

Pre- and Post- Equalization Technique Combining for Wireless Communications

Suriya Kanthalue; Pheeradej Nanan, Ph.D

Faculty of Engineering in Computer and Telecommunication

Dhurakij Pundit University

30 October 2013

Overview

1. Introduction & background
2. Models (Post-, Pre-, Pre- and Post-Equalization Combining)
3. Decision Constellation Splitter (DCS) algorithm
4. Channel estimation
5. Complexity
6. Simulation & Result
7. Conclusion & Future work

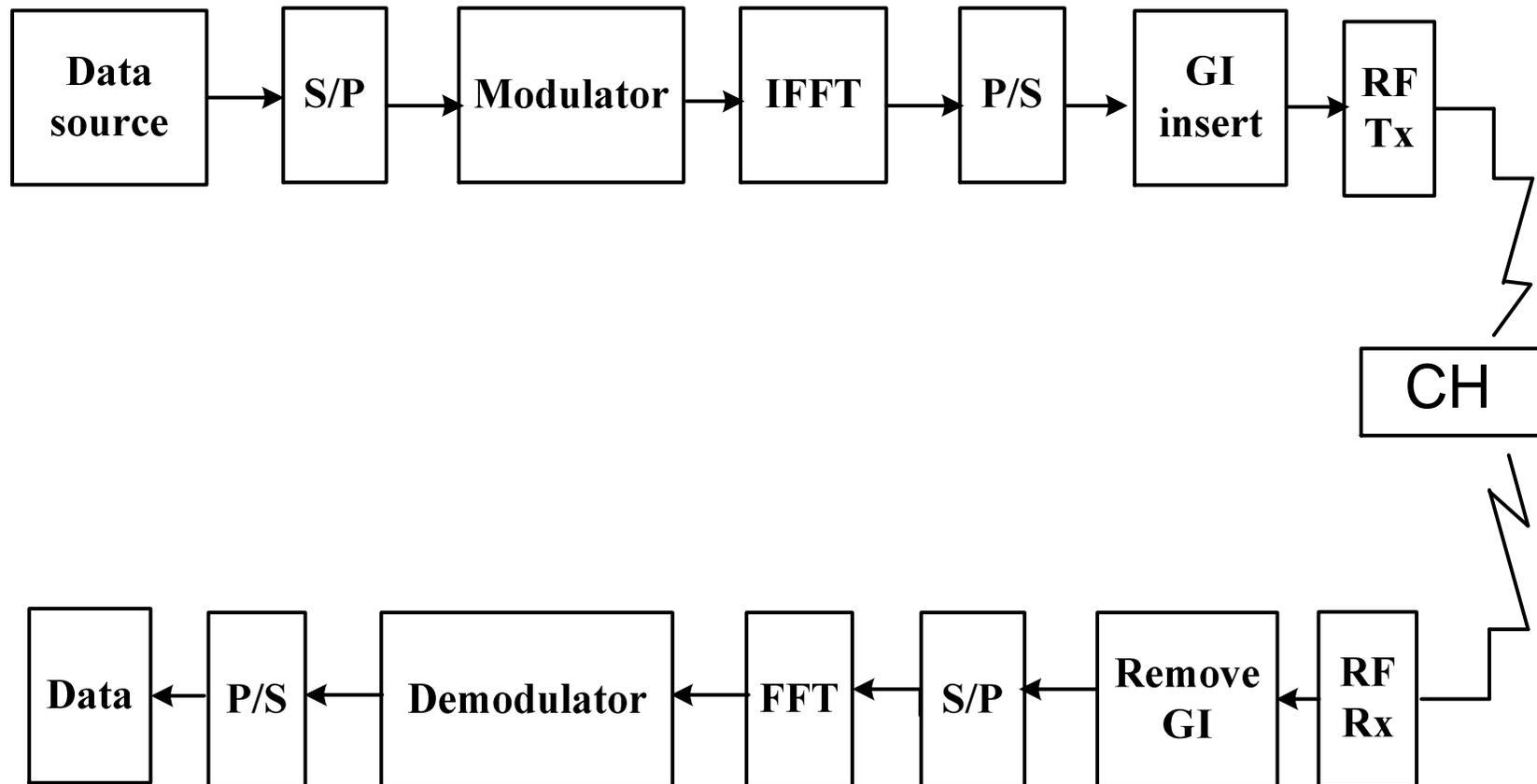
1. Introduction

- All wireless communications are always required high data rate.
- Wireless communication facing mobile limitations, especially @mobile.
 - *Complexity*
 - *Size*
 - *Power consumption (Battery)*

Wireless Communications

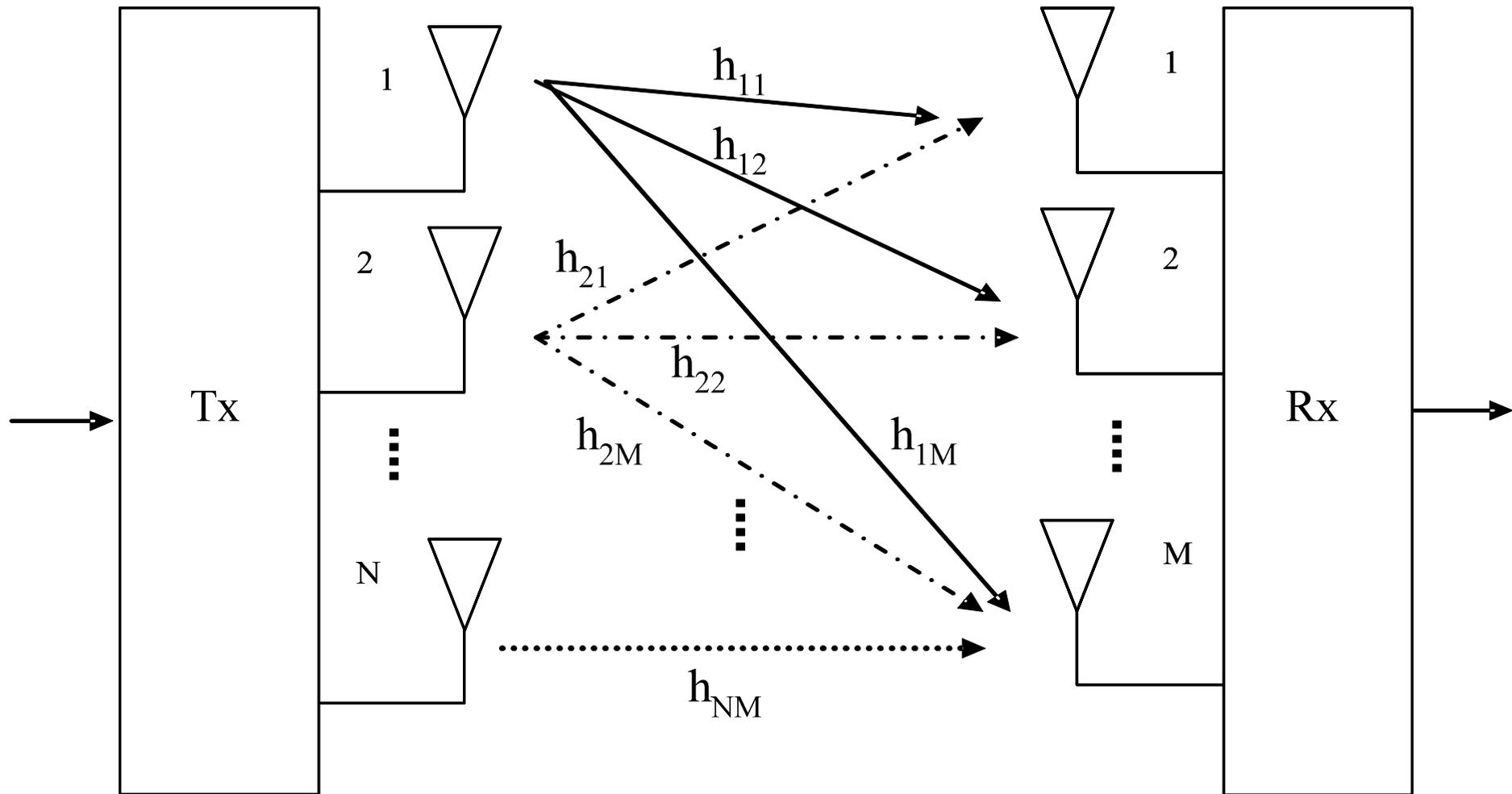
- Trade-off b/w complexity and data rate.
- Orthogonal Frequency Division Multiplexing (OFDM) is selected for high data rate.
 - Long Term Evolution-Advanced (LTE-A or 4G)
 - Multiple Input Multiple Output (MIMO)

Basic OFDM



CH = Channel model

MIMO



MIMO

$$y = Hx + n$$

$$H = \begin{bmatrix} h_{11} & h_{12} & \cdots & h_{1N} \\ h_{21} & h_{22} & \cdots & h_{2N} \\ \vdots & \vdots & \ddots & \vdots \\ h_{M1} & h_{M2} & \cdots & h_{MN} \end{bmatrix}$$

Introduction (.)

Three techniques are used independently or in tandem to improve receiver signal quality

- I. ***Equalization*** compensates for inter symbol interference (ISI) created by multipath with time dispersive channels ($W > B_C$)
(Linear equalization, nonlinear equalization)

Introduction (..)

II. Diversity also compensates for fading channel impairments, and is usually implemented by using two or more receiving antennas

(Spatial diversity, antenna polarization diversity, frequency diversity, time diversity)

The former counters the effects of time dispersion (ISI), while the latter reduces the depth and duration of the fades experienced by a receiver in a flat fading (narrowband) channel

Introduction (...)

