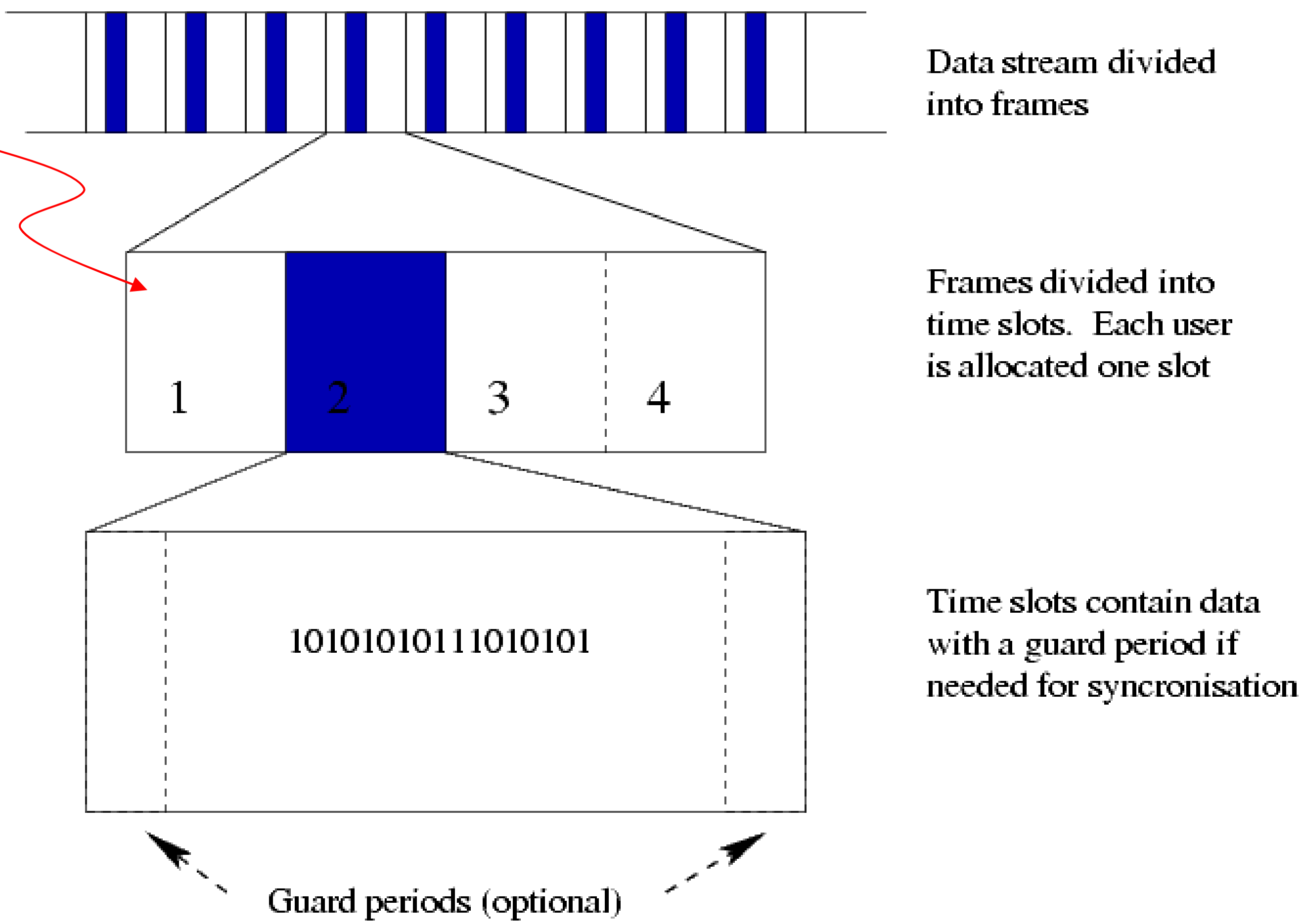
Wirless Networks

- Sharing the channel
  - TDMA, FDMA, CDMA, CSMA
- Transmitting information
  - OFDM, DSSS, FHSS
- Example: 802.11a

Sharing the channel: TDMA

Time Division Multiple Access: Share same carrier frequency by dividing signal into different time slots (used in GSM cell phone networks)

First slot is used in cell phones to contact tower for slot assignment. Tower can determine appropriate timing advance for each user (accounts for varying distance from tower) so that transmissions won't overlap at the tower.



