Link Layer (I)

Overview

- The data link layer has two components:
  - Data Link Control:
    - addressing
      - "MAC" addresses used in frame headers to identify source, destination
    - error detection
      - errors caused by signal attenuation, noise
      - receiver detects presence of errors:
    - error correction
      - receiver signals sender for retransmission or drops frame
      - receiver identifies and corrects bit error(s) without resorting to retransmission (forward error correction: receiver executes error-correcting code that generates the actual frame. e.g. Hamming Codes, Binary convolution Code, Reed-Solomon Code, Low-Density Parity-Check Code)
    - flow control
      - pacing between adjacent sending and receiving nodes
  - Media Access Control (MAC)

Media Access Control

- Media Access Control enforces a methodology to allow multiple devices access a shared media network.
  - A shared media network →single shared broadcast channel
  - Multiple devices →two or more simultaneous transmissions by nodes:
    - interference
    - collision: if node receives two or more signals at the same time
  - Methodology →multiple access protocol
    - distributed algorithm that determines how nodes share channel, i.e., determine when node can transmit
- Note: communication about channel sharing must use channel itself!
  - no out-of-band channel for coordination

An ideal multiple access protocol

- given: broadcast channel of rate R bps
- goals:
  - high utilization: when one node wants to transmit, it can send at rate R
  - fairness: when M nodes want to transmit, each can send at average rate R/M
  - fully decentralized

  - no special node to coordinate transmissions
  - no synchronization of clocks, slots
- simple

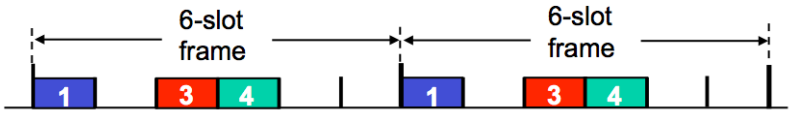
Three broad classes

- channel partitioning
  - divide channel into smaller “pieces” (time slots, frequency, code)
  - 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 can take longer turns

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TDMA

- TDMA: time division multiple access
- channel partitioning
- divide time into time frames, and then divide each frame into N time slots
- each node gets fixed length slot (length = one packet transmission time)
- when a node has packets to send, it transmits the packet during the assigned time slot in the revolving time frames
- unused slots go idle
- example: 6-host LAN, 1, 3, 4 have packets to send, slots 2, 5, 6 idle



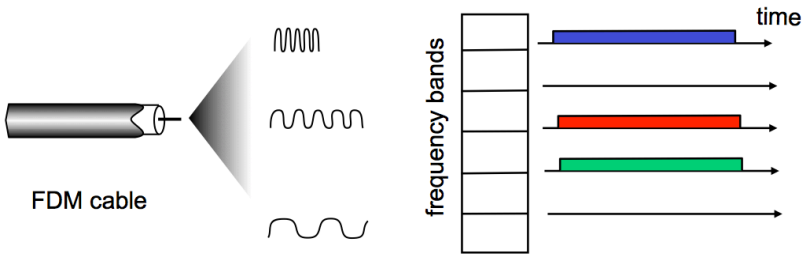
- advantages:
  - eliminates collisions
  - perfectly fair (transmission rate for each node R/N bps per frame time)
- disadvantages:
  - a node is limited to an average rate R/N bps even when only one node with packets to send
  - a node must wait for its turn in the transmission sequence, even if it is the only one with packets to send

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FDMA

- FDMA: frequency division multiple access

- channel partitioning
- divide the R bps channel into different frequencies (each with R/N bps)
- each node assigned a frequency
- a node uses the assigned frequency to transmit packets
- example: 6-host LAN, 1, 3, 4 have packet to send, frequency bands 2, 5, 6 ideal



