Master Course
Computer Networks
IN2097

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Outline

Packet Networks

Link Layer

Internet Protocol

The Internet

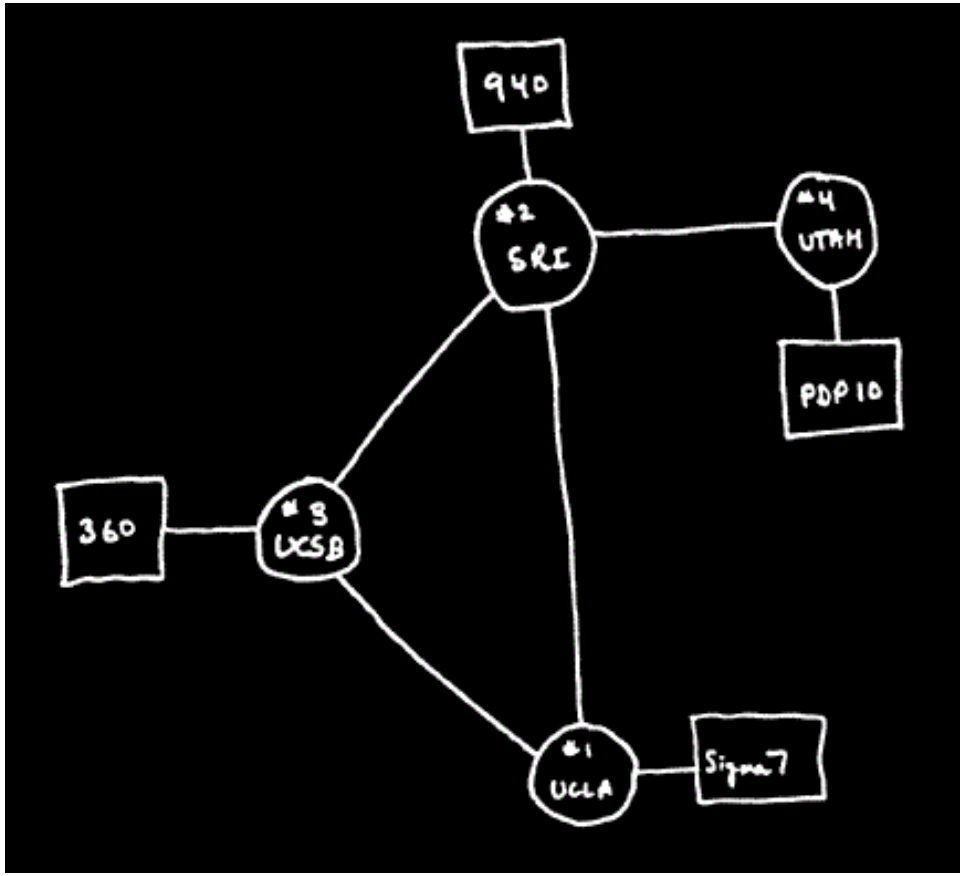
David D. Clark (MIT)

- Acted as Internet chief protocol architect
- Chaired the Internet Activities Board

- Attends meeting of EU Network of Excellence on InterNet Science (EINS) on 25 and 26 November, 2013

- Doctoral Student: Radia Perlman
  - Worked with Digital Equipment, now Intel
  - Author of book Interconnections: Bridges, Routers, Switches, and Internetworking Protocols (2 ed.) Addison-Wesley, 1999

Internet Structure



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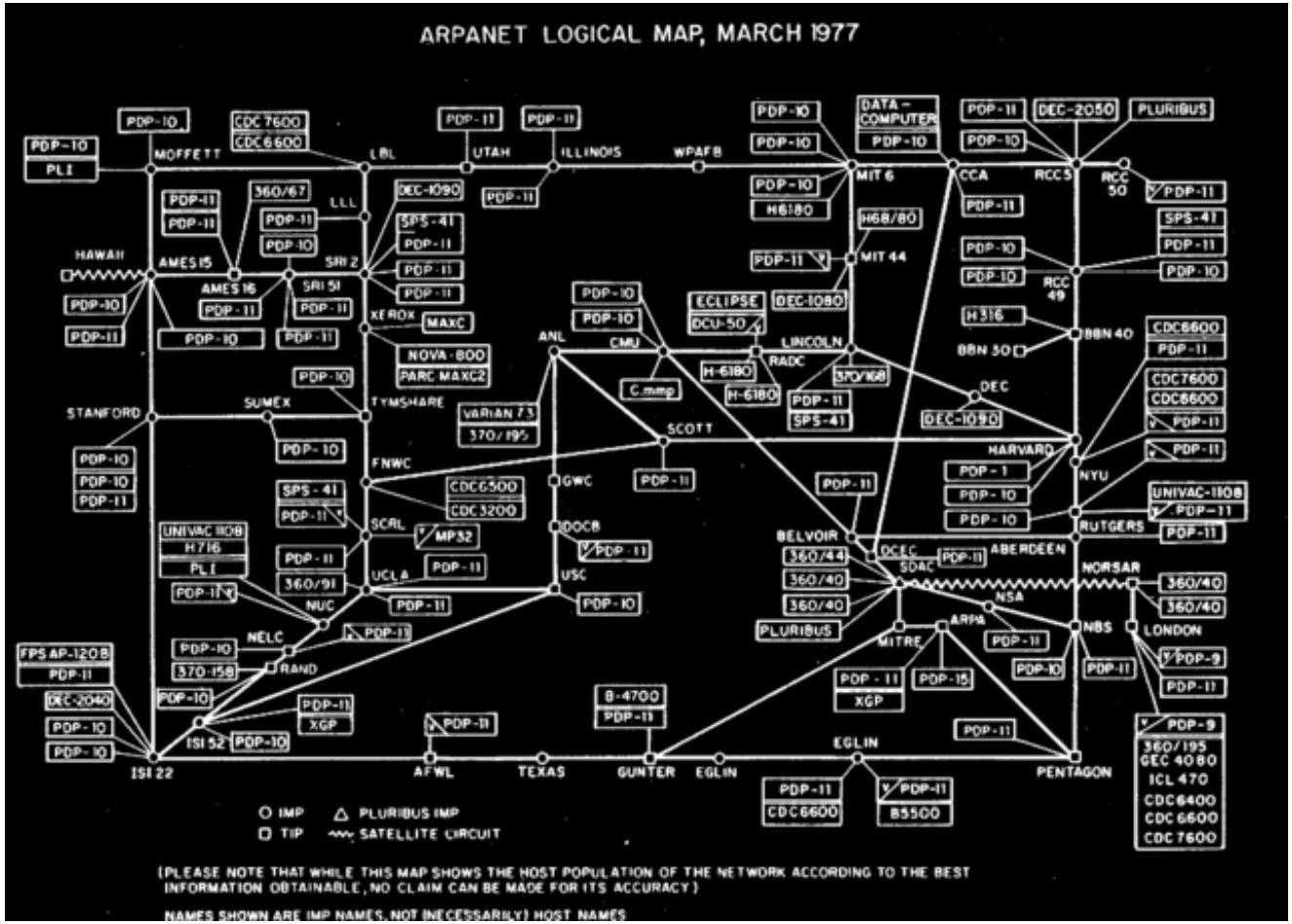

