CSCE 463/612
Networks and Distributed Processing
Spring 2025

Data-link Layer I

Dmitri Loguinov
Texas A&M University

April 17, 2025

Homework #4

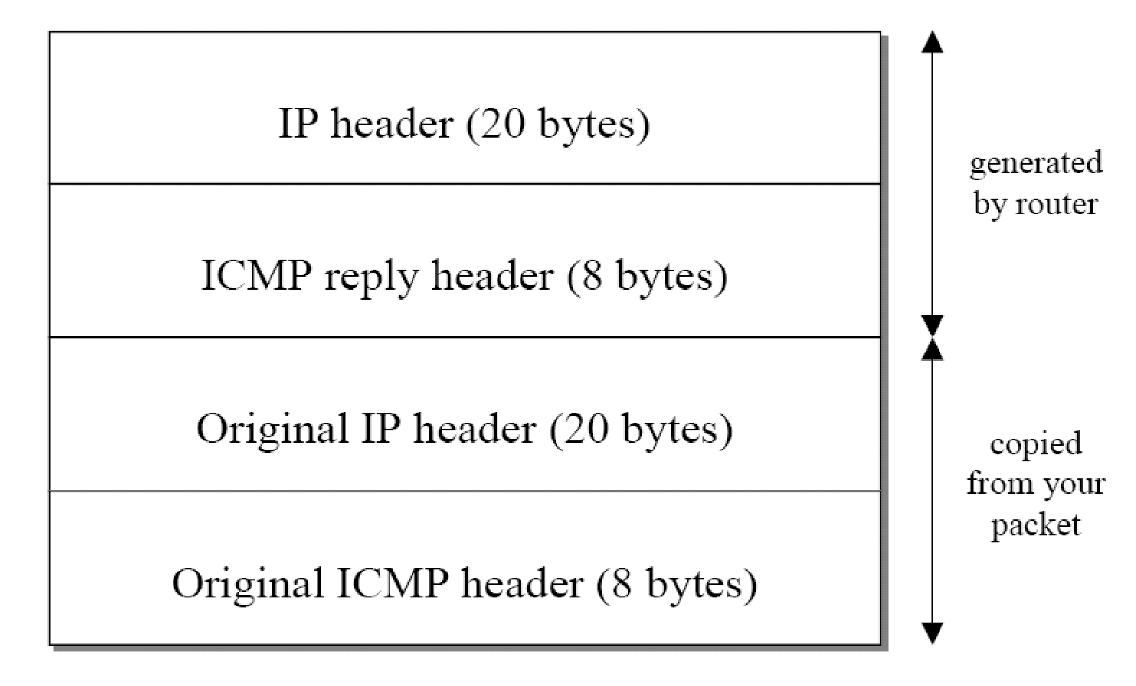
- ICMP header:

```
class ICMPHeader{
public:
     u_char type;                  /* ICMP packet type */
     u_char code;                  /* ICMP type subcode */
     u_short checksum;             /* checksum */
     u_short ID;                   /* usually process ID */
     u_short seq;                  /* sequence */
};
```

- Received ICMP pkts are delivered to all open ICMP sockets (since ICMP has no port numbers)
  - Routers will echo your entire IP packet in their TTL expired messages
  - Use the ID field to distinguish your pkts from junk

Homework #4

- TTL Expired pkt structure:



- Find out whether the ID field in the 4-th header matches your ID

Homework #4

- Other things to consider:
  - If your checksums are incorrect, the packet will likely be dropped and you won’t get a reply
  - If your firewall is enabled to block all incoming traffic, the kernel will not deliver ICMP packets
- Usually, you must be admin to open ICMP sockets
- Mores caveats in the handout!
  - UAC needs to be disabled or VS run as administrator
  - Custom in-bound firewall rules
  - Batch mode requires pinging the target before tracing
  - Hard limits on trace delay in batch mode