III. **Channel Coding** improves mobile communication link performance by adding redundant data bits in the transmitted message

Channel coding is used by the Rx to detect or correct some (or all) of the errors introduced by the channel (Post detection technique)

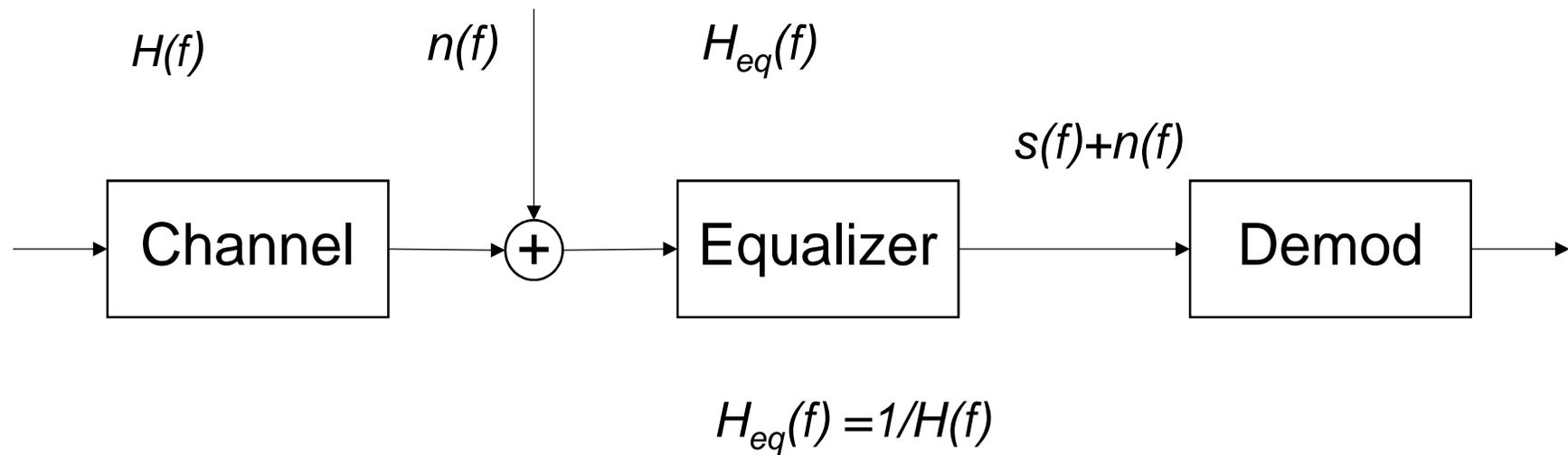
(Block code and convolutional code)

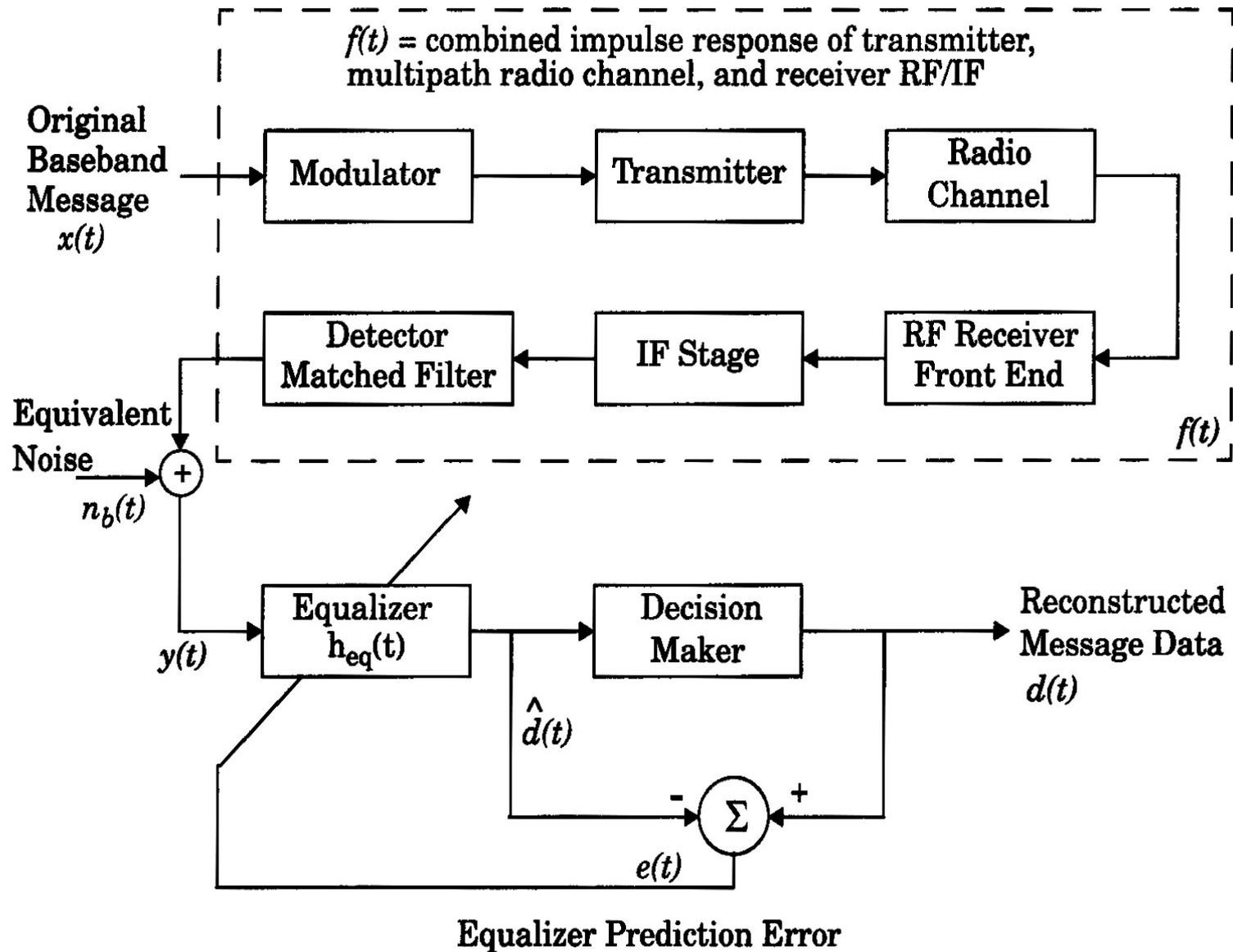
Equalization background

- The term *equalization* can be used to describe any **signal processing operation that minimizes ISI** *
- Two operation modes for an adaptive equalizer: **training** and **tracking**
- Three factors affect the time spanning over which an equalizer converges: equalizer algorithm, equalizer structure and time rate of change of the multipath radio channel
- TDMA wireless systems are particularly well suited for equalizers

* S.U.H. Qureshi, "Adaptive equalization," *Proceeding of IEEE*, vol. 37 no.9, pp.1340 -1387, Sept. 1985.

Equalization diagram





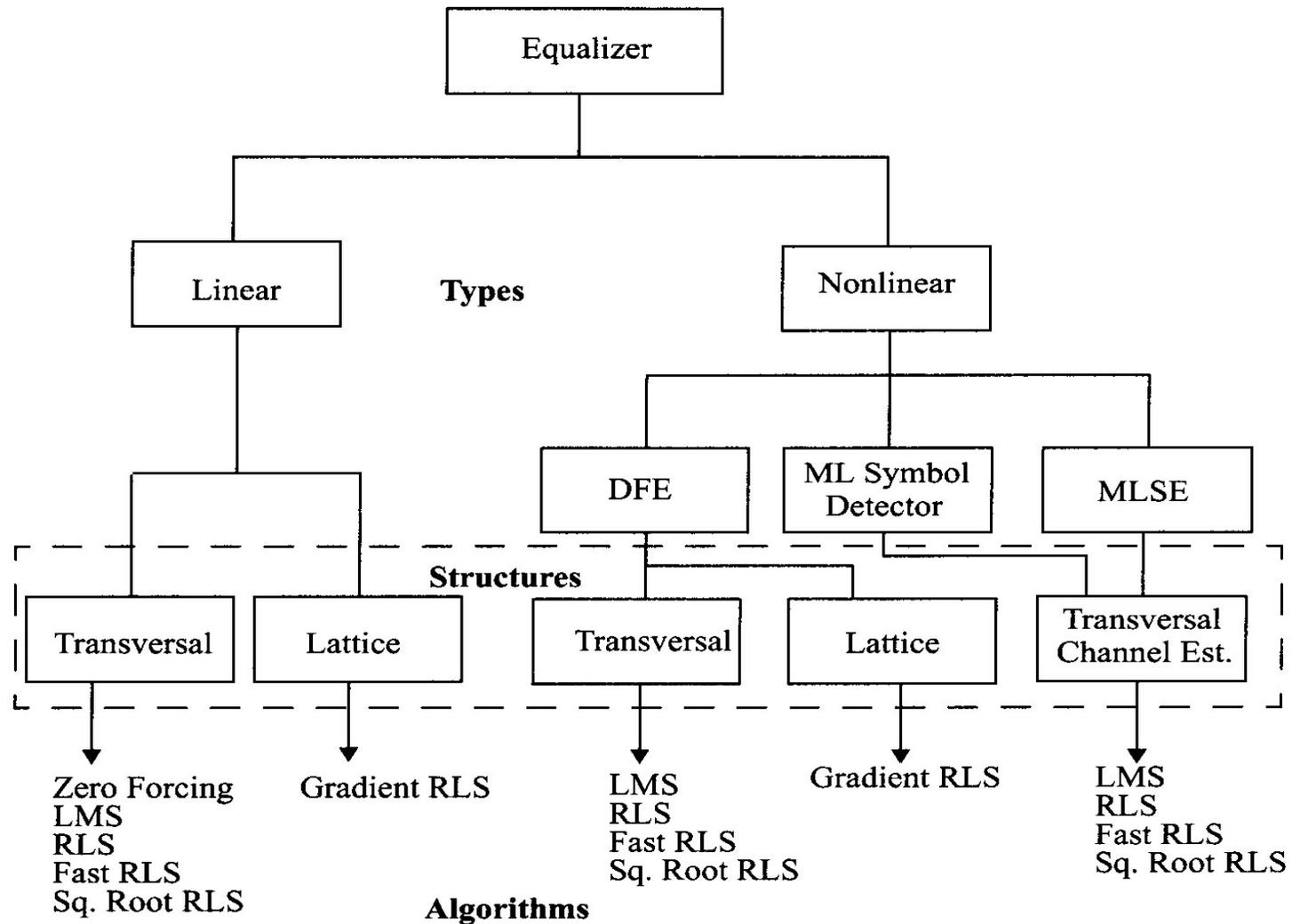
Block diagram of a simplified communications system using an adaptive equalizer at the receiver.

Classification

if $d(t)$ is not the feedback path to adapt the equalizer, the equalization is *linear*

if $d(t)$ is fed back to change the subsequent outputs of the equalizer, the equalization is *nonlinear*

Classification of Equalizers



Equalization

- Linear methods are simpler but suffer from more noise enhancement compared to nonlinear.
- DFE is the most common; suffers from error propagation over channels with low SNR.

Equalization

- No equalization – low data rate *
– unacceptable
- (Post-) equalization process on Rx
- Before / After FFT *** [1],[2]

* <http://www.ee.hacettepe.edu.tr/~toker/ELE739/Week10-11.pdf>

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

**<http://www.mathworks.com/products/communications/examples.html?file=/products/demos/shipping/comm/commadapteq.html#3>

*** <http://cost289.ee.hacettepe.edu.tr/publications/session5-5.pdf>

[1] Zou W., Y. Wu, COFDM: An overview, *IEEE Trans. Broadcasting*, vol. 41, March 1995, pp. 1-8.

