IP Protocol Addresses

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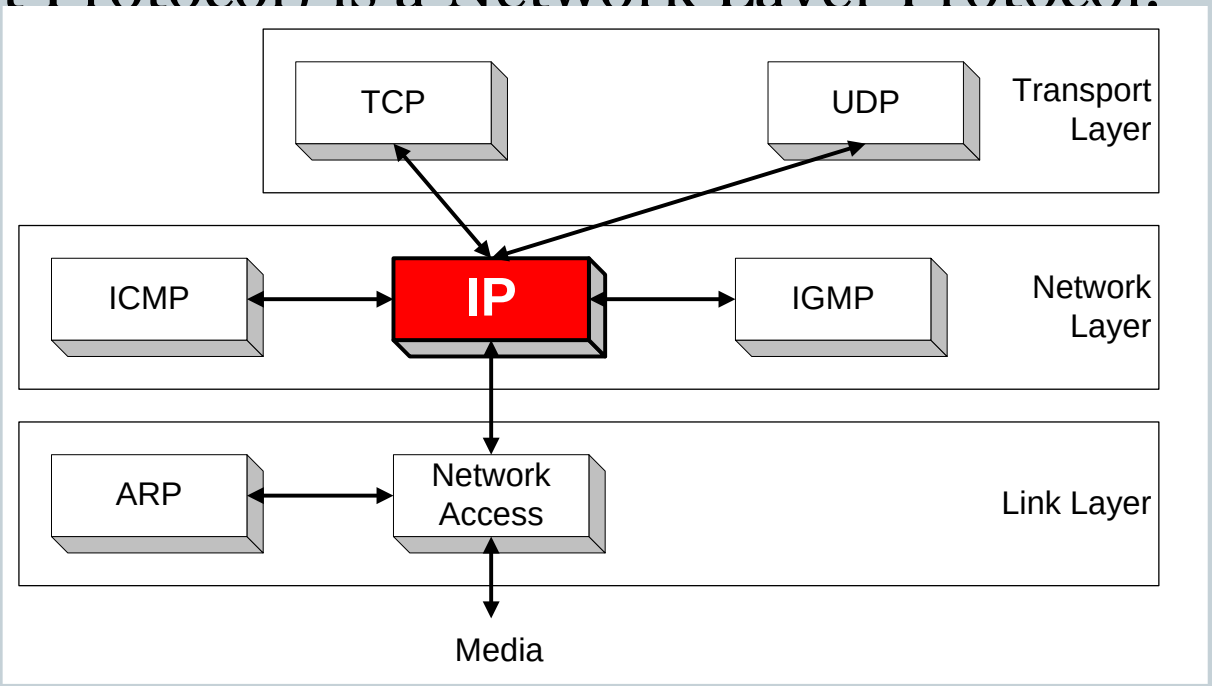
Motivation

- One key aspect of virtual network is single, uniform address format
- Can't use hardware addresses because different technologies have different address formats
- Address format must be independent of any particular hardware address format
- Sending host puts destination internet address in packet
- Destination address can be interpreted by any intermediate router
- Routers examine address and forward packet on to the destination

