南京大學
NANJING UNIVERSITY

Computer Networks

Wenzhong Li, Chen Tian

Nanjing University

Chapter 2. Link Layer

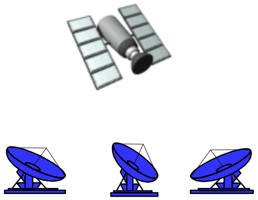
- Link Layer Service
  - Framing
  - Link access
  - Reliable delivery
  - Error detection and correction
- Local Area Network (LAN)
  - Token Ring
  - Ethernet
- Medium access control (MAC)
- Bridges and Layer-2 switch
- Wireless Networks

Link Access

- Two types of “links”:
- Point-to-point: dedicated pairwise communication
  - E.g., long-distance fiber link
  - E.g., Point-to-point link b/n Ethernet switch and host
- Broadcast: shared wire or medium
  - Traditional Ethernet (pre ~2000)
  - 802.11 wireless LAN

shared wire (e.g., cabled Ethernet)

shared RF (e.g., 802.11 WiFi)



shared RF (satellite)

humans at a cocktail party (shared air, acoustical)

Multiple Access Control (MAC)

- Properties of Multiple Access Links
  - Single shared broadcast channel
  - Two or more simultaneous transmissions by nodes: interference
  - Collision: 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

Multiple Access Protocols

- An ideal multiple access protocol

given a broadcast channel of rate R bps, we want

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

Handling Multiple Access

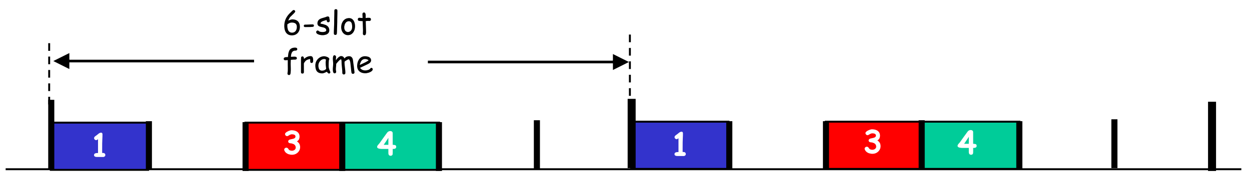
- Multiple access control (MAC)
  - Determine when node can transmit on shared media
- Three classes:
- Channel Partitioning
  - Divide channel into smaller “pieces” (time slots, frequency, code)
  - Allocate piece to node for exclusive use
- Taking turns
  - Nodes take turns to transmit, nodes with more to send can take longer turns
- Random Access
  - Channel not divided, allow collisions
  - Coordinate or recover from collisions

Channel Partitioning

Channel Partitioning with TDMA

- TDMA: time division multiple access
- Access to channel in "slots and rounds"
- Each station gets fixed length slot (packet trans time) in each round
- Unused slots go idle

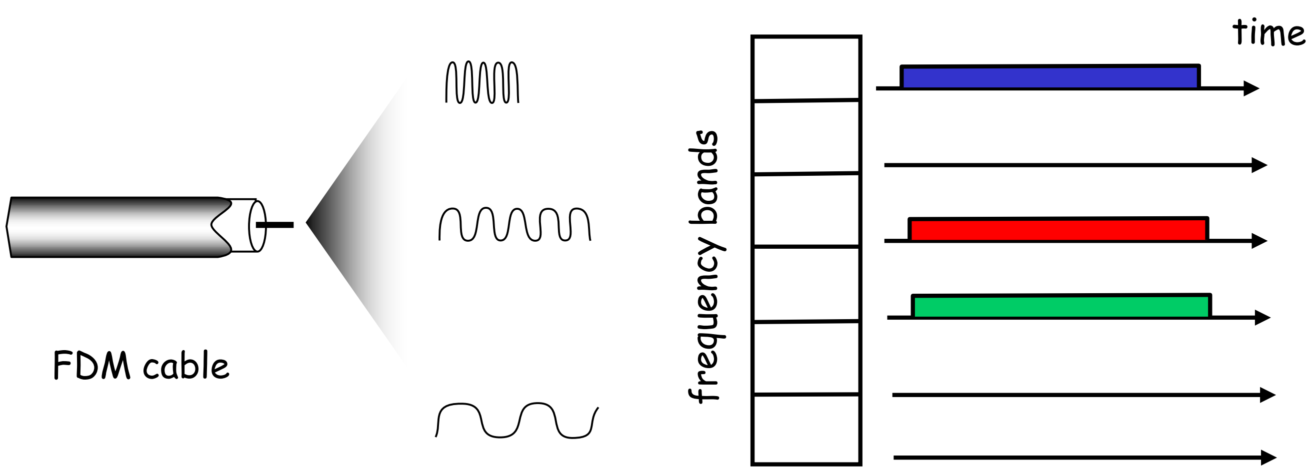
- Example: a 6-station LAN, 1,3,4 have packets, slots 2,5,6 idle



Channel Partitioning with 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: a 6-station LAN, 1,3,4 have packets, frequency bands 2,5,6 idle



