

Today

→ OFDM

→ Channel Estimation

→ Residual CFO & SFO

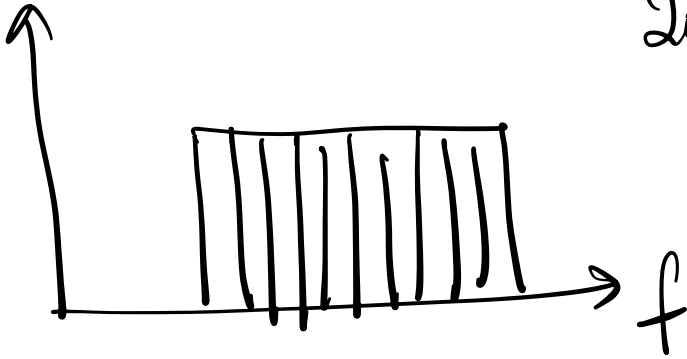
→ Guard Bands

→ OFDMA

→ FICA

Channel Estimation

20MHz \rightarrow 64 narrowband subcarriers



$x =$

$$y = \hat{h}x + n$$



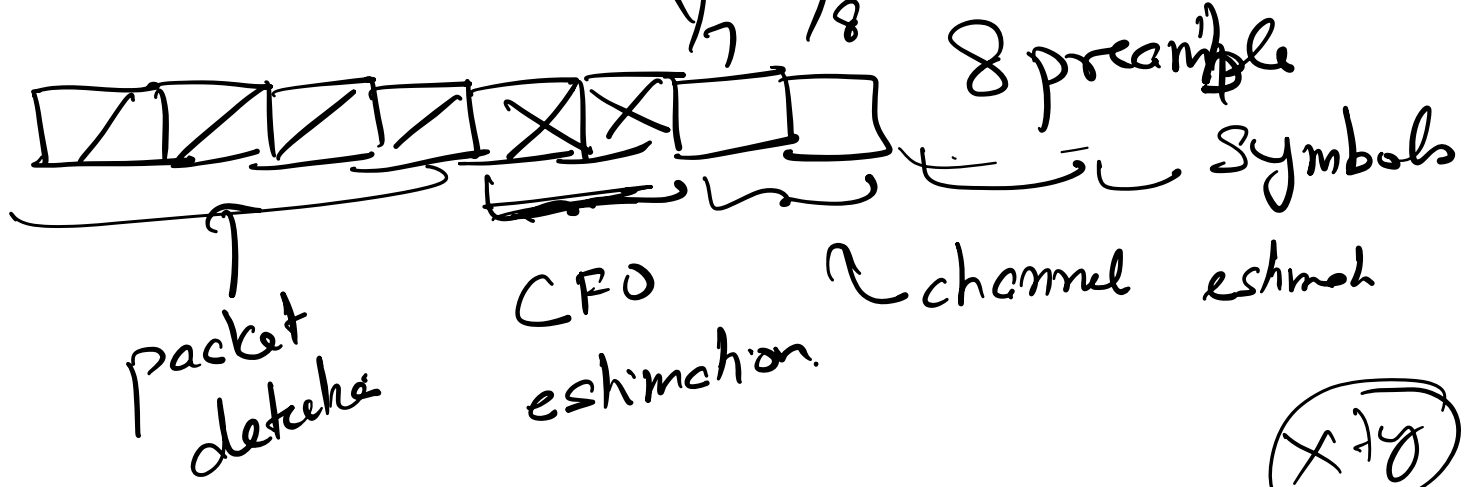
64 numbers
or h_N

x_{preamble}

y_{preamble}

$$H_i = \frac{y_{\text{preamble},i}}{x_{\text{preamble},i}} \text{ for all } i$$

$$H_{f_i} = \frac{y_{f_i}}{x_{f_i}}$$



$x + y$

$$H_{est} = \frac{y_7 + y_8}{2 \times \text{preamble.}}$$

Residual CFO/SFO

~~$x(t)$~~ $x(t) e^{j 2\pi f_c t}$

Residual CFO:

$x(t) e^{j 2\pi (f_c - f_c') t}$

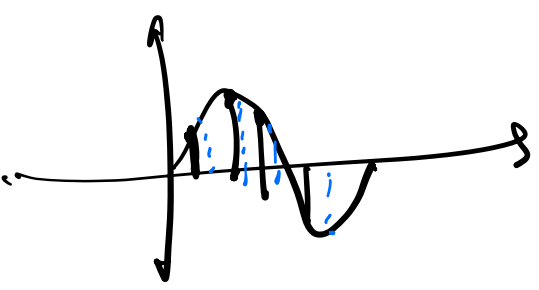
$x(t) e^{j 2\pi \delta f_c t}$

SFO

SFO: sampling freq. offset.

