OFDM system and PAPR Reduction Techniques in OFDM

Under the guidance

of

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Outline

- Problem Statement
- Method of Solving
- Theory of OFDM
- Background work
- Peak to Average Power Ratio
- Methodology Adopted
- Results and Conclusions
- References

Problem Statement

- OFDM signal – superposition of a large number of modulated subcarriers - may exhibit a high instantaneous signal peak with respect to average signal level
- PAPR is proportional to # of subcarriers

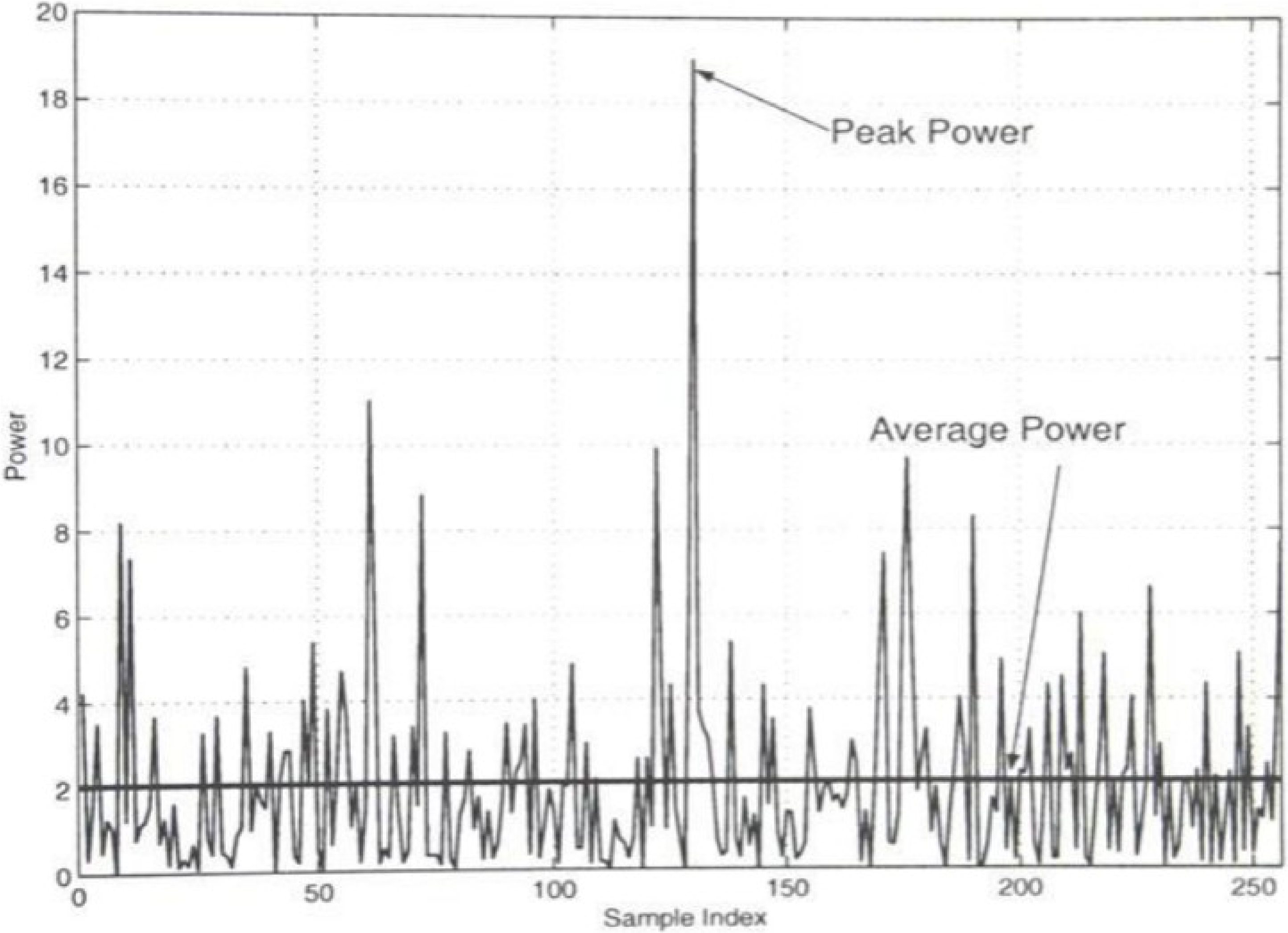
$$PAPR\left(x(t)\right)=\frac{\max\limits_{0\le t\le T_s}\left[|\,x(t)\,|^2\right]}{P_{av}}$$