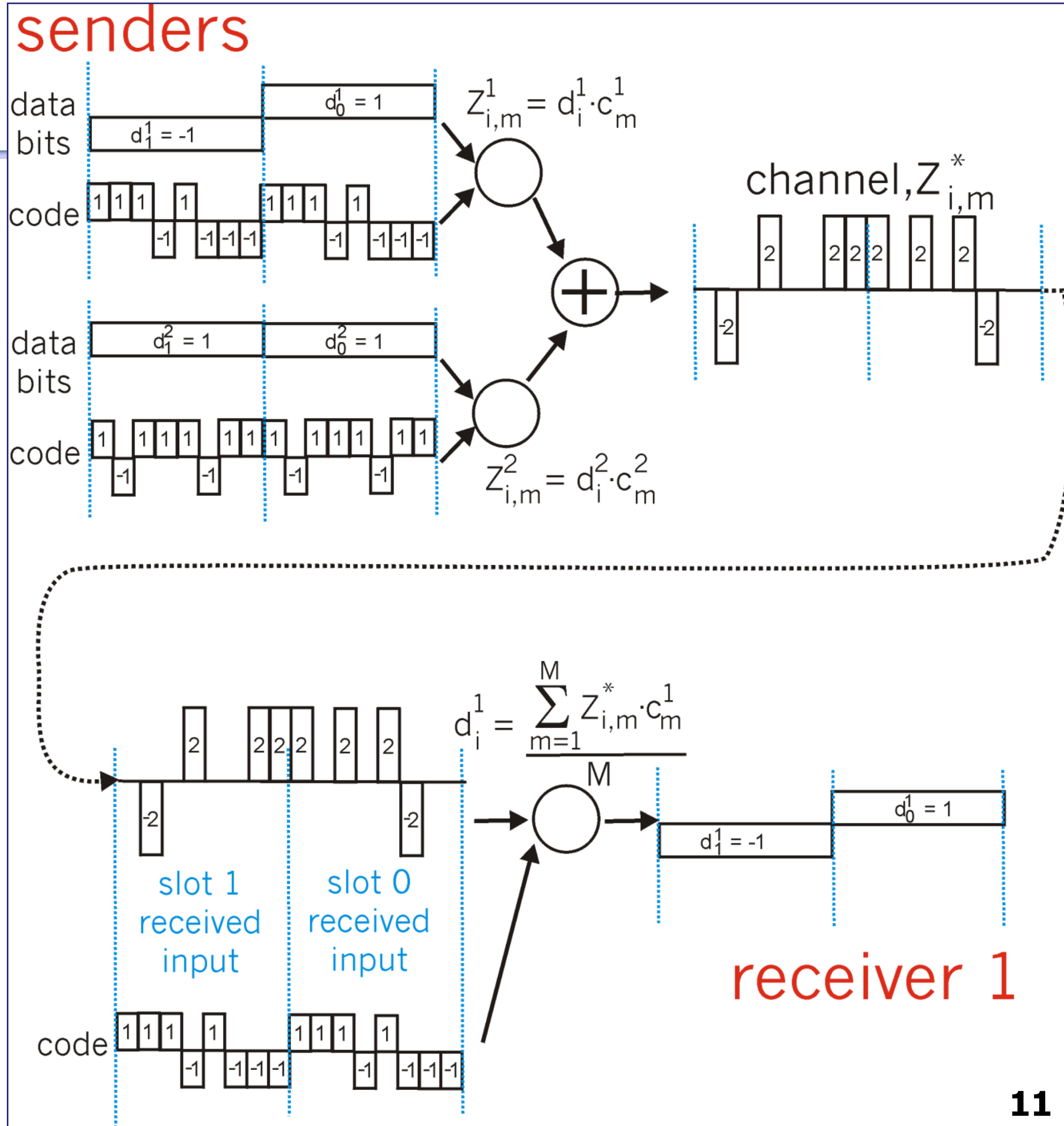
Channel Partitioning with CDMA

- CDMA: Code Division Multiple Access
  - Used in wireless broadcast channels (cellular, satellite, etc)
- All nodes share same frequency, but each node has own "chipping" sequence (i.e., code set) to encode data

- Encoded signal = (original data) $\times$ (chipping sequence)
- Decoding = inner-product of encoded signal and chipping sequence

- If codes are "orthogonal"
  - Multiple nodes can transmit simultaneously with minimal interference

