

Vector OFDM Single Transmit Antenna Systems

Xiang-Gen Xia

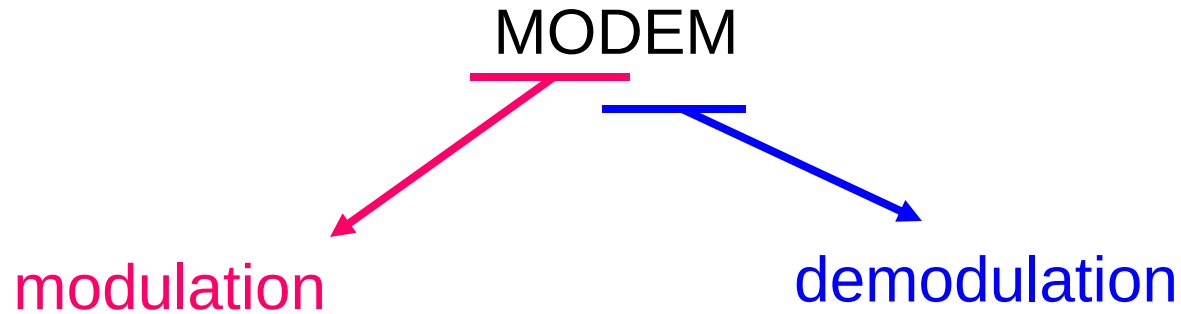
Dept of ECE

University of Delaware

Xiang-Gen Xia, “Precoded and Vector OFDM Robust to Channel Spectral Nulls and with Reduced Cyclic Prefix Length in Single Transmit Antenna Systems,” *IEEE Trans. on Communications*, vol. 49, pp.1361-1374, Aug. 2001.

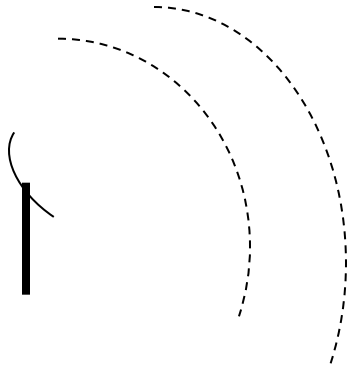
Outline

- Background
 - OFDM Overview
 - Vector OFDM
 - VOFDM with Matrix Modulation
 - Simulation
 - Conclusion
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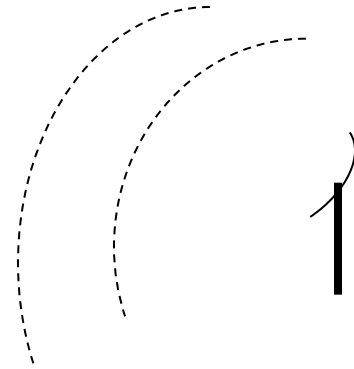


Today's focus is physical layer **modem.**

Communications

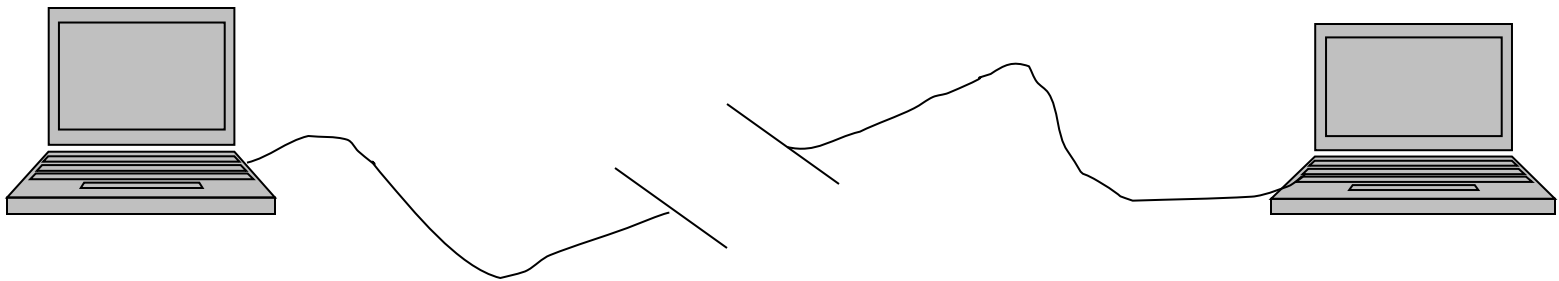


wireless



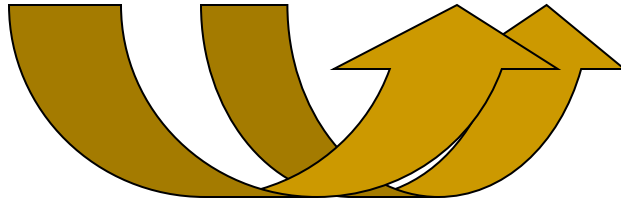
transmission through EM wave propagation

wired



Signal:

$A(t) \cos(p(t))$ carry information

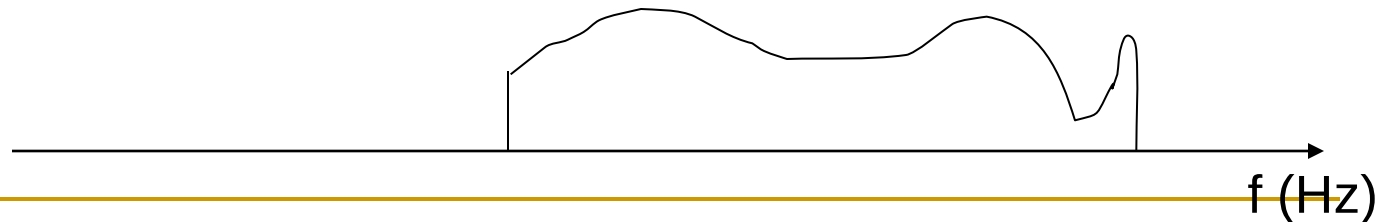


Channel:

