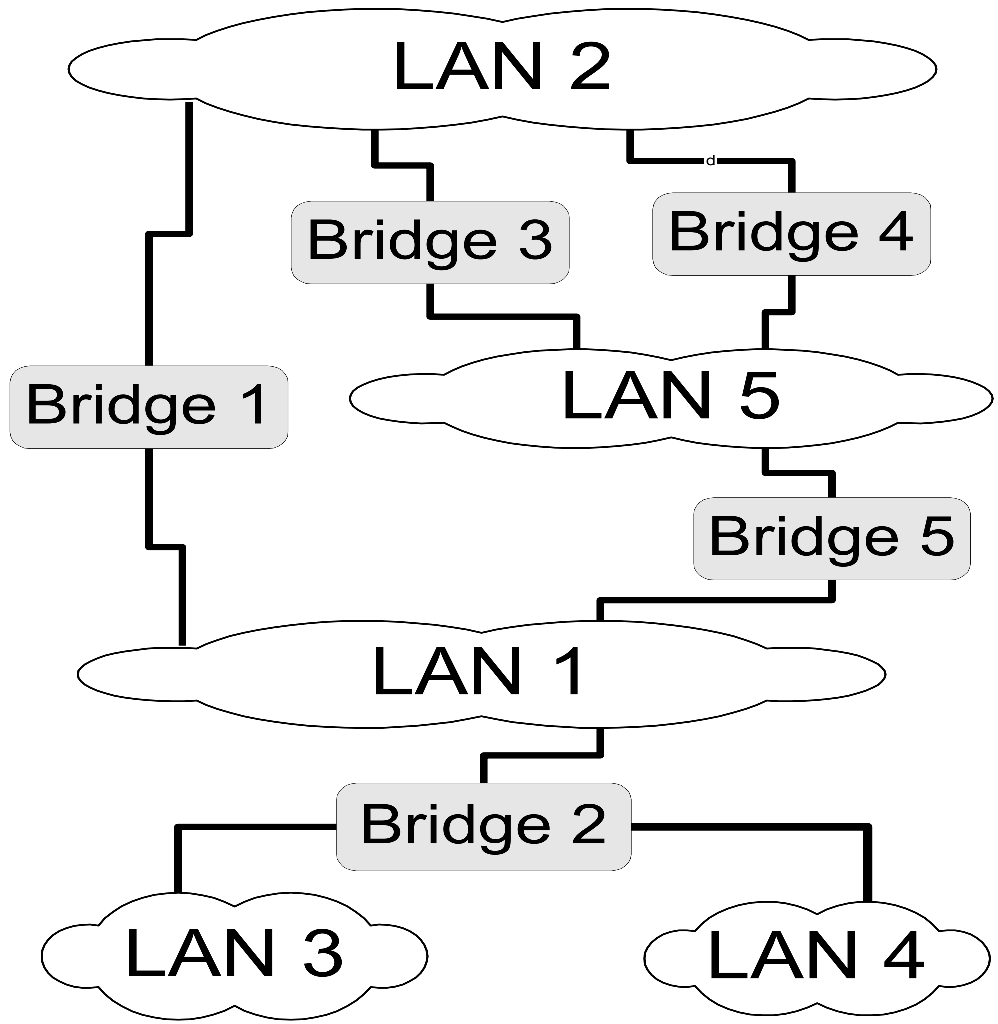
IP Layer: Introduction

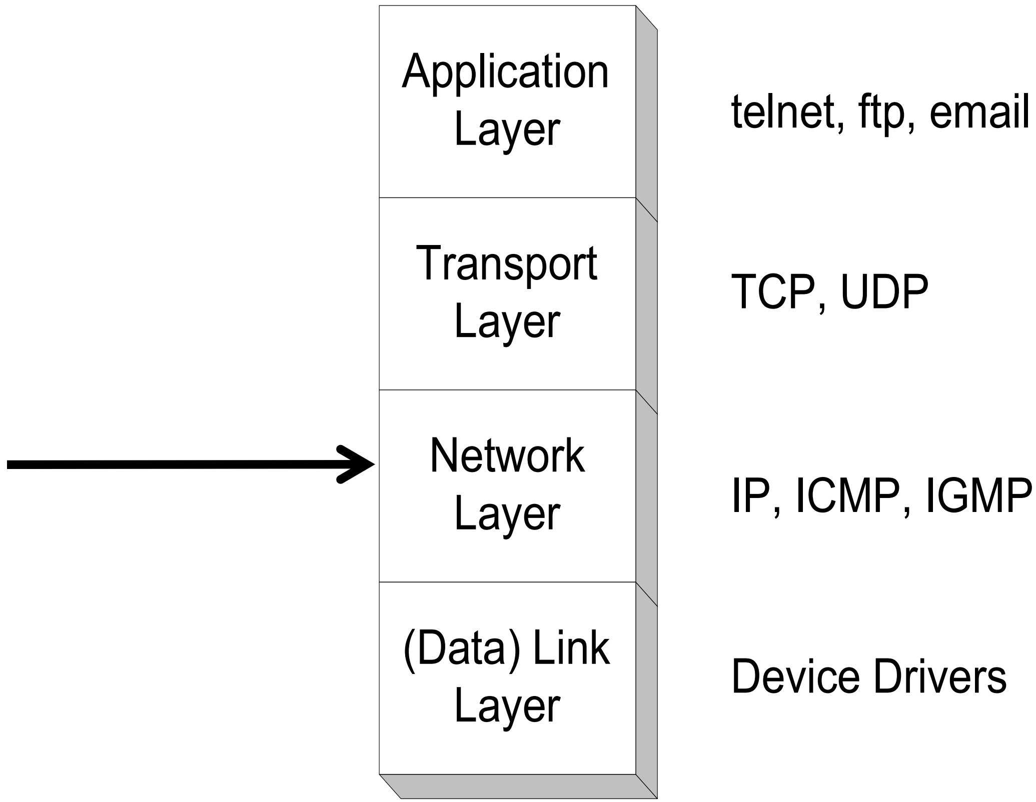
ECE 50863 – Computer Network Systems

Can the Internet be One Big Switched Ethernet?

- Inefficient
  - Too much flooding
- Explosion of forwarding table
  - Need to have one entry for every Ethernet address in the world!
- Poor performance
  - Tree topology does not have good load balancing properties
  - Hot spots