http://en.wikipedia.org/wiki/Time_division_multiple_access

Sharing the channel: FDMA, SDMA

- **Frequency Division Multiple Access: Divide frequency channel into subbands**
  - Different users assigned to different subbands
  - Each subband has its own carrier
  - Use different frequencies for transmit and receive (frequency-division duplexing). Eg, using FDD, adjacent cell towers don't "hear" each other.
  - TDMA/FDMA/FDD used in GSM cell phone networks
- **Space Division Multiple Access: adjust antenna radiation pattern (eg, using phased arrays) depending on location of the user**
  - Focus transmitter power in required direction
  - On receive, eliminate noise from other sources

Sharing the channel: CDMA

- **Two vectors are orthogonal if their dot products are 0. Here's a set of 4 mutually orthogonal vectors:**
  - ```
    V1: (1,  1,  1,  1)
    V2: (1,  1, -1, -1)
    V3: (1, -1,  1, -1)
    V4: (1, -1, -1,  1)
    ```
- **Assign each transmitter a particular one of the orthogonal vectors (Vi) to use to encode its transmissions (called the "chip code"). With vectors shown above we can support 4 transmitters.**
  - **If message bit is 0, transmit –Vi**
  - **If message bit is 1, transmit Vi**

  1 message bit → len(Vi) "chips"
- **Channel will sum the transmitted values:**
  - ```
    send 00 using V1: -1 -1 -1 -1 -1 -1 -1 -1
    send 01 using V2: -1 -1  1  1  1  1 -1 -1
    send 11 using V3:  1 -1  1 -1  1 -1  1 -1
    send 10 using V4:  1 -1 -1  1 -1  1  1 -1
    channel:           0 -4  0  0  0  0  0 -4
    ```

CDMA Receiver

- At receiver take groups of len(V) bits and form dot product with Vi for desired channel.
  - If result is negative, message bit is 0
  - If result is positive, message bit is 1

```
channel:             0 -4  0  0  0  0  0 -4

receive using V1:  1  1  1  1  1  1  1  1
dot product:                  -4          -4
message bits:                  0           0

receive using V2:  1  1 -1 -1  1  1 -1 -1
dot product:                  -4           4
message bits:                  0           1

receive using V4:  1 -1 -1  1  1 -1 -1  1
dot product:                   4          -4
message bits:                  1           0
```

Asynchronous CDMA

- Use N orthogonal vectors to multiplex N transmitters (e.g., use a NxN Walsh Matrix)
- Scheme described above works for synchronous CDMA when all symbols are transmitted starting at same moment. For example this works fine for a cell tower transmitting to mobile phones.
- But hard to synchronize mobile phone transmissions, so use asynchronous CDMA:
  - Can't create transmissions that are truly orthogonal if they start at different times
  - Approximate orthogonality with longer uncorrelated pseudo-random sequences (called pseudo-noise or PN). "pseudo" implies that sequence can be reconstructed at receiver given a known starting point.
  - Assuming equal signal strengths from each transmitter at receiver, if we decode bits using a particular PN sequence synchronized with desired transmitter, we'll get desired signal plus some uncorrelated noise from other transmitters.