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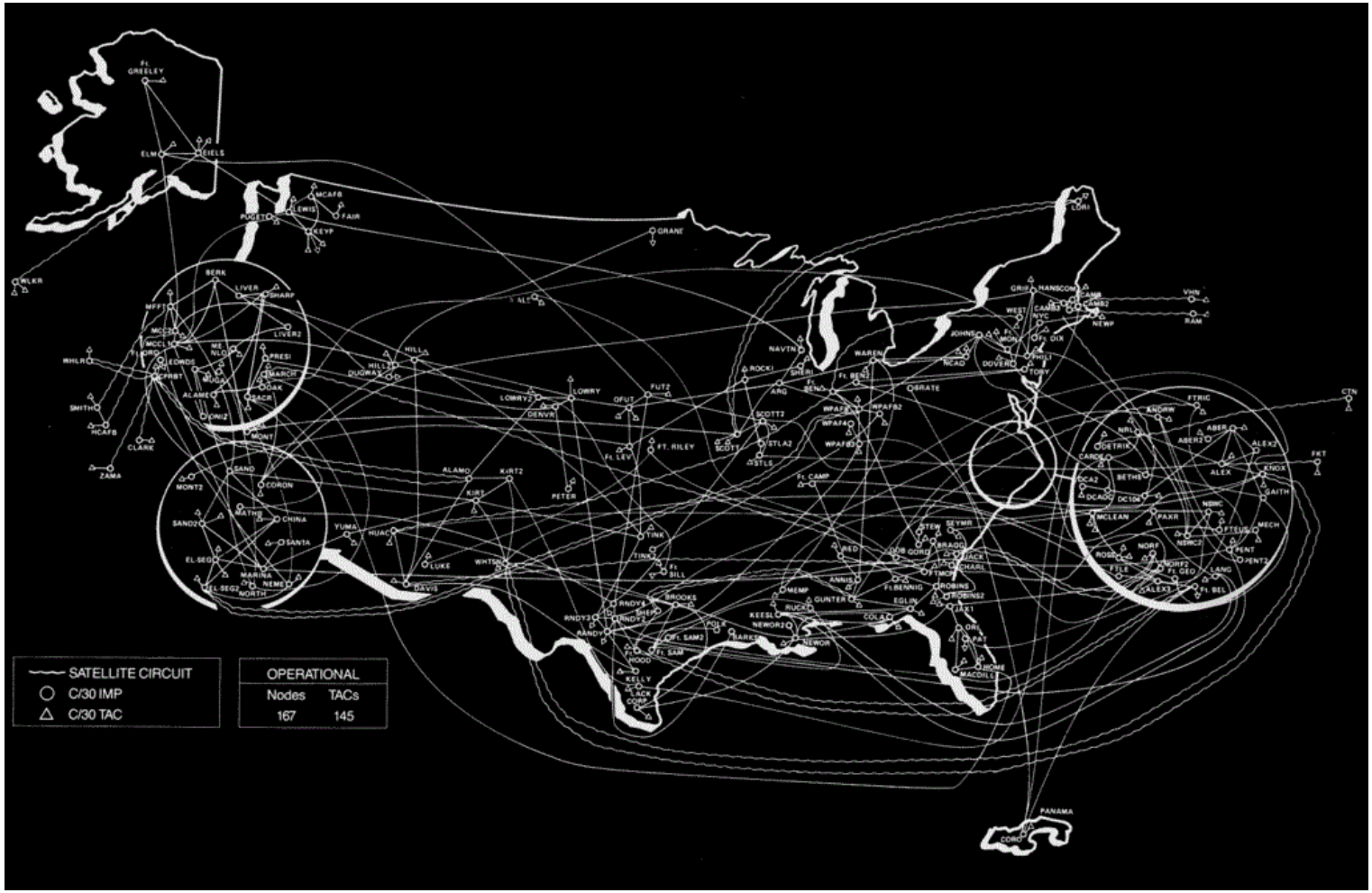

