Last time

- Link layer overview
  - Services
  - Adapters
- Error detection and correction
  - Parity check
  - Internet checksum
  - CRC
- PPP
  - Byte stuffing

This time

- Multiple access protocols
- Link-layer addressing

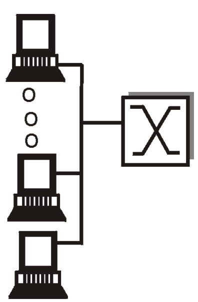
Link Layer

- 5.1 Introduction and services
- 5.2 Error detection and correction
- 5.3 Multiple access protocols
- 5.4 Link-Layer Addressing
- 5.5 Ethernet
- 5.6 Hubs and switches
- 5.7 PPP
- 5.8 Link Virtualization: ATM

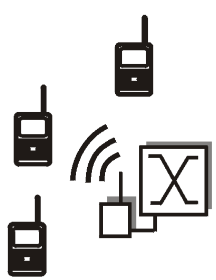
Multiple Access Links and Protocols

Two types of "links":

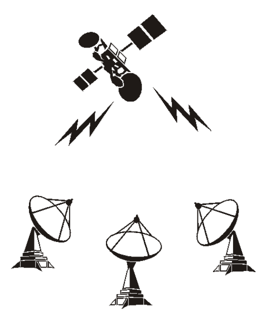
- point-to-point
  - PPP for dial-up access
  - point-to-point link between Ethernet switch and host
- broadcast (shared wire or medium)
  - Old-fashioned Ethernet
  - upstream HFC (cable modems)
  - 802.11 wireless LAN



shared wire
(e.g. Ethernet)



shared wireless
(e.g. Wavelan)



satellite

cocktail party

Multiple Access protocols

- Single shared broadcast channel
- Two or more simultaneous transmissions by nodes: interference
  - collision if node receives two or more signals at the same time

Multiple access protocol

- Distributed algorithm that determines how nodes share channel, i.e., determine when node can transmit
- Communication about channel sharing must use channel itself!
  - no out-of-band channel for coordination

Ideal Multiple Access Protocol

Broadcast channel of rate R bps

1. When one node wants to transmit, it can send at rate R.
2. When M nodes want to transmit, each can send at average rate R/M
3. Fully decentralized:
   - no special node to coordinate transmissions
   - no synchronization of clocks, slots
4. Simple

We usually don't achieve this ideal.

MAC Protocols: a taxonomy

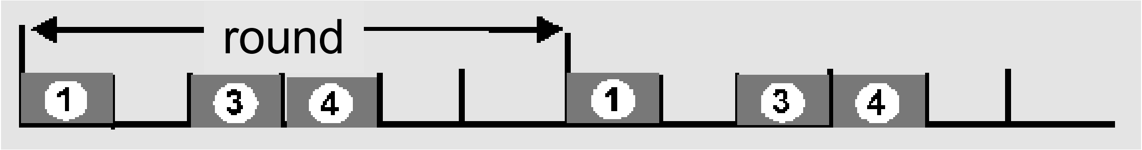
Three broad classes:

- Channel Partitioning
  - divide channel into smaller “pieces” (time slots, frequency, code)
  - allocate piece to node for exclusive use
- Random Access
  - channel not divided, allow collisions
  - “recover” from collisions
- “Taking turns”
  - Nodes take turns, but nodes with more to send can take longer turns

Channel Partitioning MAC protocols: TDMA

TDMA: time division multiple access

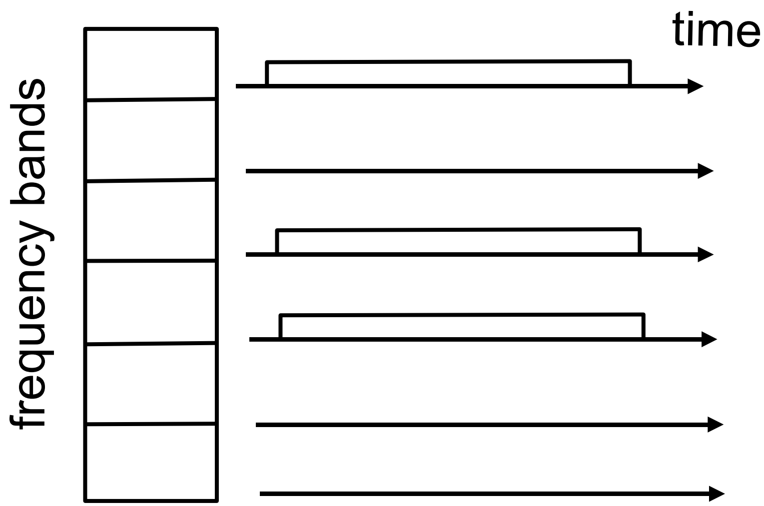
- Access to channel in "rounds"
- Each station gets fixed length slot (length = packet transmit time) in each round
- Unused slots go idle
- Example: 6-station LAN, 1,3,4 have packets, slots 2,5,6 idle