Wi-Fi BW: 20MHz, SF: 20MHz

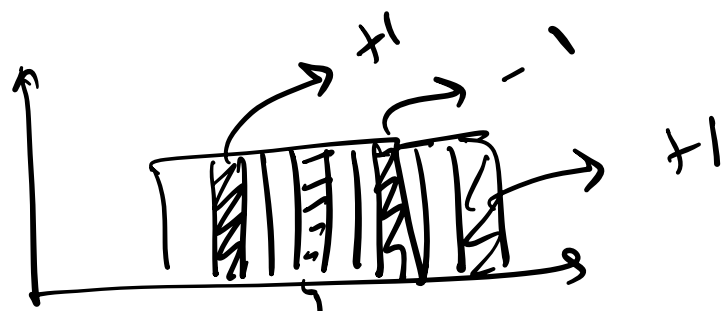
Sender: 20MHz
 20.0001 MHz, Receiver: 19.9999 MHz



$x[t]$ $x[t + t_s]$
 $x[t + 2t_s]$

$$x[k] \quad x[t + t_s + \delta] \quad x[t + 2t_s + 2\delta]$$

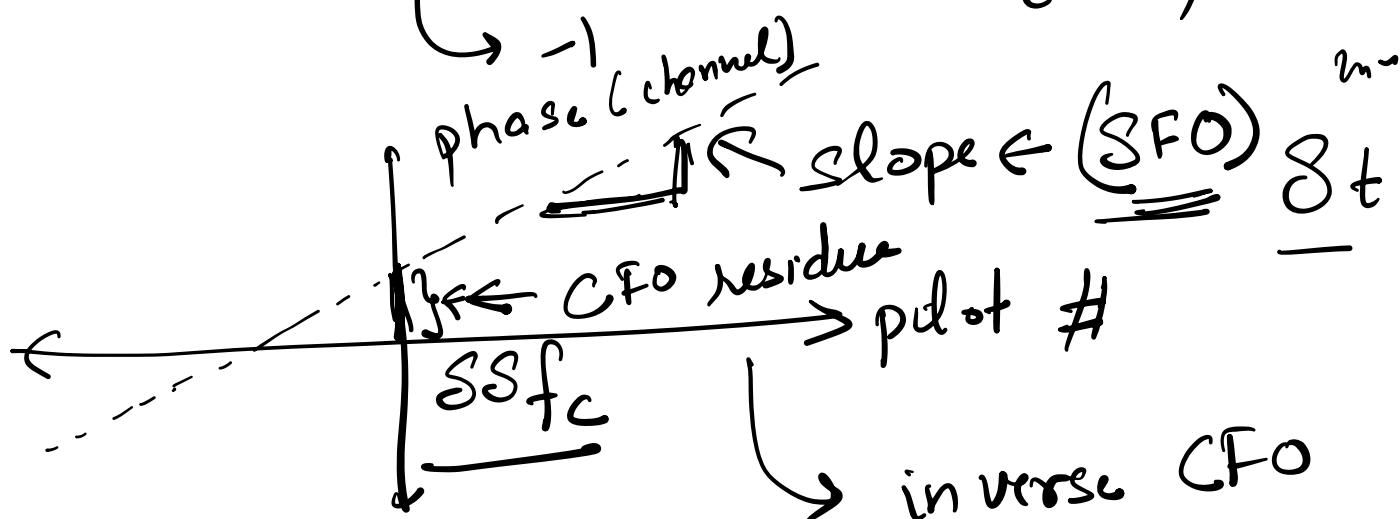
OFDM \rightarrow pilots



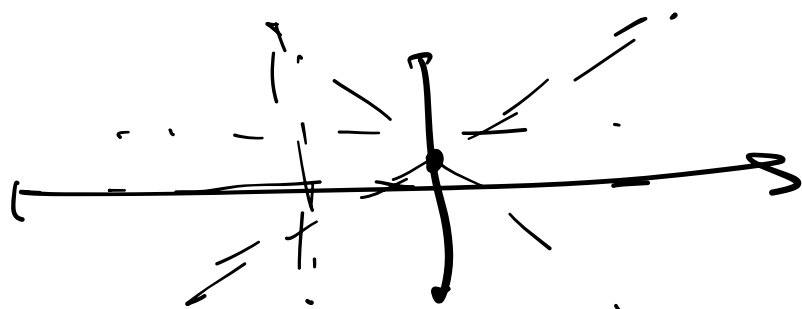
64 subcarriers

56 \rightarrow data

8 \rightarrow pilots.