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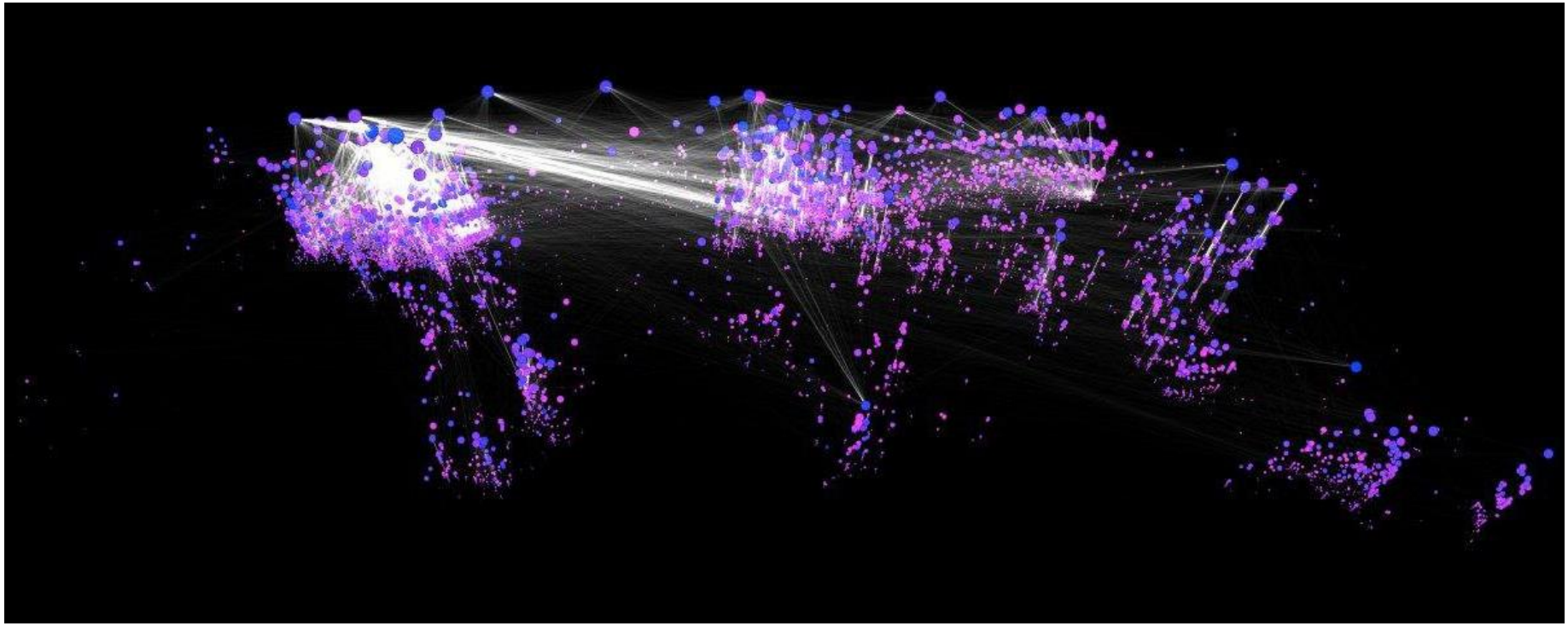
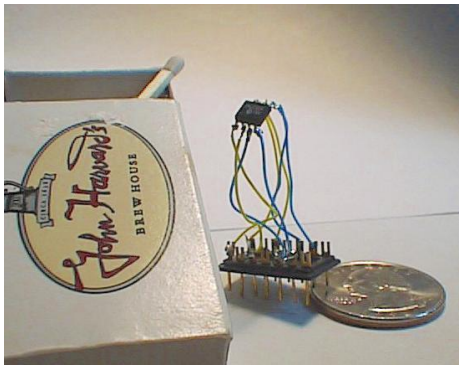


“Cool” internet appliances

IP picture frame
http://www.ceiva.com/
Free invitations for guests to send photos

Web-enabled toaster +
weather forecaster



World’s smallest web server
in 1999

Internet phones

⇨ Who knows other cool internet appliances?

Internet Components

- millions of connected computing devices:
  hosts = end systems
  - running *network apps*