Sharing the channel: CSMA

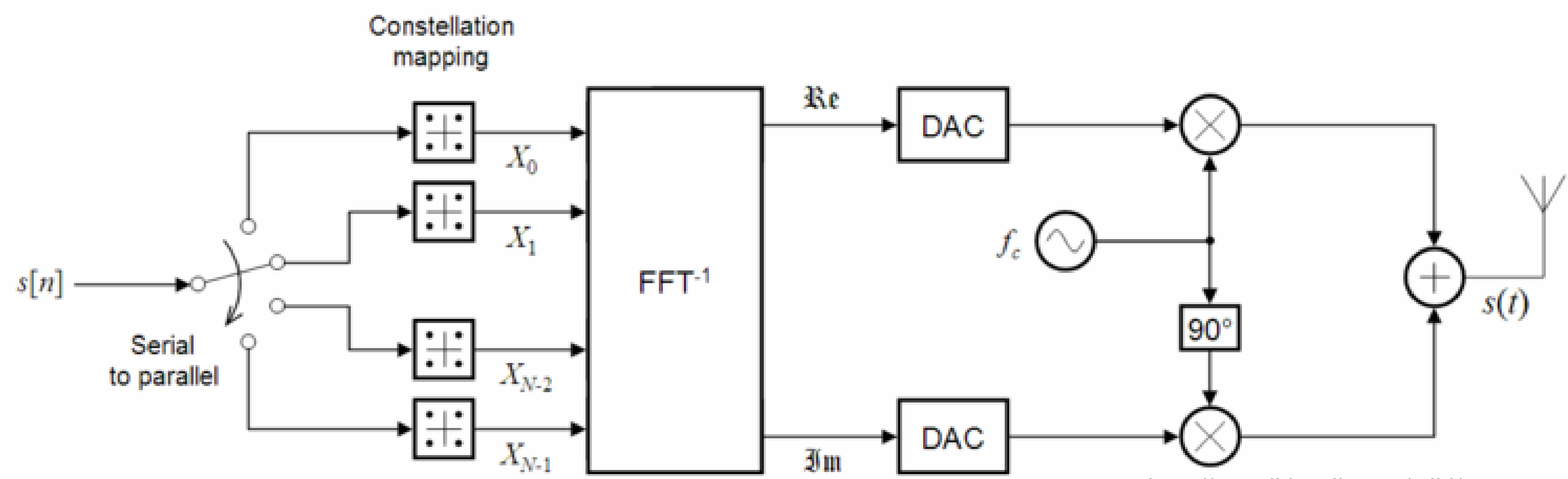
- Carrier Sense Multiple Access
  - "Carrier Sense" – transmitter listens to ensure no other carrier is present on channel before transmitting
  - "Multiple Access" – multiple transmitters share the channel, transmissions received by everyone (not quite true for wireless)
  - If two transmitters start at the same time (both having detected no other carrier), their transmissions collide and entire packet is lost (looks like other errors that cause packet to be discarded). Recover via retransmission.
- CSMA with collision avoidance (CSMA/CA)
  - Transmitter informs others of intent to transmit (costs bandwidth); collisions still possible as in pure CSMA
  - Used by 802.11, 802.15
- CSMA with collision detection (CSMA/CD)
  - Transmitter detects collision, stops, and retries after random interval.
  - Used by original Ethernet, doesn't work with radio where range effects cause some receivers not to hear certain transmitters

Transmitting Information: OFDM

Orthogonal Frequency Division Multiplexing:

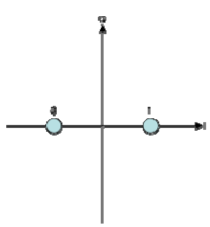
- Bit stream split into lower-bandwidth parallel bit streams each transmitted on a separate channel
  - Symbol times long relative to propagation time
  - Add guard interval to reduce inter-symbol interference (multi-path echoes die away during guard interval)
- Channels are orthogonal
  - No cross-talk
  - Don't need filters for each subchannel
  - Don't need inter-carrier guard bands
- Robust, makes good use of channel capacity
  - ADSL,VDSL (telephone line data transmission)
  - 802.11a, 802.11g, 802.16, 802.15.3 (ultra wide band)
  - Terrestrial Digital TV
  - Power line networking

OFDM Transmitter

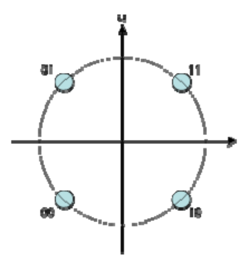


http://en.wikipedia.org/wiki/OFDM

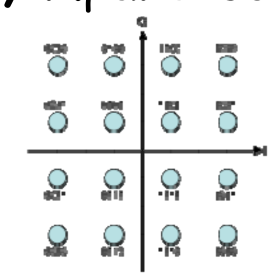
- **Signal is interleaved across multiple subchannels**
  - **For bidirectional links, can use some subchannels for each direction**
- **Constellation mapping can be chosen separately for each subchannel: for other than BPSK, X_i are complex values**