Orientation

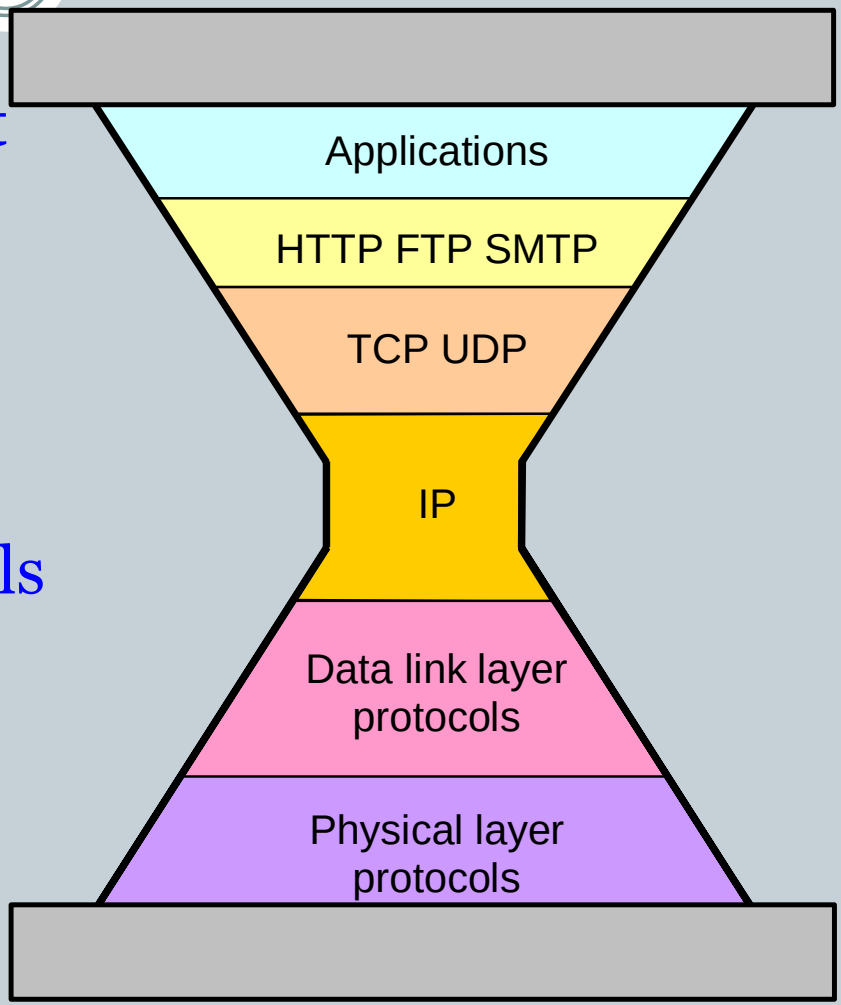
- IP (Internet Protocol) is a Network Layer Protocol.



- IP's current version is Version 4 (IPv4). It is specified in RFC 891.

