# Link Layer: Multi-user Communication

Two approaches for bandwidth sharing

- contention-free

  → also called reservation-based

  → TDMA, FDMA, OFDMA, TDMA+FDMA, CDMA

- contention-based

  → CSMA, CSMA/CD, CSMA/CA, and variants

In link layer:

→ called medium access control (MAC)

In network layer:

→ called 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, WDM, OFDMA: who gets what carrier frequency
- FDMA+TDMA: what gets what time slots in what carrier frequency
- CDMA: who gets what code

Contention-based MAC:

→ single carrier shared by multiple devices

→ less orderly than contention-free MAC

→ variable performance since resources are not reserved

→ typically decentralized

Main building block: multiple access (MA)

→ when you have data to send, send

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

→ called collision

→ distortion of signal

→ can lead to failure decoding 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 idle

→ hence CSMA

After MA (sending data) there may be collision

→ if sender can detect collision has occured: collision detection (CD)

→ hence CSMA/CD

→ if sender cannot detect collision: may engage in collision avoidance (CA)

→ hence 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)
5. receiver sends ACK frame: optional

   → positive ACK: received packet

   → negative ACK: did not receive packet
6. resend data frame: optional

   → typically finite retries

   → unreliable

   → inject 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

Collision need not result in decoding failure: by design

→ non-destructive arbitration (NDA)

→ CSMA/CD with NDA

→ used in CAN (control area network)

→ dominant standard of automotive/vehicular networks

→ bus arbitration

Simplest contention-based MAC: MA

→ just send if there is something to send

Used in pioneering real 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 50 years before boom of wireless data networks

→ precedes Internet as operational packet (radio) network

→ visionary work by Norm Abramson

→ precursor to Bob Metcalfe's Ethernet

→ underlies WLAN and other wireless networks today

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

Why not use carrier sense (CS) in ALOHA?

What about collision detection (CD)?

CS: not suited for nodes separated by long distances

→ high latency before signal reaches other senders

→ collision likelihood high

CD: not suited for long distances

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

→ 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.)

  → 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 6 and 7 support OFDMA based resource reservation

The opposite trade-off for contention-free protocols.

When to use what?

→ if load is high, contention-free protocols achieve better performance

→ vice versa if load is low