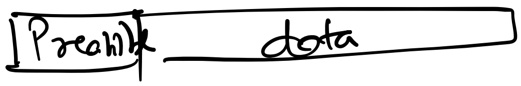
CS 598 WSI, LECTURE 7

- OFDM - Review
- FICA discussion
- Multi-antenna Systems
  - Motivation
  - Diversity
  - Multiplexing

OFDM: REVIEW

At TX:

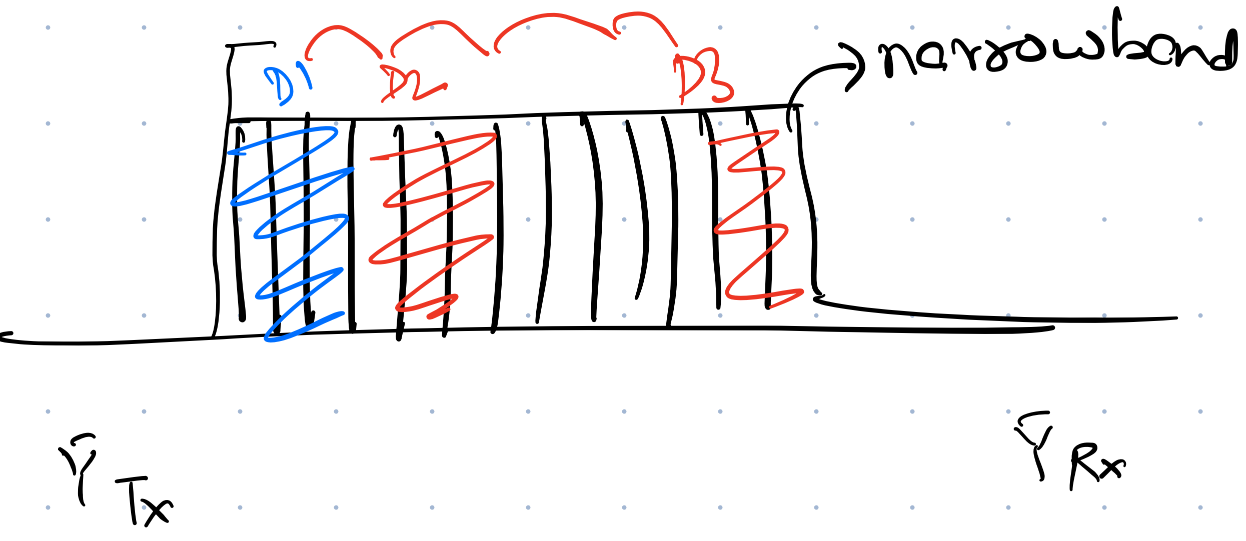


- Create preamble symbol from training sequence (Uses BPSK)
- Repeat preamble symbol:
  - 4 times for packet detection
  - 2 times for CFO estimation
  - 2 times for channel estimation
  - Add CP for the last preamble
- Create data symbol from:
  - Data bits (Uses BPSK, QPSK, M-QAM)
  - Pilot bits (Uses 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 $\widetilde{H}(f)$
  - 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 $\widetilde{H}(f)$
  - Decode Bits

OFDMA & FICA



OFD - Multiple Access.

Orthogonal Freq. Division.