- High Peak to Average Power Ratio

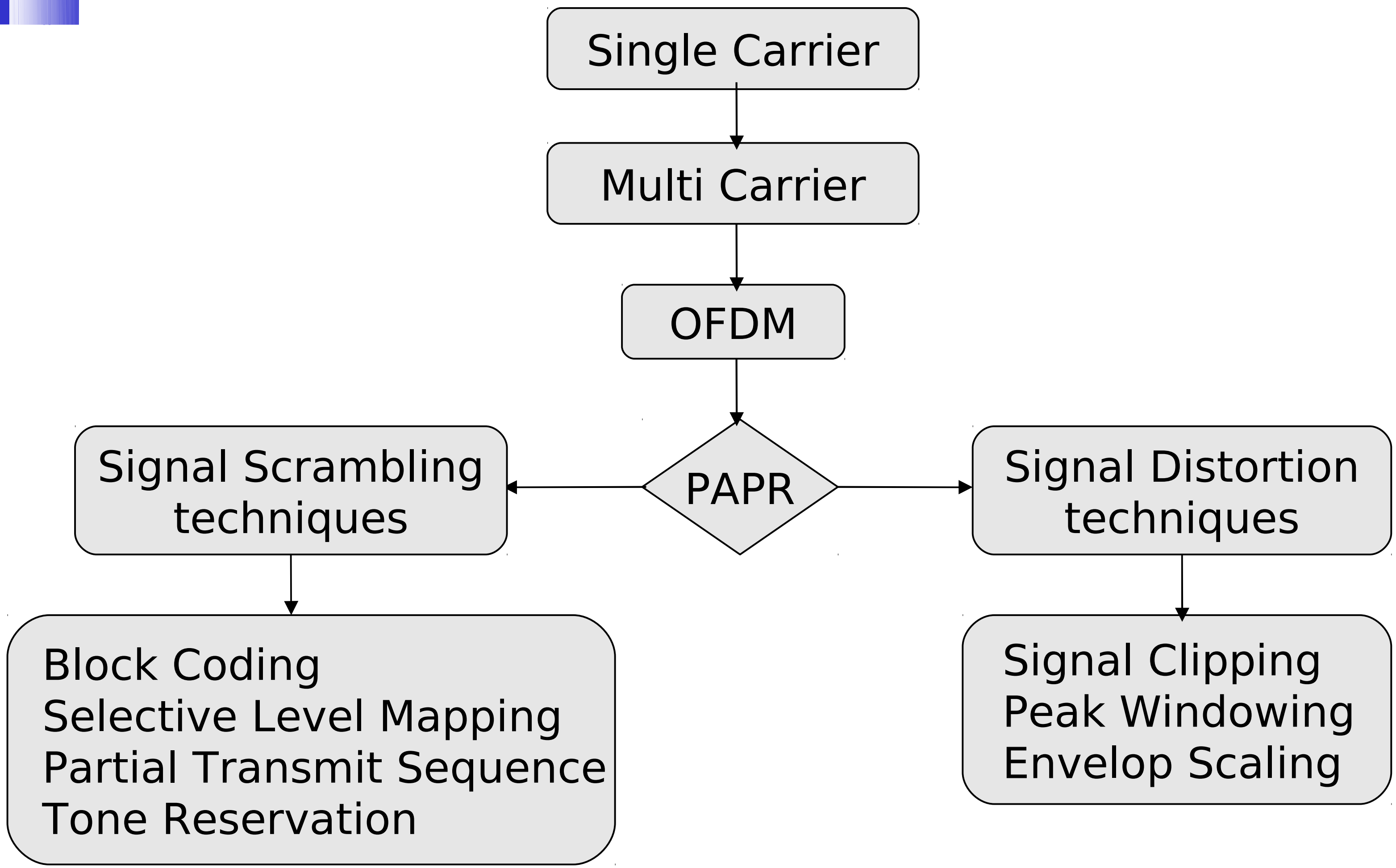
  - Increases complexity of the ADC and DAC