inverse CFO residue

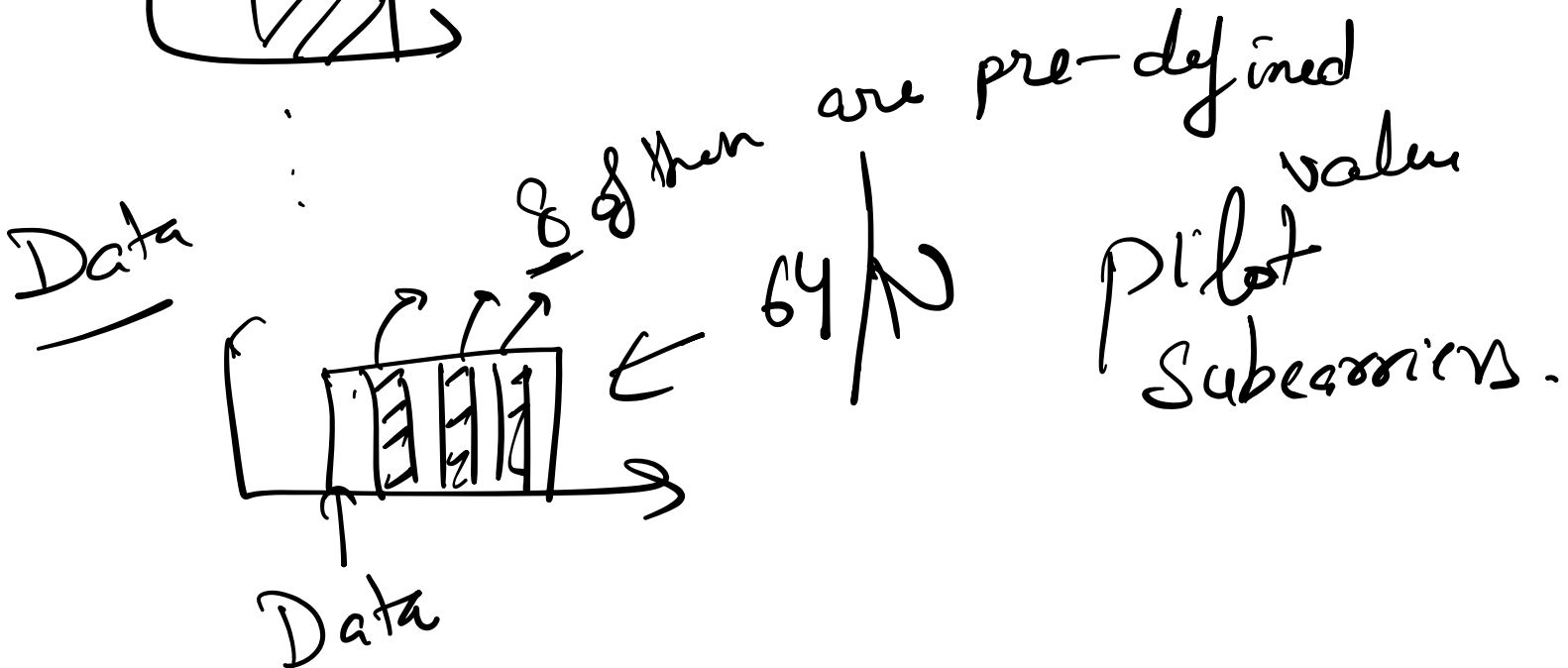
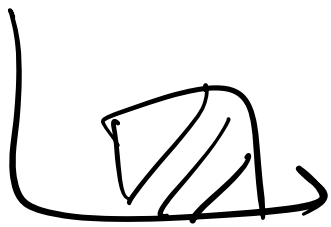
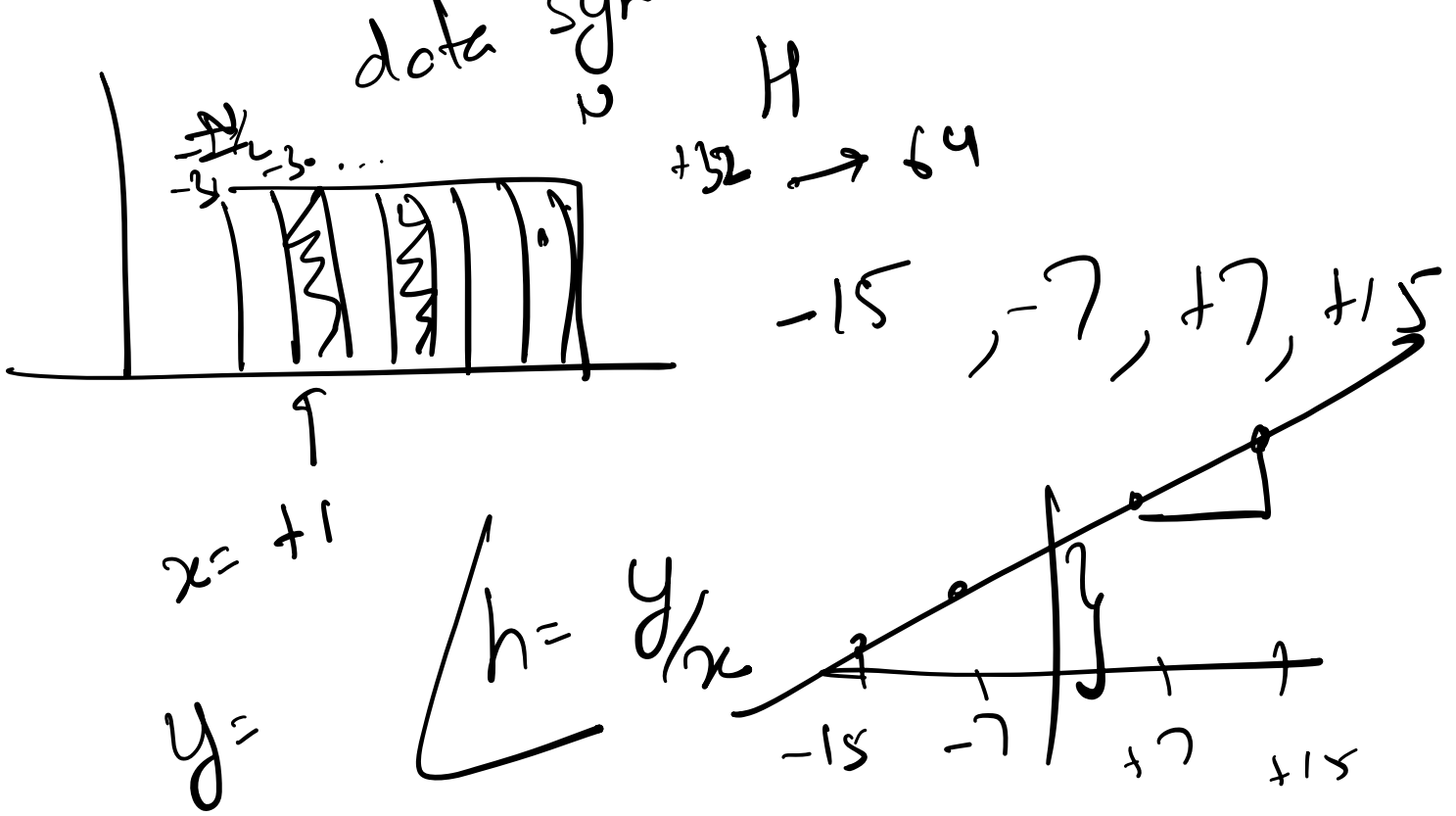