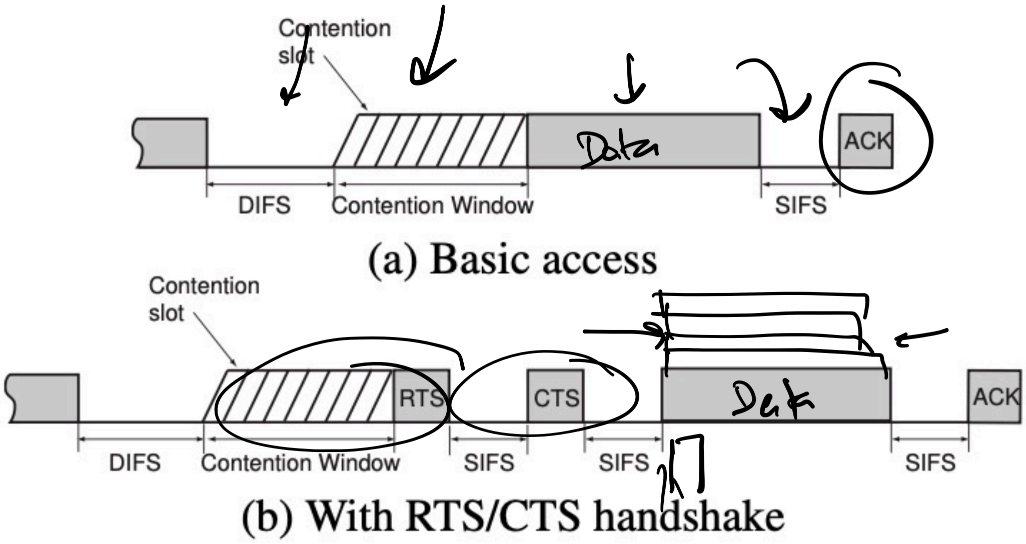


Figure 1: Illustration of CSMA/CA access method.

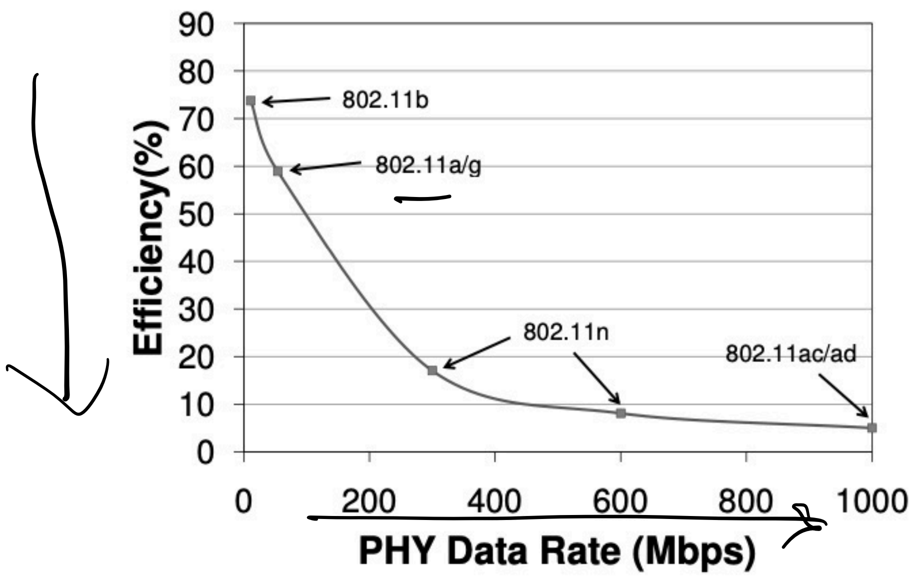
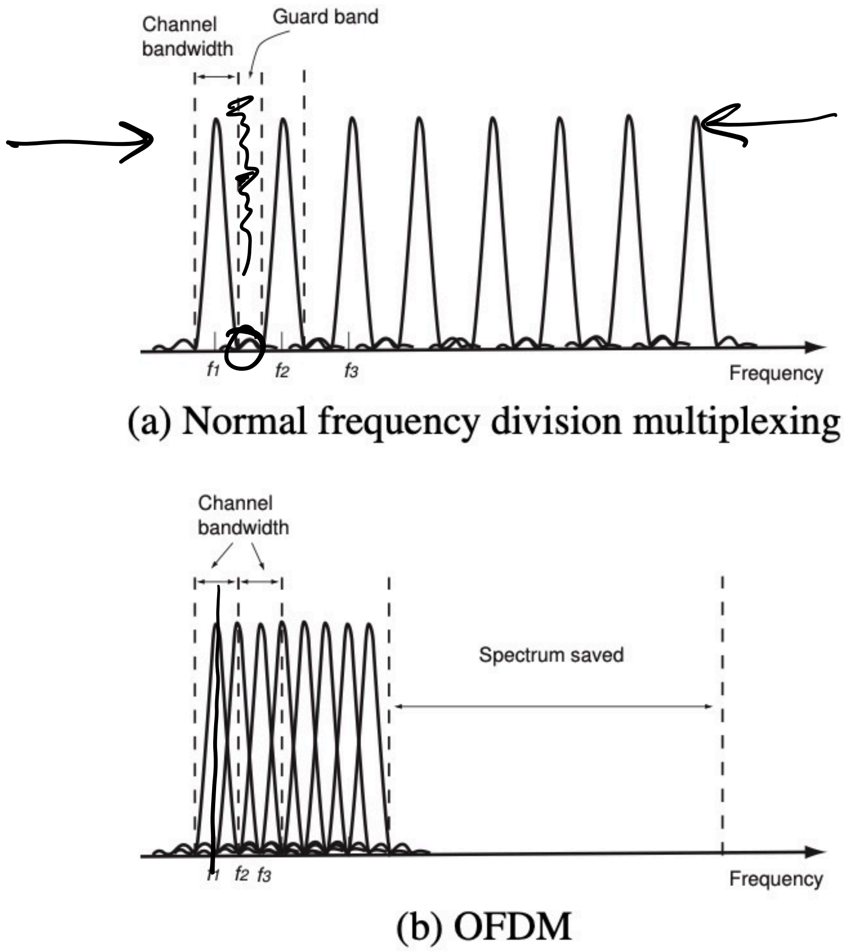