CDMA



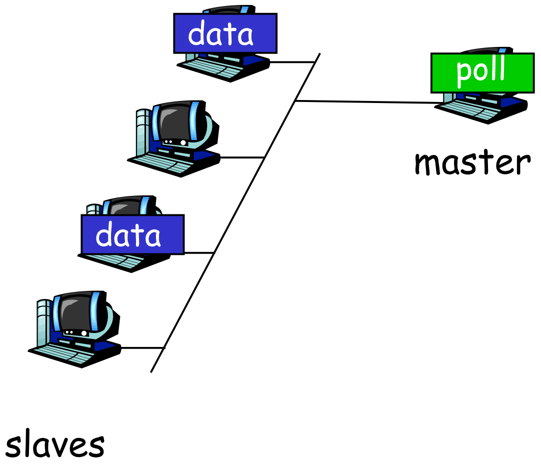
senders
data bits
$d_1^1 = -1$
$d_0^1 = 1$
code
1 1 1 -1 1 -1 -1 -1
$Z^1_{i,m} = d^1_i \cdot c^1_m$
data bits
$d_1^2 = 1$
$d_0^2 = 1$
code
1 -1 1 1 1 -1 1 1
$Z^2_{i,m} = d^2_i \cdot c^2_m$
channel, $Z^*_{i,m}$
-2 2 2 2 2 2 2 -2
slot 1 received input
slot 0 received input
code
$d^1_i = \frac{\sum_{m=1}^{M} Z^*_{i,m} \cdot c^1_m}{M}$
$d_1^1 = -1$
$d_0^1 = 1$
receiver 1

Taking Turns

Taking Turns

Polling:

- Master node "invites" slave nodes to transmit in turn
- Typically used with "dumb" slave devices



Concerns:

- Polling overhead
- Latency
- Single point of failure (master)

- e.g. Bluetooth

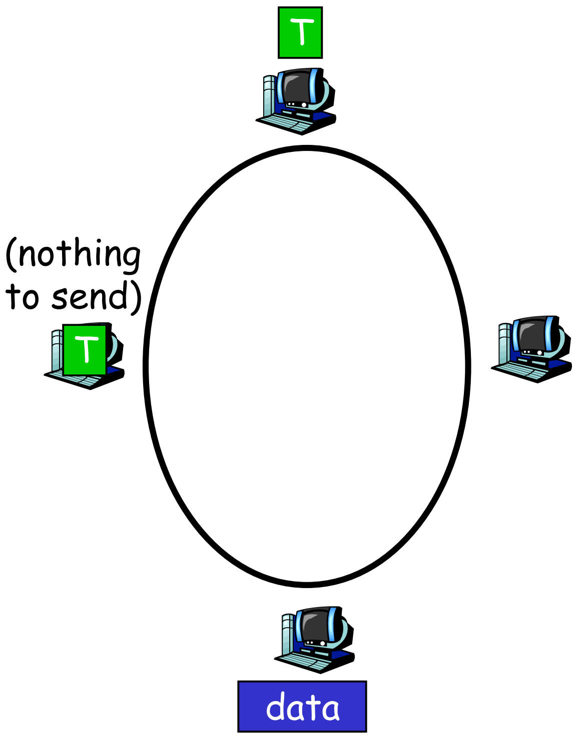
Taking Turns

Token passing:

- Control token passed from one node to next sequentially
- Token to message

Concerns:

- Token overhead
- Latency
- Single point of failure (token)



- IBM Token Ring, FDDI

Random Access

Random Access Protocols

- When node has packet to send
  - Transmit at full channel data rate R
  - No priori coordination among nodes
- Two or more transmitting nodes → collision

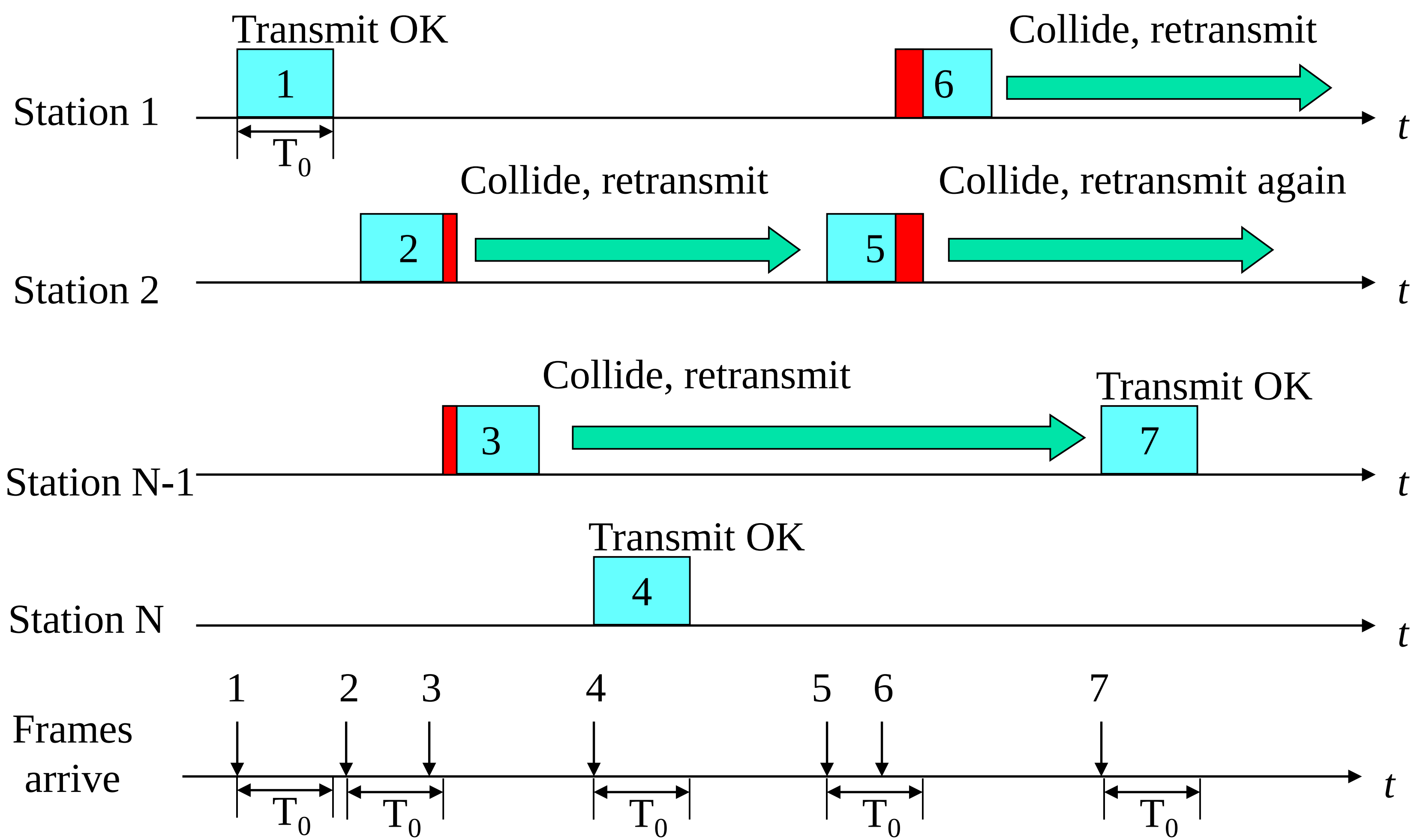
- Random access MAC protocol specifies:
  - How to detect / avoid collisions
  - How to recover from collisions (e.g. via delayed retransmissions)