effect of SFO
 $2\pi f_i n \delta$

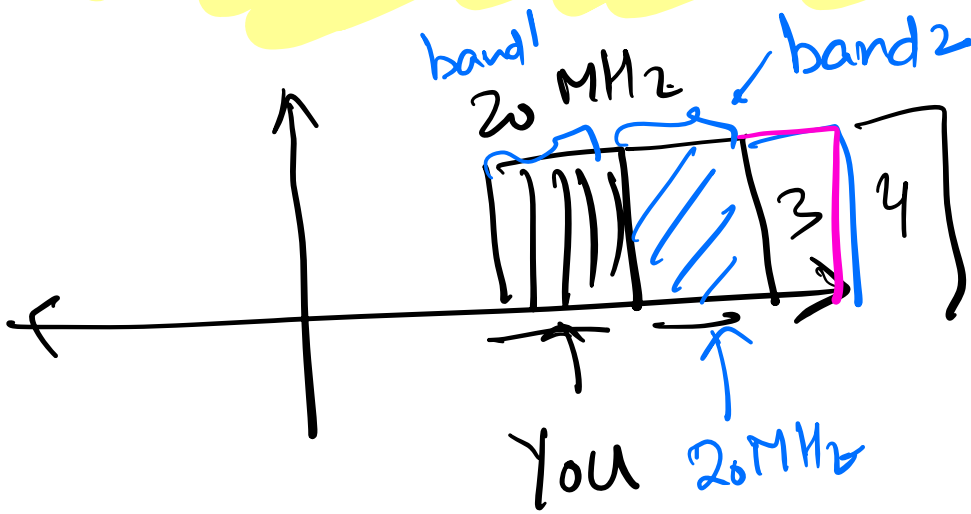
SFO $y[f] = x[f] e^{-j 2\pi f_i n \delta}$