a media that wave carrying information propagates through

→ Approximately a linear system

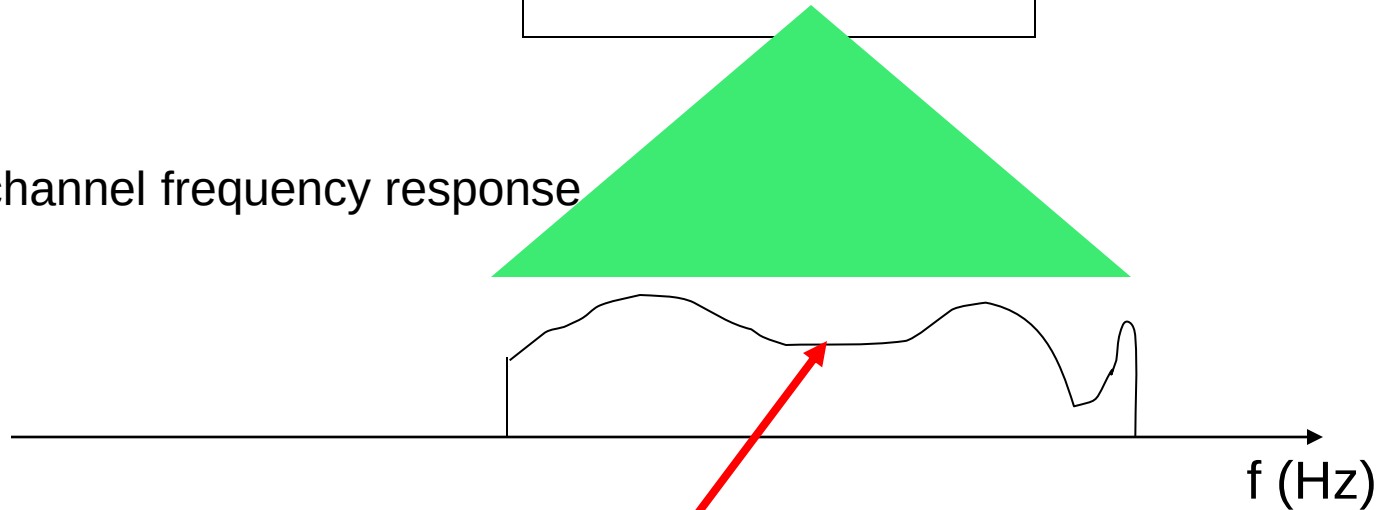
system frequency response



signal
 $\cos(p(t))$

channel

System/channel frequency response



(approximately) flat

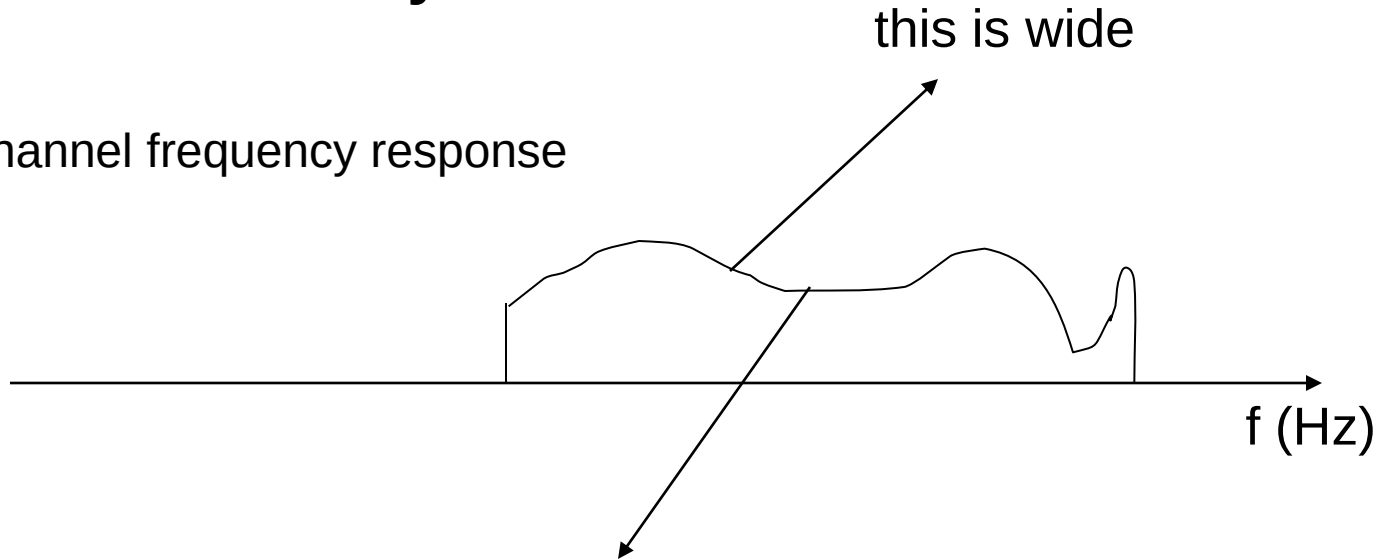
none flat

additive white Gaussian (AWGN)

intersymbol interference (ISI)

In broadband systems

channel frequency response



It is not possible to be flat → ISI occurs

Wireless: Multipath

Wired: None flat ISI channel
None ideal

Wired (modem)

< 9.6 kbs/s equalization (Lucky 60s)

9.6 kbs/s TCM +equalization (DFE)

14.4 kbs/s

28.8 kbs/s TCM + equalization

56 kbs/s

Asymmetric Digital Subscriber Line (ADSL)

6 Mbs/s

**orthogonal frequency division
multiplexing (OFDM)**

or called discrete multi-tone (DMT)

Data Rate	Wire Size	Distance
1.5 or 2 Mbps	0.5 mm	5.5 Km
1.5 or 2 Mbps	0.4 mm	4.6 Km
6.1 Mbps	0.5 mm	3.7 Km
6.1 Mbps	0.4 mm	2.7 Km

Wireless

HDTV Broadcasting

Europe

OFDM

Good and no ghost

Japan

USA

Equalization but Not OFDM

Ghost/unstable
(multipath problem)

LAN IEEE 802.11a OFDM

54 Mbps

WPAN IEEE 802.15 Multiband OFDM

480 Mbps

4G ?

