cause packets to cycle forever
- Confusing if the packet arrives much later



Time-to-live field in packet header
- TTL field decremented by each router on the path
- Packet is discarded when TTL field reaches 0…
- …and "time exceeded" message is sent to the source

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Protocol Field

Protocol (8 bits)
- Identifies the higher-level protocol
  - E.g., "6" for the Transmission Control Protocol (TCP)
  - E.g., "17" for the User Datagram Protocol (UDP)
- Important for demultiplexing at receiving host
  - Indicates what kind of header to expect next

protocol=6	protocol=17
IP header	IP header
TCP header	UDP header

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Checksum Field

- Checksum (16 bits)
  - Sum of all 16-bit words in the IP packet header
  - If any bits of the header are corrupted in transit
  - … the checksum won't match at receiving host
  - Receiving host discards corrupted packets
    - Sending host will retransmit the packet, if needed

134		134
+ 212	→	+ 216
= 346		= 350
		Mismatch!

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IP Addresses Field

Two IP addresses

Source IP address (32 bits)

Destination IP address (32 bits)

Destination address

Unique identifier for the receiving host

Allows each node to make forwarding decisions

Source address

Unique identifier for the sending host

Recipient can decide whether to accept packet

Enables recipient to send a reply back to source

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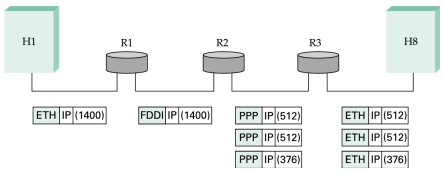
Fragmentation and Reassembly

Various networks accept different packet size

E.g.



Each fragment is itself a self-contained IP datagram transmitted over various physical networks

Each IP datagram is re-encapsulated for each physical networks

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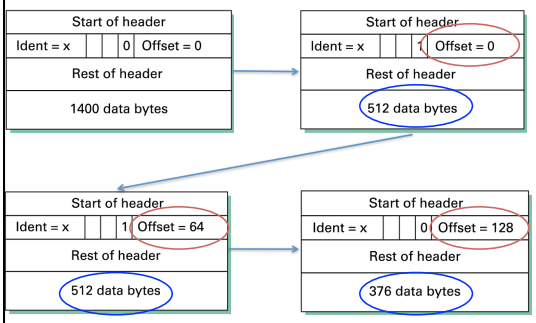
Header Fields



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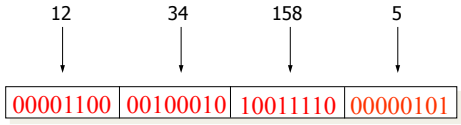
IPV4 Addresses

A unique 32-bit number
Identifies an interface (on a host, on a router, …)
Represented in dotted-quad notation



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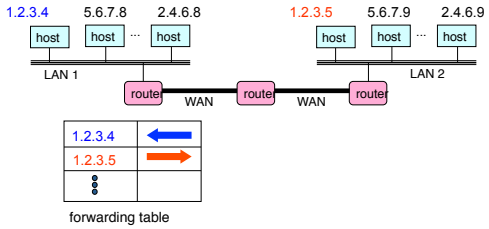
A Flat Architecture

Suppose hosts had arbitrary addresses
- Then every router would need a lot of information
- …to know how to direct packets toward the host



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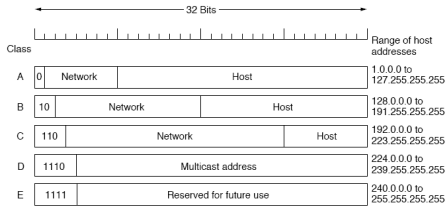
IP Addressing

Routing protocols need addresses to find the destinations

IP addresses are hierarchical (Why?)

- Network part
- Host part

Class-based Addressing



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IP Address Classes

Class A:

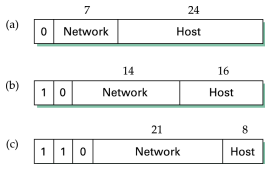
- Initial byte: 0 – 127, 126 Nets; (0, 127 reserved); 16,777,214 hosts per network
- MIT IP: 18.9.22.169

Class B:

- Initial byte: 128 – 191; 16,384 networks; 65,532 hosts per network
- Arizona IP: 129.196.134.37

Class C:

- Initial byte: 192 – 223; 2,097,152 networks; 254 hosts per network
- Your home IP: 192.168.1.67



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Think of Postal Addresses

Mail Addresses

- Zip code: 85721
- Street: E. Speedway Blvd.
- Building on street: 1230
- Room in building: 357
- Name of occupant: John Smith

Delivering mail

- Deliver letter to the post office in the zip code
- Assign letter to mailman covering the street
- Drop letter into mailbox for the building/room
- Give letter to the appropriate person

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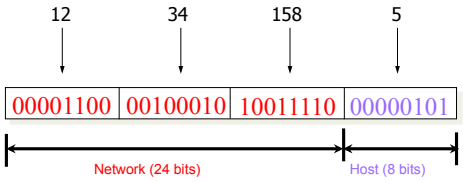
Hierarchy in IP Addresses

