

## LINK LAYER: MULTI-USER COMMUNICATION

Two approaches for bandwidth sharing

- contention-free
  - also called reservation-based
  - e.g., TDMA, FDMA, OFDMA, NDA in CAN
- contention-based
  - e.g., CSMA, CSMA/CD, CSMA/CA

In link layer:

→ medium access control (MAC)

In network layer:

→ scheduling (packet, flow, connection)

Contention-free MAC:

- orderly pre-determined sharing
- prior reservation of network resources
- typically centralized

Examples:

- TDMA: who gets what time slots
- FDMA, OFDMA: who gets what carrier frequency

Contention-based MAC:

- single carrier wave shared by multiple devices
- less orderly than contention-free MAC
- non-deterministic performance: resources are not reserved
- typically decentralized

Main building block: multiple access (MA)

- when NIC has data to send, just send

Problem of pure MA: if two or more devices sharing carrier frequency transmit at the same time

- collision
- distorted signal
- fail to decode bits

Additional capabilities of contention-based MAC:

When NIC has data to send:

- first check if there is ongoing transmission: carrier sense (CS)
- send only if link is deemed idle
- CSMA

After CS, performing MA may still lead to collision

- if sender can detect collision has occurred: collision detection (CD)
- CSMA/CD
- if sender cannot detect collision: may engage in collision avoidance (CA) methods
- CSMA/CA

## Steps of contention-based MAC:

1. CS: optional
2. CA: optional
3. MA: always (by definition)
4. CD: optional (may not be technically viable)
  - uncommon today
5. receiver sends ACK frame: optional
  - stop-and-wait: common
  - positive ACK: received packet
  - negative ACK: did not receive packet
6. resend data frame: optional
  - typically retry a number of times
  - reliable transfer not guaranteed
  - pause before retry: called backoff

Collision need not always result in decoding failure

- if two frames collide and one frames has much stronger signal strength than the other: stronger packet may be successfully decoded
- “survival of the strongest”
- called capture effect

Special case: collision is part of normal operation without causing bit decoding failure

- non-destructive arbitration (NDA)
- used in CAN (control area network)
- dominant standard of vehicular networks

Simplest contention-based MAC: MA

→ just send if there is something to send

Used in pioneering real-world system: ALOHA (early 1970s)

→ wireless packet network connecting Univ. of Hawaii island campuses

→ MA: called pure ALOHA protocol

→ deployed system to solve real-world problem

→ almost half a century before boom of wireless data networks

→ operational packet (radio) network precedes wired Internet

Visionary work by Norm Abramson.

→ precursor of Bob Metcalfe's Ethernet

→ underlies WLAN and other wireless technologies

Why MA was suited for connecting Univ. of Hawaii island campuses

→ why not use carrier sense (CS)?

→ what about collision detection (CD)?

Note similarity to satellite networks.

→ e.g., LEO (low earth orbit)

CS: not suited for nodes separated by long distances

→ high latency before signal reaches other senders

→ NIC senses idle link but in-flight frame to arrive causing collision

CD: not suited for long distances

→ need to wait a long while before being sure that no collision occurred

→ even in broadband over powerline not useful

→ “time is bandwidth”

## Pros of contention-based MAC

- When load is low (not many devices share), faster response time
  - small coordination overhead: CSMA
  - e.g., TDMA, FDMA, OFDMA need to request and reserve slots
  - management/signaling frames incur delay and consume bandwidth
- Decentralized
  - no central arbiter
  - minimal coordination overhead
  - but for security concerns (e.g., Purdue's PAL)

Cons of contention-based MAC:

- When load is high (many devices share), degraded throughput
  - retransmission due to collision
  - wastes bandwidth
- Lack of QoS (quality of service) assurance
  - “you get what you get”
  - called best-effort service

- Lack of QoS assurance (cont.)
  - can be problematic for real-time traffic (e.g., VoIP, video conferencing) and apps with timeliness constraints (e.g., streaming, games)
  - Original WLAN standard had provisions to support telephony: not used in practice
  - Wi-Fi 7 supports OFDMA based resource reservation
  - unclear whether will be used in practice

Opposite trade-off for contention-free protocols.

When to use what?

- if load is high, contention-free protocols achieve better performance
  - otherwise frequent collision can impede throughput
- vice versa if load is low
  - low overhead: no reservation step before transmission of data