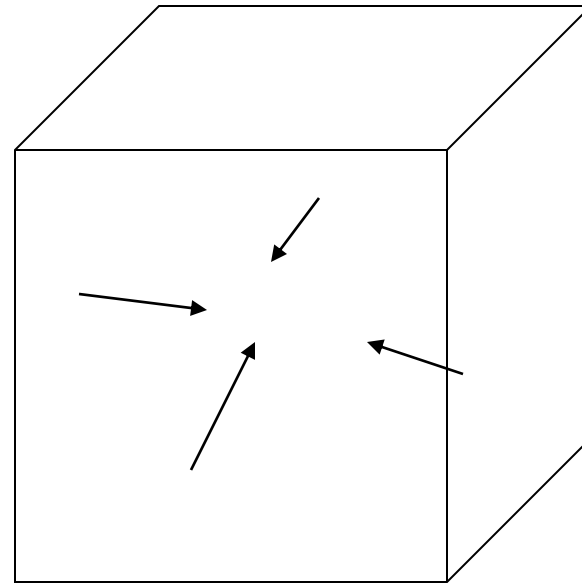
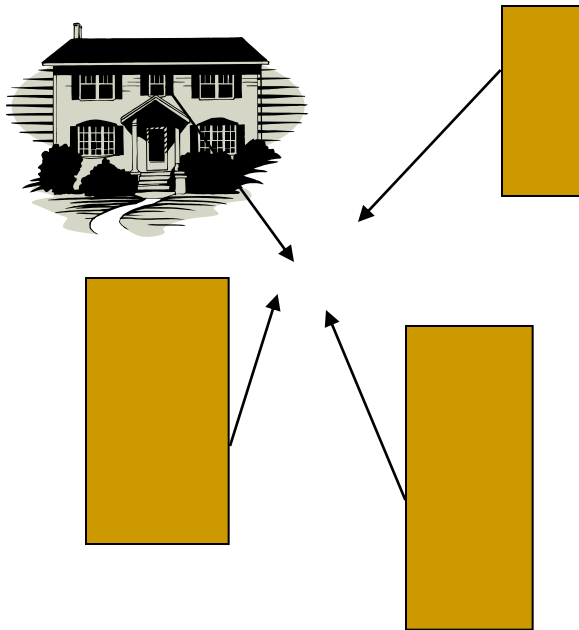
OFDM ?

VOFDM ?