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

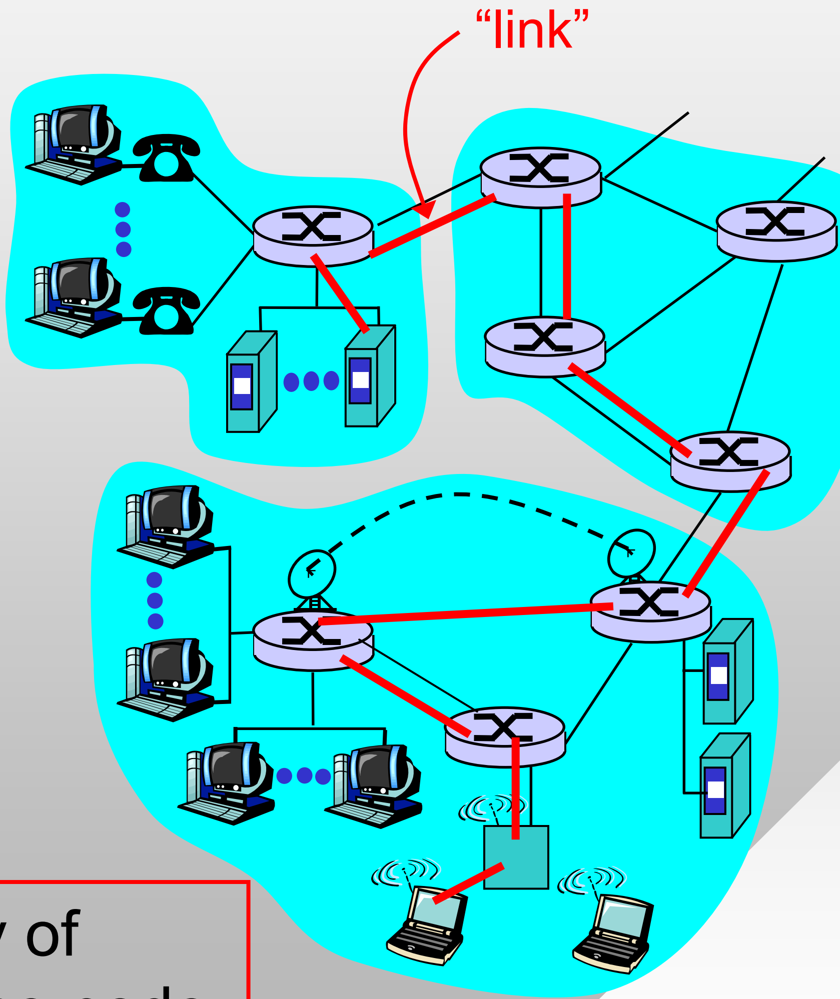
5.6 Hubs and switches

Summary

Link Layer: Introduction

Terminology:

- Hosts and routers are nodes
- Communication channels that connect adjacent nodes are layer-3 links
  - Wired or wireless
- Each link may contain multiple layer-2 devices (e.g., switches)



Data-link layer has responsibility of transferring IP datagram from one node to adjacent node over a single link

Link Layer Services

- Framing:
  - Add header, trailer to IP packet
  - Data-link addresses (completely independent of IP addresses) used in frame headers to identify source, dest
- Link access:
  - Channel access if shared medium
- Flow control:
  - Pacing between adjacent sending and receiving nodes
- Error detection:
  - Errors caused by signal attenuation, noise
  - Receiver detects presence of errors and signals data-link layer of adjacent node for retransmission or drops frame

Link Layer Services

- Forward Error Correction (FEC):
  - Receiver identifies *and corrects* bit error(s) without resorting to retransmission
- Reliable delivery (rdt) between adjacent nodes
  - Rdt 3.0 is a common technique (chapter 3)
  - Seldom used on low bit error links (fiber, twisted pair), but may be implemented in wireless networks
- More terminology
  - In half-duplex mode, nodes at both ends of link can transmit, but not at the same time
  - In full-duplex, bidirectional transfer happens concurrently