CFO: $y[f] = x[f] e^{-j 2\pi \delta f_c \frac{t}{T_s}}$

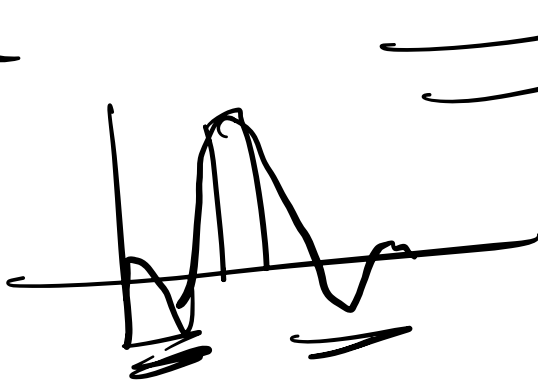
subcarrier



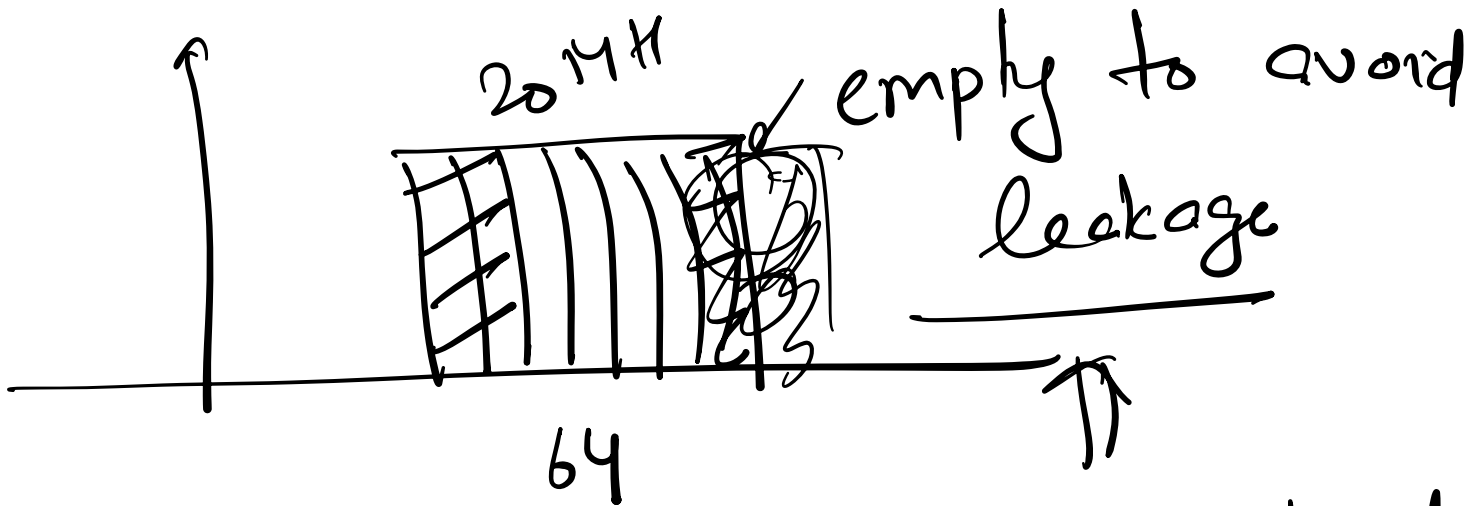
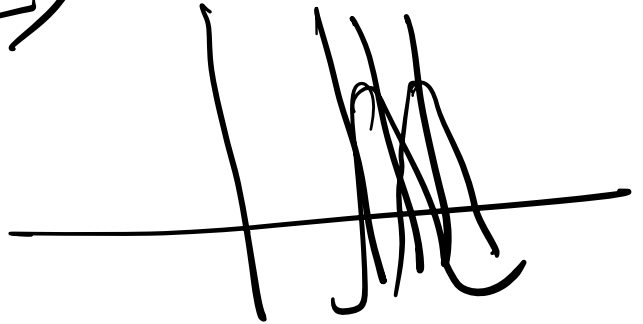
Guard Bands



Leakage



OFDM



Guard bands.