- Examples of random access MAC protocols:
  - ALOHA, Slotted ALOHA
  - CSMA, CSMA/CD, CSMA/CA

ALOHA

- Additive Link On-line HAwaii system
  - Developed for Packet Radio networks by Hawaii University
- Sender
  - When station has frame, it sends
  - If *ACK*, fine.
    - If not, retransmit with probability p, and wait with probability (1-p)
  - If no *ACK* after repeated transmissions, give up
- Receiver
  - Use frame check sequence (as in *HDLC*)
  - If frame OK and address matches receiver, send *ACK*
- Frame may be damaged by noise or collision
  - Another station transmitting at the same time
  - Any overlap of frames causes collision

Illustration of ALOHA



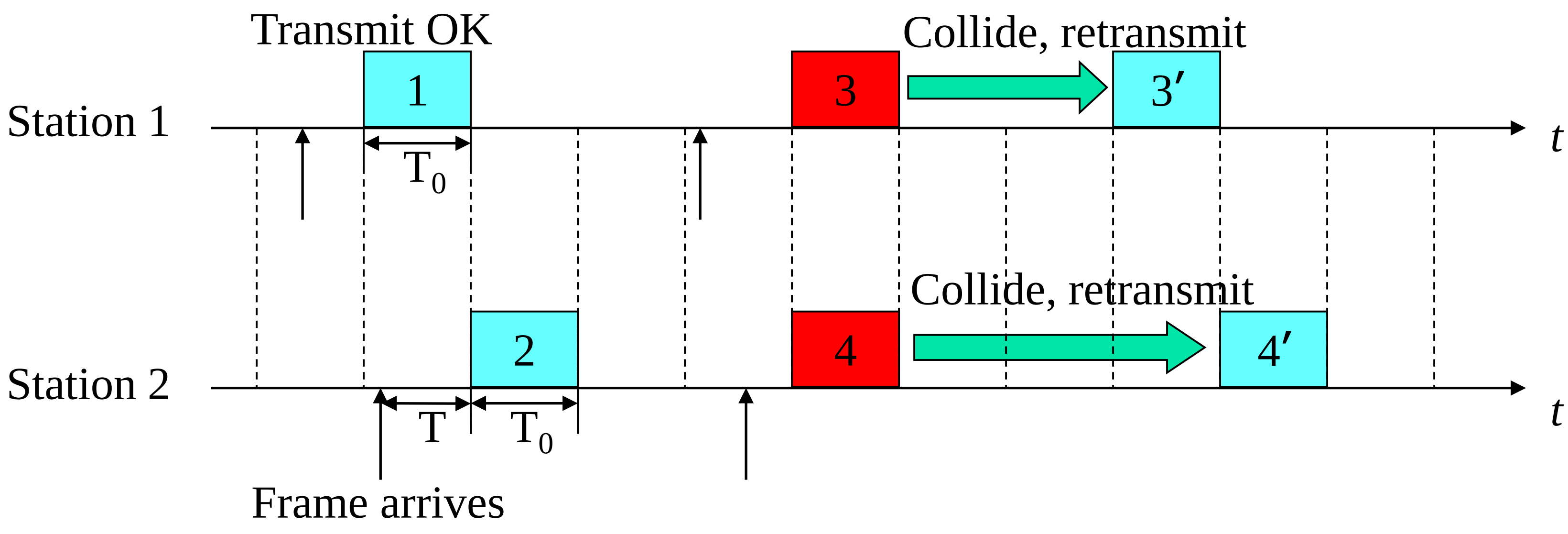
Slotted ALOHA

- All frames have same size
- Time in uniform slots equal to frame transmission time (T_0)
- Nodes are synchronized (need central clock or other sync mechanism)
- Transmission begins at slot boundary
- Frames either miss or overlap totally

operation:

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

Illustration of Slotted-ALOHA



- Node retransmits frame in each subsequent slot with prob. p until success

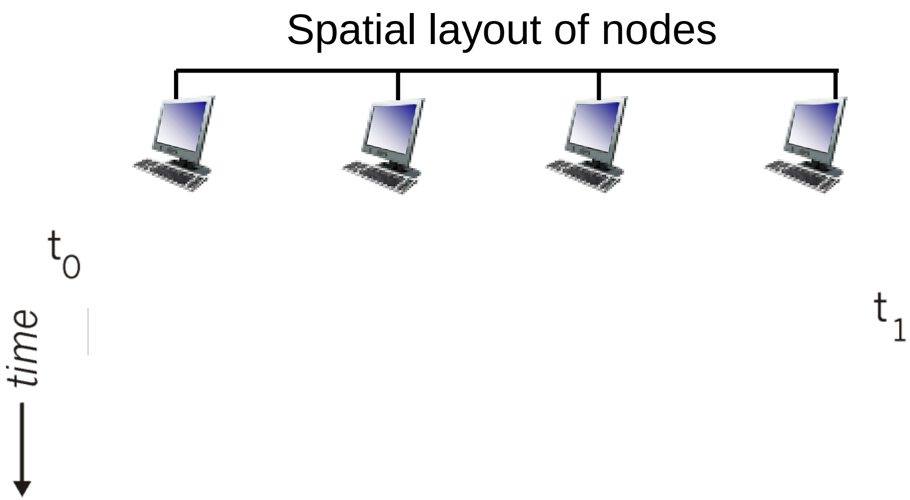
CSMA

CSMA (Carrier Sense Multiple Access)

- Carrier sense multiple access (载波侦听多路访问)
- CSMA: listen before transmit
  - If channel sensed idle: transmit entire frame
  - If channel sensed busy, defer transmission
- Human analogy: don't interrupt others!
- Does not eliminate all collisions
  - Why?
  - Hint: Propagation delay

CSMA collisions

- Propagation delay: two nodes may not hear each other before sending
- CSMA reduces but does not eliminate collisions
- Collision: entire packet transmission time wasted
  - Distance and propagation delay affect collision probability



Nonpersistent CSMA (非持续CSMA)

- Station wishing to transmit listens
  1. If medium is idle, transmit; otherwise, go to 2
  2. If busy, wait amount of random time (delay) and repeat 1

- Random delays reduces probability of collisions
  - Two stations waiting will take different time to begin transmission

- Capacity is wasted, since medium will remain idle following end of transmission
  - Even if one or more stations waiting

- Nonpersistent stations are deferential

1-persistent CSMA

- To avoid idle channel time, 1-persistent protocol used
- Station wishing to transmit listens
  1. If medium idle, transmit; otherwise, go to step 2
  2. If medium busy, listen until idle; then transmit immediately
- 1-persistent stations selfish
  - If two or more stations waiting, collision guaranteed

p-Persistent CSMA

- Try making compromise
  - Attempts to reduce collisions like Nonpersistent
  - And reduce idle time like 1-persistent

- Rules
  1. If medium idle, transmit with probability p, and delay one time unit with probability (1-p)
     - Typically, time unit = maximum propagation delay
  2. If medium busy, listen until idle and repeat step 1
  3. If transmission is delayed one time unit, repeat step 1

- What is an effective value of p?