Channel Partitioning MAC protocols: FDMA

FDMA: frequency division multiple access

- Channel spectrum divided into frequency bands
- Each station assigned fixed frequency band
- Unused transmission time in frequency bands go idle
- Example: 6-station LAN, 1,3,4 have packets, frequency bands 2,5,6 idle



Random Access Protocols

- When node has packet to send
  - transmit at full channel data rate R.
  - no *a priori* coordination among nodes
- Two or more transmitting nodes ➜ “collision”,
- Random access MAC protocol specifies:
  - how to detect collisions
  - how to recover from collisions (e.g., via delayed retransmissions)
- Examples of random access MAC protocols:
  - slotted ALOHA
  - ALOHA
  - CSMA, CSMA/CD, CSMA/CA

Slotted ALOHA

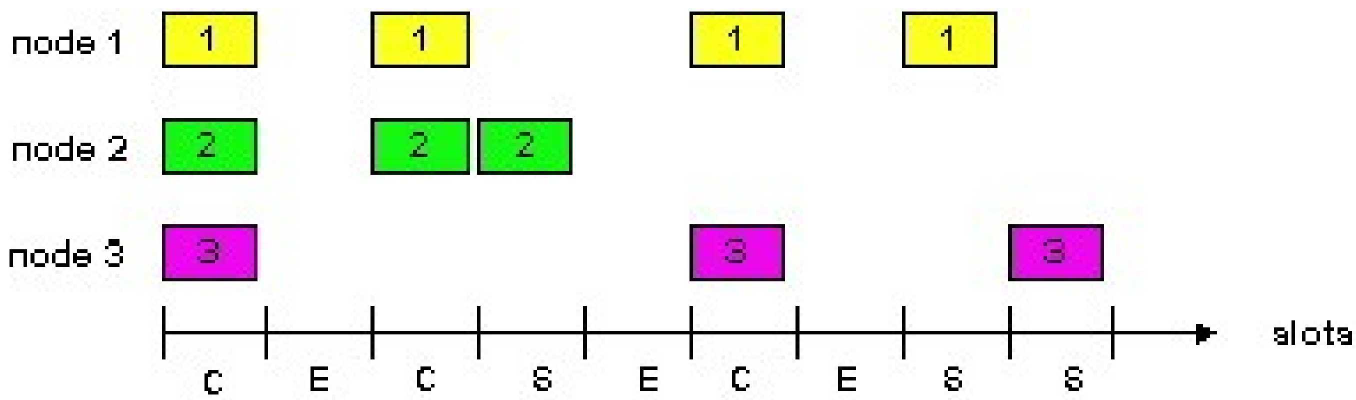
Assumptions

- all frames same size
- time is divided into equal size slots, time to transmit 1 frame
- nodes start to transmit frames only at beginning of slots
- nodes are synchronized
- if 2 or more nodes transmit in slot, all nodes detect collision

Operation

- when node obtains fresh frame, it transmits in next slot
- no collision, node can send new frame in next slot
- if collision, node retransmits frame in each subsequent slot with prob. p until success

Slotted ALOHA



Pros

- single active node can continuously transmit at full rate of channel
- highly decentralized: only slots in nodes need to be in sync
- simple

Cons

- collisions, wasting slots
- idle slots
- nodes may be able to detect collision in less than time to transmit packet
- clock synchronization

Slotted Aloha efficiency

Efficiency is the long-run fraction of successful slots when there are many nodes, each with many frames to send