PC

server

wireless laptop

cellular handheld

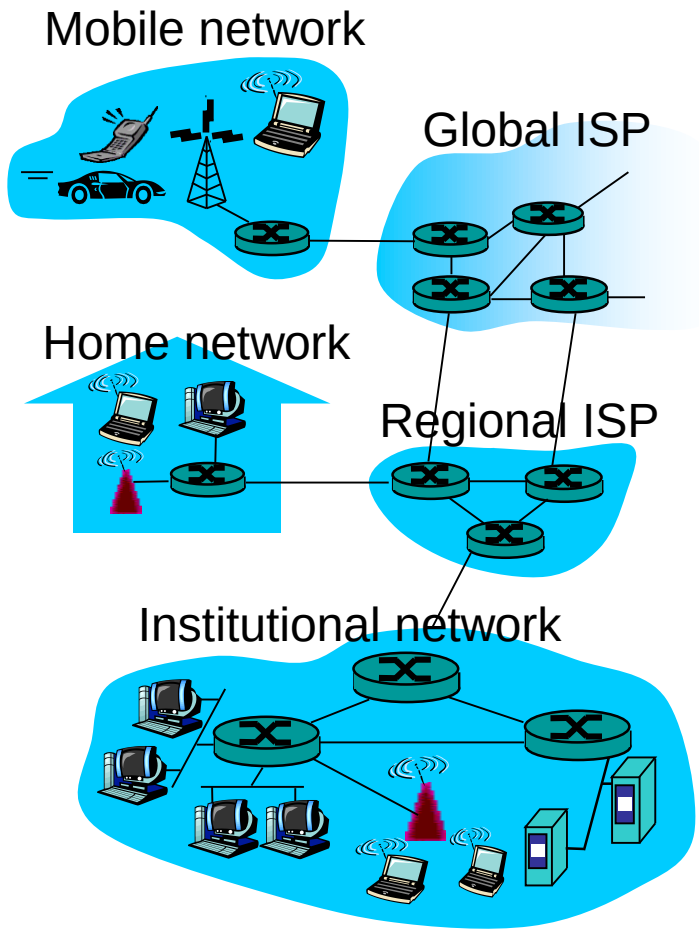
- *communication links*
  - fiber, copper, radio, satellite
  - transmission rate = *bandwidth*

access points

wired links

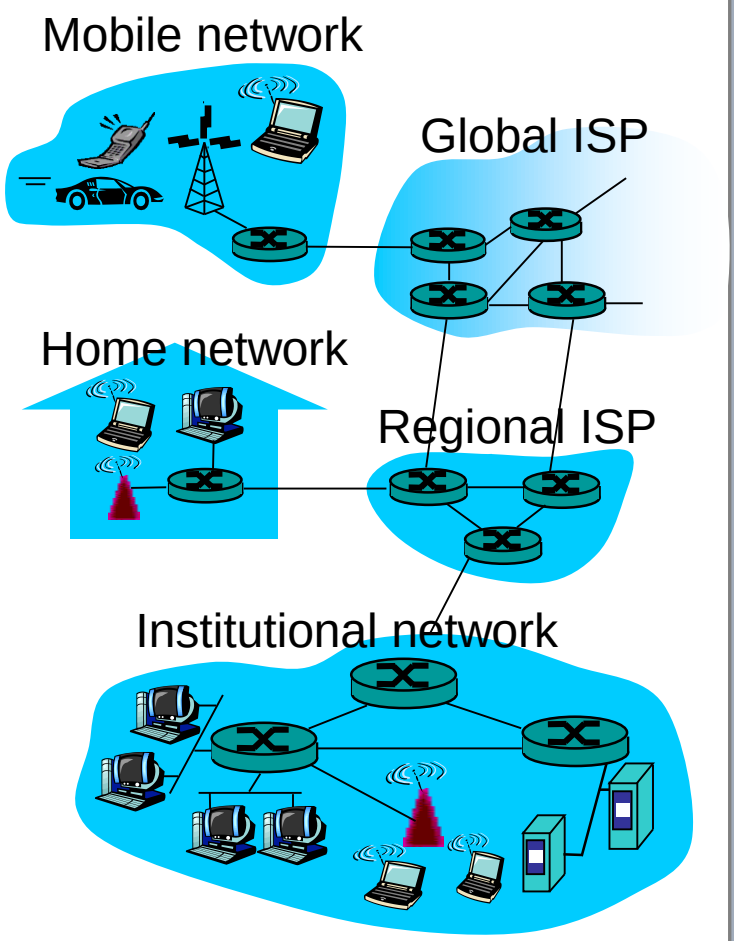
- *routers:* forward packets (chunks of data)