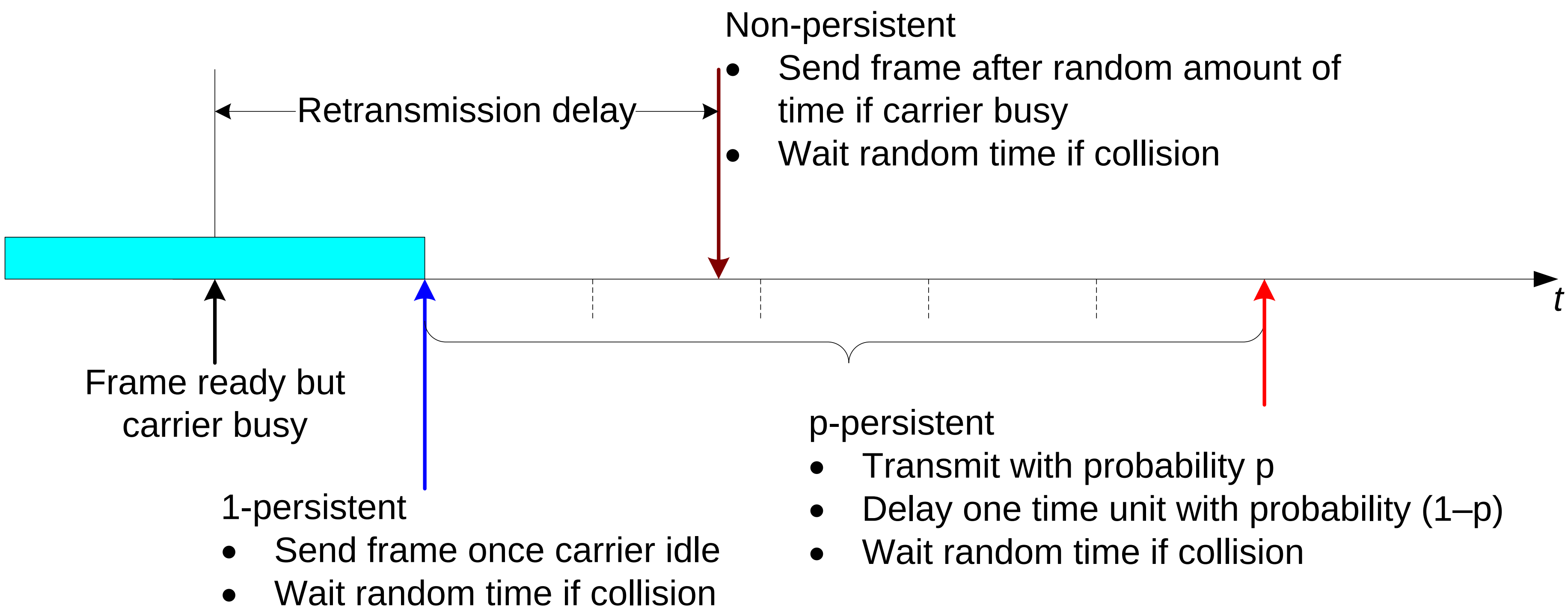
Value of p

- Objective: avoid instability under heavy load
- Suppose: N stations waiting to send
  - The best value of p in theory is 1/N

- If heavy load expected, p small
- However, as p made smaller, stations wait longer

- In general, this gives very long delays

Different Types of CSMA



CSMA/CD (Collision Detection)

- With CSMA, collision occupies medium for duration of transmission
  - Colliding transmissions aborted once detected

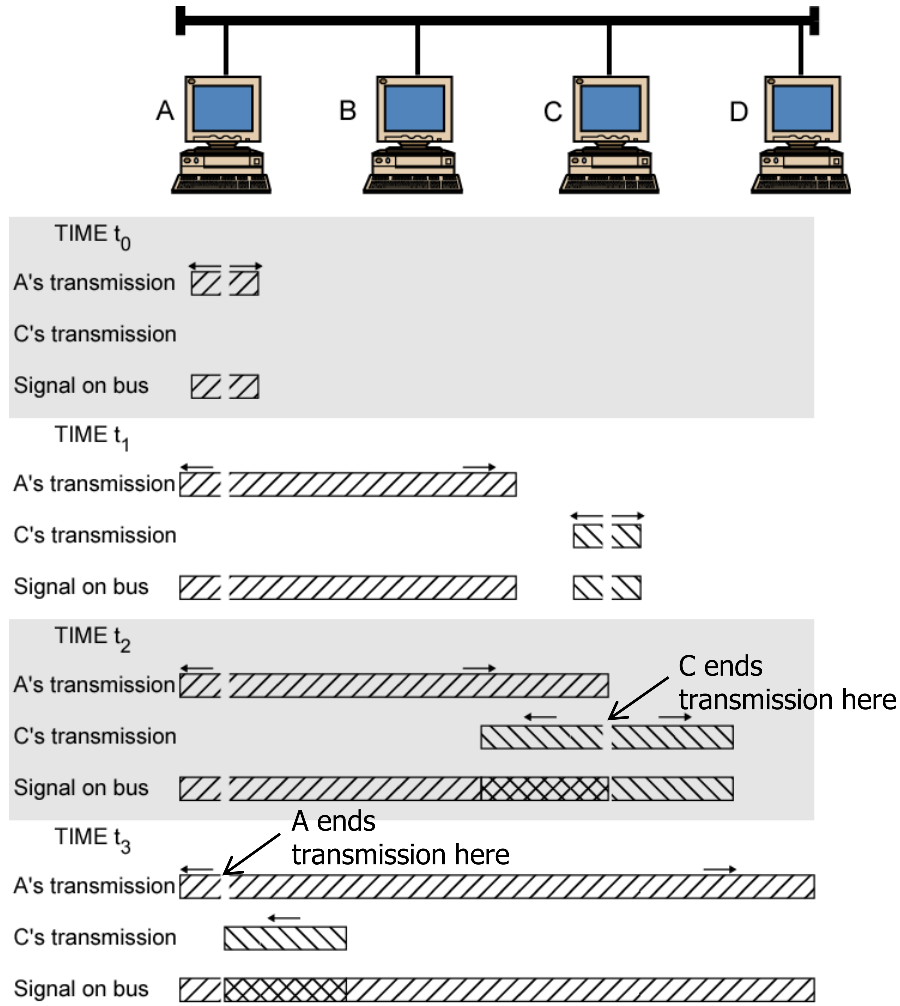
- Stations listen whilst transmitting
  1. If medium idle, transmit; otherwise, step 2
  2. If busy, listen for idle, then transmit immediately
  3. If collision detected, send jam signal then abort
  4. After jam, wait random time then start from step 1