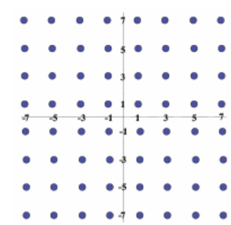
BPSK



QPSK

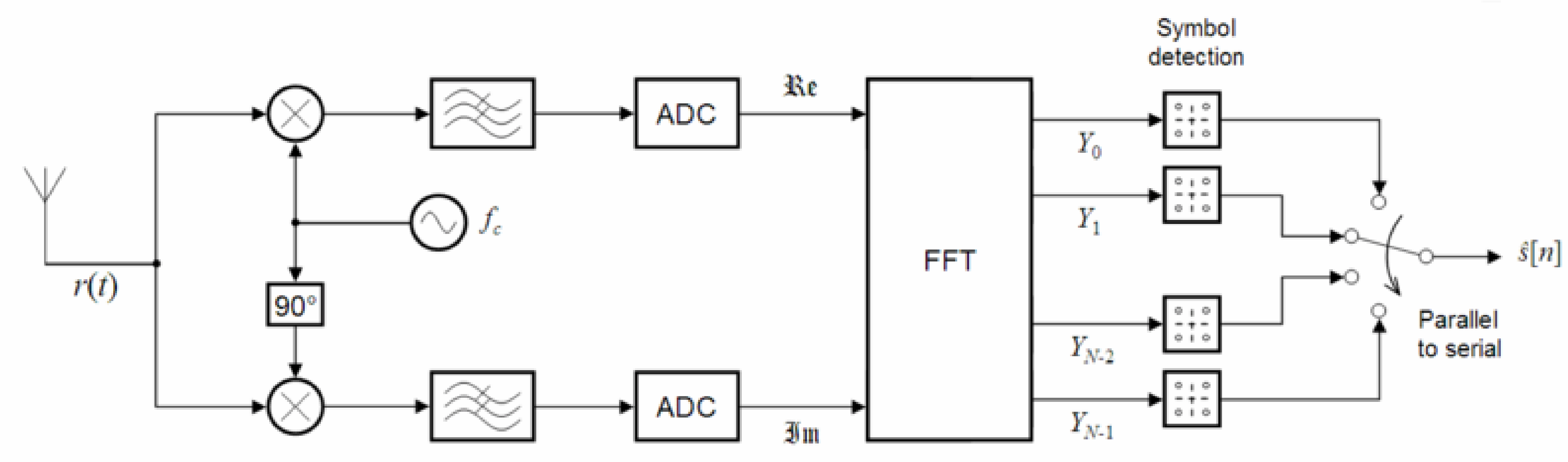


16-QAM



64-QAM

OFDM Receiver



- **Need good frequency synchronization at receiver to keep subchannels orthogonal, need good gain control to keep amplitudes correct for slicing.**
- **Low-pass filter selects demodulated baseband signal**
- **Symbol detection for each subchannel is matched to modulation scheme selected by transmitter**

Transmitting Information: Spread Spectrum

- Direct Sequence Spread Spectrum (DSSS)
  - Used in asynchronous CDMA where each "chip" from pseudo-random "chip vector" is used to change phase of transmission.
  - Chip rate is many times higher than message rate (i.e., we transmit many chips per message symbol), so message is spread out over large spectrum
    - Highest freq is twice the chip rate
  - Longer PN sequences and higher chip rate increase rejection of uncorrelated transmissions ("process gain")
  - Used in 802.11b, CDMA phones
- Frequency-Hopping Spread Spectrum (FHSS)
  - Like DSSS except adjust carrier frequency instead of phase.
  - Adapt sequence to avoid crowded frequencies (Bluetooth)

Wireless Data Networks

Current wireless networks use standards developed by the IEEE LAN/MAN Standards Committee (aka IEEE 802).

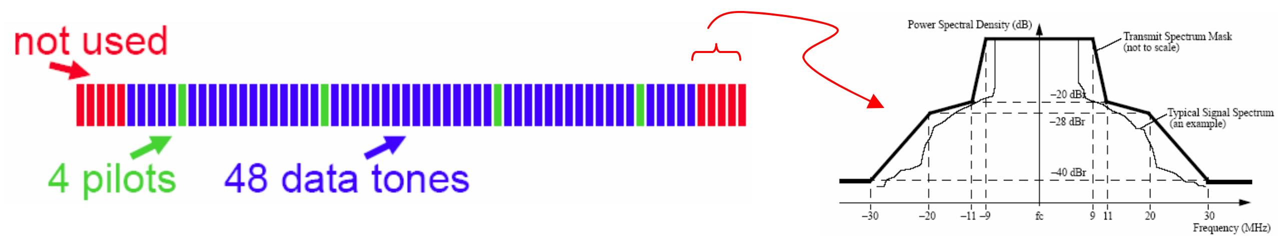
802.11: Wireless Local-Area Networks (Wi-Fi)
- **802.11b: 11Mbps (6.5Mbps typ) @ 2.4GHz, 100m**
- **802.11a: 54Mbps (25Mbps typ) @ 5GHz, 50m**
- **802.11g: 54Mbps (11Mbps typ) @ 2.4GHz, 100m**
- **802.11n: 540Mbps (200Mbps typ) @ 2.4GHz or 5GHz, 250m**