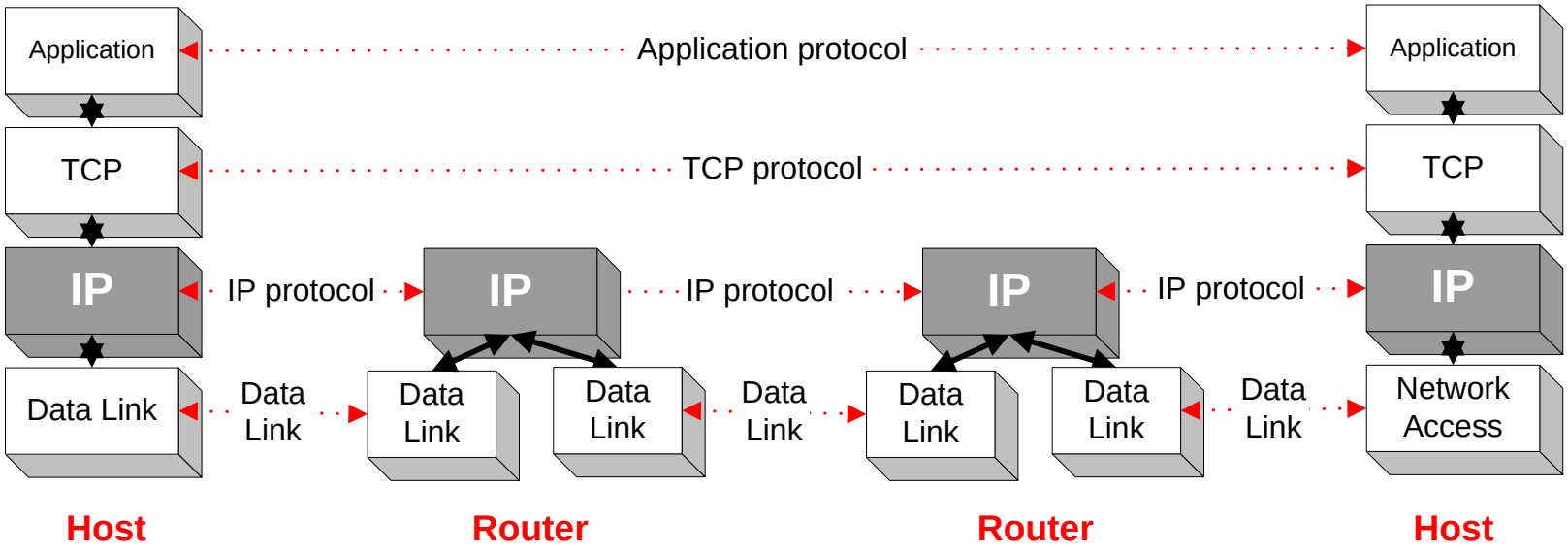
IP: The waist of the hourglass

- **IP is the waist of the hourglass of the Internet protocol architecture**
- Multiple higher-layer protocols
- Multiple lower-layer protocols
- Only one protocol at the network layer.



Application protocol

- IP is the highest layer protocol which is implemented at both routers and hosts



IP Service

- Delivery service of IP is minimal
- IP provide provides an unreliable connectionless best effort service (also called: “datagram service”).
  - **Unreliable:** IP does not make an attempt to recover lost packets
  - **Connectionless:** Each packet (“datagram”) is handled independently. IP is not aware that packets between hosts may be sent in a logical sequence
  - **Best effort:** IP does not make guarantees on the service (no throughput guarantee, no delay guarantee,…)
- Consequences:
  - Higher layer protocols have to deal with losses or with duplicate packets
  - Packets may be delivered out-of-sequence

Addresses for the virtual internet

- The goal of internetworking is to provide a seamless communication system.
- To achieve the goal, internet protocol software must hide the details of physical networks and offer the facilities of a large virtual network.
- The virtual internet operates much like any network, allowing computers to send and receive packets of information.

IP Addressing

- Addressing is a critical component of the internet abstraction.
- To give the appearance of a single, uniform system, all host computers must use a uniform addressing scheme, and each address must be unique.
- Unfortunately, physical addresses do no suffice because an internet can include multiple network technologies and each technology defines its own address format.
- Thus, the addresses used by two technologies may be incompatible because they are different sizes or have different formats

Uniform Addressing

- To guarantee uniform addressing for all hosts, protocol software defines an addressing scheme that is independent of the underlying physical addresses.
- Although an internet addressing scheme is an abstraction created by software, protocol addresses are used as destination for the virtual network analogous to the way hardware addresses are used as destinations on a physical network.
- To send a packet across an internet, the sender places the destination's protocol address in the packet and passes the packet to protocol software for delivery

Bottom line

- *To provide uniform addressing in an internet, protocol software defines an abstract addressing scheme that assigns each host a unique address. Users, application programs, and higher layers of protocol software use the abstract addresses to communicate*

TCP/IP addresses

- Addressing in TCP/IP is specified by the *Internet Protocol* (IP)
- Each host is assigned a 32-bit number
- Called the *IP address* or *Internet address*
- Unique across entire Internet

IP address hierarchy

- Each IP address is divided into a prefix and a suffix
  - Prefix identifies network to which computer is attached
  - Suffix identifies computer within that network
- Address format makes routing efficient
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Network and host numbers

- Every network in a TCP/IP internet is assigned a unique *network number*
- Each host on a specific network is assigned a *host number* or *host address* that is unique *within that network*
- Host's IP address is the combination of the network number (prefix) and host address (suffix)