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

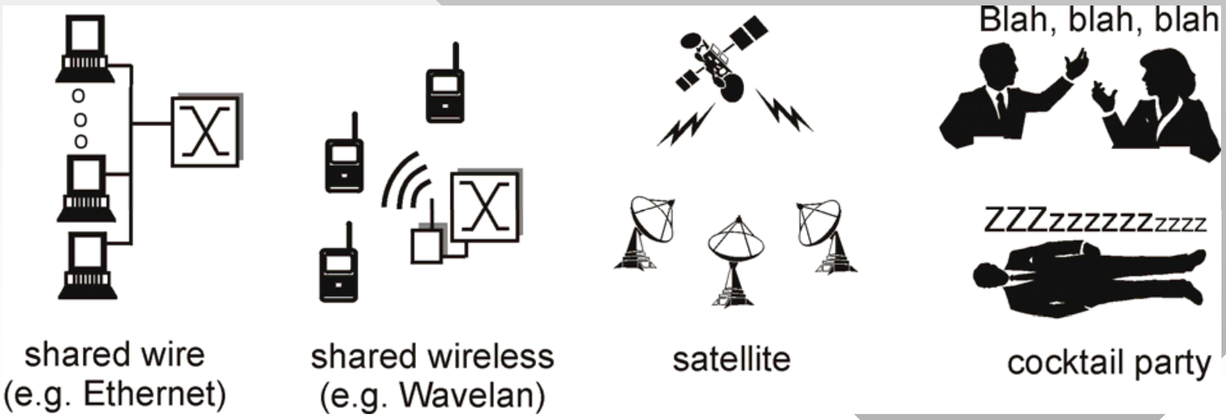
5.6 Hubs and switches

Summary

Multiple Access Links and Protocols

Two types of links:

- Point-to-point, e.g.:
  - PPP for dial-up, DSL, fiber home access
  - Dedicated cable between Ethernet switch and host
- Broadcast (shared wire/medium)
  - Traditional Ethernet
  - Upstream HFC (hybrid fiber coax)
  - 802.11 wireless LAN, satellite



Multiple Access Protocols

- Assume a single shared broadcast channel
- Two or more simultaneous transmissions by nodes is called interference or collision
  - Receiver cannot discern packets when multiple signals are jammed together

Link access protocol

- Distributed algorithm that determines how nodes share channel
- Communication about channel sharing must use the channel itself!
  - No out-of-band channel for coordination
- MAC (Media Access Control) layer = data-link layer = layer 2

Ideal Multiple Access Protocol

Desired properties

1. Single node can achieve full channel rate C (high utilization without competition)
2. When N nodes want to transmit, each can send at average rate C / N (fairness and high utilization during competition)
3. Fully decentralized:
   - No special node to coordinate transmissions
   - No synchronization of clocks
4. Simple

MAC Protocols: Taxonomy

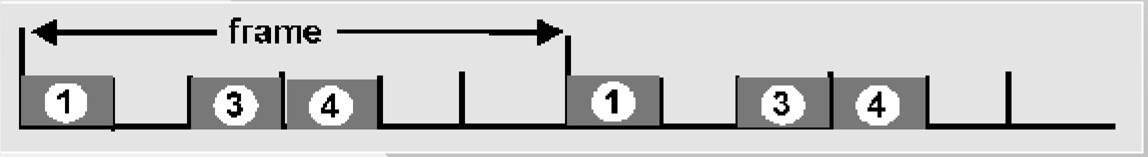
Three broad classes:

- Channel Partitioning
  - Divide channel into smaller “pieces” (time slots, frequency, wavelengths)
  - 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 may take longer turns

Channel Partitioning MAC protocols: TDMA

TDMA: time division multiple access

- Access to channel in “rounds” (time frames)
  - Each station gets fixed length slot in each round (1/N of frame time to each node), unused slots go idle
- Example: 6-device LAN

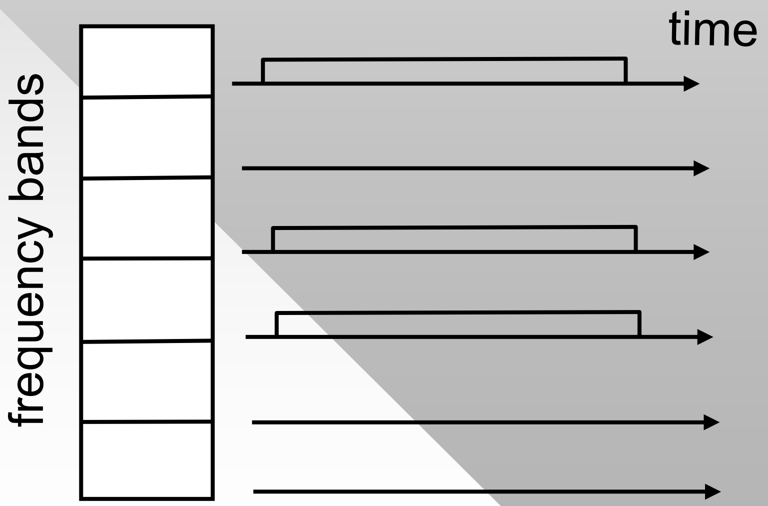


- Maximum throughput for a single user is C / N, which is far from ideal!