Why Multipath in Wireless Systems

outdoor

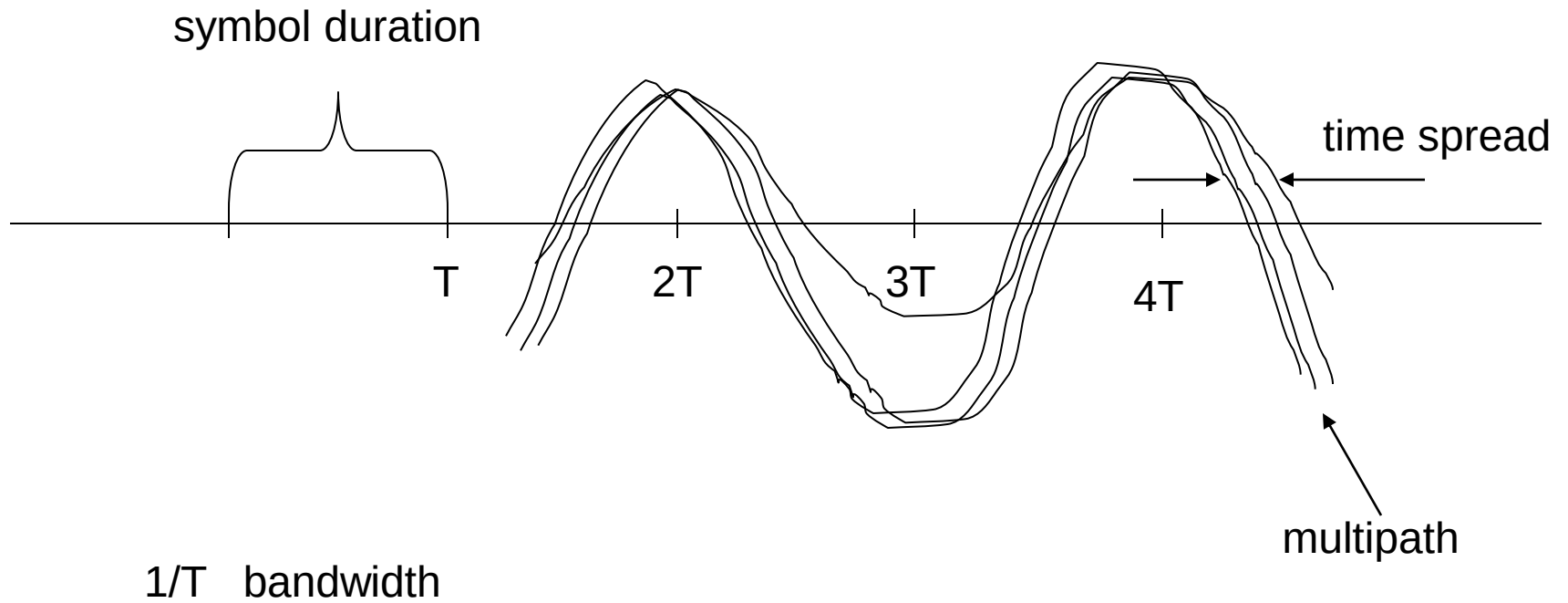
indoor



multiple reflections

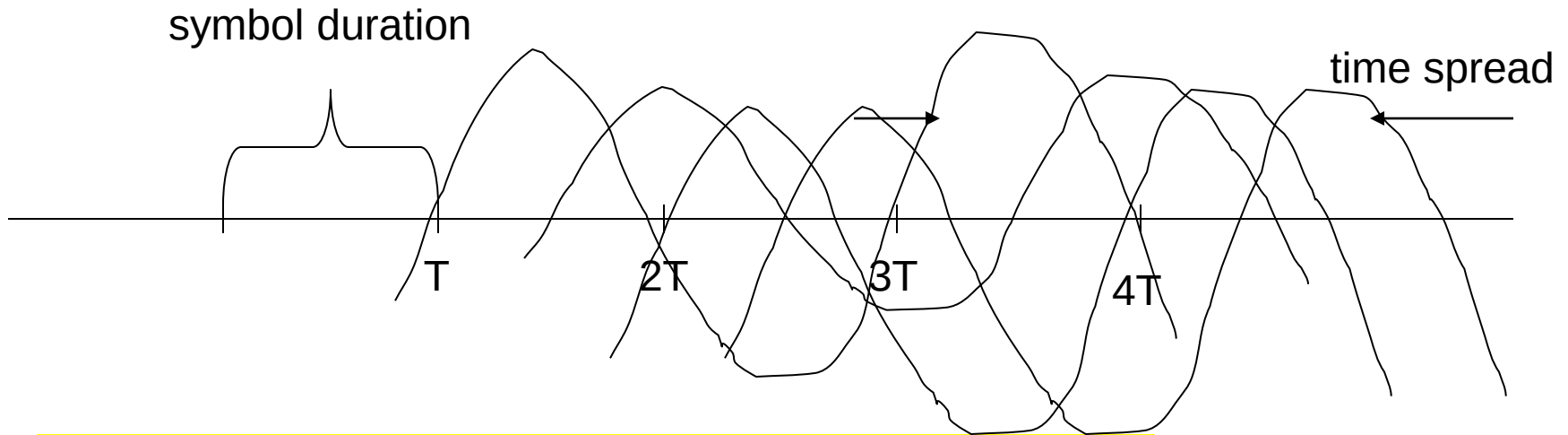
Multipath

narrow band case



When the bandwidth is too wide or T is too small, the time spread may be across over multiple symbols. In this case, intersymbol interference (ISI) occurs.

wide band case



$x(t)$: transmitted signal; $r(t)$: received signal

$$r(t) = \sum_{n=0}^L h(n)x(t - nT) + W(t)$$

ISI

AWGN

Number of Multipath vs. Modulation Methods in Wireless Applications

2G (IS-95)	1.3 MHz	Almost optimal for single path
3G (WCDMA)	< 11 MHz	6--8 multipath almost the crashing point to use CDMA
IEEE 802.11b (LAN)	similar to 3G	
IEEE 802.11a (LAN)	20 MHz	16 multipath OFDM
IEEE 802.15 (WPAN)	UWB	multi-band OFDM
4G	> 20 MHz	VOFDM ???

Wireless

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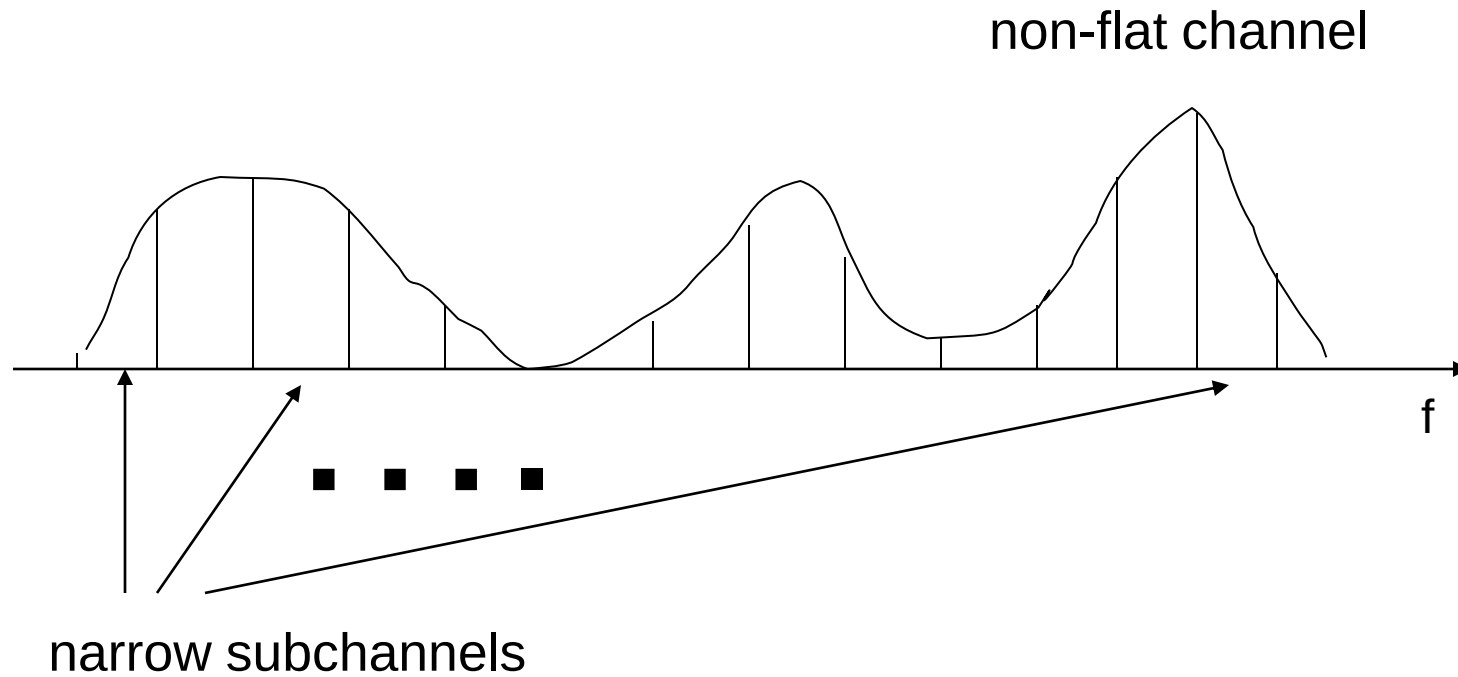
480 Mbps

4G ?