802.15: Wireless Personal-Area Networks
- **802.15.1: (Bluetooth) 1-3Mbps @ 2.4GHz, 1:10:100m**
- **802.15.3: (UWB) 100-500Mbps @ 3.1-10.6GHz, 1-3m**
- **802.15.4: (ZigBee) 40kbps @ 915MHz, 250kbps @2.4GHz, 10-75m**

802.16: Broadband Wireless Access (WiMAX)
- **up to 70Mbps and up to 100km (but not at the same time!)**
- **@ 1-10GHz, or @ 10-66GHz**

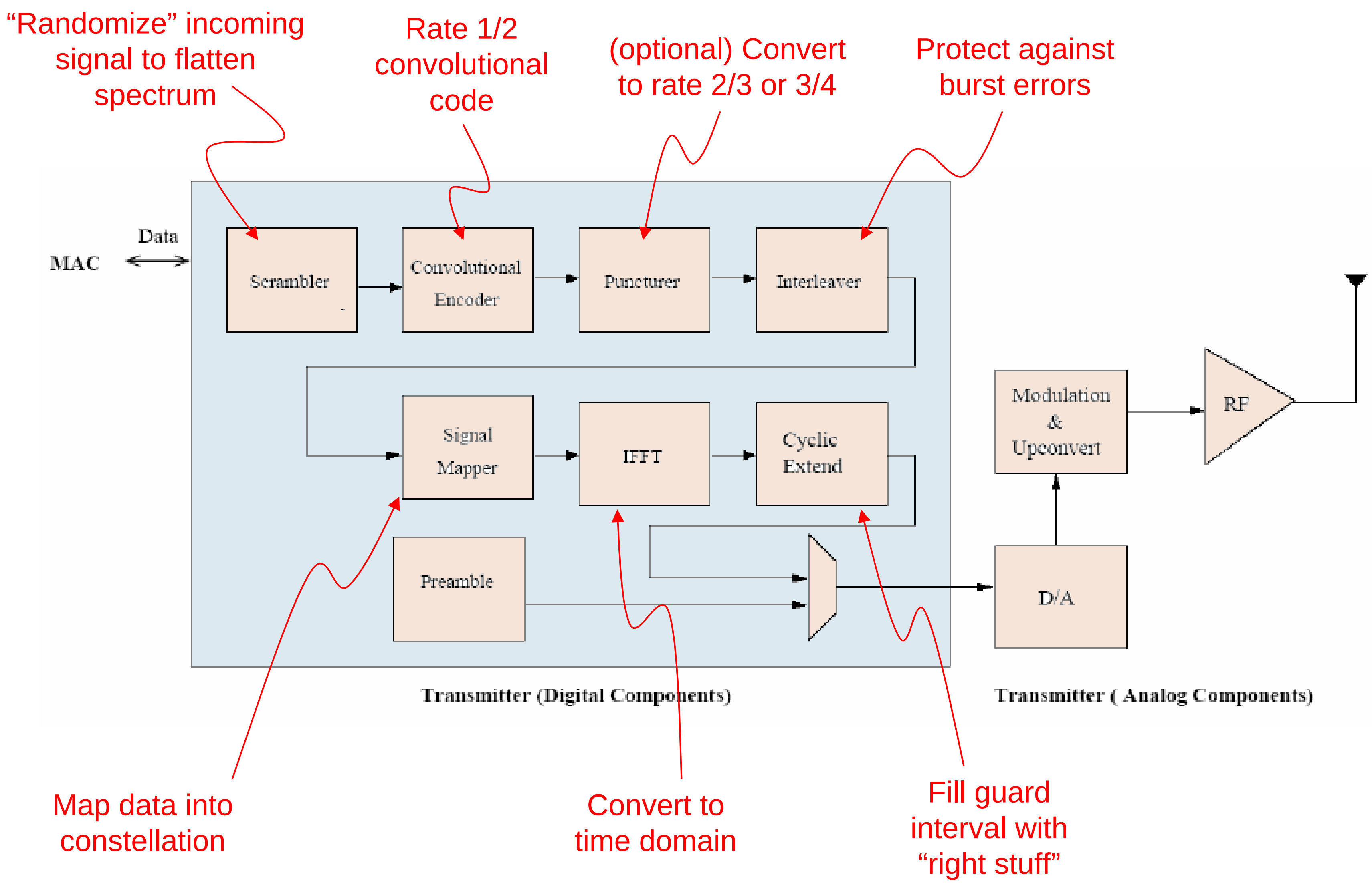
802.11a

- 12 channels in 5GHz band
- 20MHz bandwidth (16.6MHz occupied)
  - Orthogonal Frequency Division Multiplexing (OFDM)
  - 52 subcarriers (48 data, 4 pilot), (20MHz/64) = .3125MHz separation