Summary

At TX:

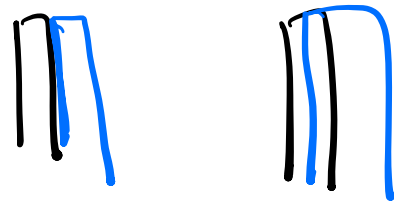
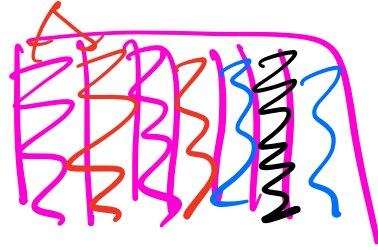
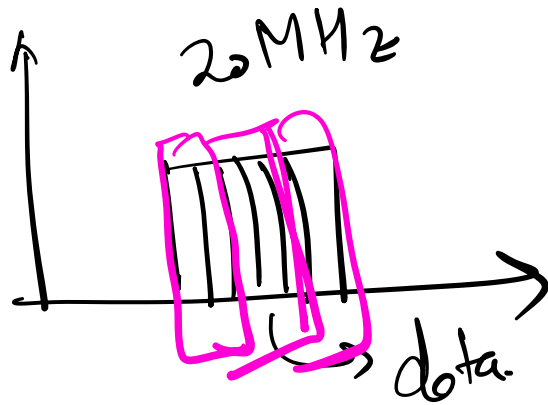
- Create preamble symbol from training sequence (Uses BPSK)
- Repeat preamble symbol:
 - 4 times for packet detection
 - 2 times for CFO estimation
 - 2 times for channel estimation
 - Add CP for the last preamble
- Create data symbol from:
 - Data bits (Uses BPSK, QPSK, M-QAM)
 - Pilot bits (Uses BPSK)
- Add cyclic prefix to data symbols.

At RX:

- Detect beginning of packet.
- Estimate & correct for CFO.
- Jump $\approx 0.75 CP$ samples into symbol to avoid ISI
- Estimate the channel.
- For each subsequent data symbol:
 - Remove CP
 - Take FFT of Size N
 - Correct for channel by dividing with $\tilde{H}(f)$
 - Use linear regression to estimate residual CFO and SFO
 - Estimate accumulated phase $\Delta\phi(f)$ for each frequency bin
 - Add $\Delta\phi(f)$ to channel estimate $\tilde{H}(f)$
 - Decode Bits