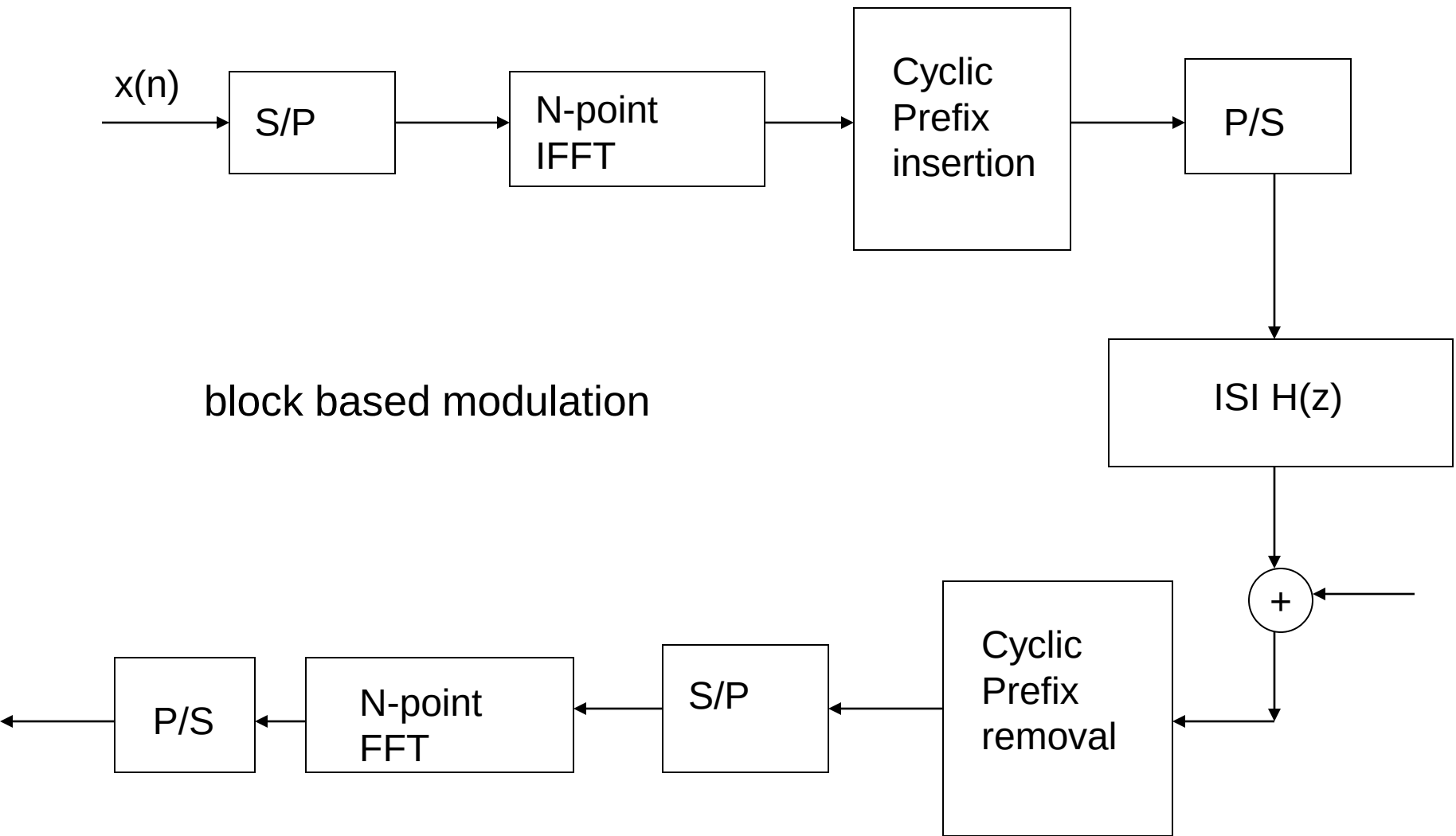
OFDM ?

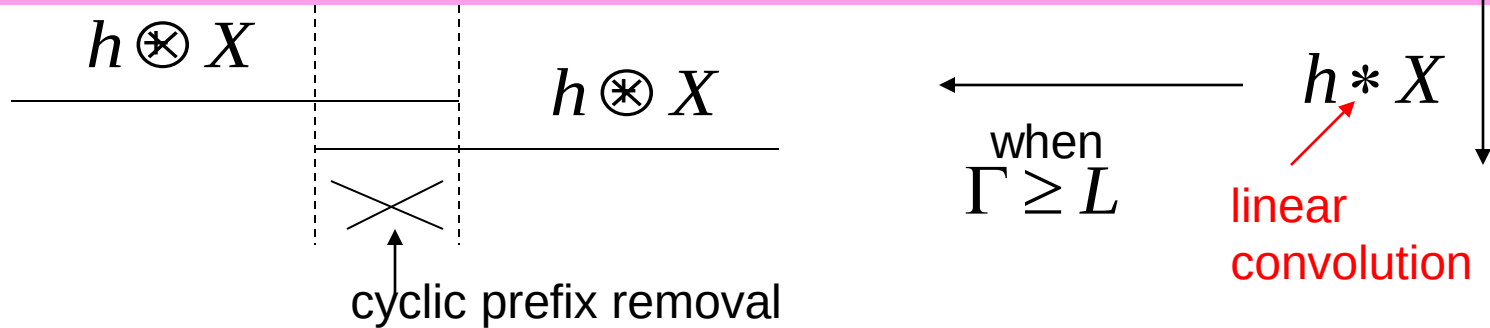
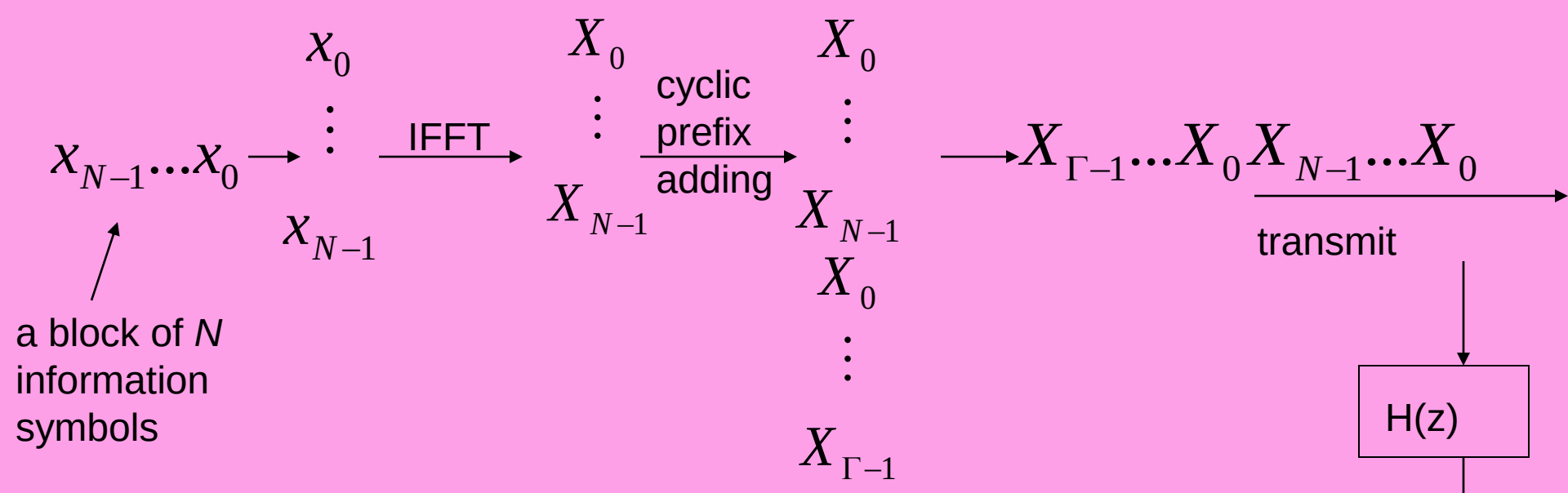
VOFDM ?