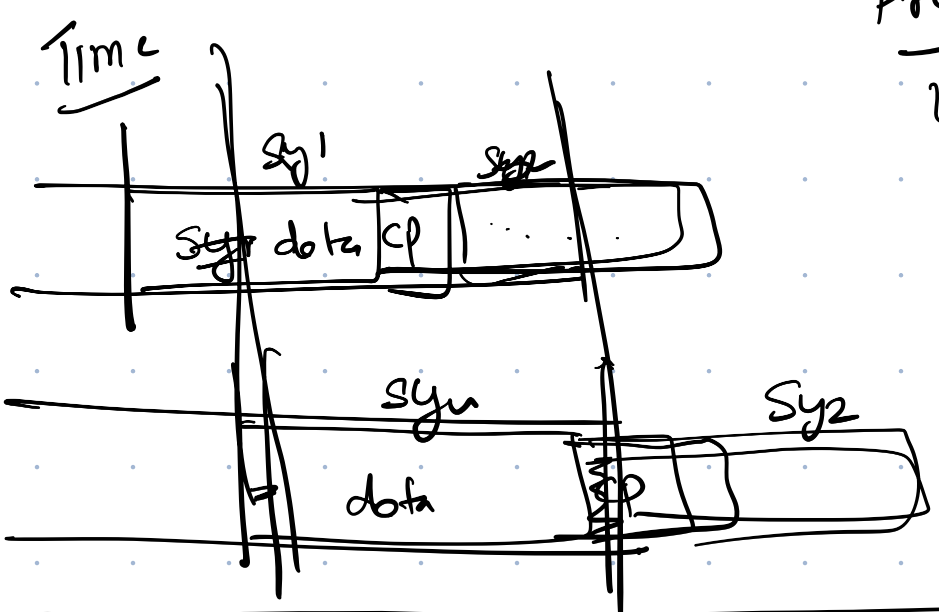
Figure 2: Inefficiency of 802.11 MAC at high data rates with a typical Ethernet MTU (1500B).



(a) Normal frequency division multiplexing

(b) OFDM

Figure 3: OFDM achieves higher spectrum efficiency.



Freq. Synchronization
↳ ~~BS~~ Access point
→ how your channel signal is shifting in time
→ correct for freq. errors.