  - Reduces efficiency of the RF power amplifier

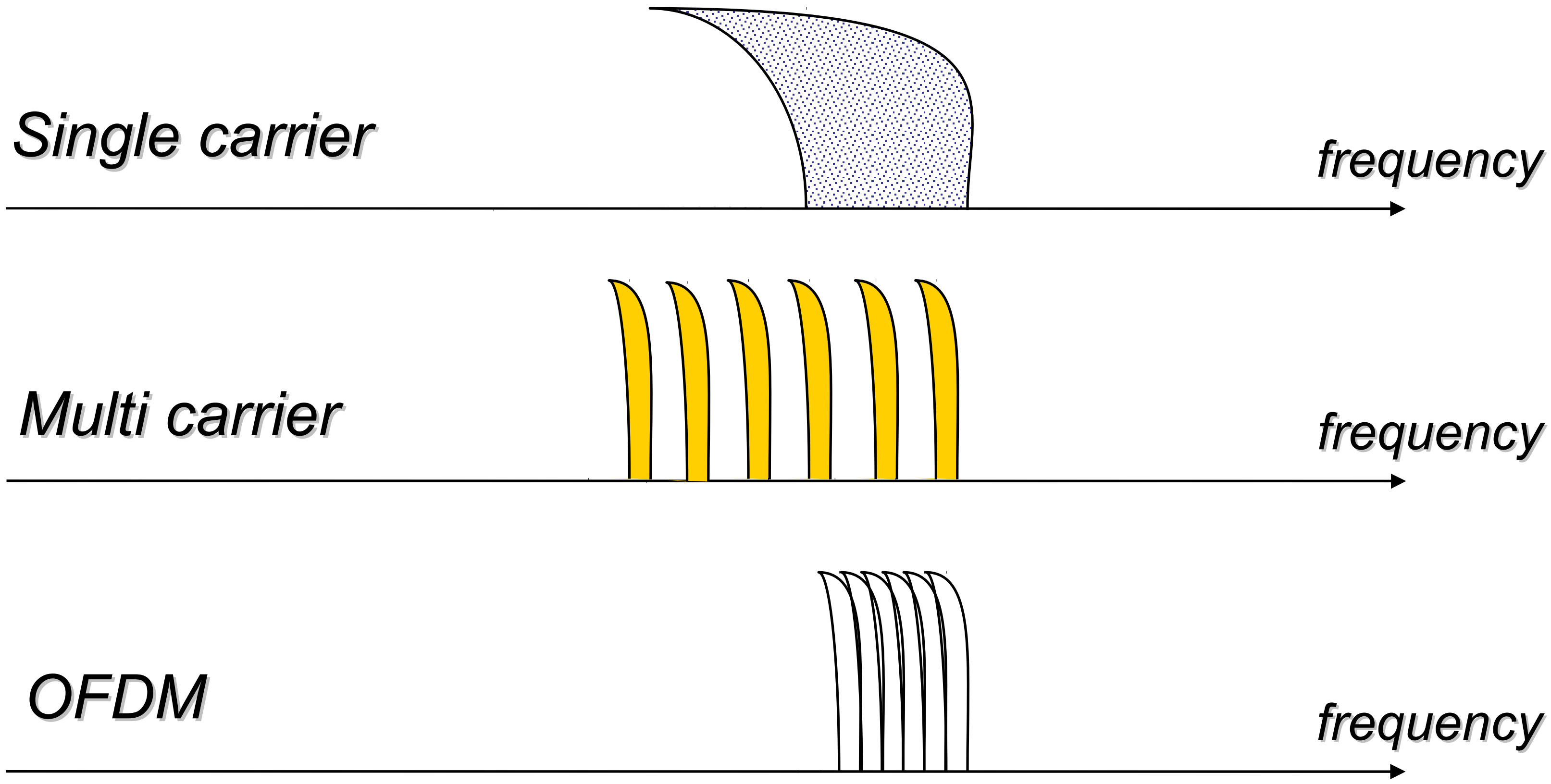
Problem Statement



Method of Solving