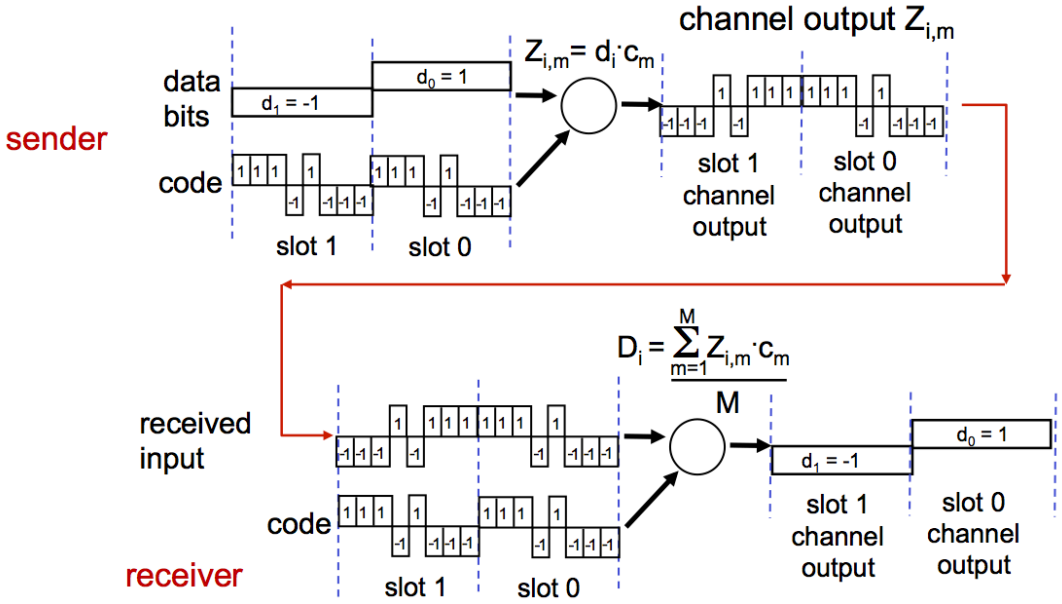
- advantages:
  - same as TDMA
- disadvantage:
  - a node is limited to an average rate R/N bps even when only one node with packets to send
- improvement:
  - no need to wait till the assigned slot in next time frame to transmit

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CDMA

- CDMA: code division multiple access
- channel partitioning
- unique “code” assigned to each user; i.e., code set partitioning
- all users share same frequency, but each user has own “chipping” sequence (i.e., code, a signal that changes at a much faster rate than the original sequence of data bit) to encode data
  - each bit being sent is encoded by multiplying the bit by the code
- allows multiple users to “coexist” and transmit simultaneously with minimal interference (if codes are “orthogonal”)
- used in 2G network, and widely used in wireless network in rural area and telephony network

- example: one sender (ideal case)



encode:

$$Z_{i,m} = d_i \cdot c_m$$

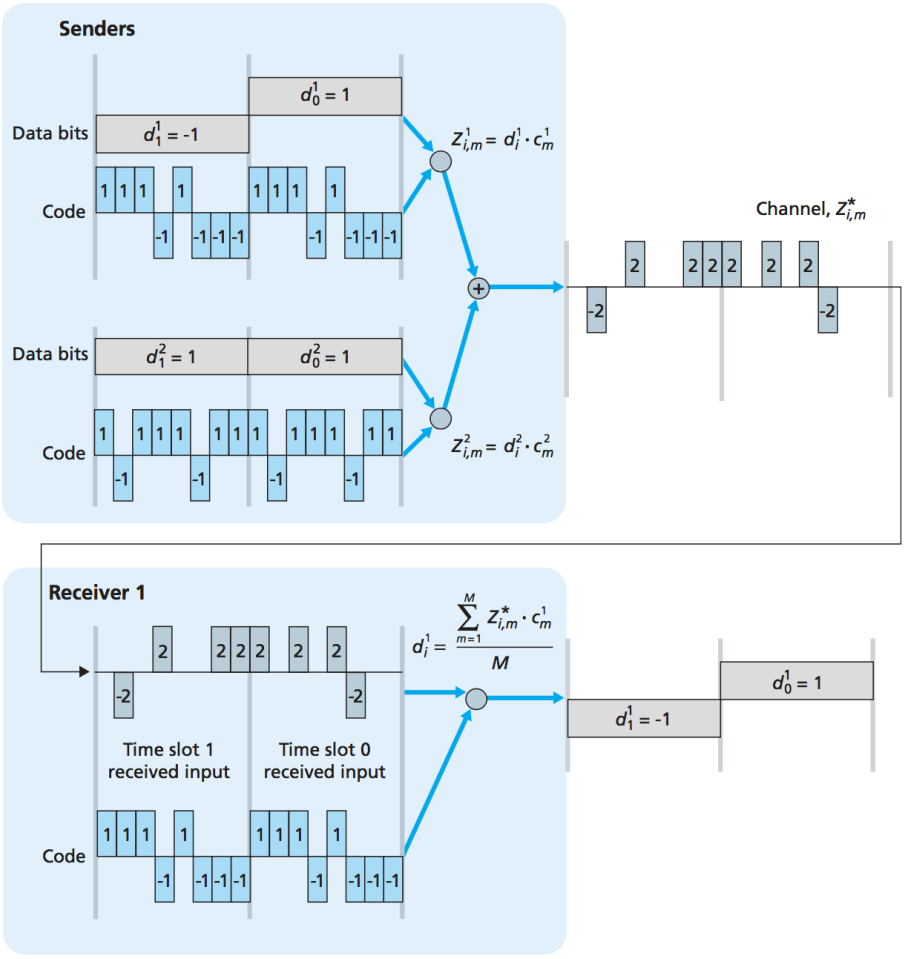
decode:

$$d_i = \frac{1}{M} \sum_{m=1}^{M} Z_{i,m} \cdot c_m$$

where $\mathbf{d_i}$ is the its data bit, the bit-transmission time of $\mathbf{d_i}$ is divided into M mini-slot. $\mathbf{Z_{i,m}}$ is the output of the encoder for the $\boldsymbol{m}$**th** mini-slot of the transmission time, $\mathbf{c_m}$ is the $\boldsymbol{m}$**th** bit of the code

- Note: for mathematic simplicity, data bit 0 is represented in -1.

- example: two sender (conflict)



encode: $$Z^*_{i,\,m} = \sum_{s=1}^{N} Z^s_{i,\,m}$$

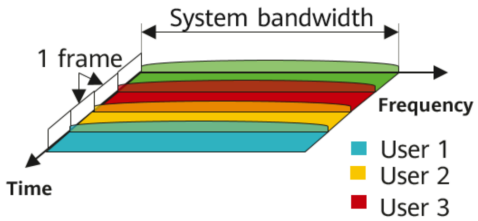
decode: $$d_i = \frac{1}{M}\sum_{m=1}^{M} Z^*_{i,\,m} \cdot c_m$$

where N is the number of senders

- Note:
  - The CDMA **codes must be carefully chosen** in order for the CDMA receivers to be able to extract a particular sender's signal.
  - The above discussion has **assumed that the received signal strengths from various senders are the same**.

OFDM & OFDMA

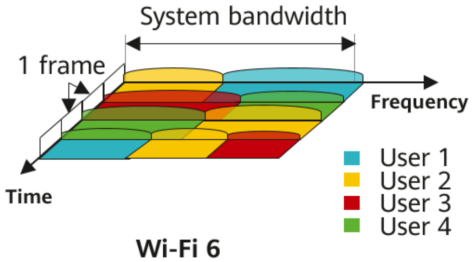
- OFDM (Orthogonal Frequency Division Multiplexing)
  - A technology for data transmission used by Wi-Fi 5 and prior versions.
  - OFDM divides the available frequency spectrum into multiple orthogonal subcarriers, each operating at a lower data rate. These subcarriers are closely spaced but orthogonal, meaning they do not interfere with each other. This allows multiple users to transmit data simultaneously on different subcarriers without causing mutual interference.
  - OFDM distinguishes users based on time frame. A user can occupy all subcarriers on a channel (aka the system bandwidth) to send a complete data packet in an time frame.



Wi-Fi 5
OFDM
(Each user exclusively occupies channel resources.)

  - However, if the data packets are small, OFDM is inefficient, and it may introduce high voice/video delay.

- OFDMA (Orthogonal Frequency Division Multiple Access)
  - used by Wi-Fi 6/7
  - OFDMA allows multiple users to reuse channel resources by allocating subcarriers to different users and adding multiple access in the OFDM system.
  - Although the implementation is more complicate than OFDM, it allows multiple users send packets per time frame, reducing the voice/video delay and leading to a higher efficiency.



Wi-Fi 6
OFDMA
(Multiple users share channel resources.)

Reference: https://info.support.huawei.com/info-finder/encyclopedia/en/OFDMA.html

Disclaimer: Notes adapted from the textbook and online resources.