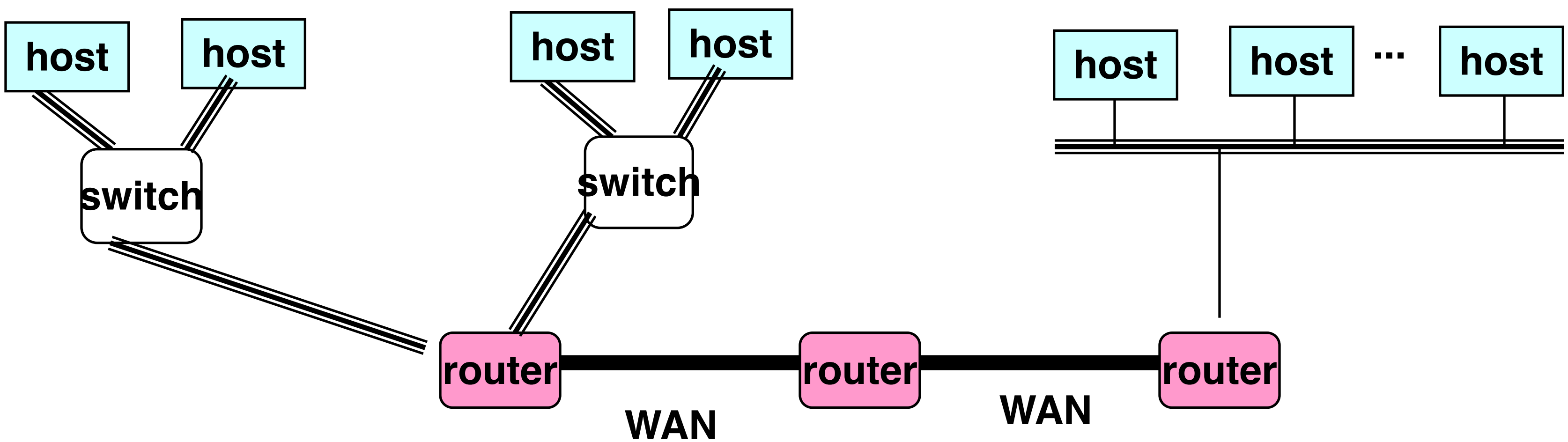


Layered Protocol Architecture



What is an Internetwork?

- Multiple incompatible LANs can be physically connected by specialized computers called *routers*.
- The connected networks are called an *internetwork*.
  - The "*Internet*" is one (very big & successful) example of an internetwork

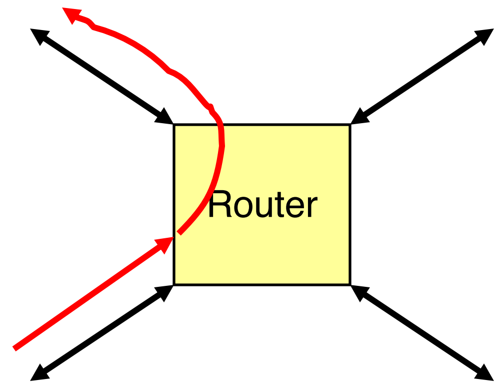


Connected LANs might be completely different (e.g., Ethernet and ATM)

Issues in Designing an Internetwork

- How do I designate a distant host?
  - Addressing / naming
- How do I send information to a distant host?
  - Routing
- Challenge
  - Scalability
    - Ensure ability to grow to worldwide scale