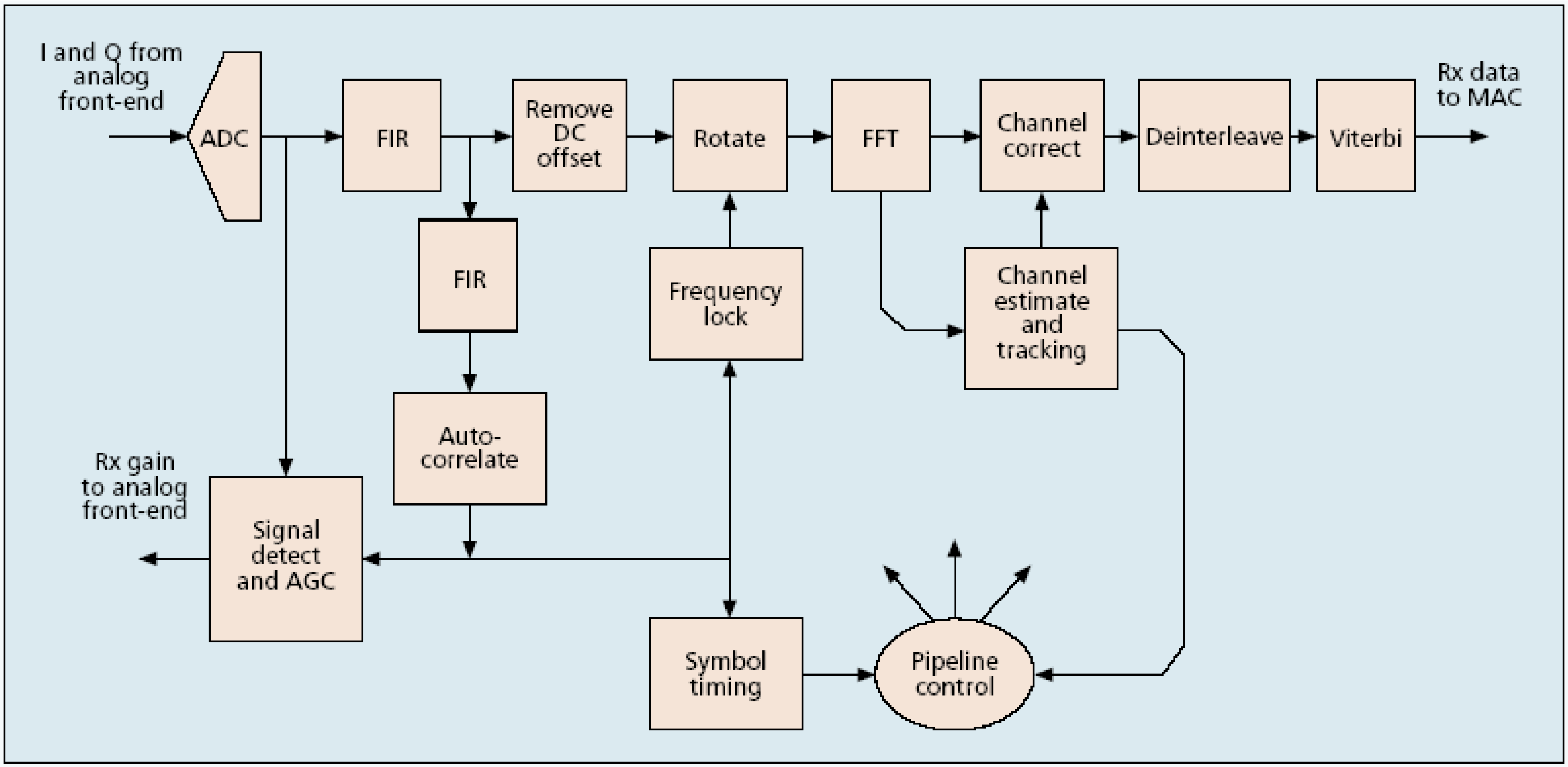


  - Modulation and channel coding scheme can be chosen to reflect actual channel capacity (choice based on SNR):
    - BPSK (6Mbps @ rate 1/2, 9Mbps @ rate 3/4, 1 bit)
    - QPSK (12Mbps @ rate 1/2, 18Mbps @ rate 3/4, 2 bits)
    - 16-QAM (24Mbps @ rate 1/2, 36Mbps @ rate 3/4, 4 bits)
    - 64-QAM (48Mbps @ rate 2/3, 54Mbps @ rate 3/4, 6 bits)
  - Symbol duration 4us (includes guard interval of 0.8us)
    - ~250k combined symbols per second, 48 data channels
    - ~Data rate = (48)(250k)(# bits/symbol)(code rate)
      = (12M)(# bits/symbol)(code rate)