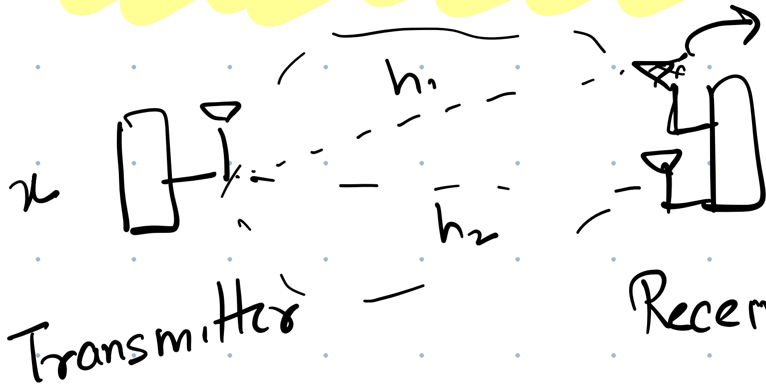
Pros

Cons → compute + communication heavy

MULTIPE ANTENNAS

Version	Year	Technology	Modulation	Freq.	Bandwidth	Maximum Data Rate
WiFi 1 (802.11b)	1999	DSSS	DBPSK, DQPSK,	2.4 GHz	22 MHz	11 Mb/s
WiFi 3 (802.11g)	2003	OFDM (N=64)	BPSK, QPSK, 16-QAM, 64-QAM	2.4 GHz	20 MHz	54 Mb/s
WiFi 4 (802.11n)	2009	OFDM (N=64) MIMO (4x4)	BPSK, QPSK, 16-QAM, 64-QAM	2.4 GHz 5 GHz	20 MHz 40 MHz	600 Mb/s
WiFi 5 (802.11ac)	2014	OFDM (N=64, 128, 256, 512) MIMO (8x8) MU-MIMO (Downlink)	BPSK, QPSK, 16-QAM, 64-QAM 256-QAM	5 GHz	20 MHz 40 MHz 80 MHz 160 MHz	6.933 Gb/s
WiFi 6 (802.11ax) **WiFi 6E**	**2020**	OFDM (N=256, 512, 1024, 2048) MIMO (8x8) MU-MIMO (Up & Down) OFDMA	BPSK, QPSK, 16-QAM, 64-QAM 256-QAM, 1024-QAM	2.4 GHz 5 GHz **6 GHz**	20 MHz 40 MHz 80 MHz 160 MHz	9.608 Gb/s

Rx DIVERSITY



→ 2 antennas

$y_1 = h_1 x + n_1$

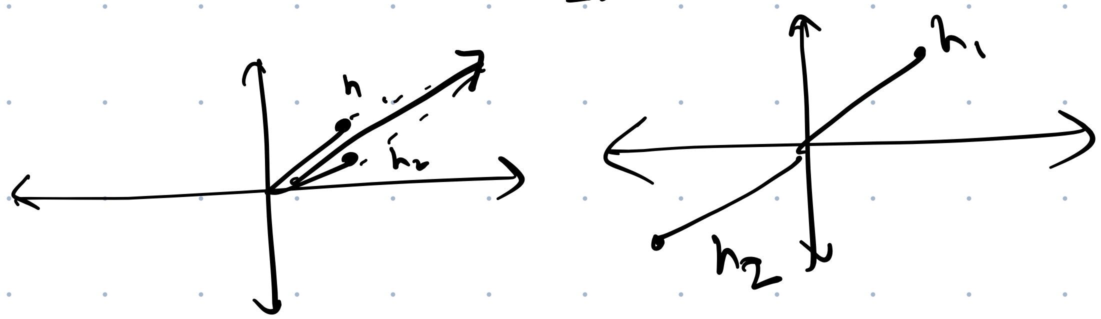
$y_2 = h_2 x + n_2$

(1, 0, . . .)

1. Decode each signal independently & (maybe) average.

2. Add the two signals & decode.

$y = y_1 + y_2 = (h_1 + h_2)x + (n_1 + n_2)$



can cancel

No guarantee that this helps.

Maximal Ratio Combining (MRC)

$*$ → complex conjugate

$$y = h_1^* y_1 + h_2^* y_2$$

$$= h_1^* (h_1 x + n_1) + h_2^* (h_2 x + n_2)$$

$$= \left(|h_1^*|^2 + |h_2|^2 \right) x + \left(h_1^* n_1 + h_2^* n_2 \right)$$

real number + real number

$$SNR_1 = \frac{|h_1|^2 x^2}{n_1^2} \qquad SNR_2 = \frac{|h_2|^2 x^2}{n_2^2}$$

$|n|^2 = \sigma^2$

$$SNR_{MRC} = \frac{\left(|h_1|^2 + |h_2|^2\right)^2 x^2}{\left| E\left(h_1^* n_1 + h_2^* n_2 \right)\right|^2}$$

$$= \frac{\left(|h_1|^2 + |h_2|^2\right)^2 x^2}{\left(|h_1|^2 + |h_2|^2\right) \sigma^2}$$