[2] Armour S., A. Nix, D. Bull, Pre-FFT equalizer design for OFDM, *Electronics Letters*, vol. 35, Apr. 1999, pp. 539-540.

algorithms for adaptive equalization

Algorithm	Number of Multiply Operations	Advantages	Disadvantages
LMS Gradient DFE	$2N + 1$	Low computational complexity, simple program	Slow convergence, poor tracking
Kalman RLS	$2.5N^2 + 4.5N$	Fast convergence, good tracking ability	High computational complexity
FTF	$7N + 14$	Fast convergence, good tracking, low computational complexity	Complex programming, unstable (but can use rescue method)
Gradient Lattice	$13N - 8$	Stable, low computational complexity, flexible structure	Performance not as good as other RLS, complex programming
Gradient Lattice DFE	$13N_1 + 33N_2 - 36$	Low computational complexity	Complex programming
Fast Kalman DFE	$20N + 5$	Can be used for DFE, fast convergence and good tracking	Complex programming, computation not low, unstable
Square Root RLS DFE	$1.5N^2 + 6.5N$	Better numerical properties	High computational complexity

2. Models

2.1 Post-equalization

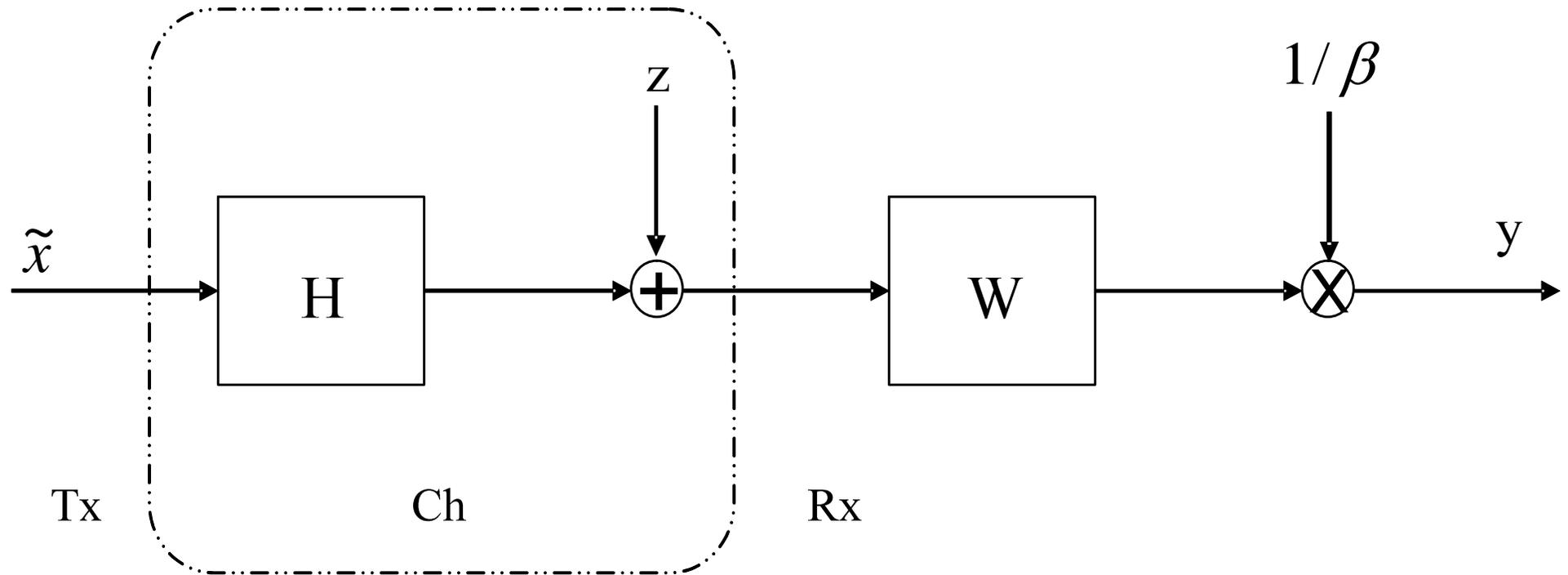
2.2 Pre-equalization

2.3 Pre- and Post-Equalization
Combining (PPE)

Linear Equalization;

- ZF (Zero forcing)
- MMSE (Minimum mean square error)

2.1 (Post-) Equalization



$$y = \frac{1}{\beta} W_{MMSE} (H\tilde{x} + z)$$

$$W_{ZF} = \beta H^{-1}$$

$$W_{MMSE} = \beta \times H^H \left(HH^H + \frac{\sigma_z^2}{\sigma_x^2} I \right)^{-1}$$

$$\beta = \sqrt{\frac{N_T}{\text{Tr}(H^{-1} (H^{-1})^H)}}$$

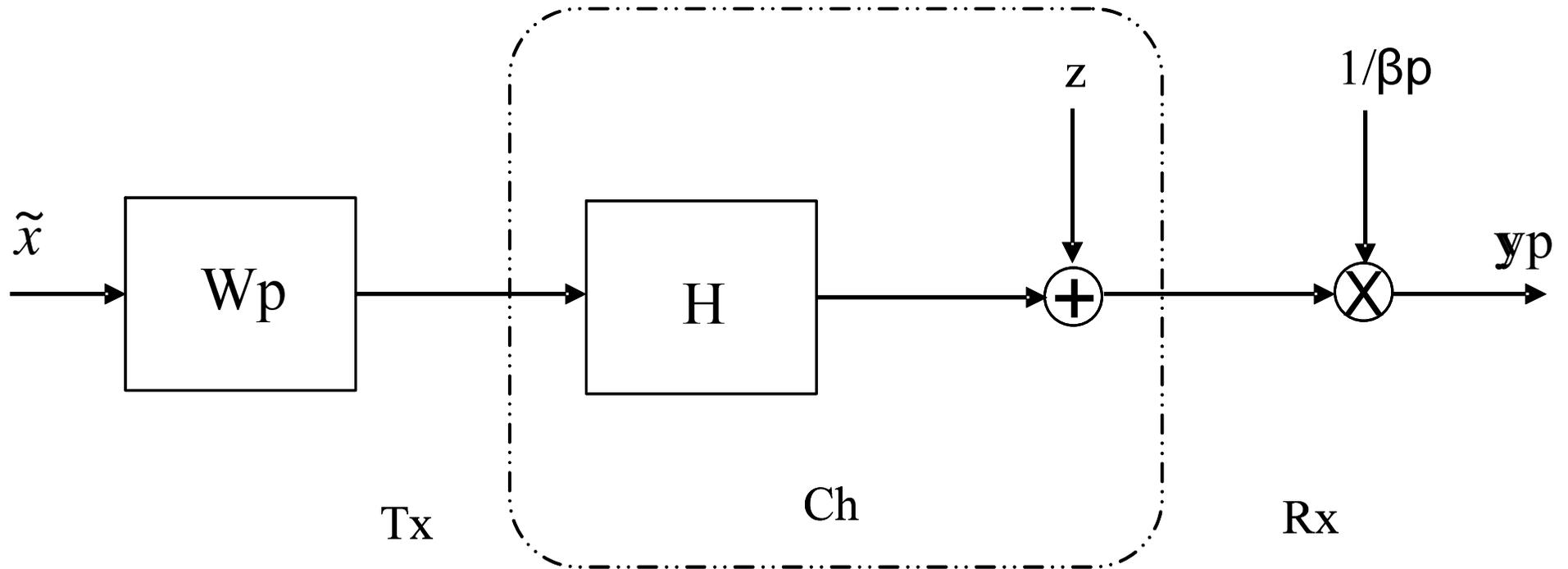
2.2 Pre-equalization

- Pre-equalization is selected for low complexity @Rx.
- Pre-equalization process @Tx
- Advantage base station, no power limitation

pre-equalization reference

- Target to **low complexity** at receiver
 - “Pre-equalization Technique for Interference Cancellation in the UMTS-TDD Downlink Channel” P. BISAGLIA¹, L. SANGUINETTI², M. MORELLI², N. BENVENUTO¹ and S. PUPOLIN¹
 - “Pre-equalization Techniques for Downlink and Uplink TDD MC-CDMA Systems”, P. BISAGLIA¹, L. SANGUINETTI², M. MORELLI², N. BENVENUTO¹ and S. PUPOLIN¹
 - Pre-equalization with Sub-Band Blocking (SBB)
 - Pre-equalization with Normalized Power (NP)