Jam信号是连续几个字节全1的信号，旨在加强冲突，使其他设备易于检测

Collision Detection

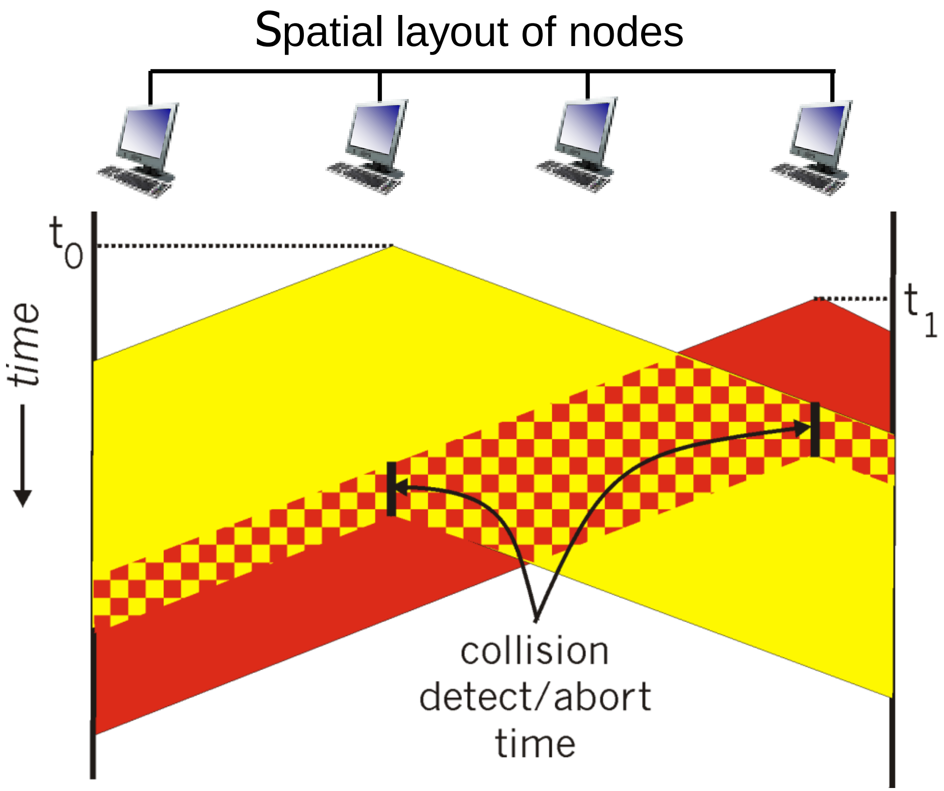
- On baseband bus, collision produces much higher signal voltage than signal
  - Collision detected if cable signal greater than single station signal
- Signal attenuated over distance
  - Jam needed
  - Limit distance to 500m (10Base5) or 200m (10Base2)
- For twisted pair (star-topology) activity on more than one port is collision
  - Special collision presence signal

CSMA/CD Operation

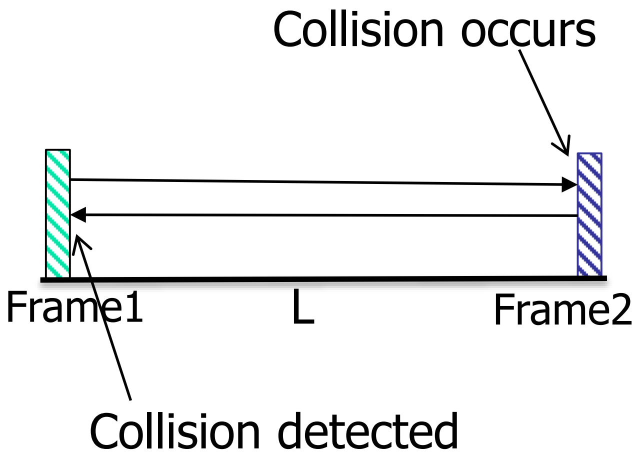


CSMA/CD (Collision Detection)

- For this to work, need restrictions on minimum frame size and maximum distance
  - Why?