Why OFDM ? ----- Rough Idea



OFDM: One of the simplest communication systems





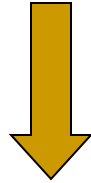
$$Y_k = H_k \cdot x_k, \quad k = 0, 1, \dots, N-1 \quad \xleftarrow{\text{FFT}} \quad h \otimes X$$

$$H_k = H(e^{j2\pi \frac{k}{N}}) = \sum_{n=0}^L h(n) e^{-j \frac{2\pi n k}{N}}$$

cyclic convolution

ISI channel

$$y(k) = \sum_{n=0}^L h(n)x(k-n) + w(k)$$



adding cyclic prefix as an additional data rate **overhead**

N ISI-free subchannels

$$Y_k = H_k \cdot x_k + W_k, \quad k = 0, 1, \dots, N-1$$

Each subchannel corresponds to a DFT component H_k of the ISI channel.
If the frequency component H_k is small (bad), then this subchannel is bad.

In **IEEE 802.11a**,

$$L \leq 16$$

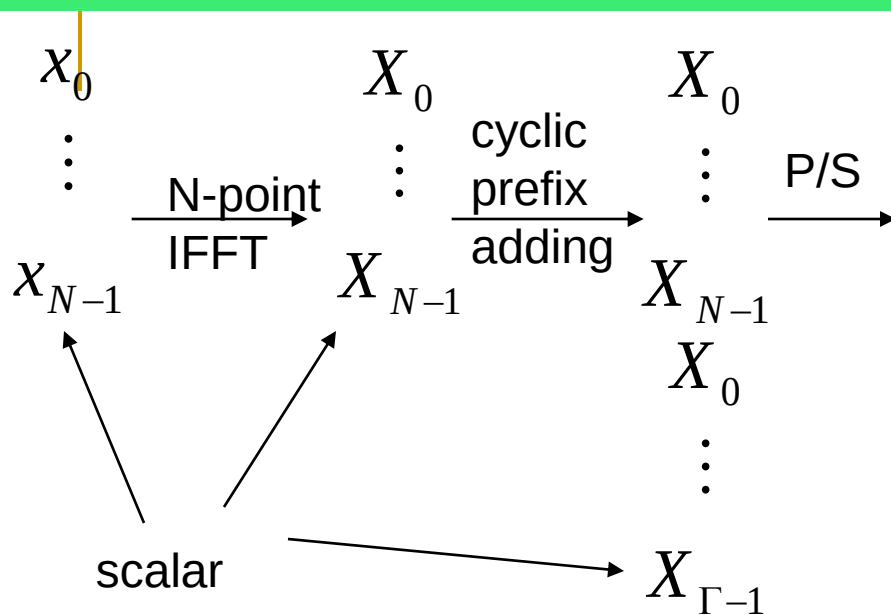
$$N=64$$

$$\Gamma=L=16, \quad 25\% \text{ data rate overhead}$$

Among 64 subchannels, only 52 (fixed indices) of them are used

12 subchannels H_k , $k=0, 27, \dots, 37$, are not used, i.e.,
no information is sent over these subchannels

Basic Idea for Vector OFDM Single Transmit Antenna System

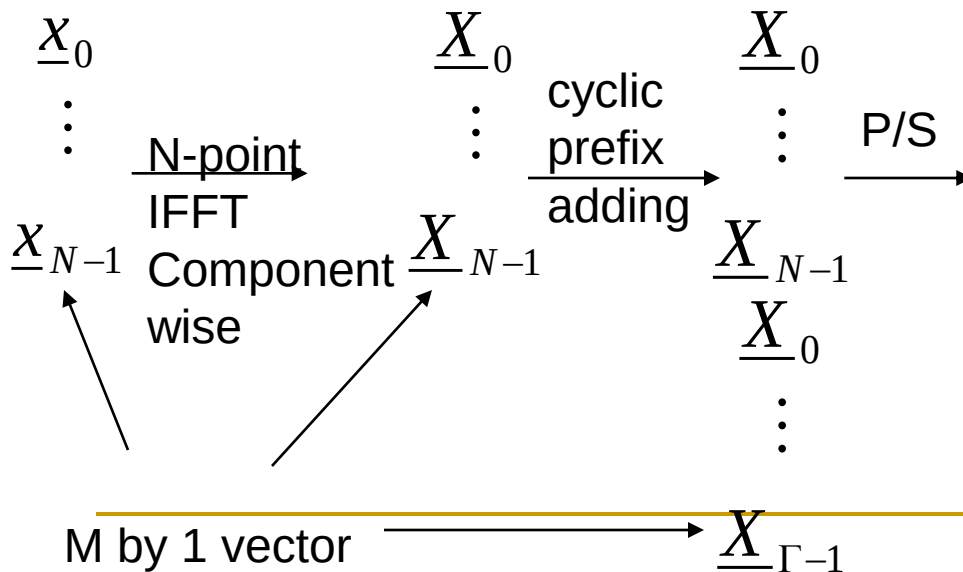


OFDM, when
data rate overhead $\Gamma \geq L$

Receiver:

$$Y_k = H_k x_k + W_k$$

N scalar channels/equations



VOFDM, when
data rate overhead $\tilde{\Gamma} \geq \tilde{L} \approx \frac{L}{M}$

Receiver:

$$\underline{Y}_k = \underline{H}_k \underline{x}_k + \underline{W}_k$$

$N M$ by 1 vector channels/equations

Why Single Transmit Antenna (Not Multiple)

- Simplicity in implementation
 - Simpler sync.
 - Simpler channel estimation
 - Achieve similar multipath diversity as in multiple antennas.
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VOFDM

- The ISI channel $H(z)$ is converted into N vector channels

$$\underline{Y}_k = \underline{H}_k \underline{x}_k + \underline{W}_k, \quad k=0,1,\dots,N-1$$

where $\underline{H}_k$ is the M by M blocked version of the original frequency responses of the ISI $H(z)$:

$$\underline{H}_k = \underline{H}(e^{j2\pi k/N})$$
$$\underline{H}(z) = \begin{bmatrix} H_0(z) & z^{-1}H_{M-1}(z) & \cdots & z^{-1}H_1(z) \\ H_1(z) & H_0(z) & \cdots & z^{-1}H_2(z) \\ \vdots & \vdots & \vdots & \vdots \\ H_{M-1}(z) & H_{M-2}(z) & \cdots & H_0(z) \end{bmatrix}$$

$$H_m(z) = \sum_l h(Ml + m)z^{-l}, \quad 0 \leq m \leq M-1.$$

VOFDM: Advantages

- Cyclic prefix data rate overhead reduction when the FFT/IFFT size is fixed
 - For OFDM, it is $\frac{L}{N}$
 - For VOFDM, it is $\frac{L}{MN}$
- For fixed cyclic data rate overhead, the FFT/IFFT size can be reduced by M times
 - The IFFT size reduction reduces the peak-to-average power ratio (PAPR), which is important in cellular communications.

VOFDM: Advantages

- VOFDM can be combined with **matrix modulation**: at the receiver $\underline{Y}_k = \underline{H}_k \underline{X}_k + \underline{W}_k$ where $\underline{X}_k$ are vectors of information bits or symbols. By grouping two vectors of size 2 together considering BPSK for each information symbol, these vectors become 16 matrices

$$\left\{ \begin{bmatrix} x_{11} & x_{12} \\ x_{21} & x_{22} \end{bmatrix} : x_{ij} \in \{1, -1\} \right\}$$

- These 16 matrices are not good in terms of matrix modulation due to the channel matrices have random components (fading).
 - These 16 matrices can be replaced by the ones with the best known diversity product.