Pre-Equalization



$$y = \frac{1}{\beta} \left(\hat{H} W_{MMSE} \tilde{x} + z \right)$$

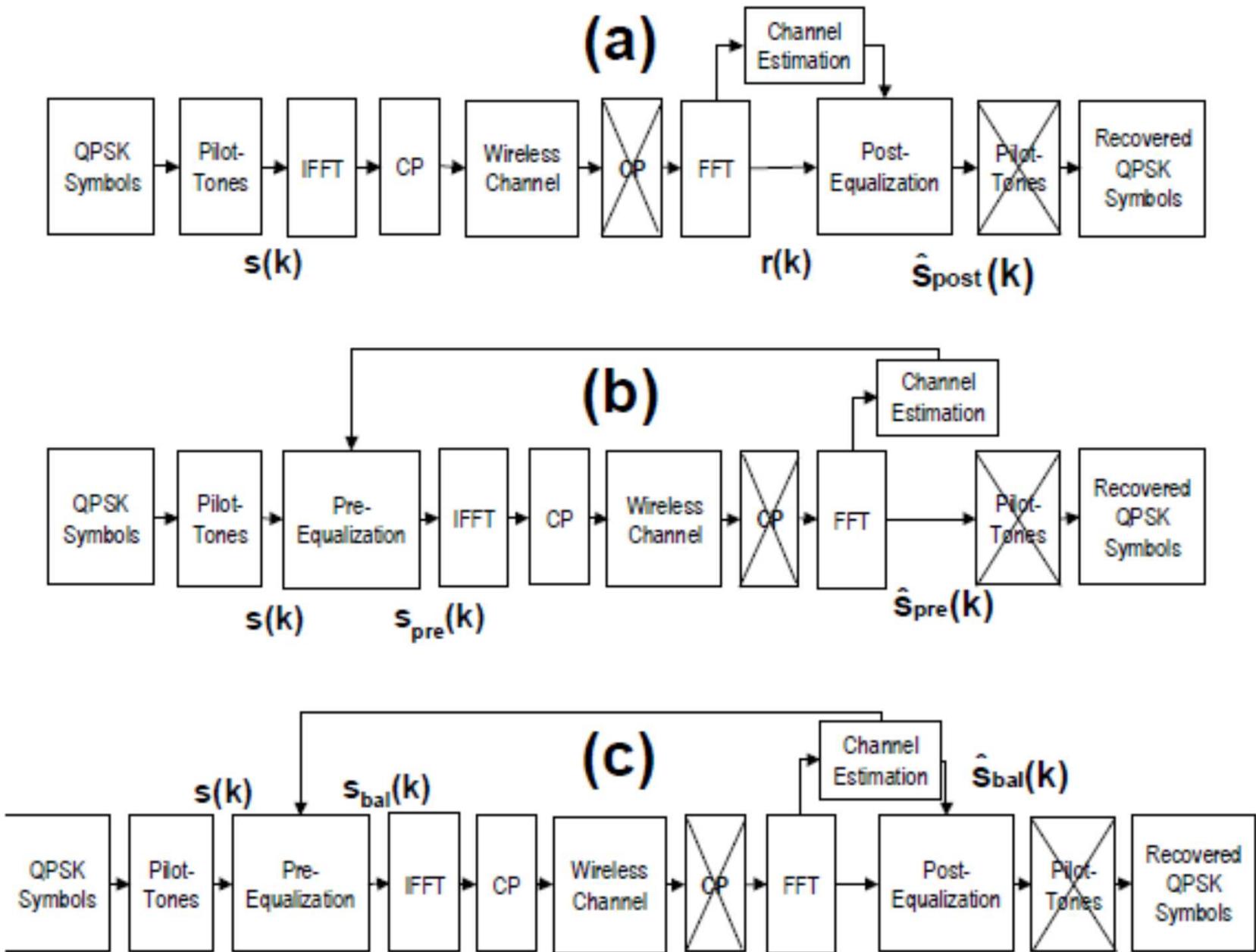
2.3 Combined pre- & post-equalization

- Combined Pre- and Post- equalization scheme should be provided better performance.
 - MRC (Maximal Ratio Combining)
 - Split to 2 main stream and added at the end

Recent combining

This enables pre-equalization to be applied at the transmitter together with post-equalization at the receiver.

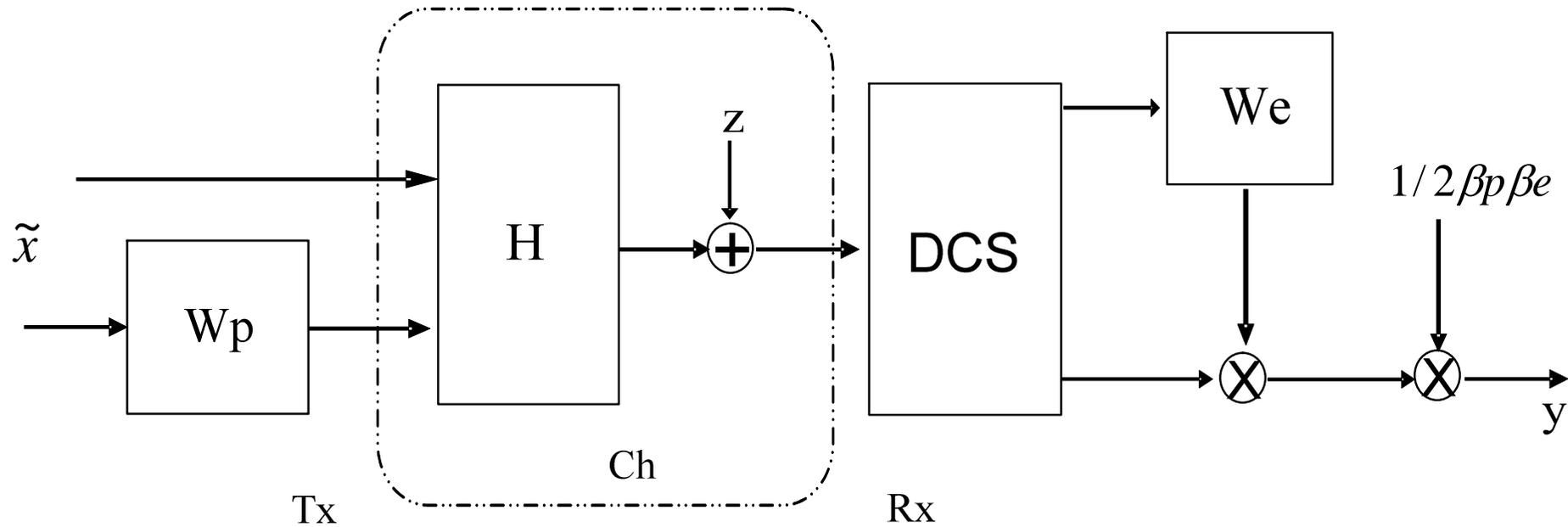
- MRT–MRC combined equalization and is based on the combination of the MRT principle at the transmitter and the MRC principle at the receiver.
- selection diversity combined equalization and is the optimal single-user combined-equalization technique in the sense of BER minimization.
- The third technique is actually a class of techniques that represent a certain tradeoff between MRT–MRC combined equalization and SD combined equalization.
- **Pre- Post- and Balanced Equalization in OFDM**



Challenge

- How to separate mixed symbols to Pre- and Post- equalized symbol?
- How much complexity we have to pay for better performance?
- How about Imperfect Channel Estimation and noise immunity?

PPE+DCS



$$y = \frac{W_{e,MMSE} \left(\hat{H} \tilde{x} + z \right) + \left(\hat{H} W_{p,MMSE} \tilde{x} + z \right)}{2 \beta_e \beta_p}$$

3. Decision Constellation Splitter (DCS)

- Mixed symbols are separated to Pre- and Post-equalized symbols by DCS algorithm.
- Calculate symbol distance from received symbol to reference symbol
- The detected symbol that is closest to the reference symbol is decided to be a Pre-equalized symbol

Reference symbol

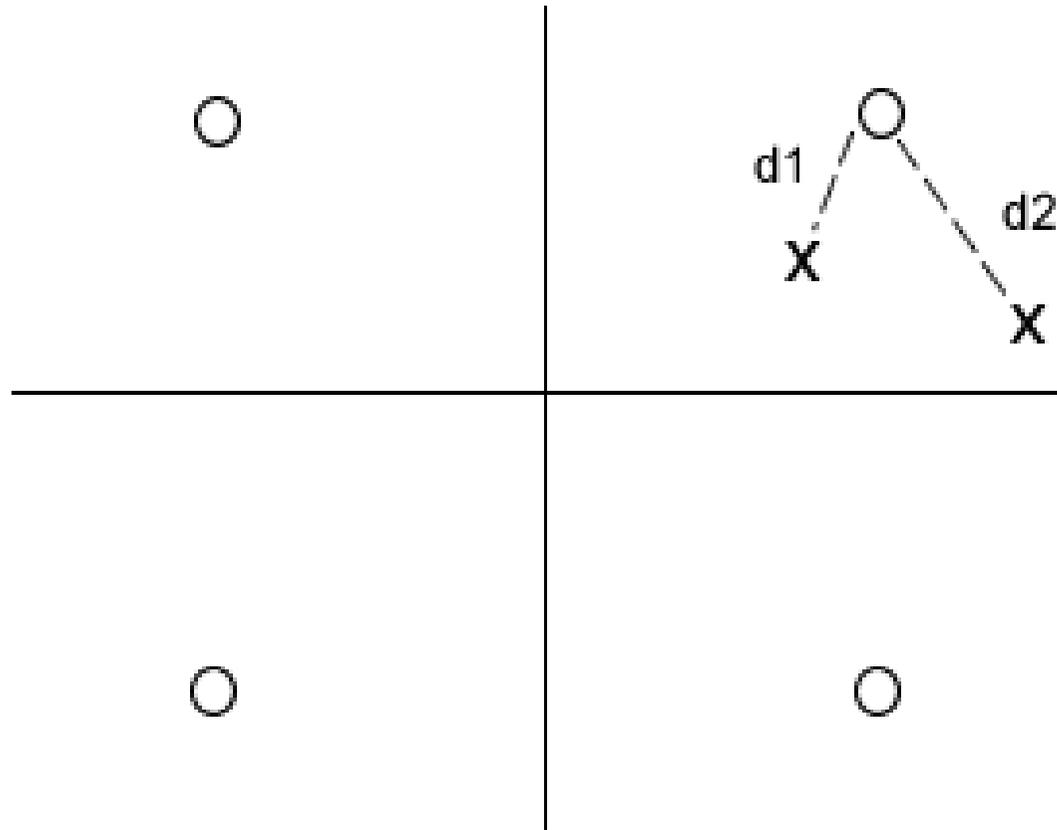
Depend on modulation type

– Ex. QPSK (1+i, 1-i, -1+i, -1-i)