Properties of IP addresses

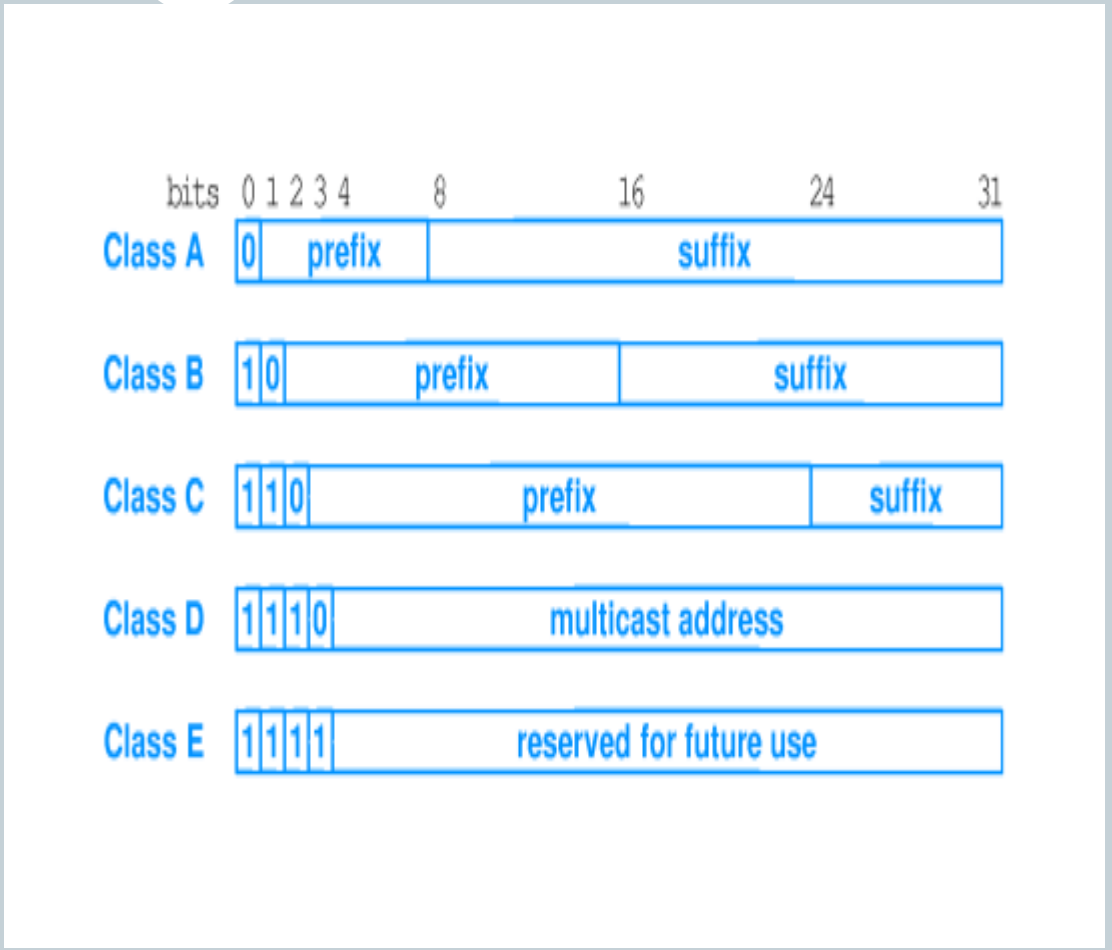
- Network numbers are unique
- Host addresses may be reused on different networks; combination of network number prefix and host address suffix will be unique
- Assignment of network numbers must be coordinated globally; assignment of host addresses can be managed locally

Designing the format of IP addresses

- IP designers chose 32-bit addresses
- Allocate some bits for prefix, some for suffix
  - Large prefix, small suffix - many networks, few hosts per network
  - Small prefix, large suffix - few networks, many hosts per network
- Because of variety of technologies, need to allow for both large and small networks

Classes of addresses

- Designers chose a compromise - multiple address formats that allow both large and small prefixes
- Each format is called an address *class*
- Class of an address is identified by first four bits



Computing the class of an address

- IP software computes the class of the destination address whenever it receives a packet.
- Because the computation is repeated frequently, it must be efficient.
- IP addresses are called *self-identifying* because the class of an address can be computed from the address itself.
- Part of the motivation for using leading bits to denote an address class instead of using a range of values arises from computational considerations.