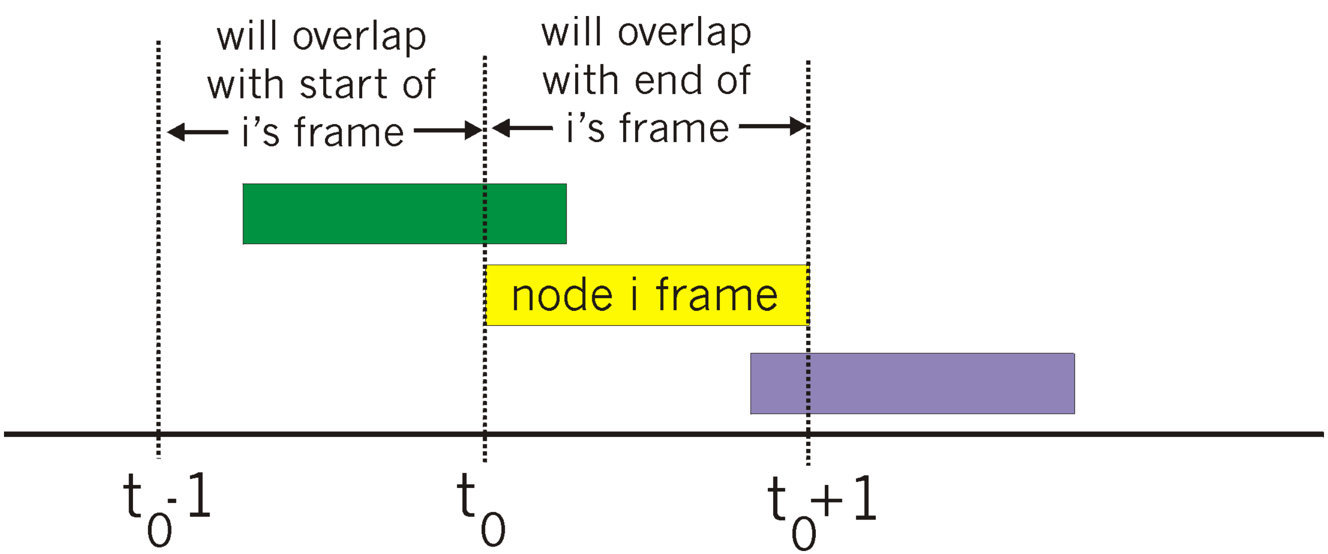
- Suppose N nodes with many frames to send, each transmits in slot with probability *p*
- prob that node 1 has success in a slot $= p(1-p)^{N-1}$
- prob that any node has a success $= Np(1-p)^{N-1}$

- For max efficiency with N nodes, find p* that maximizes $Np(1-p)^{N-1}$
- For many nodes, take limit of $Np^*(1-p^*)^{N-1}$ as N goes to infinity, gives $1/e = .37$

At best: channel used for useful transmissions 37% of time!

Pure (unslotted) ALOHA

- unslotted Aloha: simpler, no synchronization
- when frame first arrives
  - transmit immediately
- collision probability increases:
  - frame sent at t_0 collides with other frames sent in $[t_0-1, t_0+1]$



Pure Aloha efficiency

P(success by given node) = P(node transmits) ·

P(no other node transmits in $[t_0-1,t_0]$) ·

P(no other node transmits in $[t_0,t_0+1]$)

$= p \cdot (1-p)^{N-1} \cdot (1-p)^{N-1}$

$= p \cdot (1-p)^{2(N-1)}$

… choosing optimum p and then letting n -> infinity ...

Even worse !

= 1/(2e) = .18

CSMA (Carrier Sense Multiple Access)

CSMA: listen before transmit:

If channel sensed idle: transmit entire frame

- If channel sensed busy, defer transmission

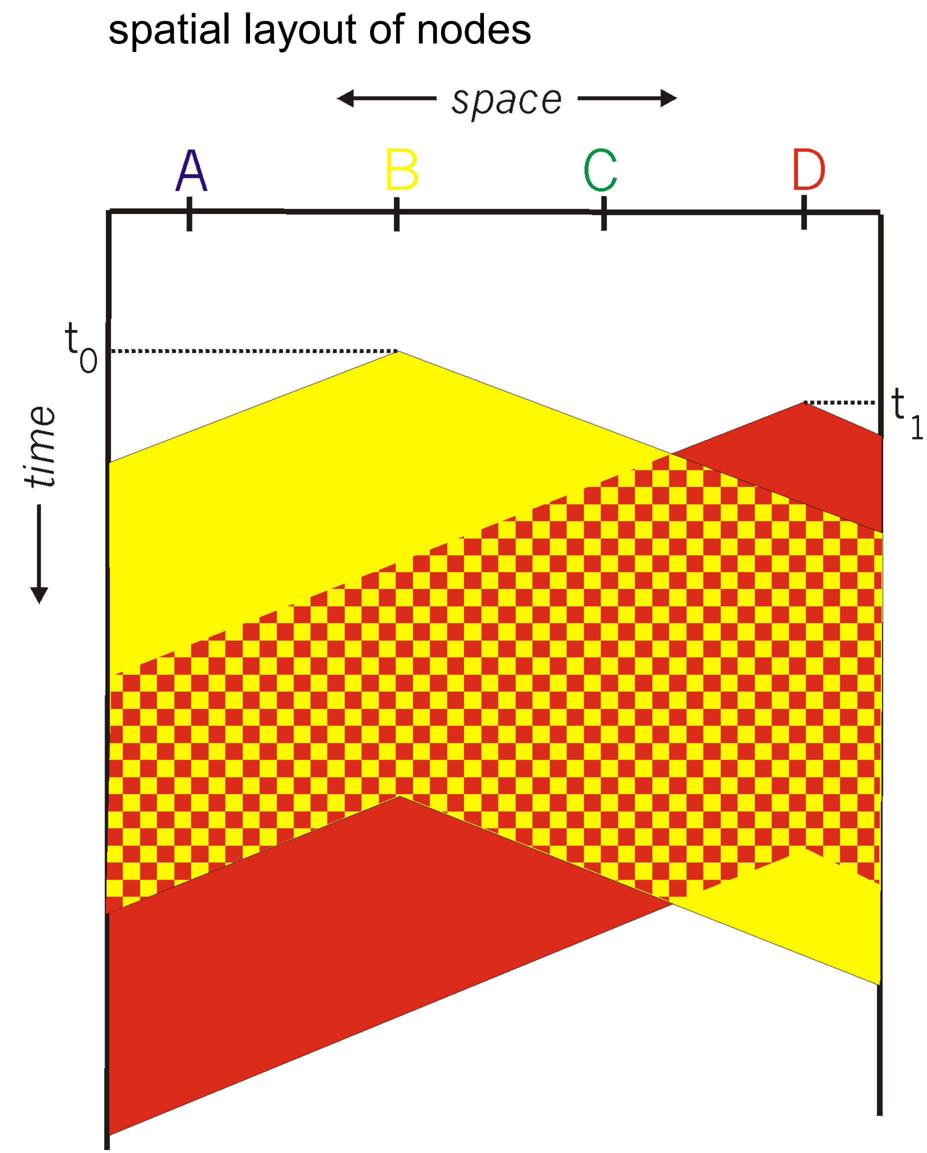
- Human analogy: don't interrupt others!

CSMA collisions

collisions *can* still occur:
propagation delay means two nodes may not hear each other's transmission

collision:
entire packet transmission time wasted

note:
role of distance & propagation delay in determining collision probability



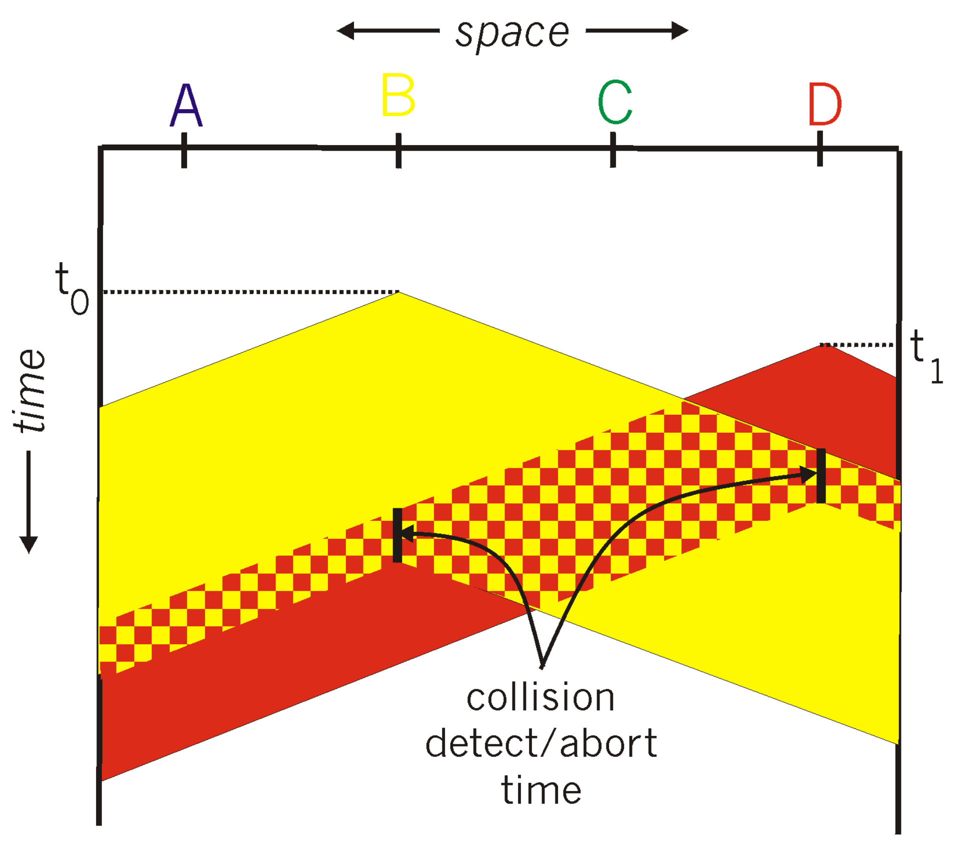
CSMA/CD (Collision Detection)