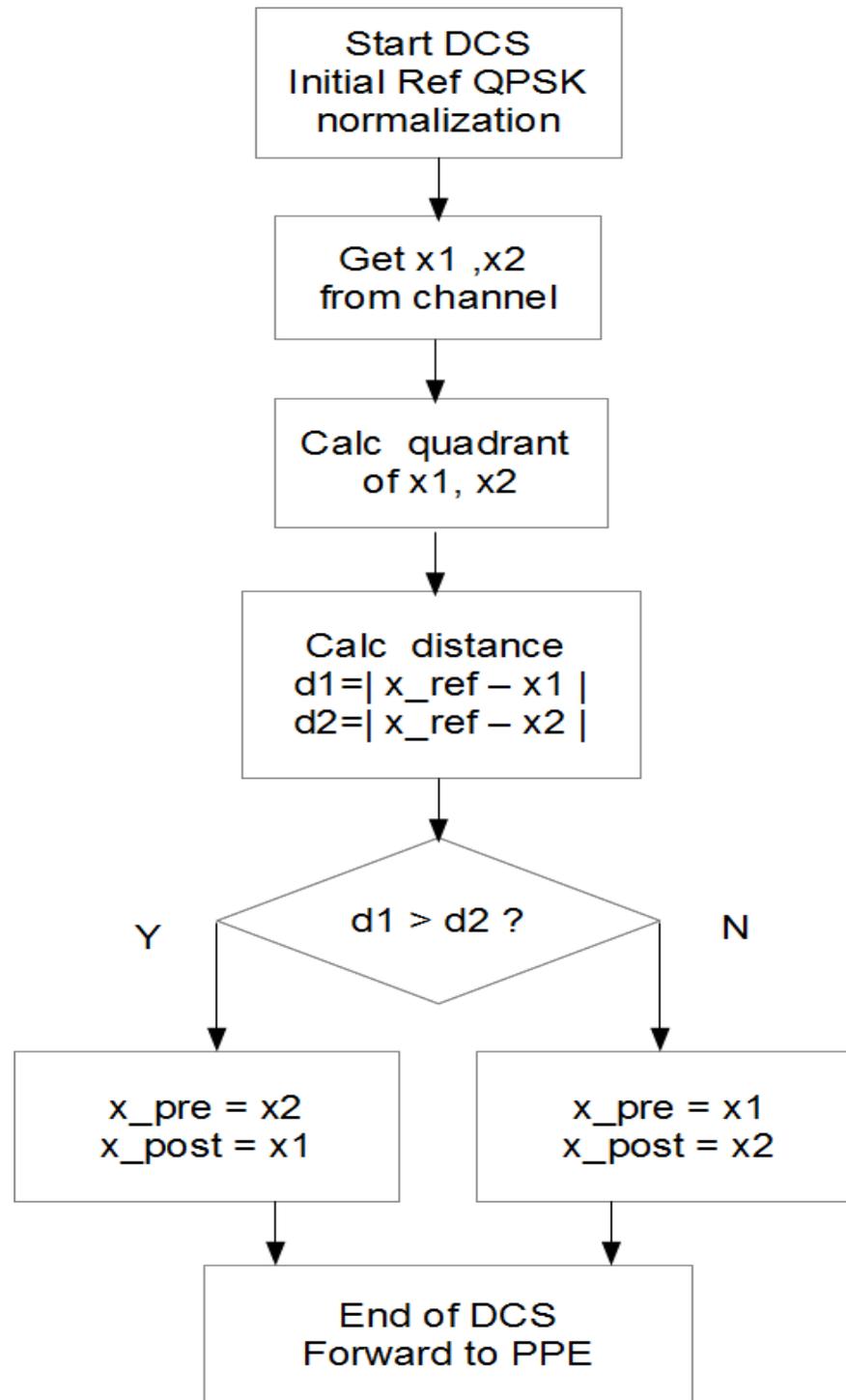
Symbol distance

$$d_1 = | \text{ref symb} - \text{received symb 1} |$$

$$d_2 = | \text{ref symb} - \text{received symb 2} |$$



○ reference signal X received signal



4. Channel estimation

- Perfect
 - Estimation error ($\sigma^2 = 0$) or no error
 - Estimated Channel (\hat{H}) = Channel (H)
- Imperfect
 - Estimation error ($\sigma^2 > 0$)
 - Estimated Channel (\hat{H}) = Channel (H) with error probability (σ^2)
 - Simulation $0 < \sigma^2 < 1$

Imperfect channel estimation

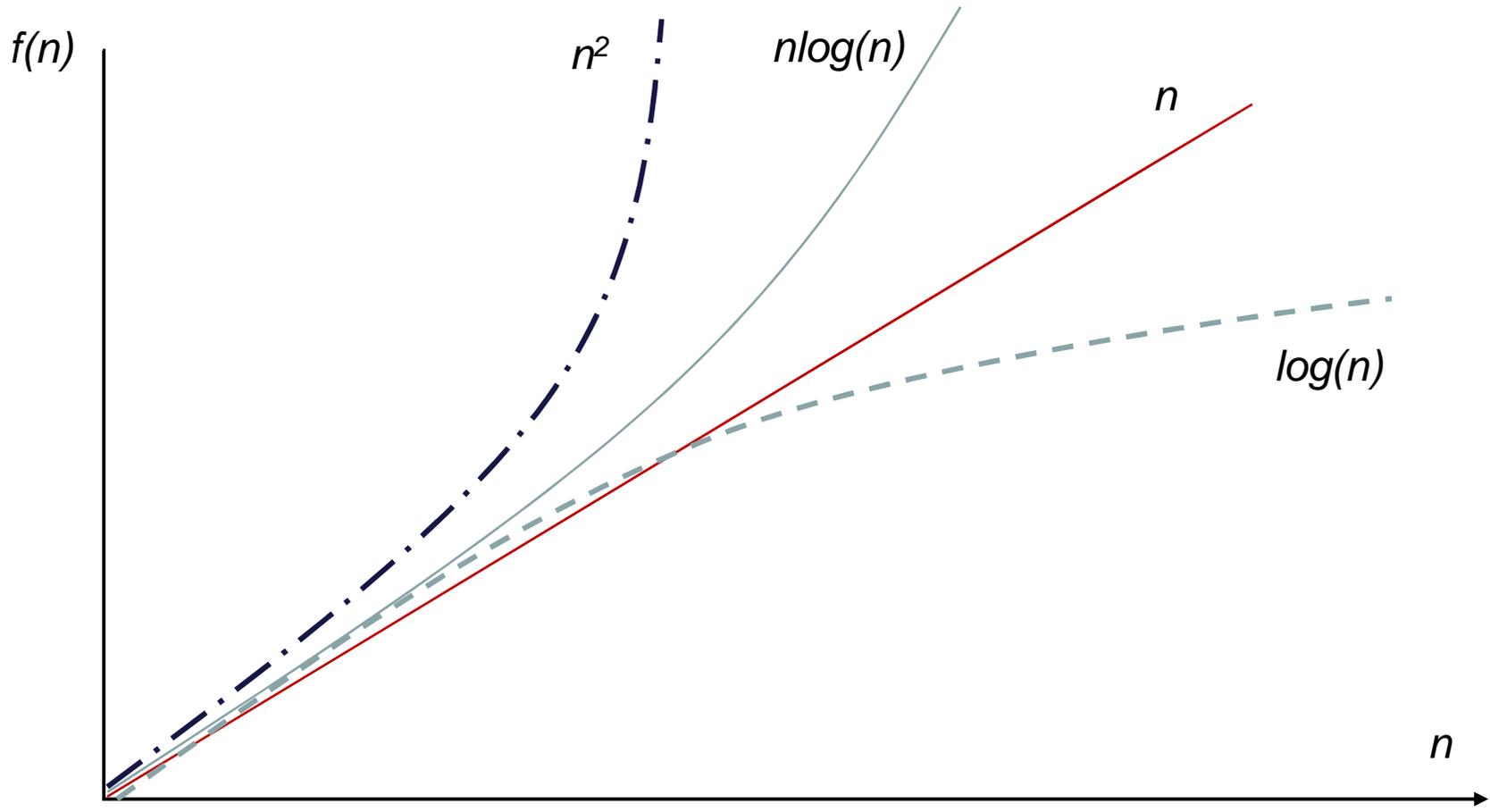
- In fact, H_{est} is imperfect. Other word non ideal or non perfect channel estimation.

$$H = \eta \hat{H} + \sqrt{1 - \eta} G_w$$

$$\eta = \frac{1}{1 + \sigma_\varepsilon^2} \quad [G_w]_{ij} \sim CN(0,1)$$

5. Complexity

- ความซับซ้อน
- High Complexity
 - High power consumption
 - Hard to design a small size



Complexity measurement

- ประสิทธิภาพทางเวลา
- Big-O
- Count process
 - Object-Oriented (OO) technology

Complexity	Terminology
$O(1)$	Constant complexity
$O(\log n)$	Logarithmic complexity
$O(n)$	Linear complexity
$O(n \log n)$	$n \log n$ complexity
$O(n^b)$	Polynomial complexity
$O(b^n)$ where $b > 1$	Exponential complexity
$O(n!)$	Factorial complexity

Computational complexity of operation

Operation	Inputs		Output	Complexity
	#real	#complex		
Complex multiplication	0	2	Complex	$4M+2A$
Complex multiply by real	1	1	Complex	$2M$
Square root	1	0	Real	M
Complex power	0	1	Real	$2M+A$
Real division	2	0	Real	M
Complex division	0	2	Complex	$8M+3A$
Complex divide by real	1	1	Complex	$2M$

Auda M. Elshokry, "Complexity and Performance Evaluation of Detection Schemes for Spatial Multiplexing MIMO Systems,
" Thesis Submitted to Faculty of Engineering, Islamic University Gaza, Palestine, 2010.

Rx Complexity

Scheme	Addition	Multiplication
Equalization	6,144	12,288
Pre-equalization	0	4,096
PPE – ideal	10,240	12,290
PPE - DCS	30,720	24,578

(512FFT, QPSK, MIMO 4x4)

6. Simulation

- Simple OFDM
- Equalization, Pre-Equalization, Combined Pre- and Post- Equalization (PPE)
- PPE with Decision Constellation Splitter (DCS)
- Imperfect Channel Estimation