Example

First four Bits of address	Table index (in decimal)	Class of Address
0000	0	A
0001	1	A
0010	2	A
0011	3	A
0100	4	A
0101	5	A
0110	6	A
0111	7	A
1000	8	B
1001	9	B
1010	10	B
1011	11	B
1100	12	C
1101	13	C
1110	14	D
1111	15	E

Using IP address classes

- Class A, B and C are *primary classes*
- Used for ordinary host addressing
- Class D is used for multicast, a limited form of broadcast
  - Internet hosts join a *multicast group*
  - Packets are delivered to all members of group
  - Routers manage delivery of single packet from source to all members of multicast group
  - Used for *mbone* (multicast backbone)
- Class E is reserved

Dotted decimal notation

- Class A, B and C all break between prefix and suffix on byte boundary
- *Dotted decimal notation* is a convention for representing 32-bit internet addresses in decimal
- Convert each byte of address into decimal; display separated by periods (``dots'')

32-bit Binary Number	Equivalent Dotted Decimal
10000001 00110100 00000110 00000000	129.52.6.0
11000000 00000101 00110000 00000011	192.5.48.3
00001010 00000010 00000000 00100101	10.2.0.37
10000000 00001010 00000010 00000011	128.10.2.3
10000000 10000000 11111111 00000000	128.128.255.0

NYU's IP addresses

- NYU has a single Class B network: 128.122.0.0
- NYU a block of Class C addresses at 216.165.0.0/17
- NYU has 34 other Class C addresses
- Hosts at NYU:
  - 128.122.140.98 - artg.cs.nyu.edu
  - 128.122.140.10 - webproxy.cs.nyu.edu
  - 128.122.130.15 - SALES.STERN.NYU.EDU
- Suffix bytes are used to determine local network and host through *subnetting*

Address classes at a glance

- While dotted decimal makes separating network address from host address easier, determining class is not so obvious
- Look at first dotted decimal number, and use this table:

Class	Range of Values
A	0 through 127
B	128 through 191
C	192 through 223
D	224 through 239
E	240 through 255

Networks and hosts in each class

- Classing scheme does not yield equal number of networks in each class
- Class A:
  - First bit must be 0
  - 7 remaining bits identify Class A net
  - 2^7 (= 128) possible class A nets

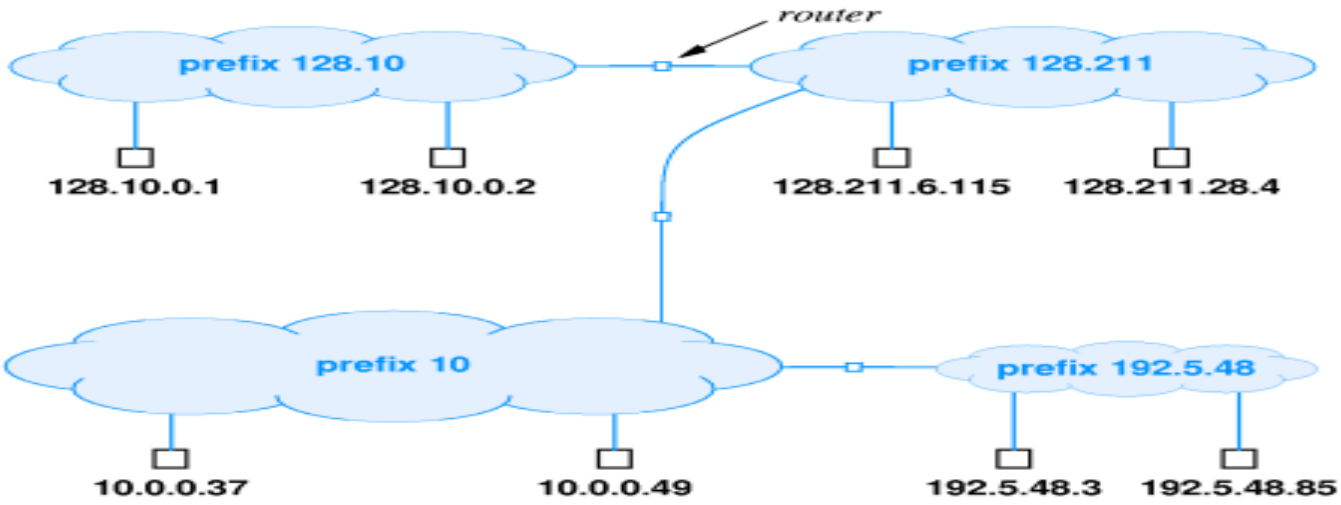
Address Class	Bits In Prefix	Maximum Number of Networks	Bits In Suffix	Maximum Number Of Hosts Per Network
A	7	128	24	16777216
B	14	16384	16	65536
C	21	2097152	8	256