Router Operation

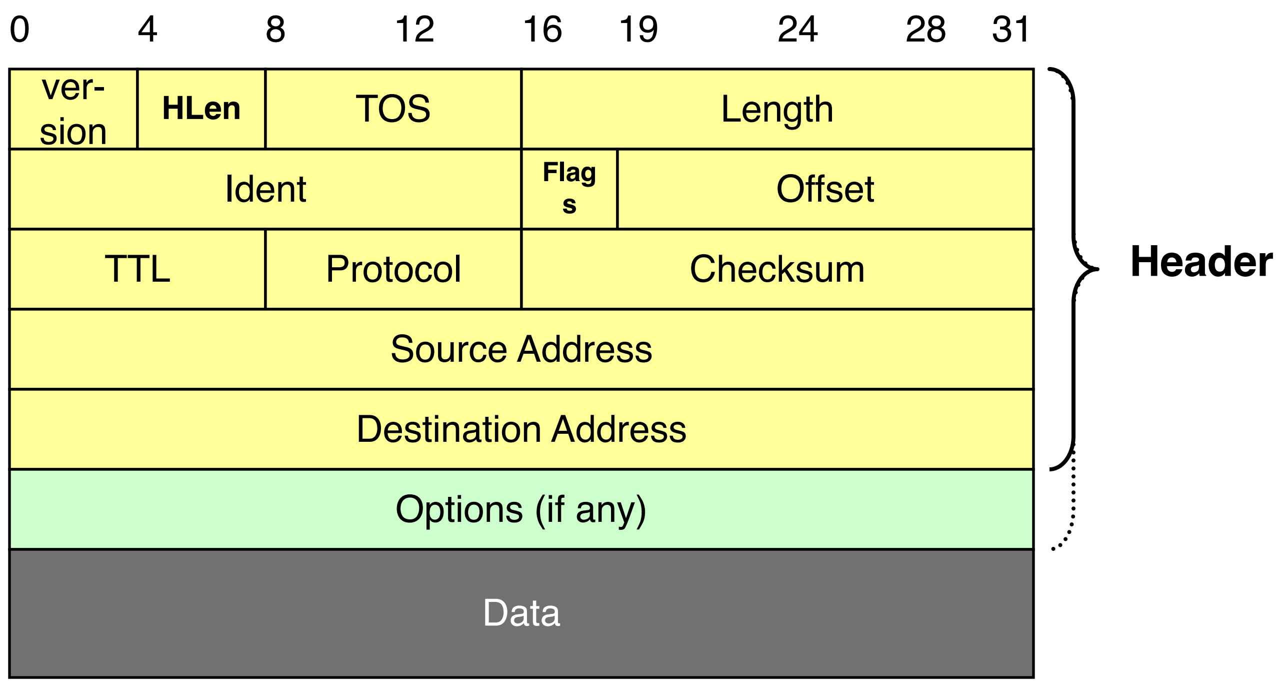


- Destination-Based Routing
  - Move packet through network via series of hops
- Forwarding:
  - Hardware table-lookup to determine next hop
  - Fast, must be done at line rate (i.e., per packet basis)
- Route table computation
  - How routers determine the routes in the first place
  - Software: more involved protocols

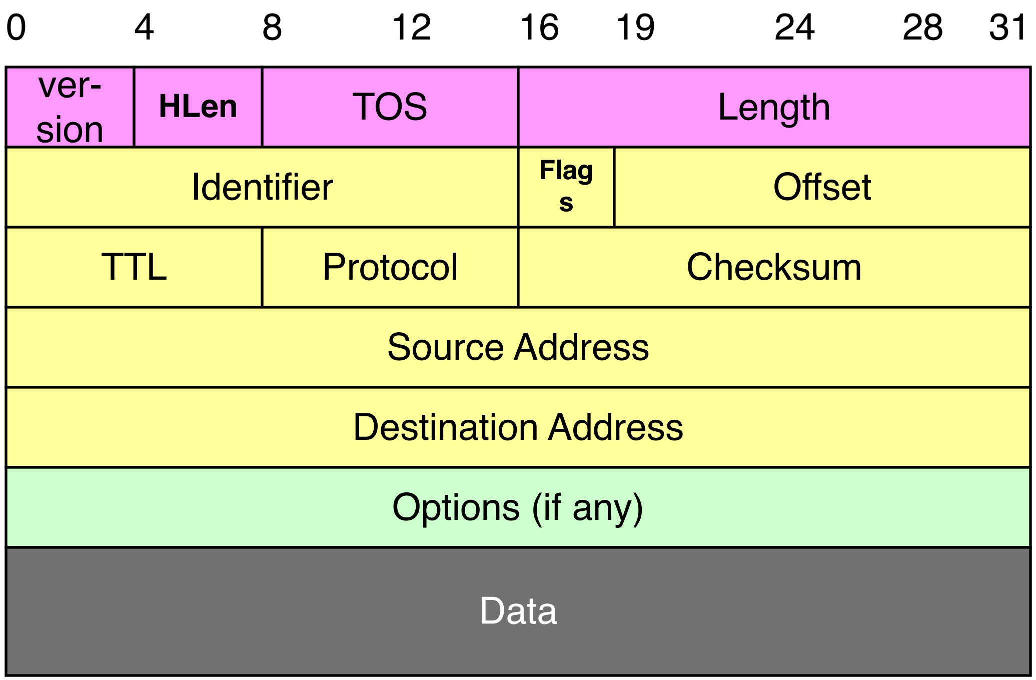
IP Service Model

- Datagram
  - Each packet self-contained
    - Contains all information needed to get to destination