$$\frac{SNR_{MRC}}{SNR_1} = \frac{|h_1|^2 + |h_2|^2}{|h_1|^2}$$

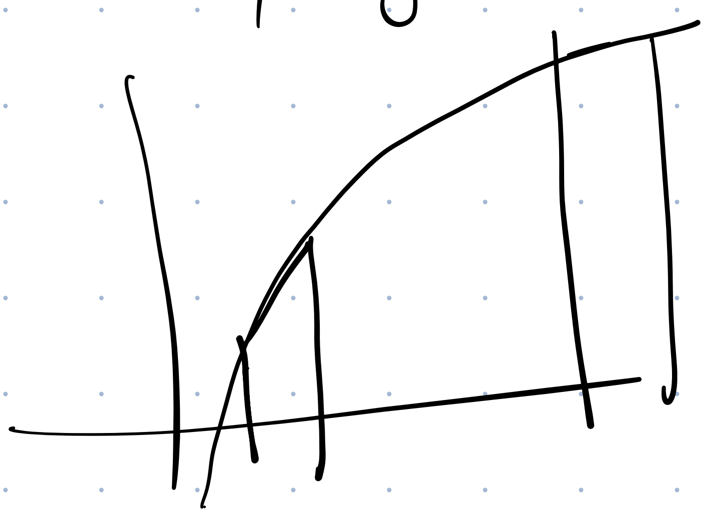
~~$|h_1|^2 =$~~ $|h_1| \approx |h_2| \rightarrow$ SNR is double

$|h_1| \gg |h_2| \rightarrow$ SNR is almost like h_1

$|h_1| \ll |h_2| \rightarrow$ SNR is almost like h_2

$\ll 10\,|h_1|$

~~SN~~ Capacity $= BW \log(1+SNR)$



TX DIVERSITY

$$y = h_1 x + h_2 x + n$$

$$= (h_1 + h_2)\, x + n$$

$$y' = \alpha h_1 x + \beta h_2 x + n$$

$$\downarrow \qquad\qquad \downarrow$$

$$h_1^* \qquad\qquad h_2^*$$

Feedback

Power

$$= |h_1|^2 x + |h_2|^2 x + n$$

$$= (|h_1|^2 + |h_2|^2)\, x + n$$

$$SNR = \frac{(|h_1|^2 + |h_2|^2)^2 x^2}{n^2}$$

→ Power → reducing power on each antenna

→ Feedback → ?

Spatial coding

SPACE TIME CODES

$$\begin{matrix} Tx_1 \\ Tx_2 \end{matrix} = \begin{bmatrix} x_1 & x_2 & x_3 & \cdots \\ x_1 & x_2 & x_3 & \cdots \end{bmatrix}$$

$$Rx = \begin{bmatrix} h_1 x_1 & h_1 x_2 & & \\ + & + & + & \cdots \\ h_2 x_1 & h_2 x_2 & & \end{bmatrix}$$

$$= (h_1 + h_2) \begin{bmatrix} x_1 & x_2 & \cdots & x_n \end{bmatrix}$$

011 ← (101)

$$\begin{matrix} Tx1 \\ Tx2 \end{matrix} \begin{bmatrix} x_1 & -x_2^* \\ x_2 & x_1^* \end{bmatrix} \Leftarrow \text{Alamouti Codes.}$$

$$y_1 = h_1 x_1 + h_2 x_2 + n_1$$

$$y_2 = -h_1 x_2^* + h_2 x_1^* + n_2$$

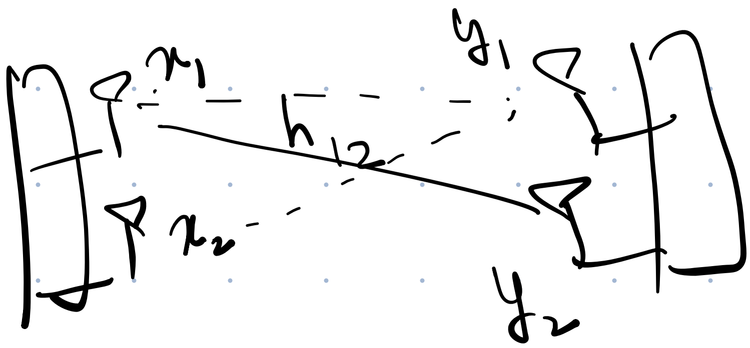
h_1, h_2

$$h_1^* y_1 + h_2 y_2^* = h_1^* h_1 x_1 + \cancel{h_1^* h_2 x_2}$$

$$\cancel{- h_1^* h_2 x_2} + h_2 h_2^* x_1$$

MIMO

Multiple input, multiple output



n antennas.
↓
n parallel streams of data.