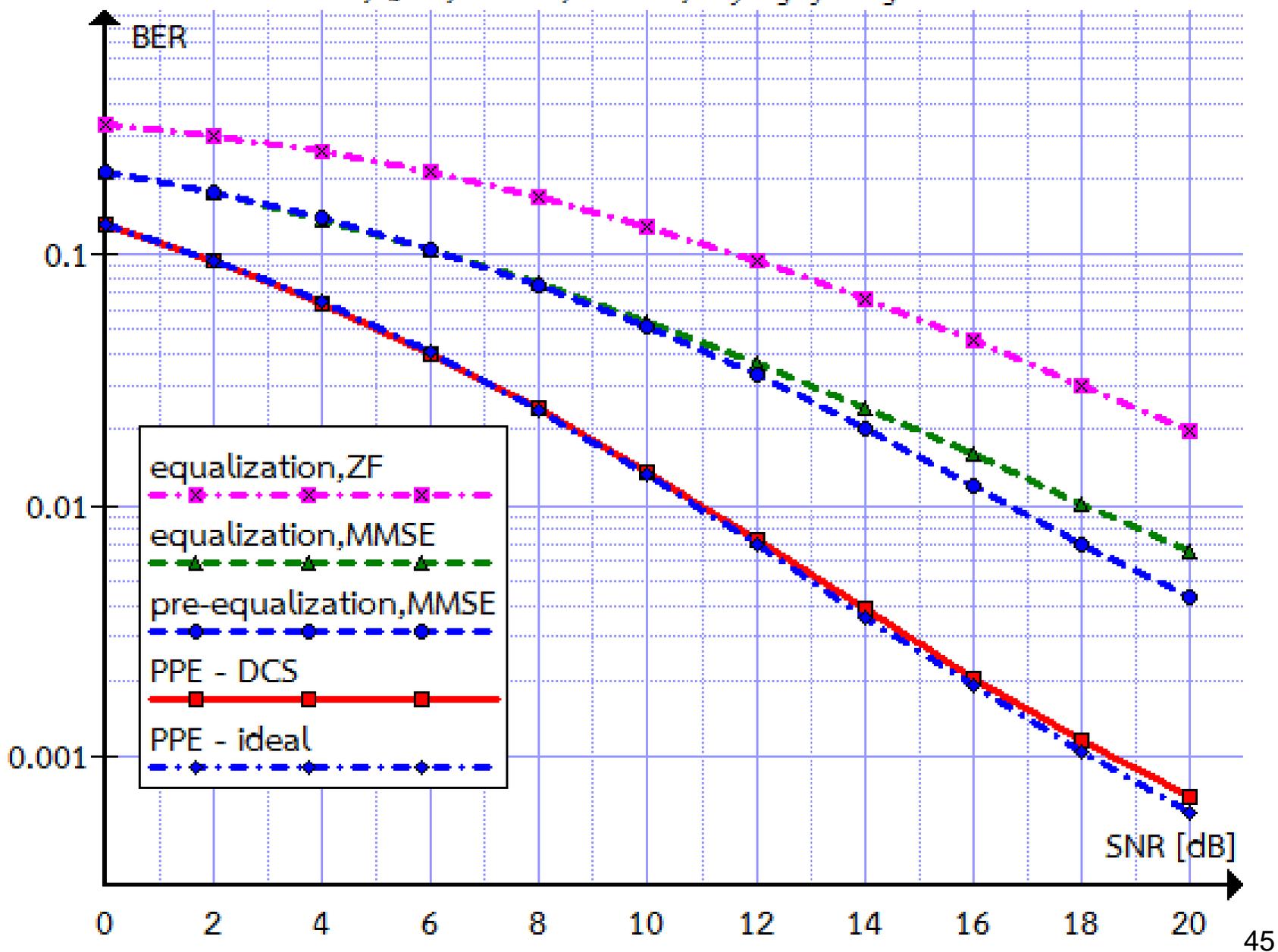
Model & Scope

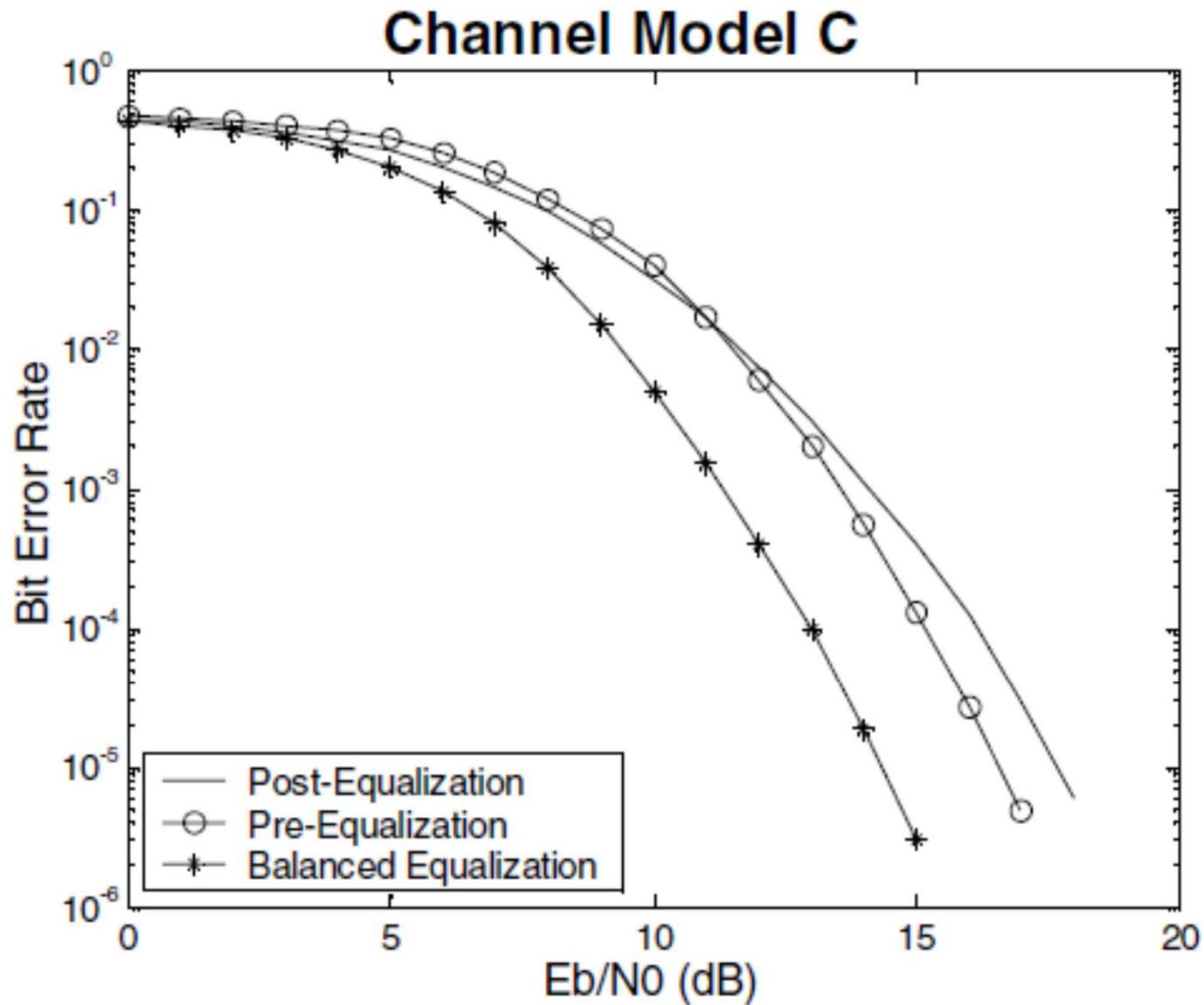
- OFDM performance with different equalization algorithm.
- OFDM under imperfect channel estimation.
- Consider Complexity, SNR, BER, Data rate.
- Prove PPE is a good choice for performance.

Simulation parameters

Parameter	Value
FFT size	512
CP	25%
Modulation	QPSK
Multiple antenna	MIMO 4x4
Equalization	ZF, MMSE (Pre-, Post-, Combined)

MIMO 4x4, QPSK, CP 25%, FFT 512, Rayleigh fading channel

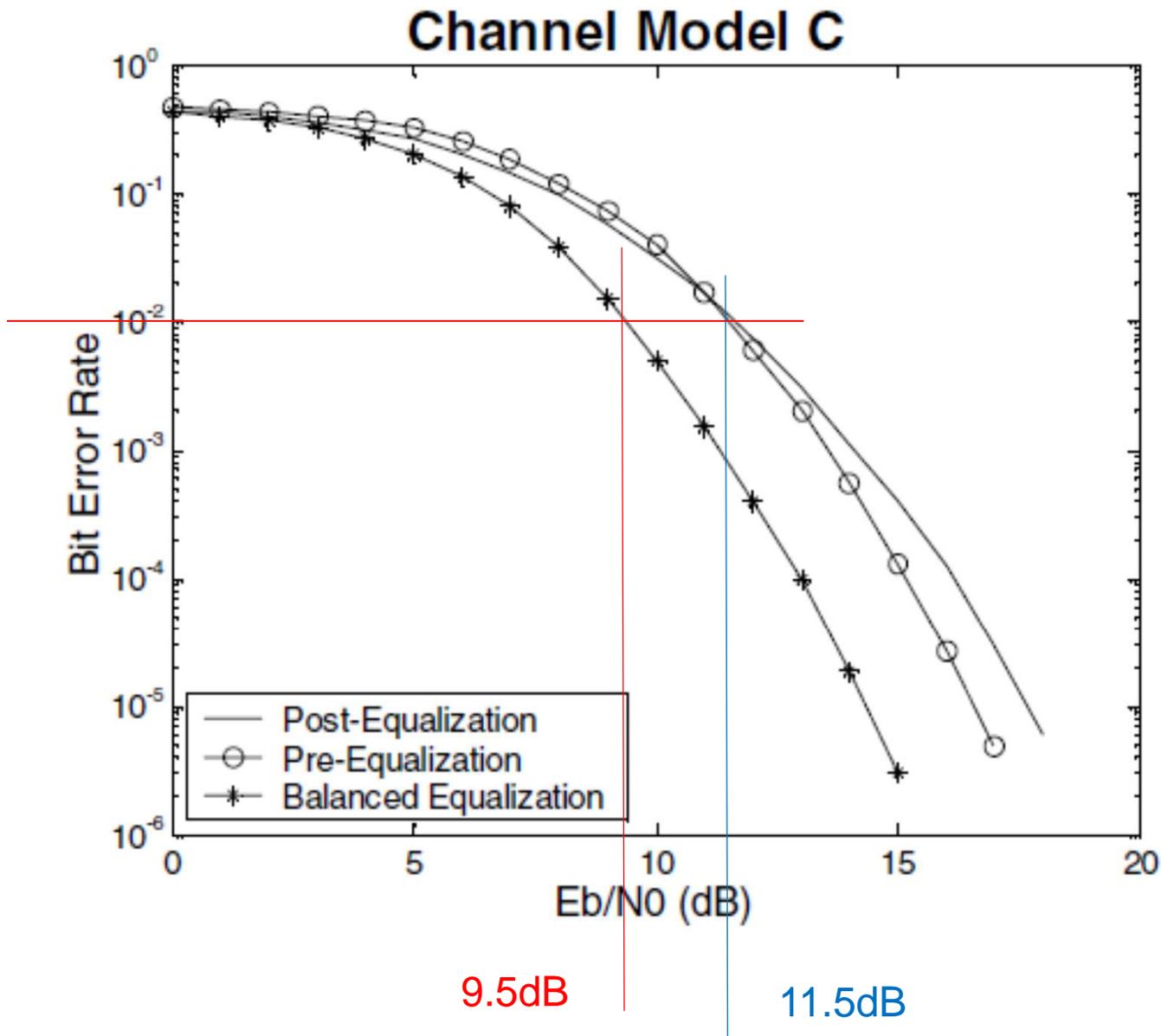




* *Pre- Post- and Balanced Equalization in OFDM,*
 G. Charalabopoulos¹, P. Stavroulakis², A. H. Aghvami¹

Comparison with recent proposed

- Different environment, not “all equals”
- Pre-equalization Reference Point
- Consider BER @ 10^{-2}



* *Pre- Post- and Balanced Equalization in OFDM,*
 G. Charalabopoulos¹, P. Stavroulakis², A. H. Aghvami¹