Divided into network and host portions (left and right)
12.34.158.0/24 is a 24-bit prefix with 2^8 addresses



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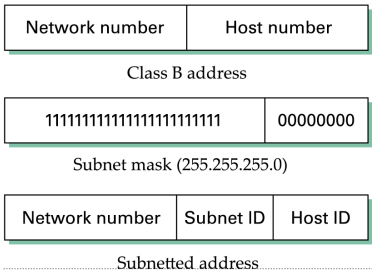
Subnetting



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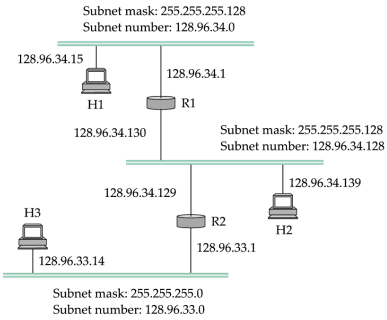
An Example of Subnetting



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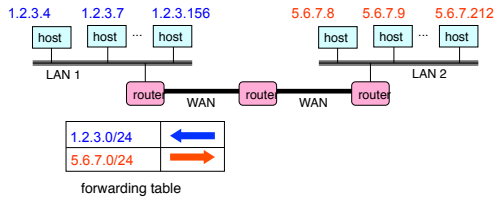
Easier to Route Packets

Number related hosts from a common subnet

- 1.2.3.0/24 on the left LAN
- 5.6.7.0/24 on the right LAN



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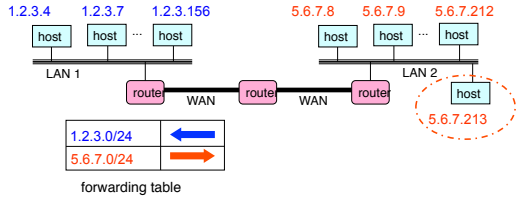
Easy to Add New Hosts

No need to update the routers

- E.g., adding a new host 5.6.7.213 on the right
- Doesn't require adding a new forwarding entry



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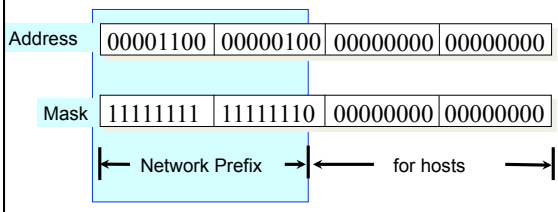
Classless Inter-Domain Routing (CIDR)

Use two 32-bit numbers to represent a network.
Network number = IP address + Mask

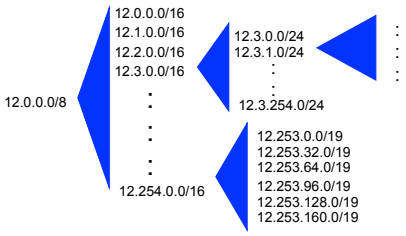
IP Address : 12.4.0.0 IP Mask: 255.254.0.0



Written as 12.4.0.0/15

CIDR: Hierarchal Address Allocation

Prefixes are key to Internet scalability
- Address allocated in contiguous chunks (prefixes)
- Routing protocols and packet forwarding based on prefixes
- Today, routing tables contain ~150,000-200,000 prefixes



Obtaining a Block of Addresses

Separation of control
- Prefix: assigned *to* an institution
- Addresses: assigned *by* the institution to their nodes

Who assigns prefixes?
- Internet Corporation for Assigned Names and Numbers
  - Allocates large address blocks to Regional Internet Registries
- Regional Internet Registries (RIRs)
  - E.g., ARIN (American Registry for Internet Numbers)
  - Allocates address blocks within their regions
  - Allocated to Internet Service Providers and large institutions
- Internet Service Providers (ISPs)
  - Allocate address blocks to their customers
  - Who may, in turn, allocate to their customers…

Are 32-bit Addresses Enough?

Not all that many unique addresses
- 2^{32} = 4,294,967,296 (just over four billion)
- Plus, some are reserved for special purposes
- And, addresses are allocated in larger blocks

Many devices need IP addresses
- Computers, PDAs, routers, tanks, toasters, …

Long-term solution: a larger address space
- IPv6 has 128-bit addresses ($2^{128} = 3.403 \times 10^{38}$)

Short-term solutions: limping along with IPv4
- Private addresses
- Network address translation (NAT)
- Dynamically-assigned addresses (DHCP)

Hard Policy Questions

How much address space per geographic region?

- Equal amount per country?
- Proportional to the population?
- What about addresses already allocated?

Address space portability

- Keep your address block when you change providers?
- Pro: avoid having to renumber your equipment
- Con: reduces the effectiveness of address aggregation

Keeping the address registries up to date

- What about mergers and acquisitions?
- Delegation of address blocks to customers?
- As a result, the registries are horribly out of date