CSMA/CD: carrier sensing, deferral as in CSMA

- collisions *detected* within short time
- colliding transmissions aborted, reducing channel wastage

- collision detection:
  - easy in wired LANs: measure signal strengths, compare transmitted, received signals
  - difficult in wireless LANs: receiver shut off while transmitting
- human analogy: the polite conversationalist

CSMA/CD collision detection



“Taking Turns” MAC protocols

channel partitioning MAC protocols:

- share channel efficiently and fairly at high load
- inefficient at low load: delay in channel access, 1/N bandwidth allocated even if only 1 active node!

Random access MAC protocols

- efficient at low load: single node can fully utilize channel
- high load: collision overhead

“taking turns” protocols

look for best of both worlds!

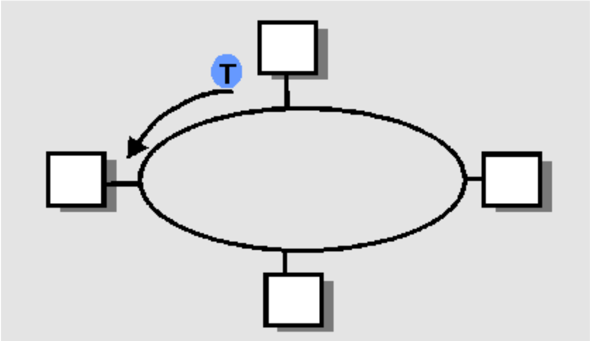
“Taking Turns” MAC protocols

Polling:

- master node “invites” slave nodes to transmit in turn
- concerns:
  - polling overhead
  - latency
  - single point of failure (master)

Token passing:

- control **token** passed from one node to next sequentially.
- token message
- concerns:
  - token overhead
  - latency
  - single point of failure (token)



Summary of MAC protocols

- What do you do with a shared medium?
  - Channel Partitioning, by time, frequency or code
    - Time Division, Frequency Division
  - Random partitioning (dynamic),
    - ALOHA, S-ALOHA, CSMA, CSMA/CD
    - carrier sensing: easy in some technologies (wire), hard in others (wireless)
    - CSMA/CD used in Ethernet
    - CSMA/CA used in 802.11
  - Taking Turns
    - polling from a central site, token passing

LAN technologies

Data link layer so far:

- services, error detection/correction, PPP, multiple access

Next: LAN technologies

- addressing
- Ethernet
- hubs, switches

Link Layer

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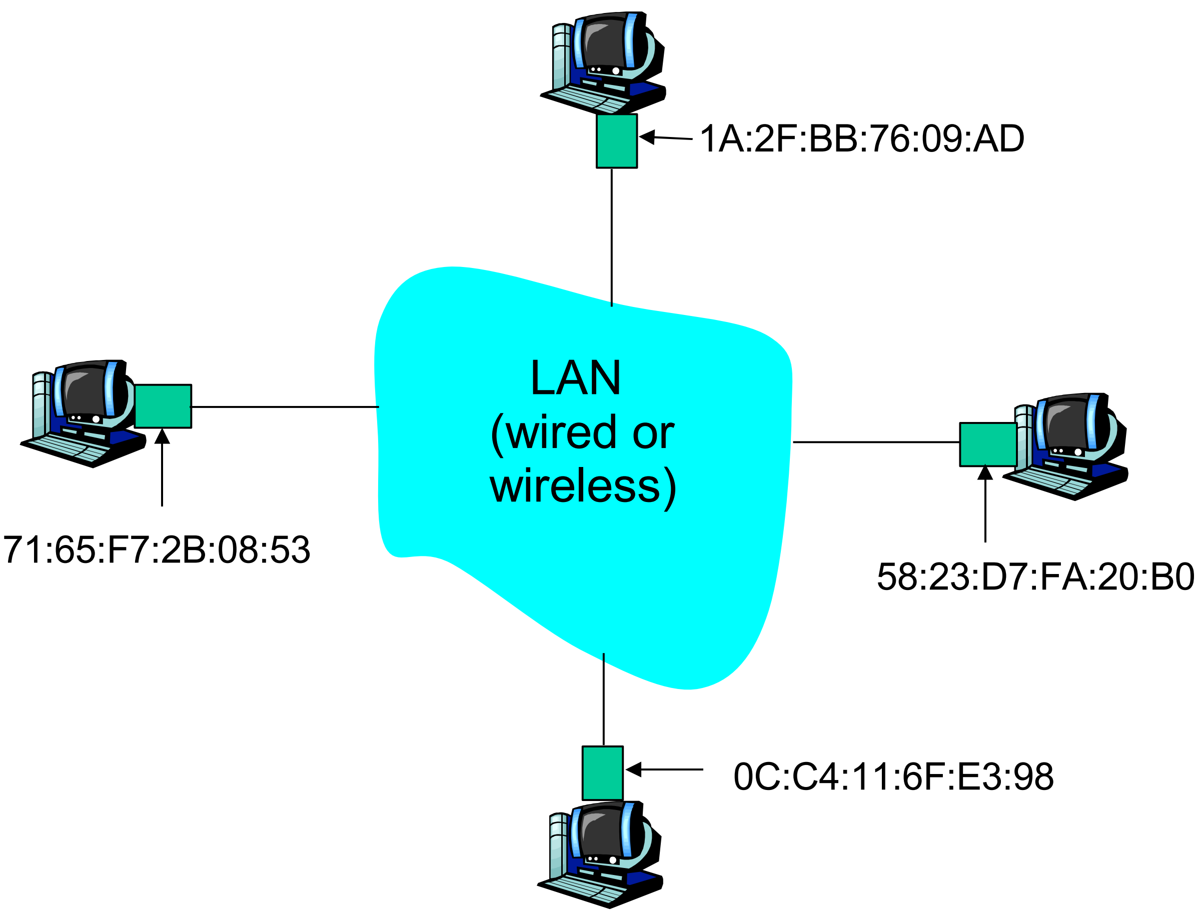
MAC Addresses

- Each node in a LAN has a link-layer address called a **MAC** (or LAN or physical or Ethernet) **address**
  - used to indicate intended recipient of frame from one interface to another physically-connected interface (on the same network link)
  - 48 bit MAC address (for most LANs) burned in the adapter ROM
  - usually written like this:

00:13:02:4B:80:D3

MAC Addresses

Each adapter on LAN has a unique MAC address



Broadcast address =
FF:FF:FF:FF:FF:FF

= adapter

MAC Addresses

- Each adapter needs to have a unique MAC address on its LAN (why?)
  - The easiest way to ensure this is to give each adapter a *globally* unique MAC address.
  - Then any adapter can work on any LAN (plug-and-play)

- MAC address allocation is administered by IEEE
- Manufacturers buy a portion of the MAC address space (to ensure uniqueness)
  - IEEE determines first 24 bits of MAC address for each manufacturer.
  - The manufacturer creates unique combinations for the last 24 bits of each adapter.

MAC Addresses

- MAC addresses have a **flat** address structure
  - If you move an adapter from one network to another, the address **does not** change
  - We say MAC addresses are **portable**.
- We will see later that IP addresses are *not* portable
  - If you move a computer from one network to another, its IP address **does** change
- Analogy:

  (a) MAC address: like Social Insurance Number

  (b) IP address: like postal address

Recap

- Multiple access protocols
  - Channel partitioning MAC protocols
    - TDMA, FDMA
  - Random access MAC protocols
    - Slotted Aloha, Pure Aloha, CSMA, CSMA/CD
  - "Taking turns" MAC protocols
    - Polling, token passing
- Link-layer addressing

Next time

- Ethernet
- Hubs and switches