router



Internet Dimensions

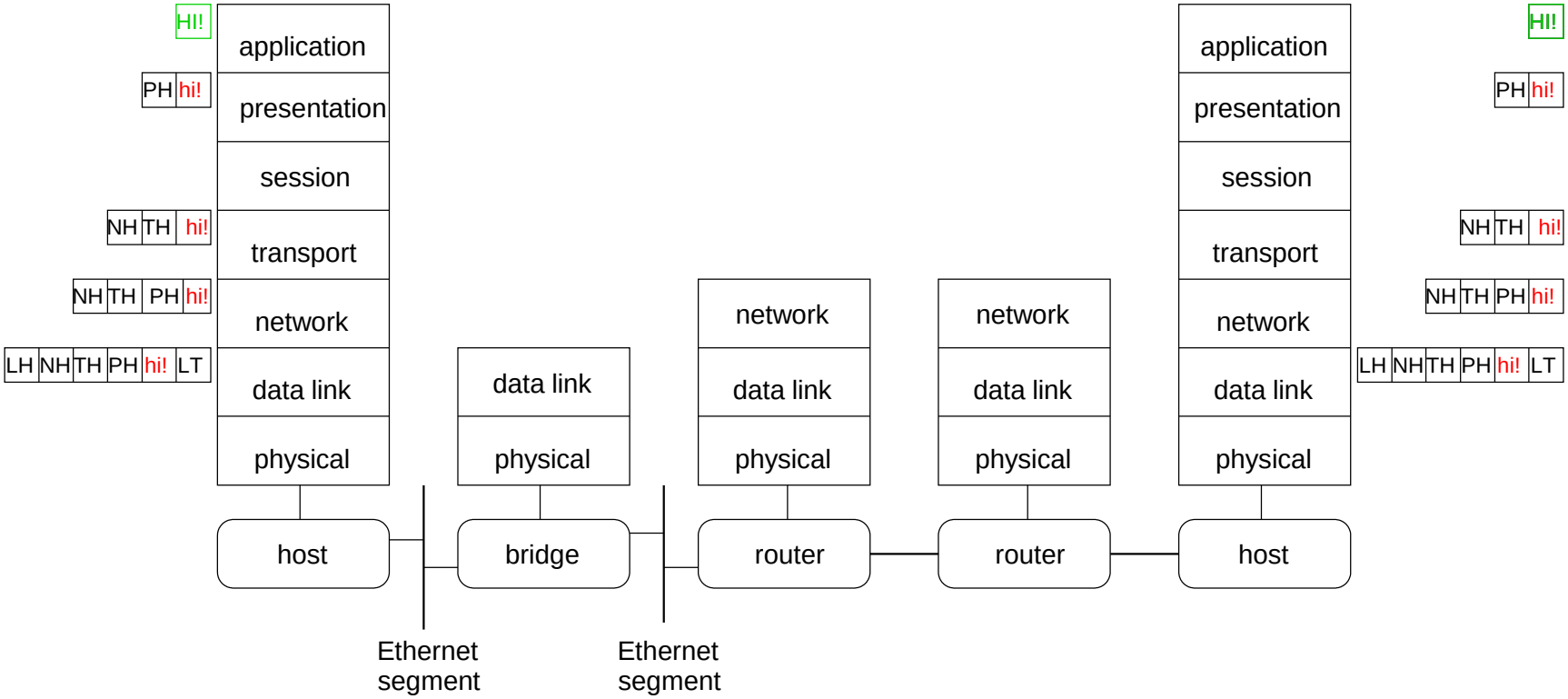
- *Protocols* control sending, receiving of messages
  - e.g., TCP, IP, HTTP, Skype, Ethernet
- *Internet:* "network of networks"
  - loosely hierarchical
  - public Internet versus private intranet
- Internet standards
  - RFC: Request for comments
  - IETF: Internet Engineering Task Force
  - IANA: Internet Assigned Numbers Authority
- Communication *infrastructure* enables distributed applications:
  - Web, VoIP, email, games, e-commerce, file sharing
- Communication ***services*** provided to applications:
  - reliable data delivery from source to destination
  - "best effort" (unreliable) data delivery



Protocol Mechanisms

- All or some of the following:
  - addressing/naming: manage identifiers
  - fragmentation: divide large message into smaller chunks to fit lower layer
  - re-sequencing: reorder out-of-sequence messages
  - error control: detection and correction of errors and losses