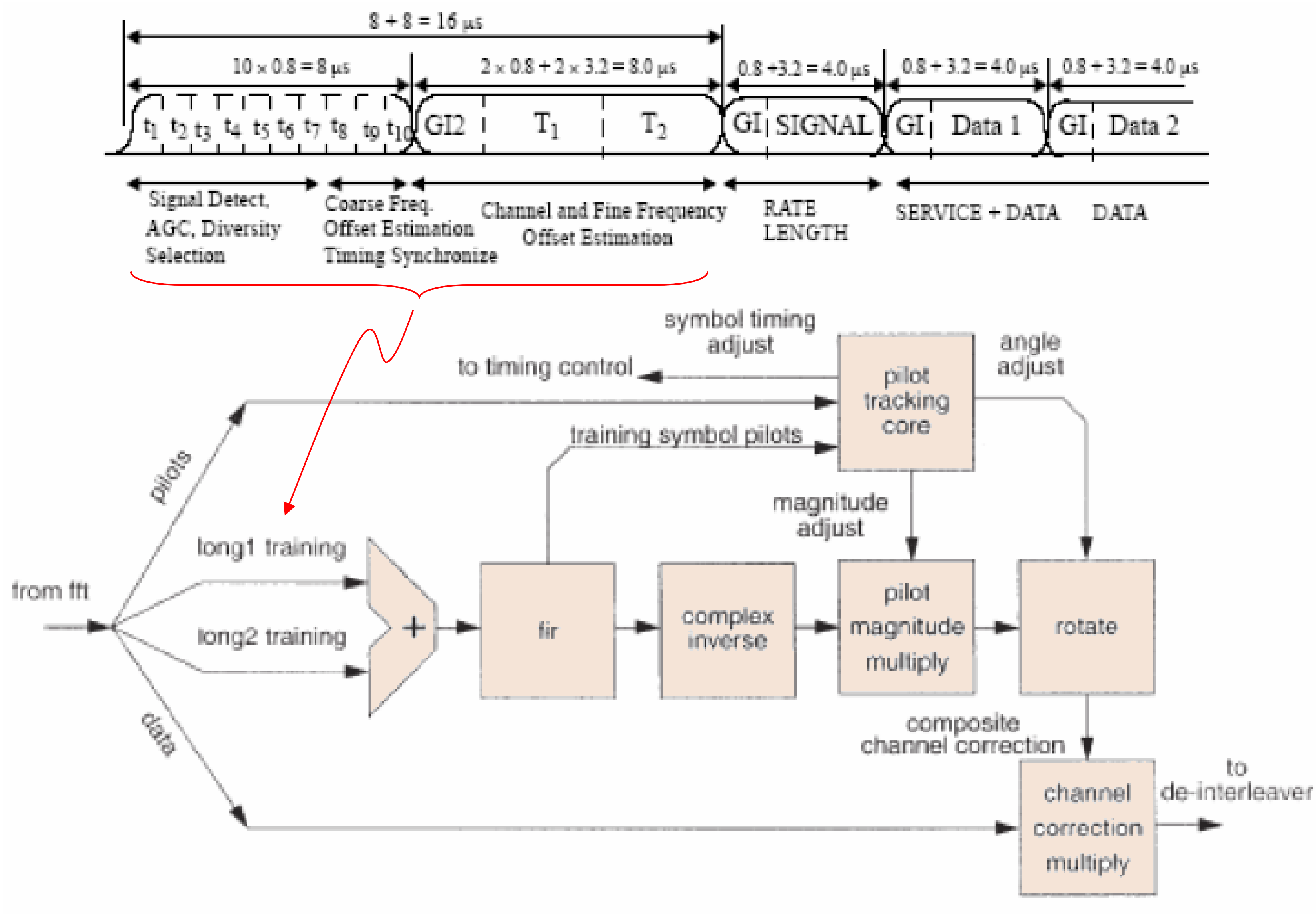
802.11a Transmitter



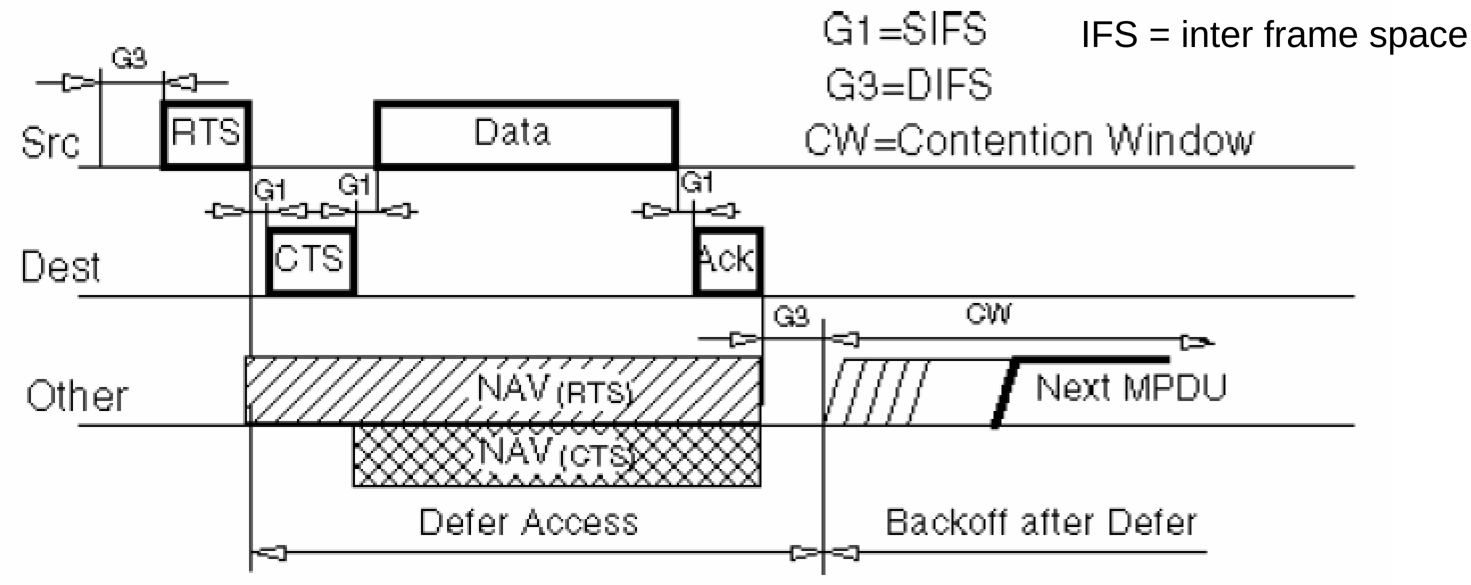
802.11a Receiver



802.11a Packet Structure



802.11a Virtual CSMA/CA



- **Full Collision Detect would require full duplex radio ($$$)**
- **Transmitter sends Request-To-Send packet specifying source, destination and duration (cts+pkt+ack)**
- **Receiver sends Clear-To-Send packet with duration (pkt+ack)**
- **Everyone receiving RTS or CTS will mark channel as busy for given duration**
- **Transmitter sends Data packet, receiver checks CRC and replies with ACK packet.**