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-device LAN



Random Access Protocols

- When node has packet to send
  - Transmit at full channel data rate C
  - No *a-priori* coordination among nodes
- Two or more transmitting nodes cause collision
  - All involved packets are useless, must be retransmitted
- Random access MAC protocol specifies:
  - How to detect collisions
  - How to recover from collisions (e.g., via delayed retransmission)
- Examples of random access MAC protocols:
  - Slotted ALOHA
  - CSMA, CSMA/CD

Slotted ALOHA (1975)

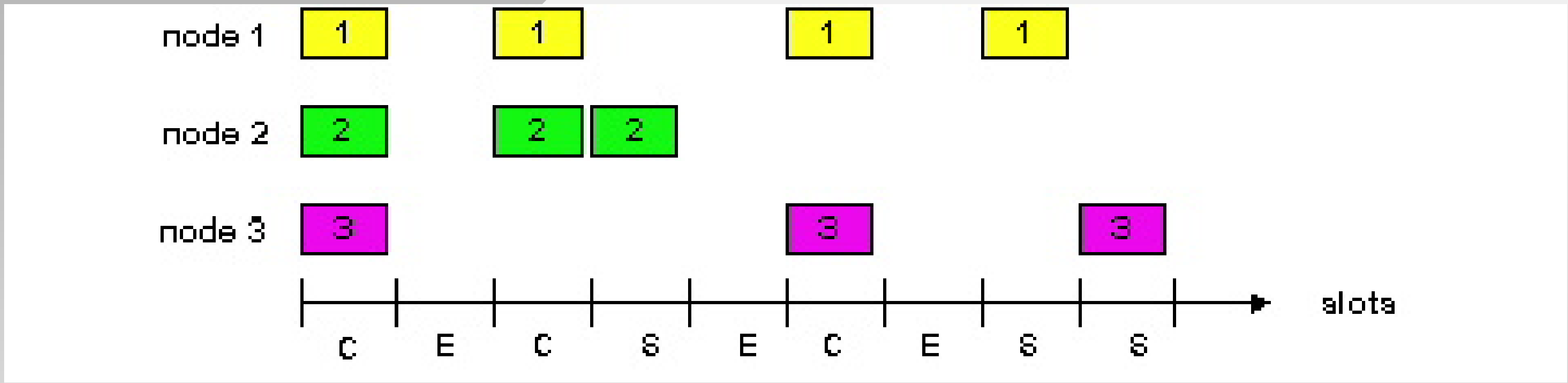
Assumptions

- All packets same size
  - Time is divided into equal size slots, time to transmit 1 packet
- Nodes start transmission only at beginning of slots
  - Clocks are synchronized
- If 2 or more nodes transmit in slot, all nodes detect collision

Operation

- When node obtains fresh frame from IP, it transmits in the next time slot
- No collision, node can send new frame in next slot
- If collision, node retransmits frame in each subsequent slot with probability *p* until success

Slotted ALOHA



Pros

- Single active node can continuously transmit at full rate of channel
- Reasonably decentralized: only slots need to be in sync
- Simple

Cons

- Collisions
- Idle/empty slots
- Full slot wasted on collision
- Accurate clock synchronization is still a headache

Slotted Aloha Efficiency

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

- Assume N nodes with infinite data to send, each transmits in every slot with probability p
- Probability that k nodes transmit in slot = $\binom{N}{k} p^k (1-p)^{N-k}$
- Prob that exactly one node transmits in a given slot (i.e., success) is $Np(1-p)^{N-1}$

- For max efficiency with N nodes, find p that maximizes $Np(1-p)^{N-1}$
- Optimal $p_0 = 1/N$
- For many nodes, take limit of $Np_0(1-p_0)^{N-1}$ as N goes to infinity, which gives optimal efficiency $1/e = 0.37$

Slotted Aloha with many users: channel utilization only 37%!