CSMA/CD: Minimum Frame Size



- B: bandwidth
- L: length of the link
- V: propagation speed
- Size: size of a frame

- Propagation time: T_a=L/v
- Transmission time for one frame: T_b=Size/B

- In the worse case, collision detection takes 2T_a.
  - Minimum contention interval= 2T_a

- Minimum frame size:
  - If the transmission time of a frame is less than 2T_a, it may not be able to detect collision if collision occurs.
  - To assure collision detection, it must satisfies T_b>=2T_a
  - Thus size/B>=2L/v, minimum frame size: size>=2*L*B/v

Three key ideas of random access

- Carrier sense
  - Listen before speaking and don’t interrupt
  - Checking if someone else is already sending data
  - … and waiting till the other node is done
- Collision detection
  - If someone else starts talking at the same time, stop
    - Make sure everyone knows there was a collision!
  - Realizing when two nodes are transmitting at once
  - …by detecting that the data on the wire is garbled
- Randomness
  - Don’t start talking again right away
  - Waiting for a random time before trying again

How long should you wait?

- Should it be immediate?
- Should it be a random number with a fixed distribution?

The Persistence Algorithm

- IEEE 802.3 uses 1-persistent
  - Both non-persistent and p-persistent have performance problems

- Collision handling for 1-persistent
  - Wasted time due to collisions is short
  - With random backoff, unlikely to collide on next tries
  - Binary exponential backoff used

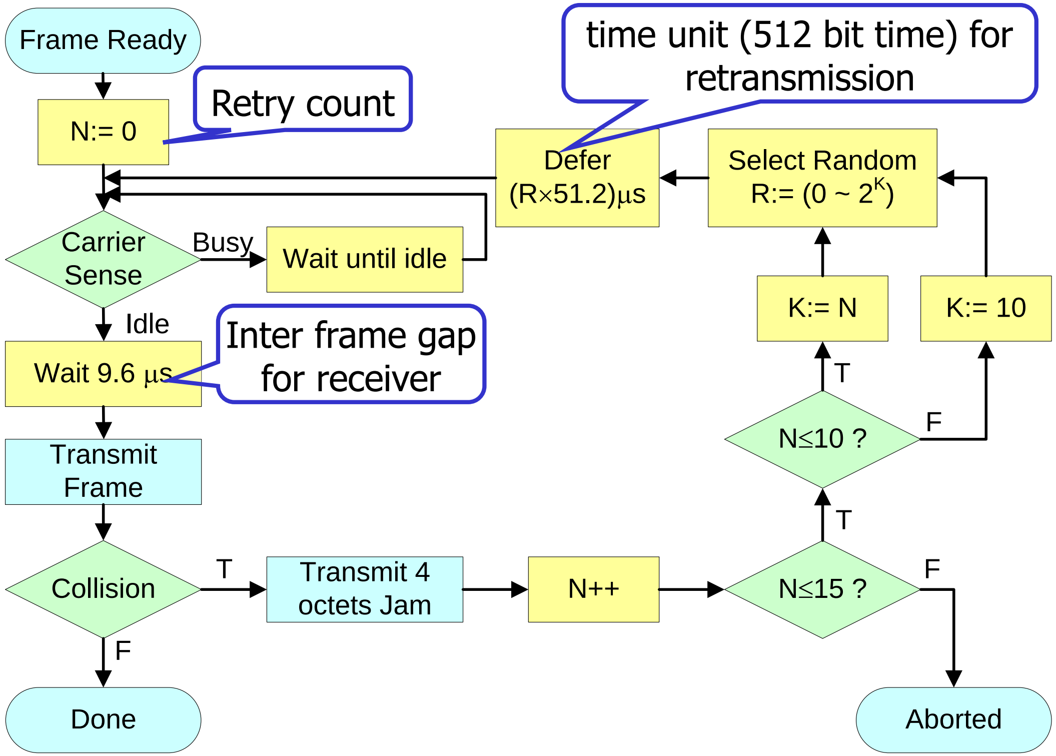
Binary Exponential Backoff

- Attempt to transmit repeatedly if repeated collisions
  - First 10 attempts, mean value of random delay doubled
  - Value then remains same for 6 further attempts
  - After 16 unsuccessful attempts, station gives up and reports error
- 1-persistent algorithm with binary exponential backoff efficient over wide range of loads
  - Low loads, 1-persistence guarantees efficiency
  - High loads, at least as stable as other techniques
- Backoff algorithm gives last-in, first-out effect
  - Stations with few collisions transmit first

Ethernet CSMA/CD algorithm

1. NIC receives datagram from network layer, creates frame
2. If NIC senses channel idle, starts frame transmission. If NIC senses channel busy, waits until channel idle, then transmits.
3. If NIC transmits entire frame without detecting another transmission, NIC is done with frame !
4. If NIC detects another transmission while transmitting, aborts and sends jam signal
5. After aborting, NIC enters binary (exponential) backoff:
   - after mth collision, NIC chooses K at random from {0,1,2, …, 2m-1}. NIC waits K·512 bit times, returns to Step 2
   - longer backoff interval with more collisions

IEEE 802.3 Transmission Algorithm



Summary

- Multiple access control
  - 信道切分
  - 轮流访问
  - 随机访问
- CSMA (载波侦听多路访问)
  - Nonpersistent，1-persistent，p-persistent
  - CSMA/CD原理，算法（IEEE 802.3，以太网）

Homework

- 第5章：R4, R5, R6