IPv4 Packet Format



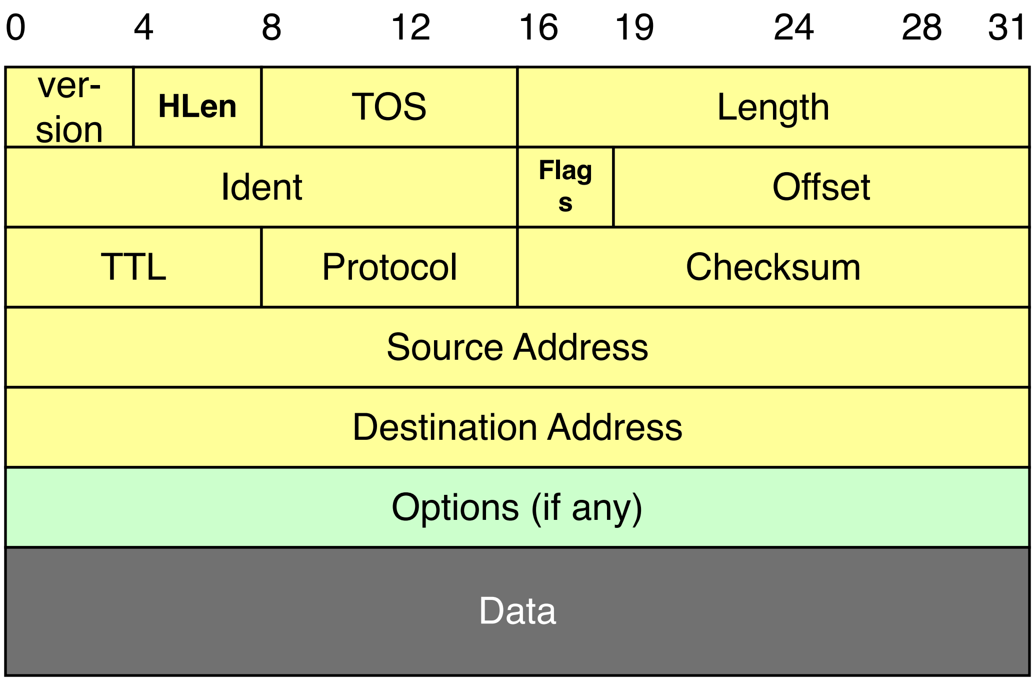
IPv4 Header Fields: Word1



- Version: IP Version
  - 4 for IPv4
- HLen: Header Length
  - 32-bit words (typically 5)
- TOS: Type of Service
  - Priority information
- Length: Packet Length
  - Bytes (including header)

- Header format can change with versions
  - First byte identifies version
- Length field limits packets to 65535 bytes
  - In practice, break into much smaller packets for network performance considerations

Other Fields



Ident, Flags, Offset; Associated with IP fragmentation (longer packet than the data link layer can handle).

TTL: "Time to Live": decremented by 1 hop at each router

Protocol: For Demultiplexing. E.g. UDP/TCP

Checksum: On header

IP Layer: Addressing

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IP Addressing

- IPv4: 32-bit addresses
  - Typically, write in dotted decimal format
    - E.g., 128.2.198.135
    - Each number is decimal representation of byte

0	8	16	24 31	
128	2	198	135	**Decimal**
80	02	c6	87	**Hexadecimal**
0100 0000	0000 0010	1100 0110	1000 0111	**Binary**

Possible Addressing Schemes

- Flat
  - e.g., every host identified by its 48-bit MAC address
  - Router would need entry for every host in the world
    - Too big
    - Too hard to maintain as hosts come & go
- Hierarchy
  - Address broken into segments of increasing specificity
    - Indiana/ W. Lafayette / Purdue/ Sanjay
  - Route to general region and then work toward specific destination
  - As people and organizations shift, only update affected routing tables

IP Addressing and Forwarding

- Routing Table Requirement
  - Flat: For every destination IP address, give next hop
  - Nearly 2^{32} (4.3×10^{9}) possibilities!
- Hierarchical Addressing Scheme

	x	y
`pfx`	`network`	`host`

  - Address split into network ID and host ID
    - Purdue has one network ID shared by all hosts within Purdue
  - All packets to given network follow same route
    - Until they reach destination network
  - Fields
    - `pfx` Prefix to specify split between network & host IDs
    - `network` 2^{x} possibilities
    - `host` 2^{y} possibilities

Uniform vs. Non-uniform hierarchy

- Uniform Hierarchy
  - All hosts have same split of network/host
- Nonuniform Hierarchy
  - Network/host splits may vary

- Discussion: Why non-uniform?

