The Link Layer

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- Link Layer: Introduction
  - Terminology
    - Hosts, routers → nodes
    - Communication channels that connect adjacent nodes along communication path → links
      - Wired links
      - Wireless links
    - Over a given link, the transmitting node encapsulates the network-layer packet in a link-layer frame
  - Link layer has responsibility of transferring network-layer packets from one node to a physically adjacent node over a link
- Link Layer: Context
  - Packets transferred by different link protocols over different links
    - WiFi on first link
    - Ethernet on next link
    - Etcetera
  - Each link protocol provides different services
- Link Layer Services
  - Framing
    - Encapsulate packet into frame, adding header and maybe trailer
    - Addressing: "MAC" addresses used in frame headers to identify transmitter/receiver node → different from IP Address
  - Link access

        * Medium access control (MAC) protocol specifies the rules by which a frame is transmitted onto the link
    - Flow control
        * Pacing between adjacent sending and receiving nodes
    - Reliable delivery between adjacent nodes
        * We learned how to do this already (Transport layer)!
        * Seldom used on low error rate links, for example: fiber, some twisted pairs
        * Commonly used on high error rate links, like wireless ones
    - Error control
        * Errors caused by signal attenuation, noise
        * Error detection: receiver detects presence of errors
            · Ask sender for retransmission or drops frame
        * Error correction: receiver identifies and corrects bit error(s) without resorting to retransmission

- Half-Duplex and Full-Duplex Links
    - Unidirectional links (Simplex Links)
        * Communication occurs in one direction only
    - Bidirectional links
        * Half-Duplex Link — Communication occurs in both directions, but not at same time
        * Full-Duplex Link — Communication occurs in both directions at same time

- Where is the Link Layer Implemented?
    - For the most part, link layer is implemented on a chip called the network adapter, aka a Network Interface Card (NIC)
        * The NIC implements Link and Physical layers
        * *E.g.* Ethernet card, WiFi card or chip
    - NIC attaches into node's system buses
    - Link layer is implemented as a combination of hardware and software
        * Hardware: NIC implements most of the functions
        * Software: activating hardware controller, responds to controller interrupts, etc.

- Error Control
    - EDC → Error Detection/Correction bits (redundant bits)

- D → Data protected by error control, may include header fields
- Error control is not 100% reliable
  - Error control technique may miss some errors; we want to keep the probability of missing the errors small
  - Larger EDC field yields better detection and correction
  - Error correction needs more redundant bits than error detection for same number of errors
- Parity Checking
  - Single bit parity: detect single bit errors
    - Even parity: set parity bit so there is an even number of 1's
    - Odd parity: set parity bit so there is an odd number of 1's
  - Two-dimensional bit parity: detect and correct single bit errors
    - Even parity: no errors
- Cyclic Redundancy Check (CRC)
  - D: d data bits (given)
  - G: generator, bit pattern of $r+1$ bits where MSB must be 1 → transmitter and receiver agree on G (given)
  - R: r CRC bits, redundant bits
  - Transmitter: choose R, such that $\langle D, R \rangle$ is exactly divisible by G (modulo-2 arithmetic) → $D \cdot 2^r \text{XOR} R = nG$
  - Receiver: knows G and divides $\langle D, R \rangle$ by G → non-zero remainder: error detected!
    - Can detect all burst errors less than $r+1$ bits
  - More powerful error-detection technique: widely used in practice (Ethernet, WiFi)