    - retransmission; forward error correction
  - flow control: avoid flooding/overwhelming of slower receiver
  - congestion control: avoid flooding of slower network nodes/links
  - resource allocation: administer bandwidth, buffers among contenders
  - multiplexing: combine several higher-layer sessions into one “channel”
  - compression: reduce data rate by encoding
  - privacy, authentication: security policy (others are listening)

Protocol Layering



- **send side** layer N takes protocol data (PDU) from layer N +1, adds header, and passed to N-1
- **receive side** layer N takes PDU from N –, strips N headers, processes and passes rest to N + 1

- Observation
  - Certain protocol mechanisms of layer 3 also used in layer 2
  - Same applies to other layers

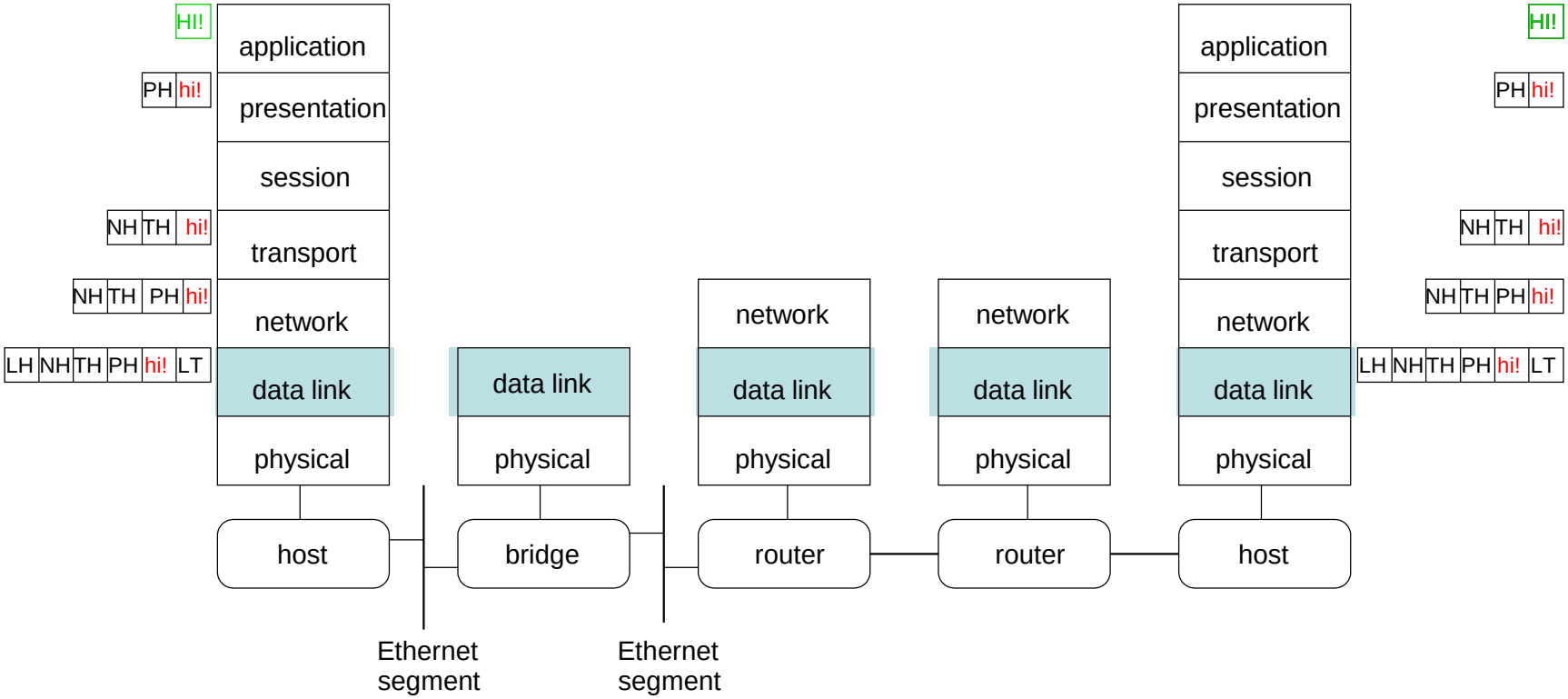
- True definition of a layer n protocol
  (by Radia Perlman)
  - Anything designed by a committee whose charter is to design a layer n protocol