Uniform vs. Non-uniform hierarchy

- Uniform Hierarchy
  - All hosts have same split of network/host
- Nonuniform Hierarchy
  - Network/host splits may vary

- Discussion: Why non-uniform?
  - Handle heterogeneous organizations
  - Large campus vs. small start-up

IP Address Classes: OLD SCHEME

- Class A

	7	24
0	network	host

18.7.22.69

First digit: 1–126

- Class B

	14	16
10	network	host

128.46.200.24

First digit: 128–191

- Class C

	21	8
110	network	host

205.201.9.200

First digit: 192–223

- Classes D, E, F
  - Not commonly used

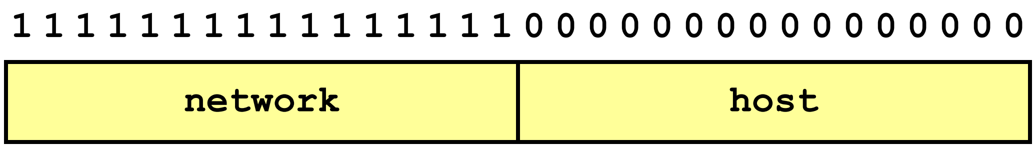
IP Address Classes

Class	Count	Hosts
A	2^7-2 = 126	2^{24}-2 = 16,777,214
B	2^{14} = 16,398	2^{16}-2 = 65,534
C	2^{21} = 2,097,512	2^8-2 = 254
Total	2,114,036	

- Partitioning too Coarse
  - Class A wasteful: Few organizations have 16.7 million hosts
  - Class C insufficient: Many organizations require multiple class C's
  - Too few Class B's.
- Too many different Network IDs
  - Routing tables must still have 2.1 million entries

Classless Interdomain Routing: NEW SCHEME

- Arbitrary Split Between Network & Host IDs
  - Specify either by mask or prefix length



  - E.g.
    - 128.46.0.0 with netmask 255.255.0.0
    - 128.46.0.0/16

Aggregation with CIDR

- Example: CIDR address 207.46.192.0/18

0	8	16	24 31	
207	46	192	0	**Decimal**
cf	2e	c0	00	**Hexadecimal**
1100 1111	0010 1110	11xx xxxx	xxxx xxxx	**Binary**

Upper 18 bits frozen **Lower 14 bits arbitrary**

- Represents $2^6 = 64$ class C networks

– Use single entry in routing table

- Just as if were single network address

IP Lookup with CIDR Addressing

Example Routing Table

Network	Next Hop
128.96.170.0/23	Interface 0
128.96.168.0/23	Interface 1
128.96.166.0/23	R2
128.96.164.0/22	R3
(default)	R4

Packet to destination 128.96.167.151: Which next hop?

Determined based on Longest Prefix Match.

Longest Prefix Matching Example

Example Routing Table

Network	Next Hop	3rd Octet
128.96.170.0/23	Interface 0	1010 1010
128.96.168.0/23	Interface 1	1010 1000
128.96.166.0/23	R2	1010 0110
128.96.164.0/22	R3	1010 0100
(default)	R4	

Packet to destination 128.96.167.151: 1010 0111

- Matches two entries.
- Forwarded to R2 (Longer Prefix Match)

Important Concepts

- Hierarchical addressing critical for scalable system
- Non-uniform hierarchy useful for heterogeneous networks
  - Class-based addressing too coarse
  - CIDR helps
- Realizing CIDR addressing scheme involves longest prefix match