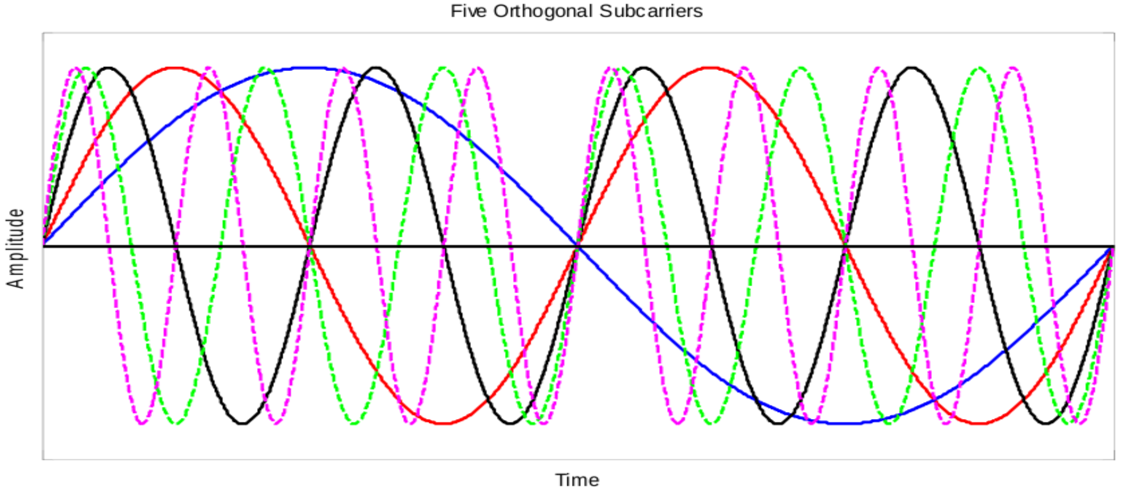
Spectrum comparison for same data rate transmission

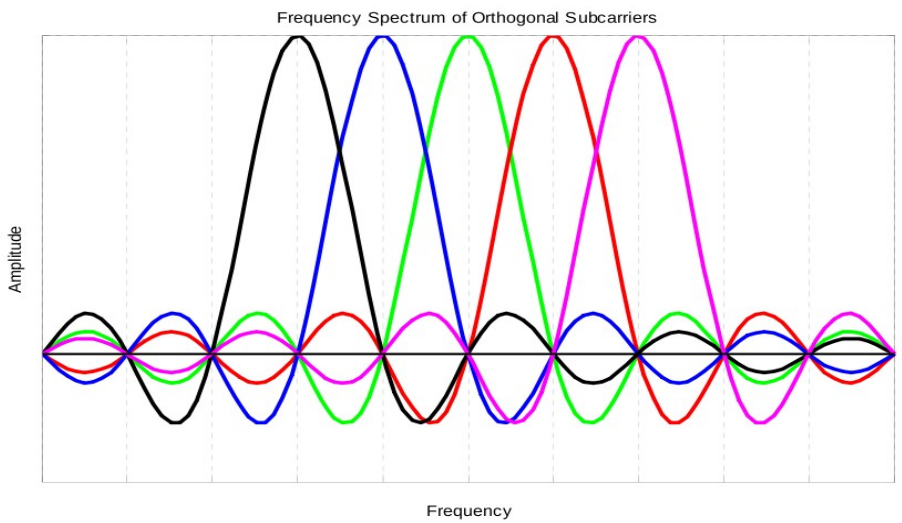


What is OFDM?