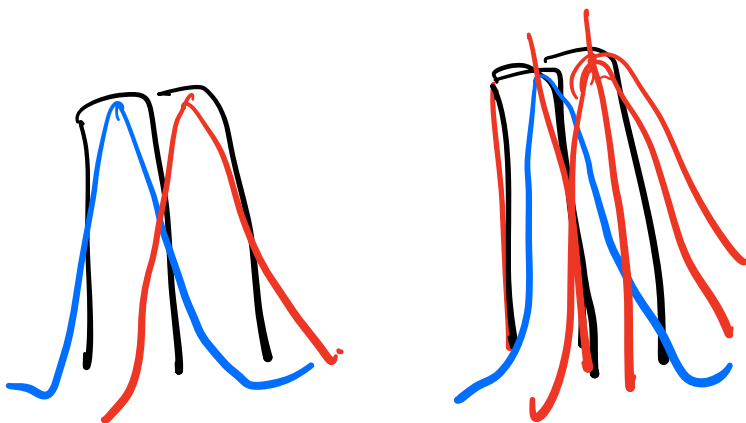
Decode Bits

OFDMA



Cellular networks → synchronization mechanism

BS → signal at time t , correct your clocks to this time



FICA Motivation

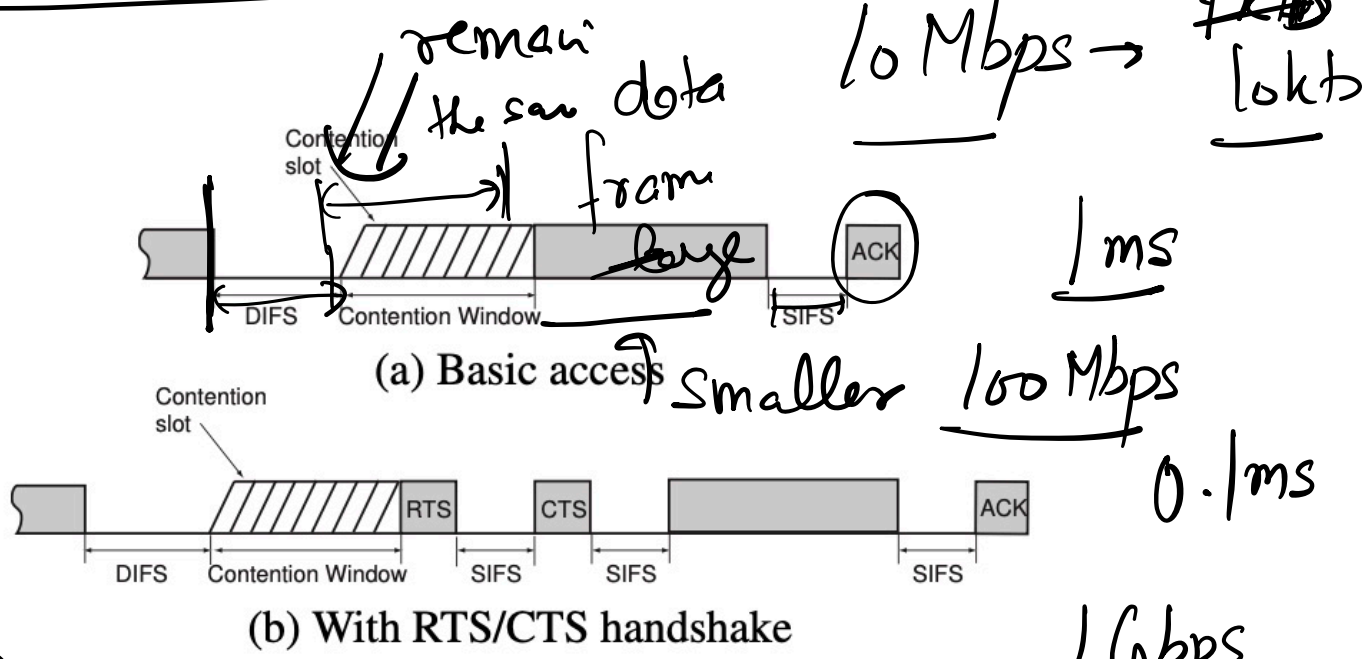


Figure 1: Illustration of CSMA/CA access method.

CSMA
 device A → 100 Mbps
 B → 100 Mbps
 420 Mbps
 60 Mbps

FICA
 dev A → 50 Mbps
 device B → 50 Mbps

1 Gbps
 0.01ms
 today
 60 Mbps

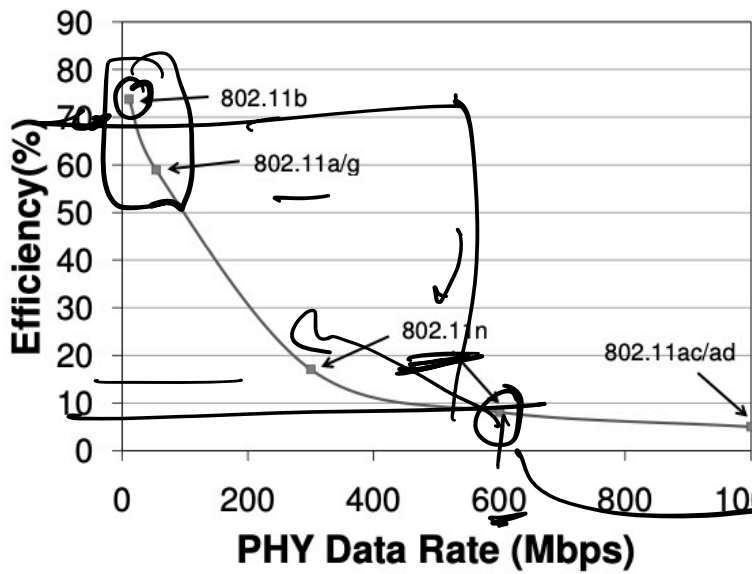
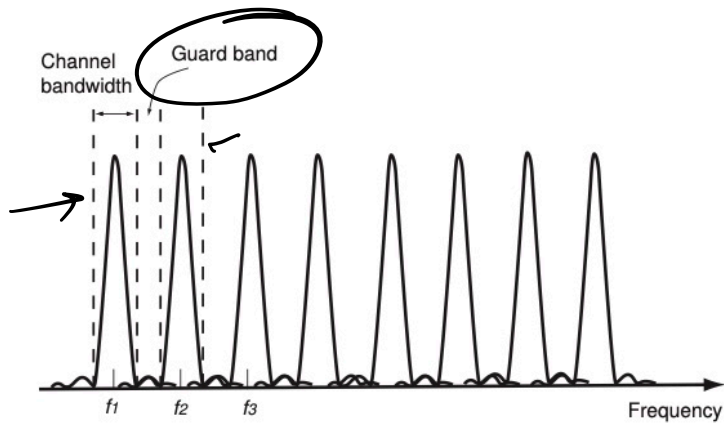
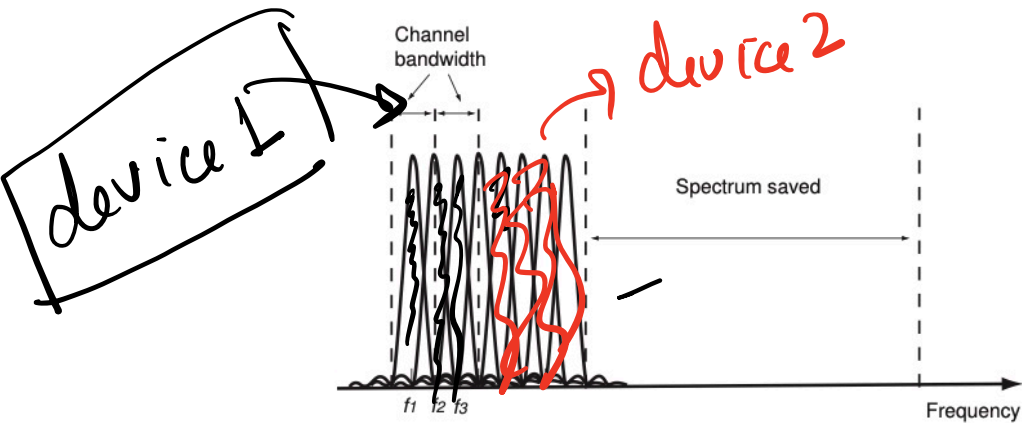