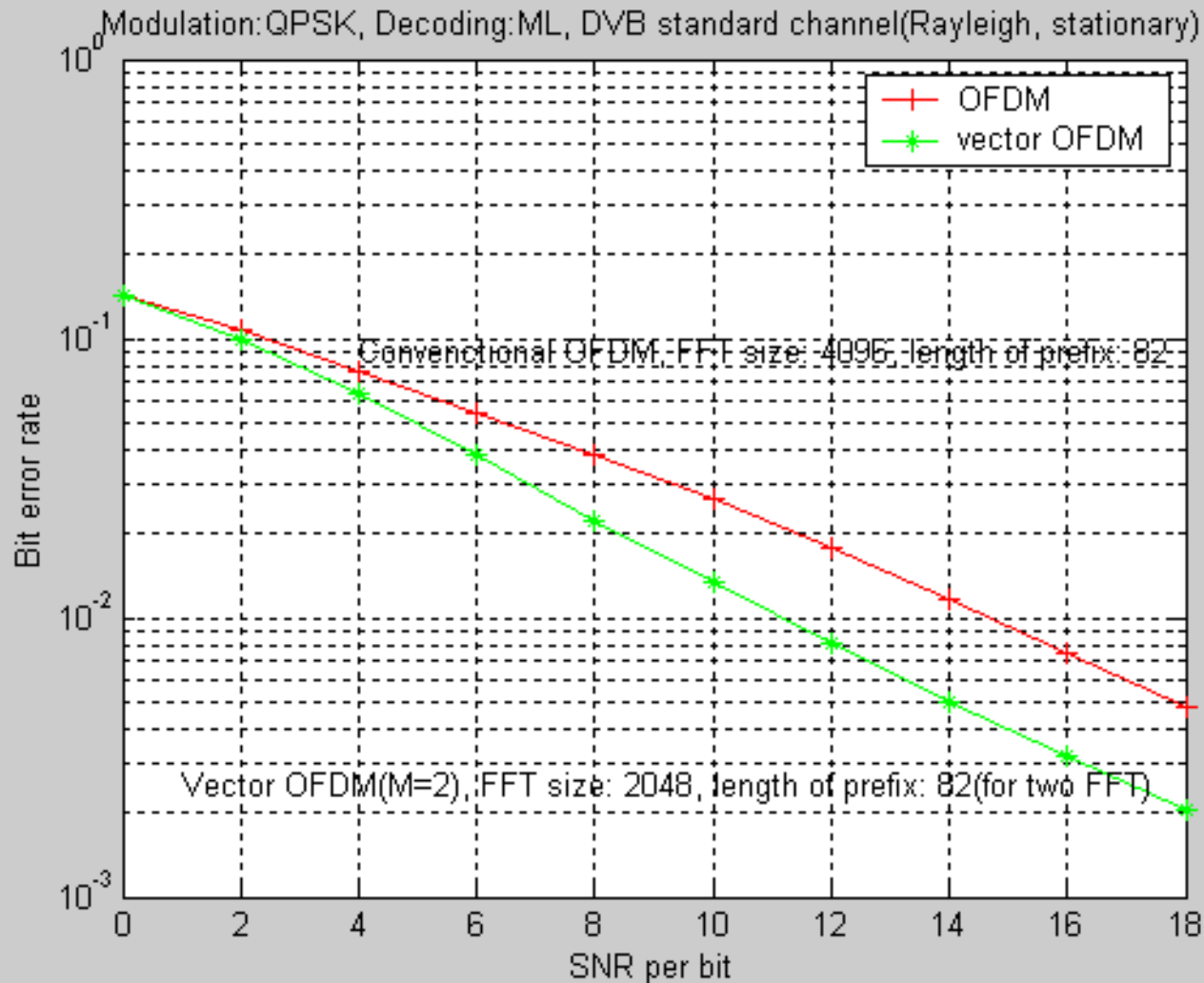
Unitary Matrix Modulation

- 16 best known 2 by 2 unitary matrices in the literature (Liang-Xia, IEEE Trans. Information Theory, Aug. 2002) with the best known diversity product (*the minimum absolute value of all the determinants of difference matrices of any two distinct matrices*):

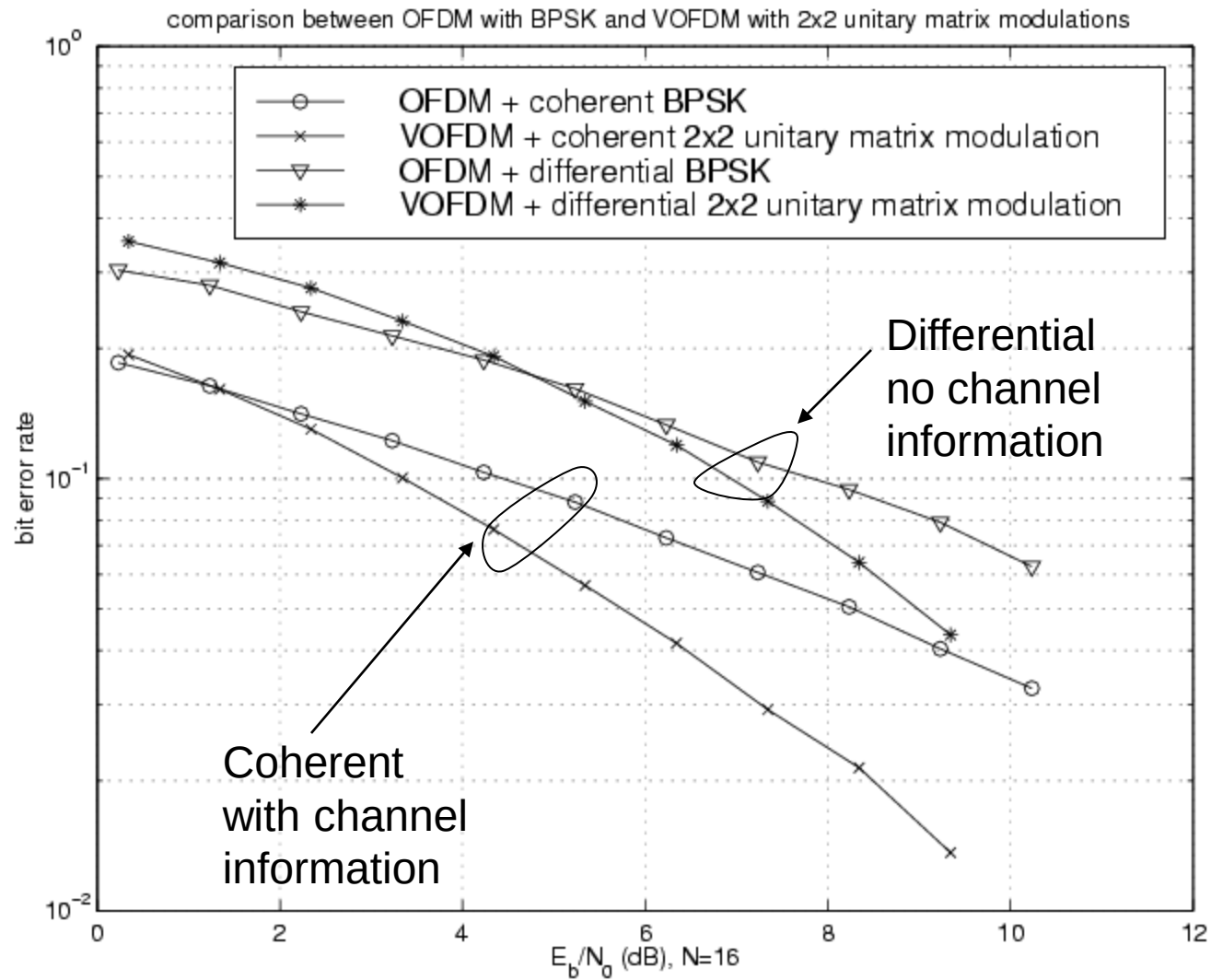
$$\left\{ \begin{bmatrix} e^{jl\pi/8} & 0 \\ 0 & e^{jl3\pi/8} \end{bmatrix} \begin{bmatrix} \cos \frac{l\pi}{2} & \sin \frac{l\pi}{2} \\ -\sin \frac{l\pi}{2} & \cos \frac{l\pi}{2} \end{bmatrix} \begin{bmatrix} e^{jl\pi/4} & 0 \\ 0 & e^{-jl\pi/4} \end{bmatrix} : 0 \leq l \leq 15 \right\}$$

Simulations

DVB



FFT/IFFT size is 256



Future Research

- Training/pilot signal design and channel estimation
 - Matrix modulation design optimally fitting to the VOFDM
 - Combination with forward error correction coding: fast soft decoding and iterative decoding
 - Applications in future generations of broadband cellular systems and digital video broadcasting systems
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