CSMA (Carrier Sense Multiple Access)

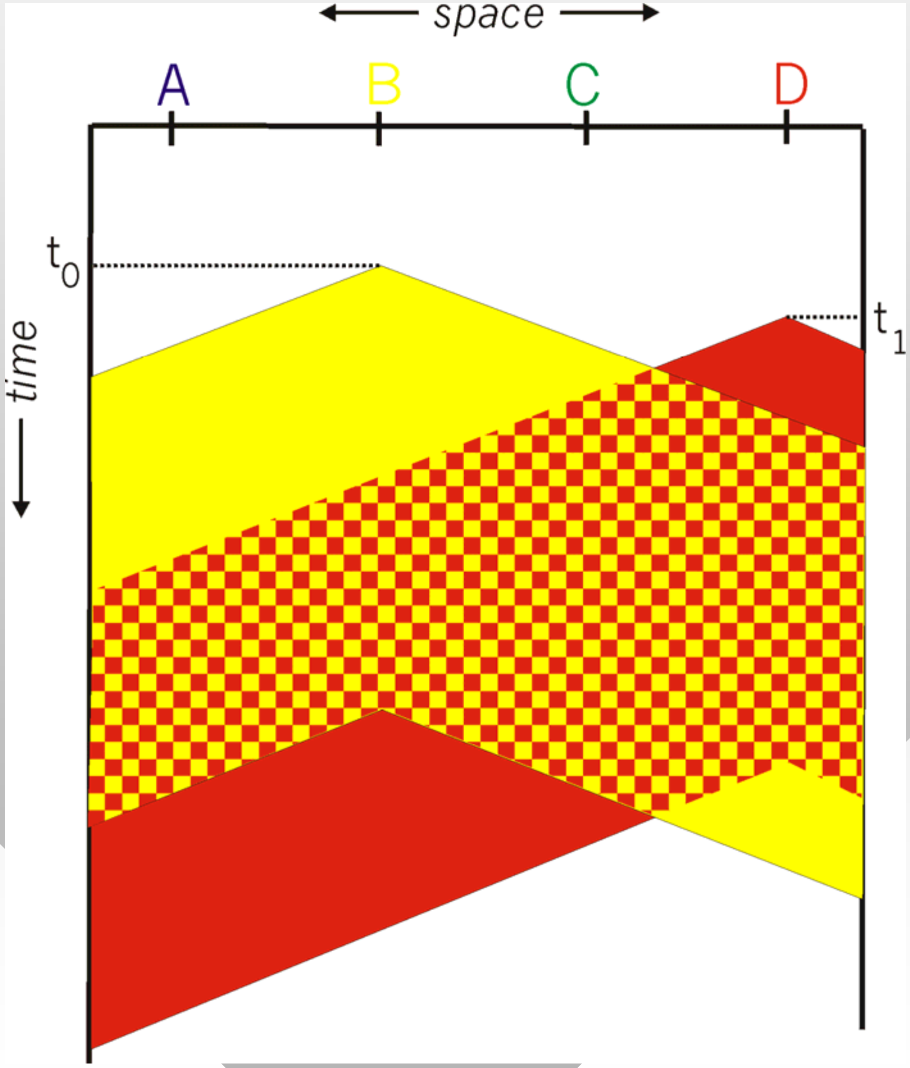
- Remove slots and allow transmission at any time

CSMA: listen before transmit

- If channel sensed idle, transmit entire frame
- If channel sensed busy, defer transmission
  - Human analogy: don't interrupt others!
- If collision is detected at the end of transfer, wait a random period of time, then retransmit
  - Human analogy: talk until you're done, pause, then repeat if someone else happened to start at the same time