Comparison with recent proposed

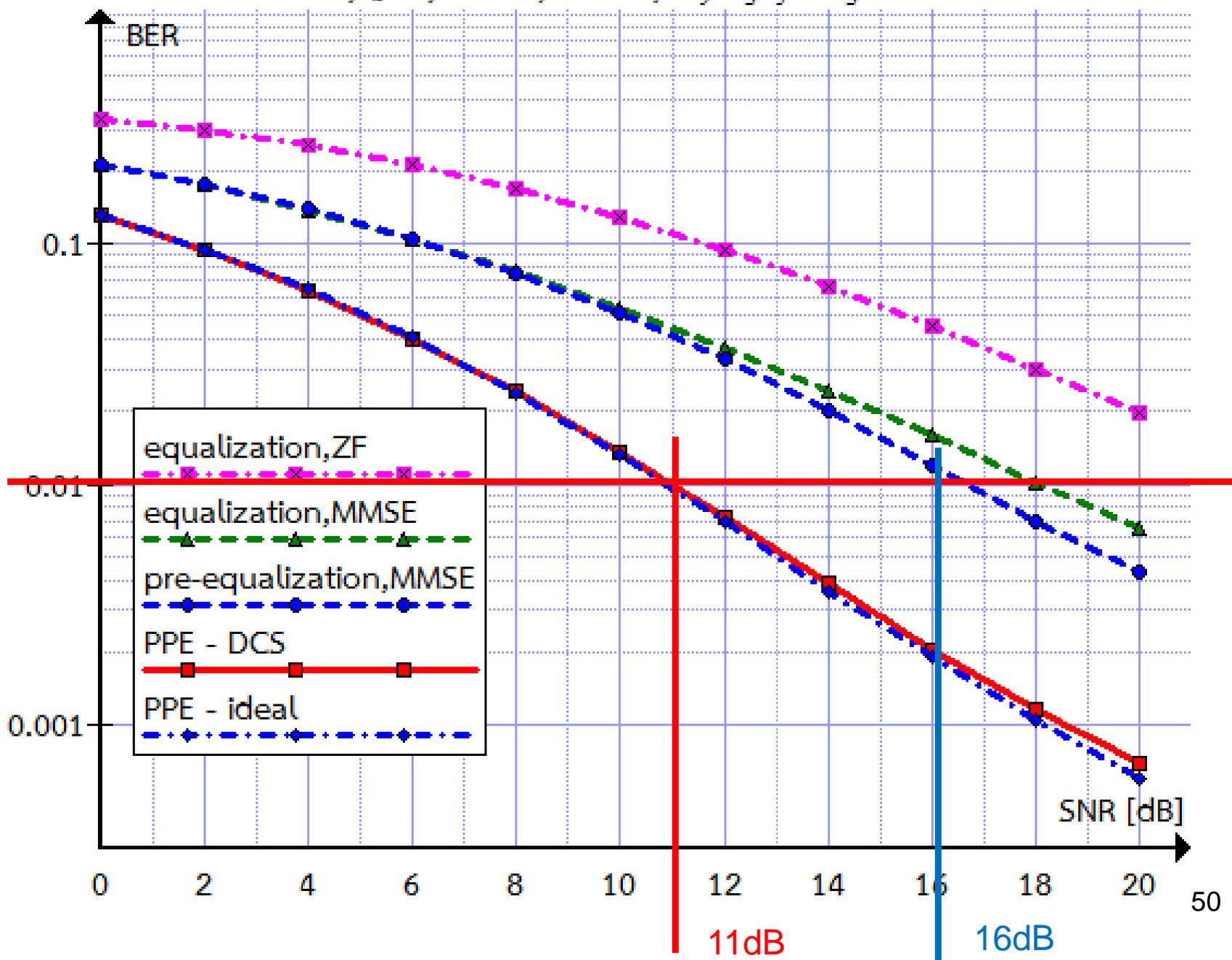
$$\text{dB} = 10 \log W$$

$$9.5 = 10 \log W_1 \rightarrow W_{balance} = 8.91 \text{ Watts}$$

$$11.5 = 10 \log W_2 \rightarrow W_{pre} = 14.12 \text{ Watts}$$

- Balance better than Pre-
 - reduce required transmit power **36.89%**

MIMO 4x4, QPSK, CP 25%, FFT 512, Rayleigh fading channel



Comparison with recent proposed

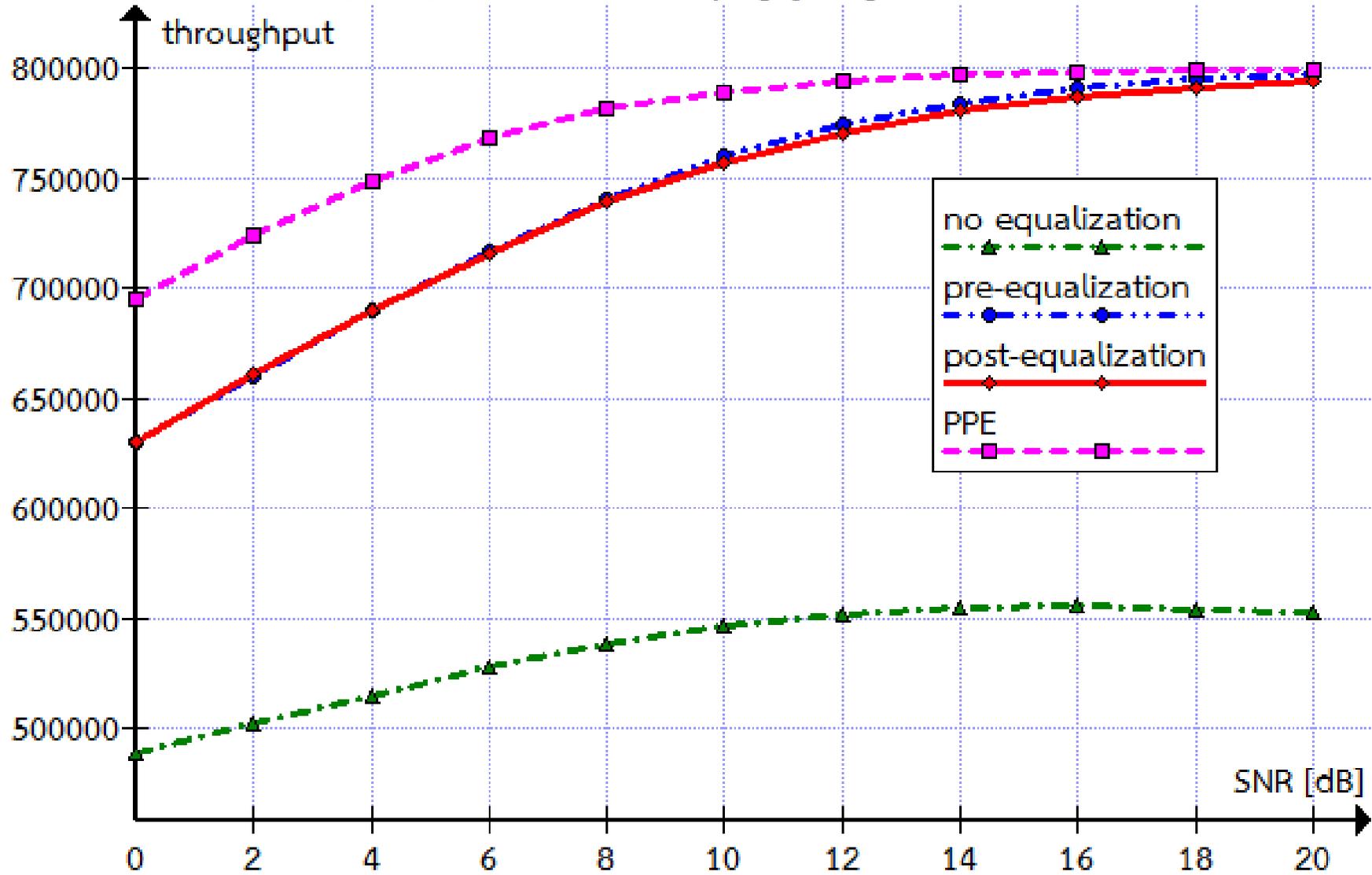
$$\text{dB} = 10 \log W$$

$$11 = 10 \log W_1 \rightarrow W_{PPE} = 12.59 \text{ Watts}$$

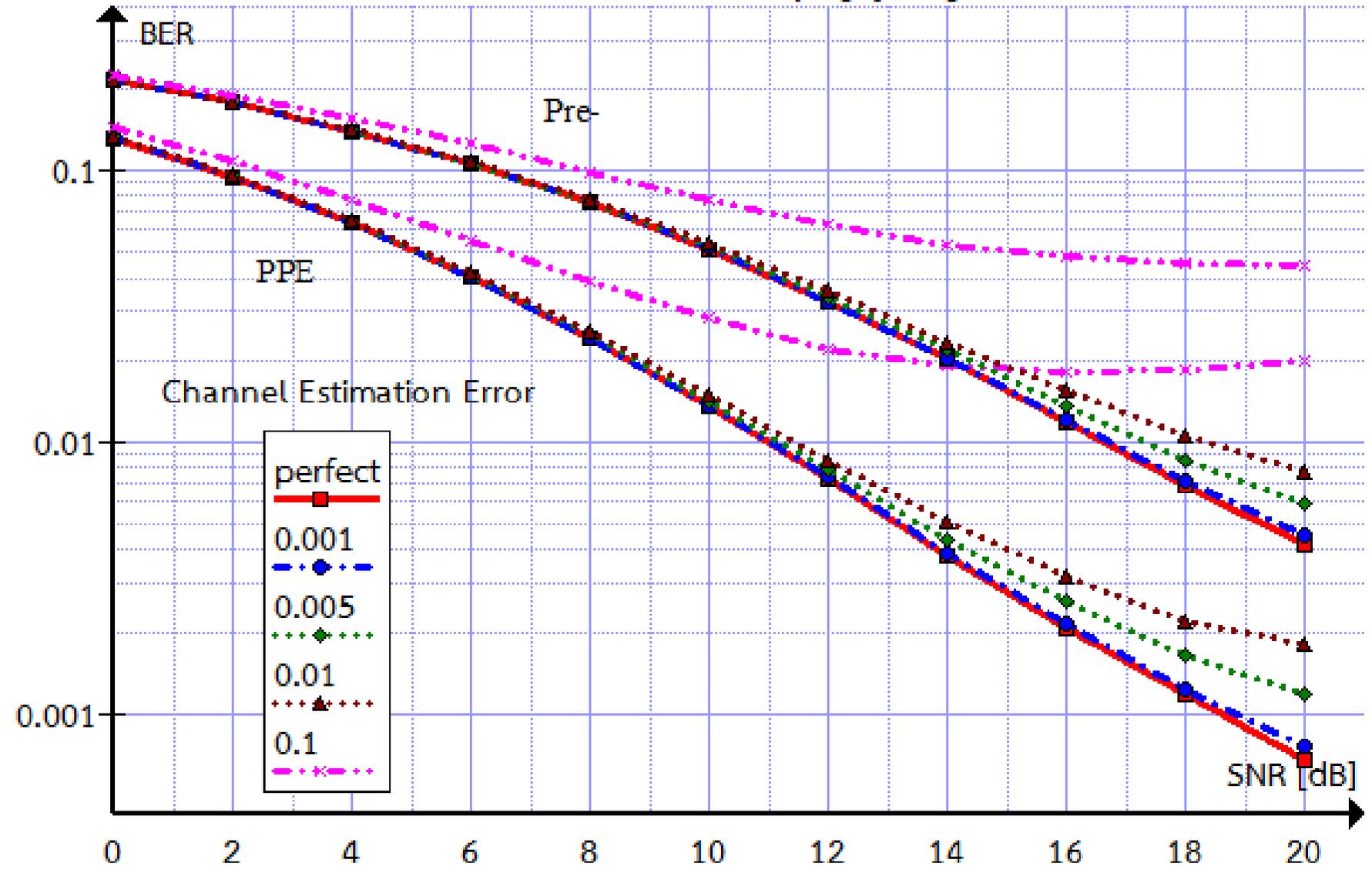
$$16.5 = 10 \log W_2 \rightarrow W_{pre} = 39.81 \text{ Watts}$$