Layering Considered Harmful?

- Benefits of layering
  - need layers to manage complexity
    - don’t want to reinvent Ethernet-specific protocol for each application
  - common functionality
    - “ideal” network
- but:
  - layer N may duplicate lower layer functionality (e.g. error recovery)
  - different layers may need same information
  - layer N may need to peek into layer N+x

Link Layer

Protocol Layering



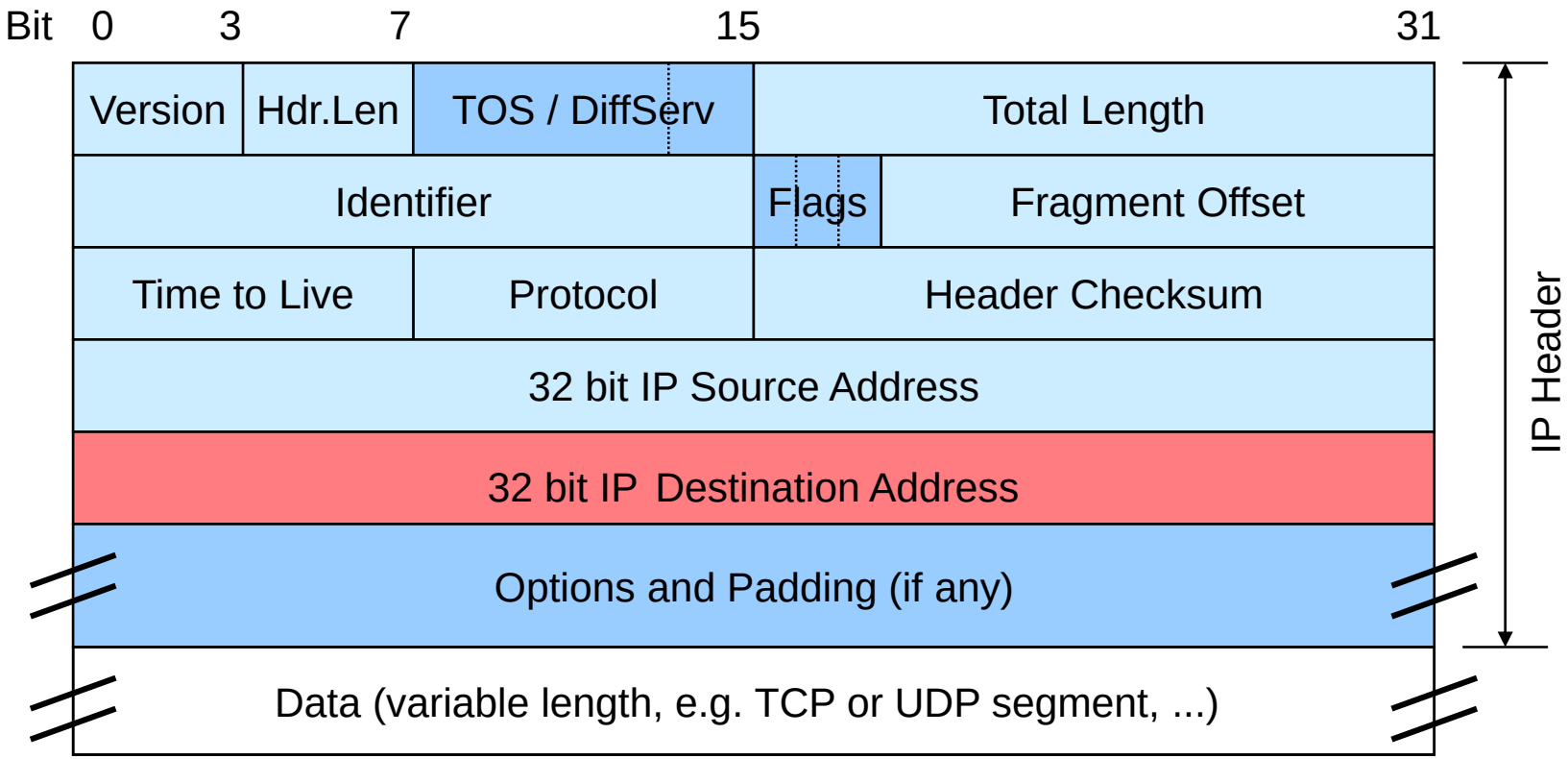
Ethernet Frame Structure

- Sending adapter encapsulates IP datagram (or other network layer protocol packet) in **Ethernet frame**

PR 56 bit	SFD (8 bit)	DA (16/48 bit)	SA (16/48 bit)	Type/Len (16 bit)	Data (≤12.000 bit)	PAD (0-368 bit)	FCS (32 bit)

PR	Preamble (1010101010...)
SFD	*Start-of-frame Delimiter* (10101011)
DA	*Destination Address*
SA	*Source Address*
Type	Protocol type of payload (e.g. IP, ARP, ...) - in Ethernet II frame format
Len	Length of payload in Byte - in Ethernet I and IEEE 802.3 frame format
Data	Data
PAD	*Padding (if data length is less than 46 byte)*
FCS	*Frame Check Sequence:* CRC32

For Comparison: IPv4 Datagram



Limitations of Layer 2

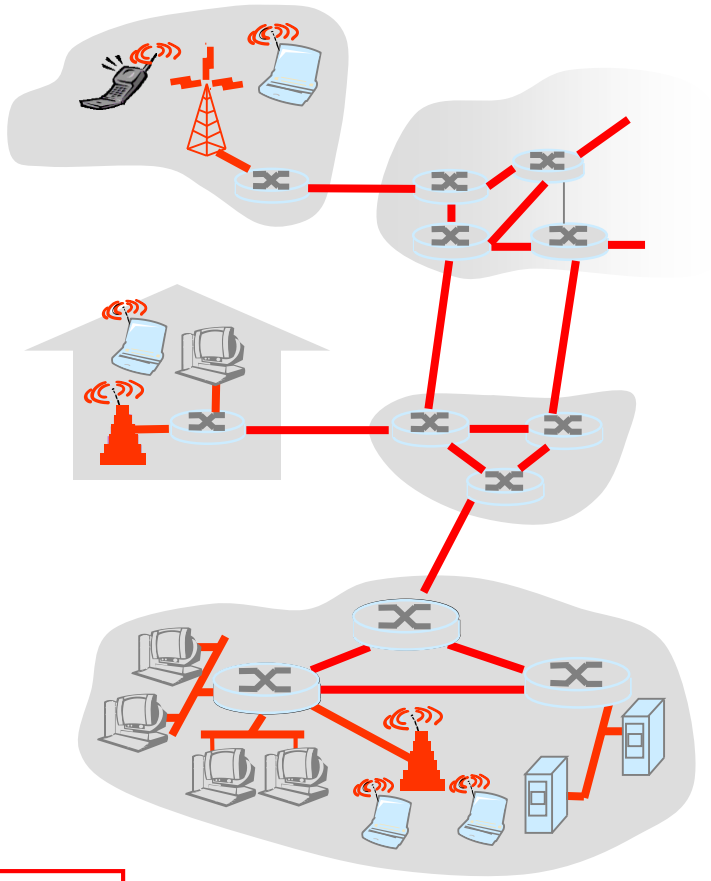
- Could Ethernet scale up to a very large (global) network?

- Scalability problems:
  - Flat addresses
  - No hop count (so loops may lead to desaster)
  - Missing additional protocols (such as ICMP)
  - Perhaps missing features (such as fragmentation, error messages, congestion feedback)

Link Layer Terminology

Some terminology:

- Hosts and routers are **nodes**
- Communication channels that connect adjacent nodes along communication path are **links**
  - wired links
  - wireless links
  - LANs
- Layer-2 packet is a **frame**, encapsulates Layer 3 packet - *datagram*



data-link layer has responsibility of transferring datagram from one node to adjacent node over a link

Link Layer Services

- Framing, link access:
  - encapsulate datagram into frame, adding header, trailer
  - channel access if shared medium
  - "MAC" addresses used in frame headers to identify source and destination node
    - different from IP address!
- Reliable delivery between adjacent nodes
  - seldom used on low bit-error link (fiber, some twisted pair)
  - wireless links: high error rates
    - Q: why both link-level and end-end reliability?