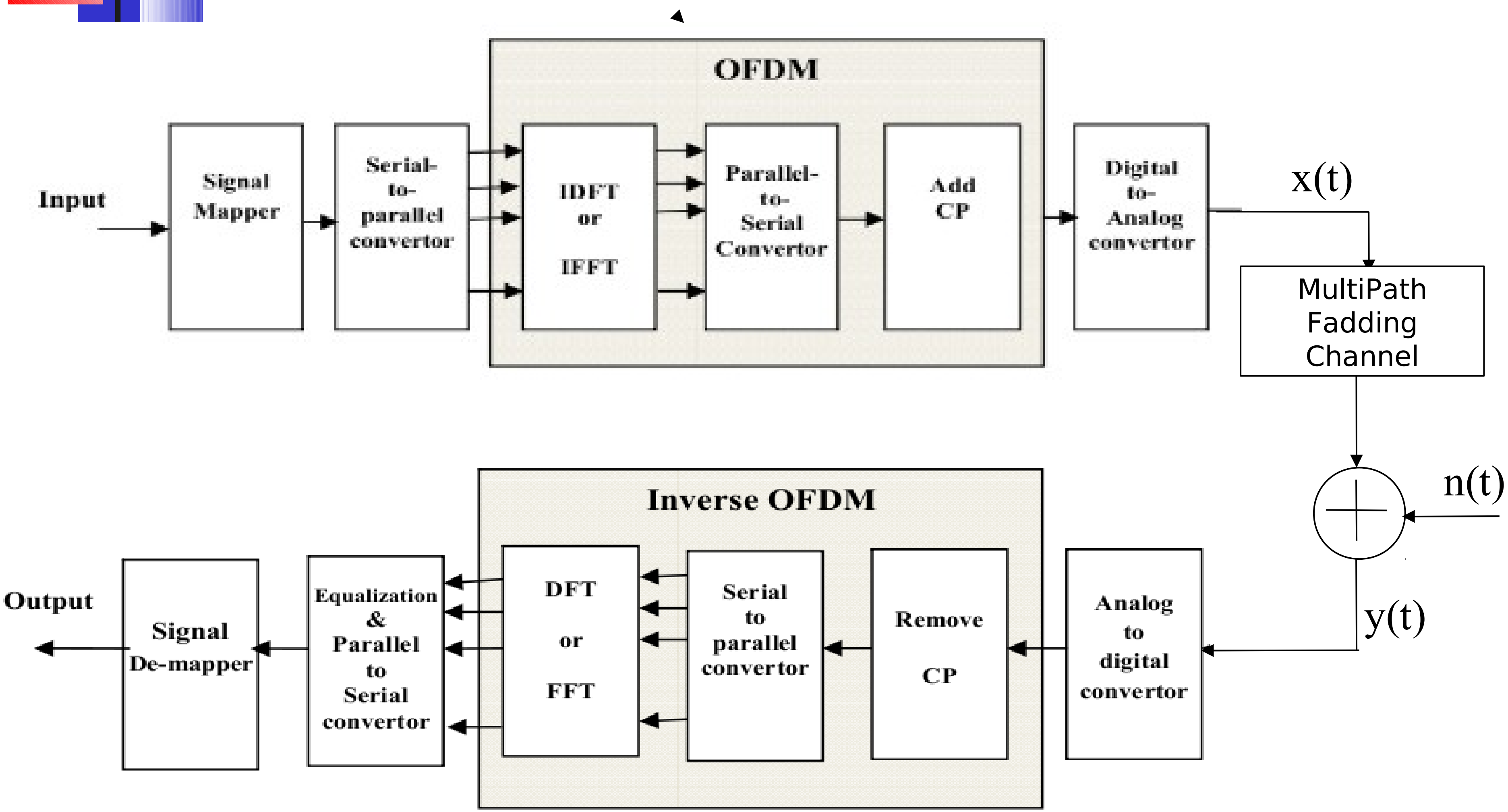
- Many orthogonal sub-carriers are multiplexed in one symbol
  - Why multicarrier?
  - What is orthogonality?
  - How modulated & multiplexed?
  - How many sub-carriers to choose?
  - Why Synchronization for OFDM?
  - What are the merits & demerits of OFDM?
  - What kind of applications?

OFDM Spectrum





Work flow of OFDM



System Architecture

1 Input to Time Domain

$$x(n) = IDFT\{X(k)\}$$
$$n = 0,1,2,\ldots,N-1$$

2 Guard Interval

$$x_f(n) = \begin{cases} x(N+n), & n = -N_g, -N_g+1, \ldots, -1 \\ x(n), & n = 0,1,\ldots,N-1 \end{cases}$$