- PPE better than Pre-
 - reduce required transmit power **68.37%**

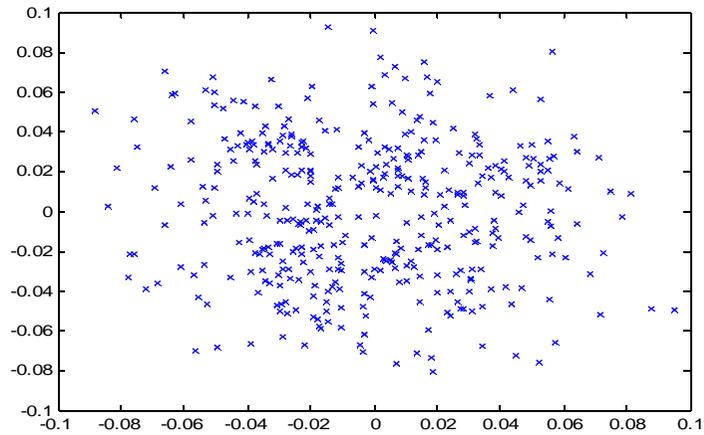
MIMO 4x4, QPSK, CP 25%, FFT 512, Rayleigh fading channel, 800000 bits



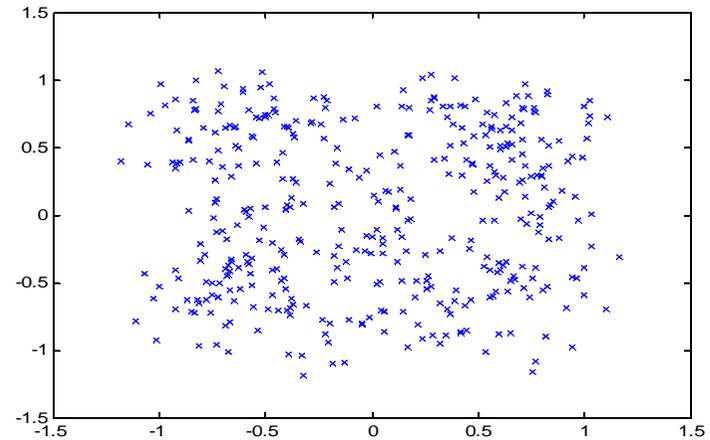
FFT 512, QPSK, MIMO 4x4, CP 25%, Rayleigh fading channel



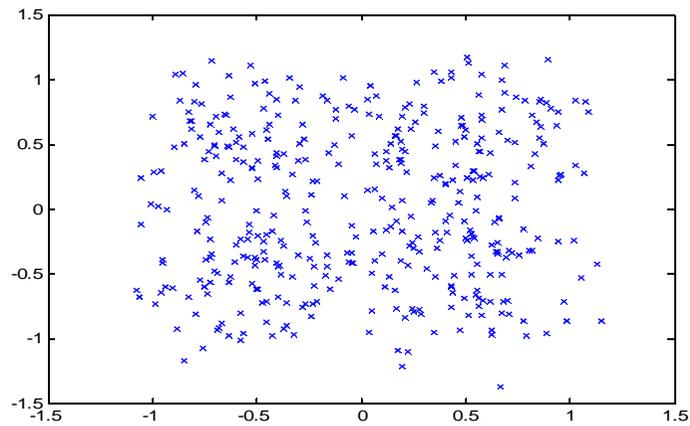
Constellation



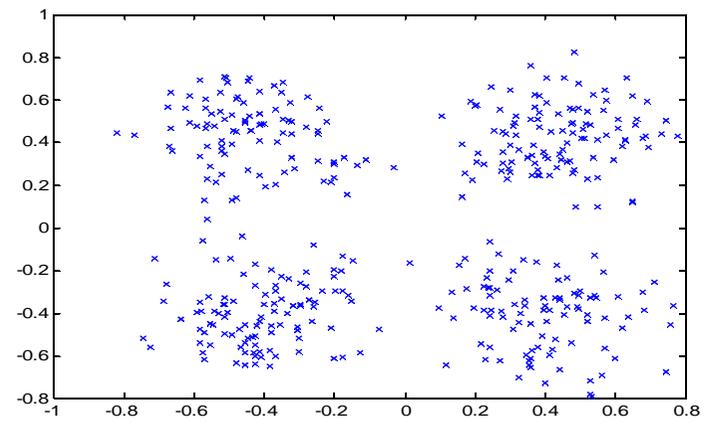
No equalization



(post-) equalization



Pre- equalization



PPE-DCS

7. Conclusion

- This paper proposes combining method of pre- and post-equalization (PPE) with decision constellation splitter (DCS) algorithm to improve the system performance for OFDM wireless communications.
- The DCS algorithm has proposed for detect and separate the mixed signals by calculates and compares symbol distance with the reference symbol.
- The simulation has been proved that, the proposed method can be achieved the performance in term of bit error rate compared with other methods. In the other words, the method show out coming of higher noise immunity.

Reference

IEEE Xplore[®]
DIGITAL LIBRARY

For Institutional Users:

- ▶ Institutional Sign In
- ▶ Athens/Shibboleth

IEEE

BROWSE ▾ | **MY SETTINGS** ▾ | **MY PROJECTS** | **WHAT CAN I ACCESS?** | About IEEE Xplore | Terms of Use | Feedback ?

SEARCH

^{beta} Author Search | Advanced Search | Preferences | Search Tips | More Search Options ▾

Browse Conference Publications > Information Networking (ICOIN ... ? [Back to Results](#)

Pre- and post- equalization technique combining for wireless communications

 **Full Text**
Sign-In or Purchase

Need Full-Text?
Request a free trial to IEEE Xplore for your organization.

FREE TRIAL

2 Author(s) | Kanthalue, S. ; Master of Comput. & Telecommun. Eng., Dhurakij Pundit Univ., Thailand ; Nanan, P.

Reference



Download Citations



Email



Print



Request Permissions



Save to Project



0



Like

0



Tweet

0



Share

This paper presents OFDM wireless communication system by using different equalization schemes. Performance and complexity are compared between pre-equalization, post-equalization and combined pre- with post- equalization (PPE) schemes. For combining technique, the received symbols are separated to pre- and post- symbols sequence by using the decision constellation splitter (DCS) algorithm. The result has shown performance in term of bit error rate (BER). In practice, channel estimation is not perfect so we also include the impact of imperfect channel estimation on BER performance in this paper.

Published in:

Information Networking (ICOIN), 2013 International Conference on

Date of Conference: 28-30 Jan. 2013

Page(s):

336 - 340

ISSN :

1976-7684

E-ISBN :

978-1-4673-5741-8

Print ISBN:

978-1-4673-5740-1

INSPEC Accession Number:

13431485

Conference Location :

Bangkok

Digital Object Identifier :

10.1109/ICOIN.2013.6496400

Pre- and Post- Equalization Technique Combining for Wireless Communications

Suriya Kanthalue

Master of Computer and Telecommunication Engineering,
Dhurakij Pundit University,
Thailand,
kanjoe71@hotmail.com

Pheeradej Nanan, Ph.D

CAT Telecom Public Company Limited,
Thailand,
pheeradej@yahoo.com

Abstract— This paper presents OFDM wireless communication system by using different equalization schemes. Performance and complexity are compared between pre-equalization, post-equalization and combined pre- with post- equalization (PPE) schemes. For combining technique, the received symbols are separated to pre- and post- symbols sequence by using the decision constellation splitter (DCS) algorithm. The result has shown performance in term of bit error rate (BER). In practice, channel estimation is not perfect so we also include the impact of imperfect channel estimation on BER performance in this paper.

Keywords— Pre-equalization, Post-equalization, Equalization, Combined pre- and post- equalization, PPE, combining, Decision Constellation Splitter, DCS, low complexity receiver, Imperfect Channel Estimation

equalizer is the MMSE equalizer which does not aim at eliminating ISI completely, but instead minimizes the total power of the noise and ISI components at the output [1] [7] [8] [9]. Feedback equalizer sends more processes and increases more complexity of the receiver. The pre-equalization technique in [10] [11] [12] have shown method how to reduce complexity at the receiver.

To achieve high data rate the combination of pre-equalization at transmitter and post-equalization at receiver scheme is applied in wireless communication system [13] [14]. When pre-equalized symbol and equalized symbol from the transmitter have been sent into the same channel and the same time, the mixed complex number of each symbol sequences are difficult to separate by demodulation at receiver.

When placed in the non-ideal channel, the ZF equalizer may amplify the noise power greatly. The better balanced linear

refer to [5], x represents the input and n represents noise with a variance and H represents the channel gain of the

Future works

- Adaptive PPE with DCS for noise immunity wireless communication systems under imperfect channel estimation.
- Pilot or Probability DCS
- PPE for LTE Advanced

Question

Thank you for your kind attention