CSMA Collisions

spatial layout of nodes



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

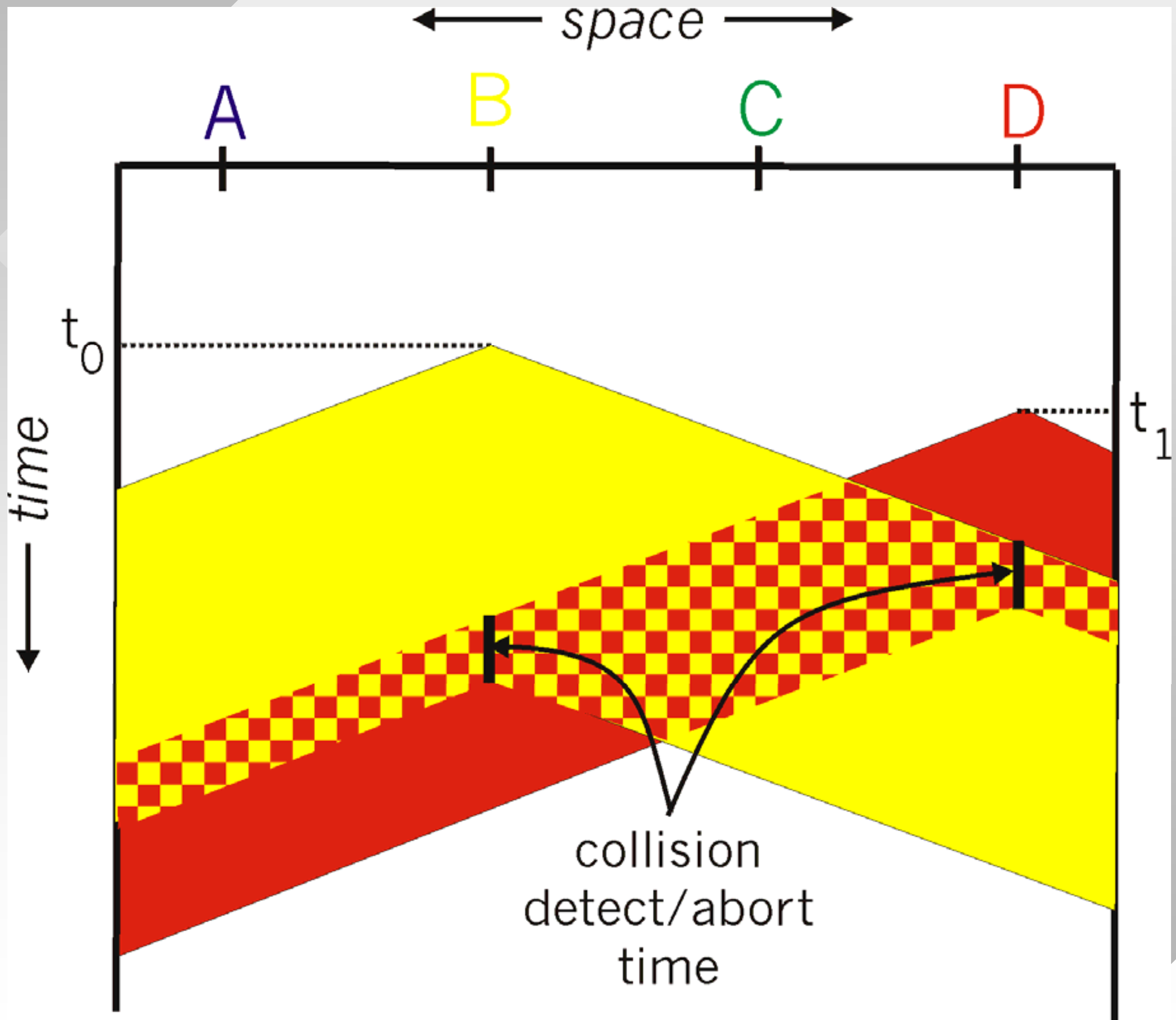
CSMA/CD (Collision Detection)

CSMA/CD: carrier sensing, deferral as in CSMA

- But now collisions are detected immediately
- Colliding transmissions aborted, reducing channel waste

- Human analogy: the polite conversationalist
- Collision detection:
  - Easy in wired LANs: measure signal strengths, compare transmitted, received signals
  - Difficult in wireless LANs: receiver shut off while transmitting

CSMA/CD Collision Detection



Features

TDMA/FDMA:

- 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:

- Efficient at low load: single node can fully utilize channel
- High load: potentially huge collision overhead?

"Taking turns" protocols:

- Look for best of both worlds?

“Taking Turns” MAC Protocols

A) Polling:

- Coordinator “invites” other nodes to transmit in turn
- Concerns:
  - Polling overhead
  - Latency
  - Single point of failure (coordinator)

B) Token passing:

- Control **token** passed from one node to next sequentially
- Can send only if holding token
- Concerns:
  - Token overhead
  - Latency
  - Single point of failure (token)