Figure 2: Inefficiency of 802.11 MAC at high data rates with a typical Ethernet MTU (1500B).

FICA: OFDM



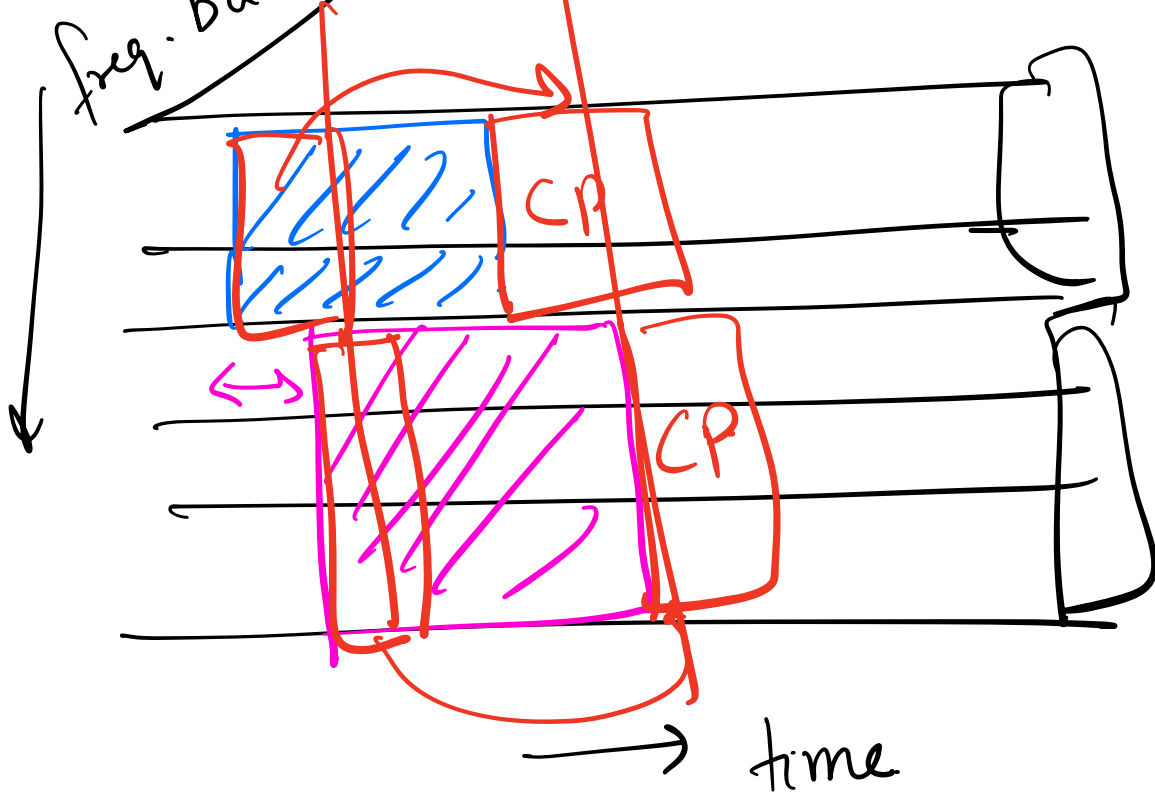
(a) Normal frequency division multiplexing



(b) OFDM

Figure 3: OFDM achieves higher spectrum efficiency.

bands -



RTS/CTS for each sub-band

MIMO ← Multi-antenna devices