3 Channel

$$y_f = x_f(n) \otimes h(n) + w(n)$$

4 Guard Removal

$$y(n) = y_f(n) \quad n = 0,1,\ldots,N-1$$

5 Output to Frequency Domain

$$Y(k) = DFT\{y(n)\}$$
$$k = 0,1,2,\ldots,N-1$$

6 Output

Channel | ICI | AWGN

$$Y(k) = X(k)H(k) + I(k) + W(k)$$
$$k = 0,1,\ldots,N-1$$

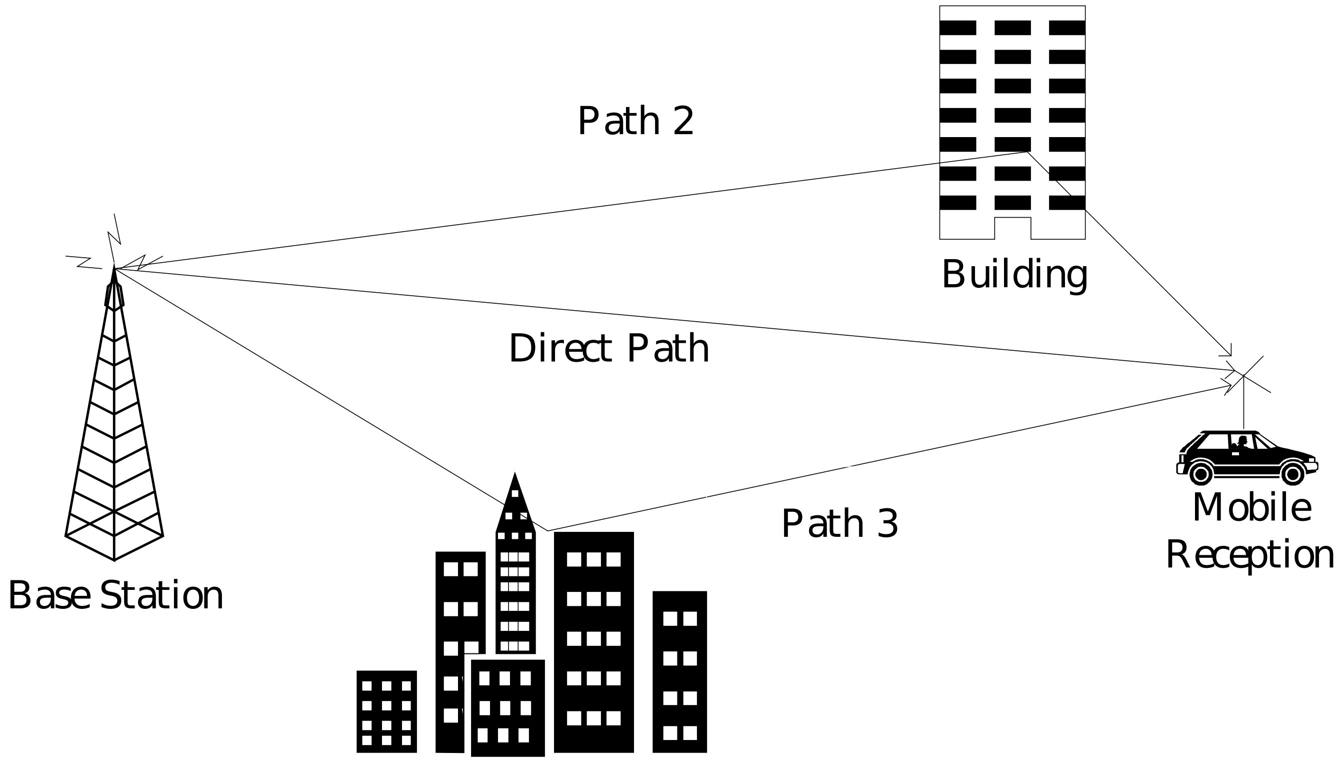
7 Channel Estimation

Estimated Channel

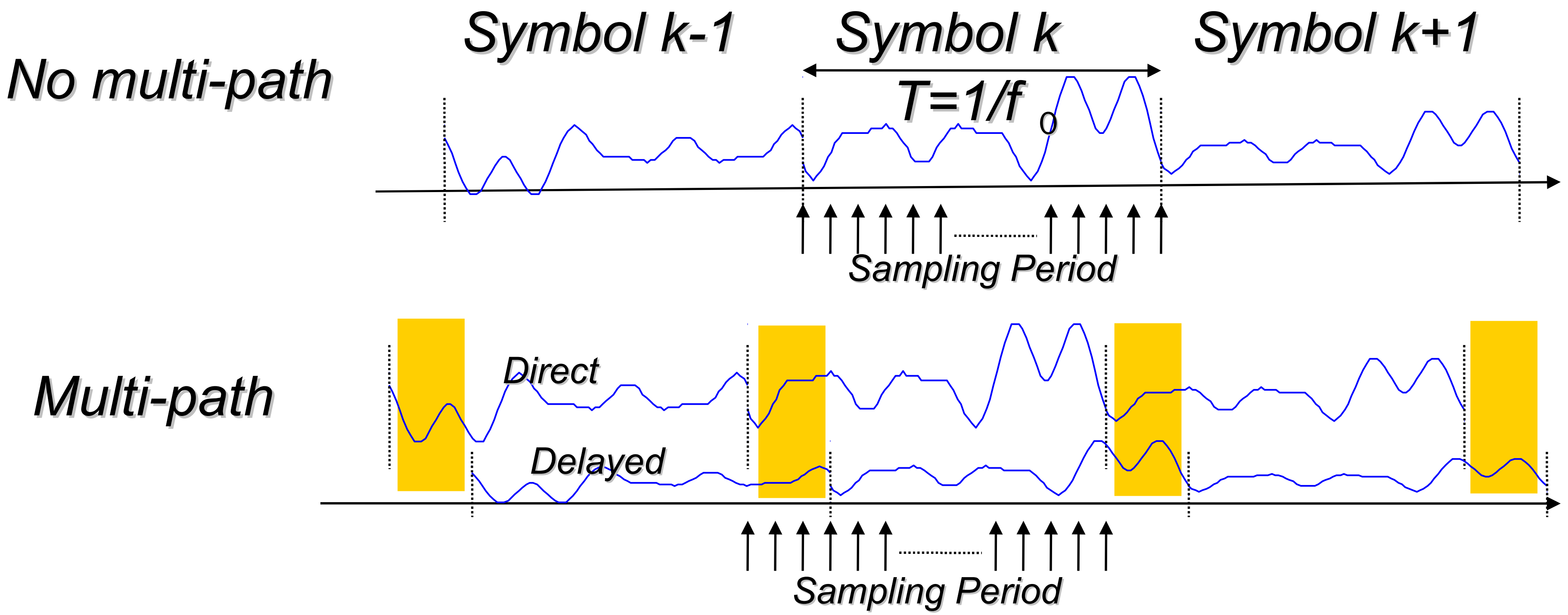
$$X_e(k) = \frac{Y(k)}{H_e(k)} \quad k = 0,1,\ldots,N-1$$