$$y_1 = h_{11}(x_1) + h_{21}x_2 + n$$

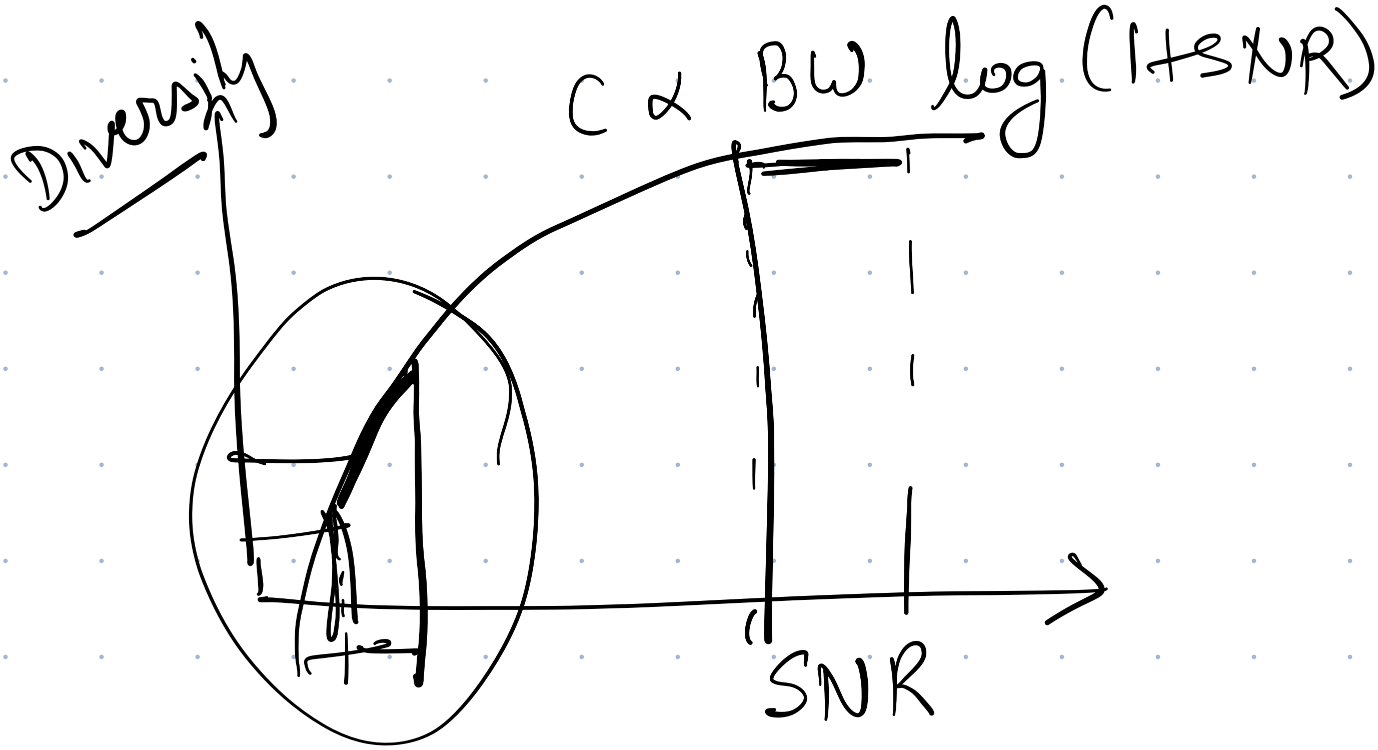
$$y_2 = h_{12}x_1 + h_{22}x_2 + n$$

$$\begin{bmatrix} y_1 \\ y_2 \end{bmatrix} = \begin{bmatrix} h_{11} & h_{21} \\ h_{12} & h_{22} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \end{bmatrix}$$

$$\bar{y} = H\bar{x} + \bar{n}$$

$$H^{-1}y = \bar{x} + H^{-1}n$$

$O(n^3)$



$\downarrow$

MIMO → 2x datarate

~ at the same