Link Layer Services (more)

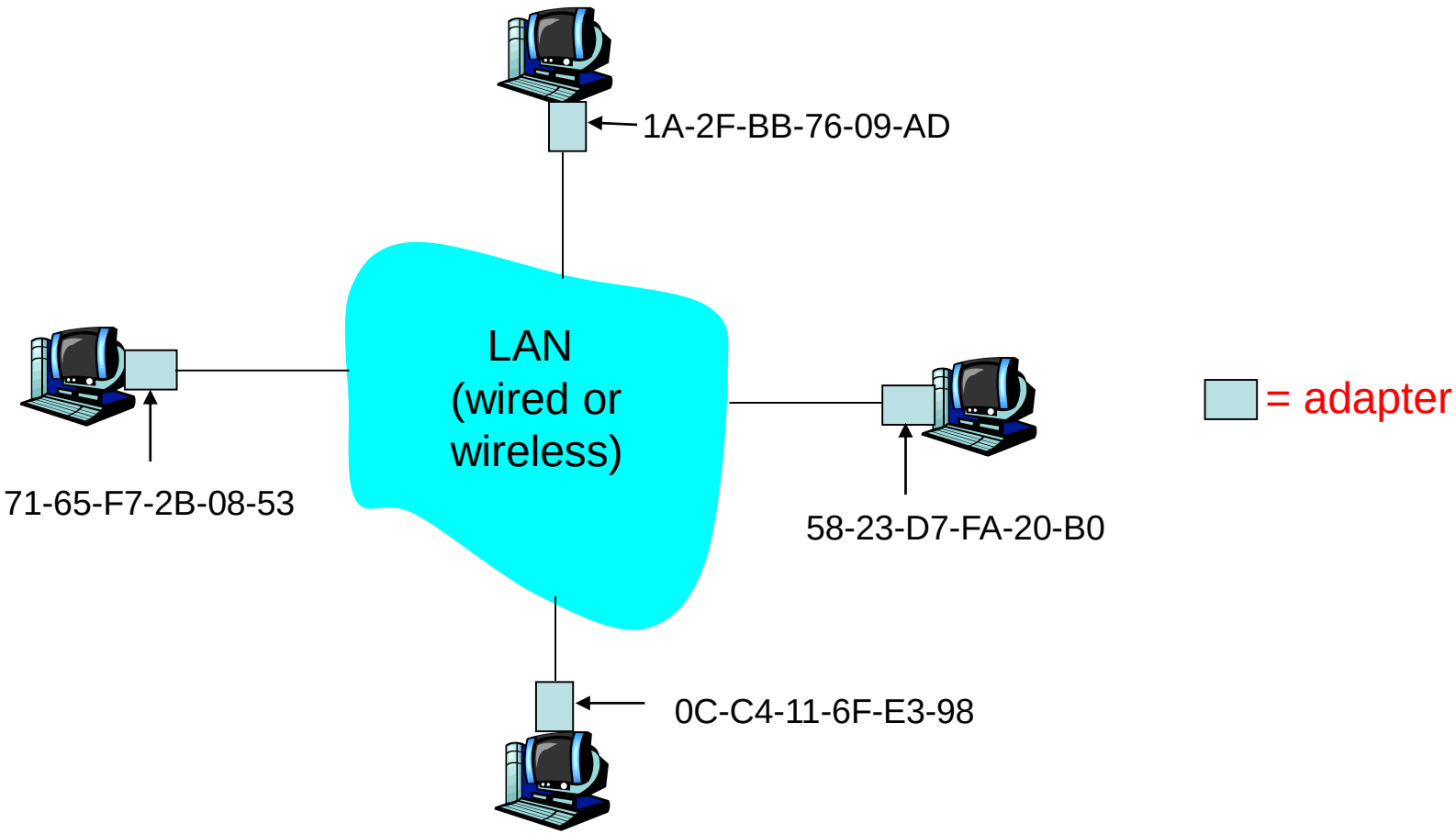
- *Flow control:*
  - pacing between adjacent sending and receiving nodes
- *Error detection*:
  - errors caused by signal attenuation, noise
  - receiver detects presence of errors:
    - signals sender for retransmission or drops frame
- Error correction:
  - receiver identifies *and corrects* bit error(s) without resorting to retransmission
- *Half-duplex and full-duplex*
  - with half duplex, nodes at both ends of link can transmit, but not at same time

MAC Addresses

- 32-bit IP address:
  - *network-layer* address
  - used to get datagram to destination IP subnet
- MAC (or LAN or physical or Ethernet) address:
  - function: *transmit frame from one interface to another physically-connected interface (same network)*
  - 48 bit MAC address (for most LANs)
    - burned in network adapter ROM, or software settable

LAN Addresses and ARP

- Each adapter on LAN has unique LAN address



LAN Addresses

- Transmission of addresses over the wire
  - Canonical form (also known as "LSB format" and "Ethernet format")
    First bit of each byte on the wire maps to
    least significant (i.e., right-most) bit of each byte in memory
    (c.f. RFC 2469)
  - Token Ring (IEEE 802.5) and FDDI (IEEE 802.6)
    do not use canonical form, but instead: most-significant bit first

- Human-friendly notation for MAC addresses: six groups of two hex digits, separated by “-”, in transmission order,
  e.g. 0C-C4-11-6F-E3-98

LAN Address

- Bit-reversed representation of MAC address
  - corresponds to convention of transmitting *least-significant-bit* of each byte *first* in serial data communications
- Multicast and broadcast
  - Broadcast address: FF-FF-FF-FF-FF-FF
  - Multicast addr.: least-significant bit of first byte has value “1”
- Organisation Unique Identifier (OUI): company_id
  - manufacturer purchases portion of MAC address space from IEEE Registration Authority (assuring uniqueness)
  - OUI: First 3 byte of address in transmission order
  - OUI enforced: 2nd least significant bit has value “0”, otherwise: locally administered MAC address
- MAC flat address ➜ portability
  - can move LAN card from one LAN to another
- IP hierarchical address NOT portable
  - address depends on IP subnet to which node is attached