Internet address allocation

- Addresses in the Internet are not used efficiently
- NYU is typical, using 34,037 out of possible 2^16 + 2^15 + 34 * 2^8
- Large organizations may not be able to get as many addresses in the Internet as they need
- Example - UPS needs addresses for **millions** of computers
- Solution - set up *private internet* and allocate addresses from entire 32-bit address space

Example

- Select address class for each network depending on expected number of hosts
- Assign network numbers from appropriate classes
- Assign host suffixes to form internet addresses for all hosts



Special IP addresses

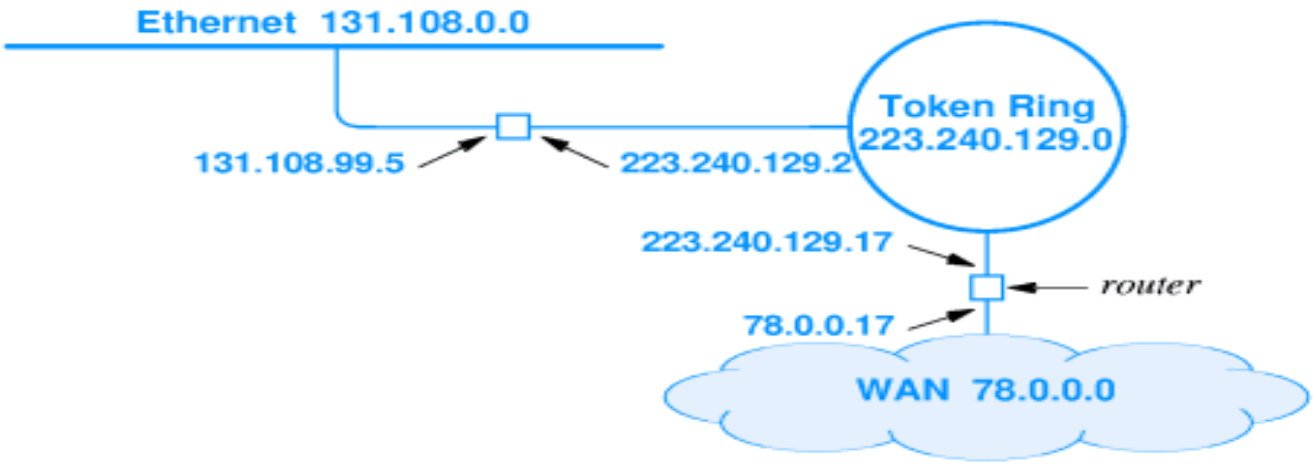
Prefix	Suffix	Type Of Address	Purpose
all-0s	all-0s	this computer	used during bootstrap
network	all-0s	network	identifies a network
network	all-1s	directed broadcast	broadcast on specified net
all-1s	all-1s	limited broadcast	broadcast on local net
127	any	loopback	testing

Berkeley broadcast address

- First BSD implementation (Berkeley Software Distribution) of UNIX used all 0s for broadcast instead of all 1s
- This non-standard implementation spread with BSD UNIX
- Still in common use today
- ``There are two major developments that have come out of Berkeley: BSD UNIX and LSD. This is not a coincidence."

Routers and IP addressing

- IP address depends on network address
- What about routers - connected to two networks?
- IP address specifies an *interface*, or network attachment point, *not* a computer
- Router has multiple IP addresses - one for each interface



Multi-homed hosts

- Hosts (that do not forward packets) can also be connected to multiple networks
- Can increase reliability and performance
- Multi-homed hosts also have one address for each interface

Summary

- Virtual network needs uniform addressing scheme, independent of hardware
- IP address is a 32-bit address; each interface gets a unique IP address
- IP address is composed of a network address and a host address
- Network addresses are divided into three primary classes: A, B and C
- Dotted decimal notation is a standard format for Internet addresses: 134.82.11.70
- Routers have multiple addresses - one for each interface