Multi-path

- Delayed wave causes interference

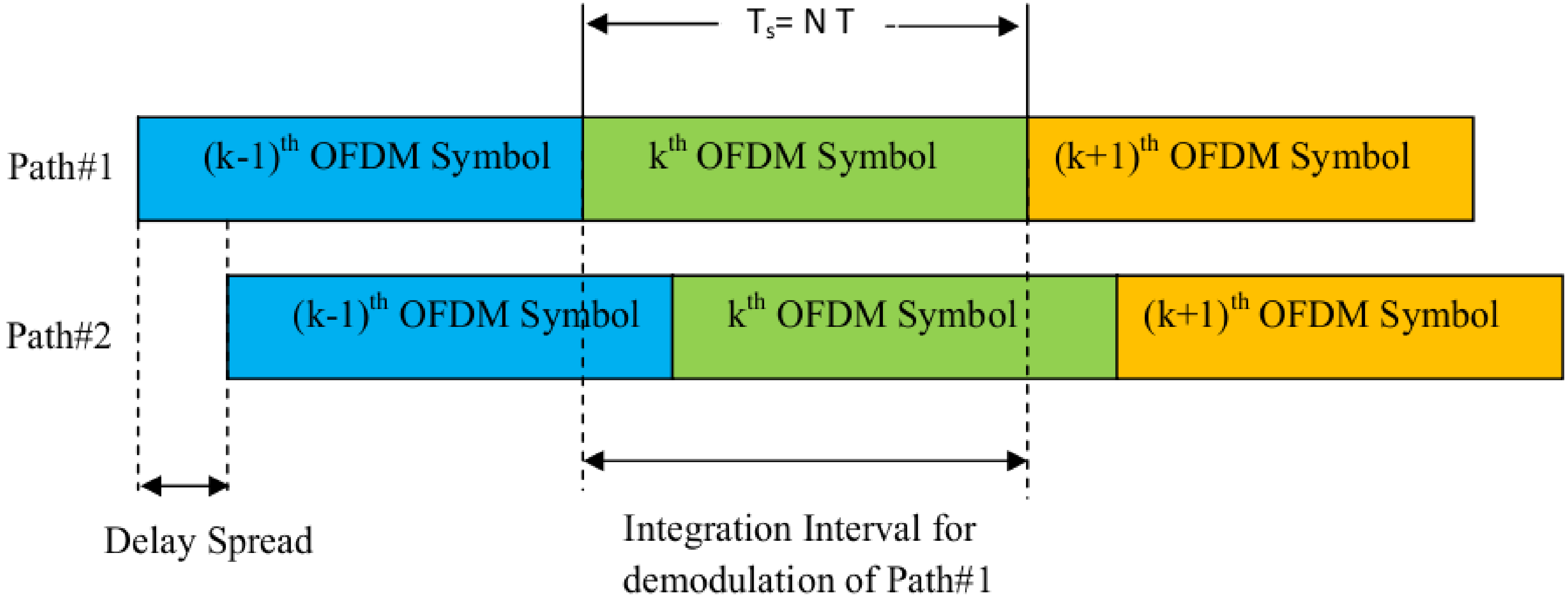


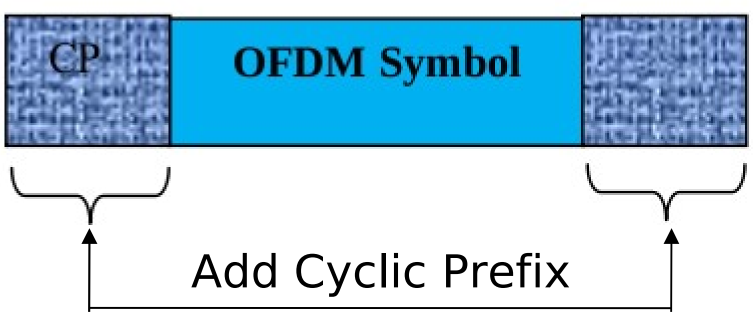
Multi-path effect



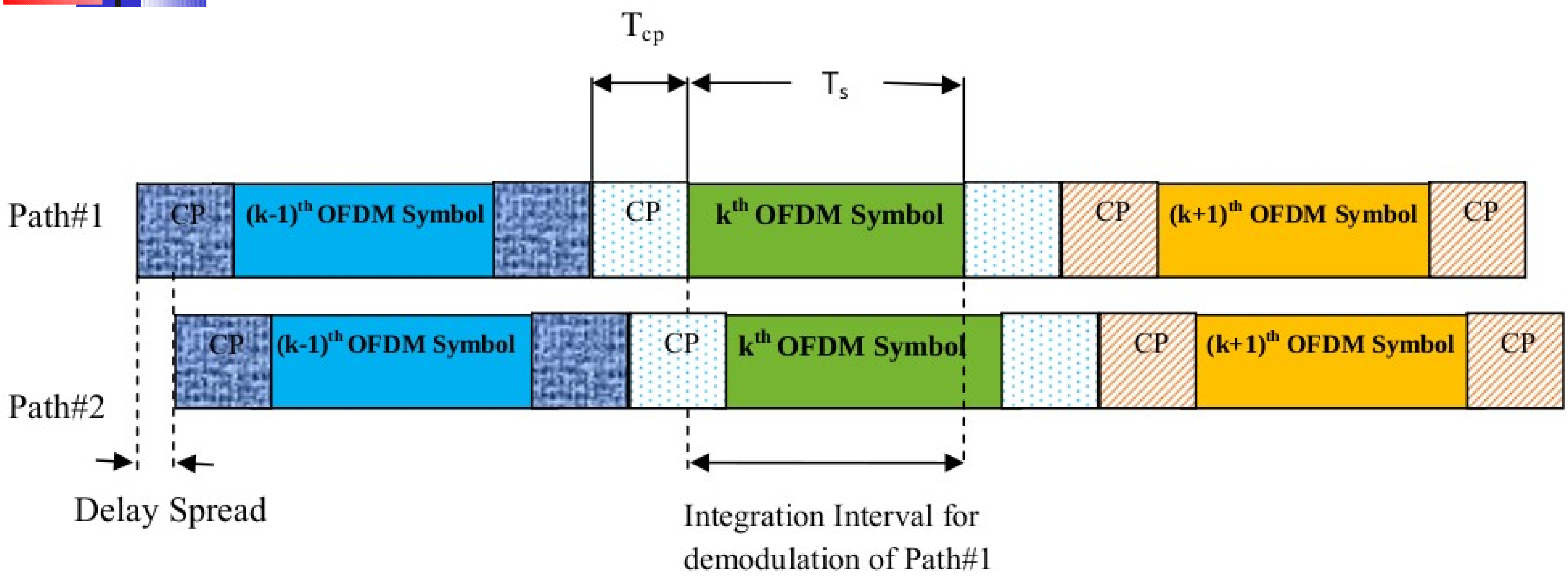
- Inter symbol interference (ISI) occurs due to Multi-path condition.
- Only initial samples are being subjected to ISI.
- Add Guard Interval to avoid ISI.

Guard Interval T_g





Cyclic Prefix

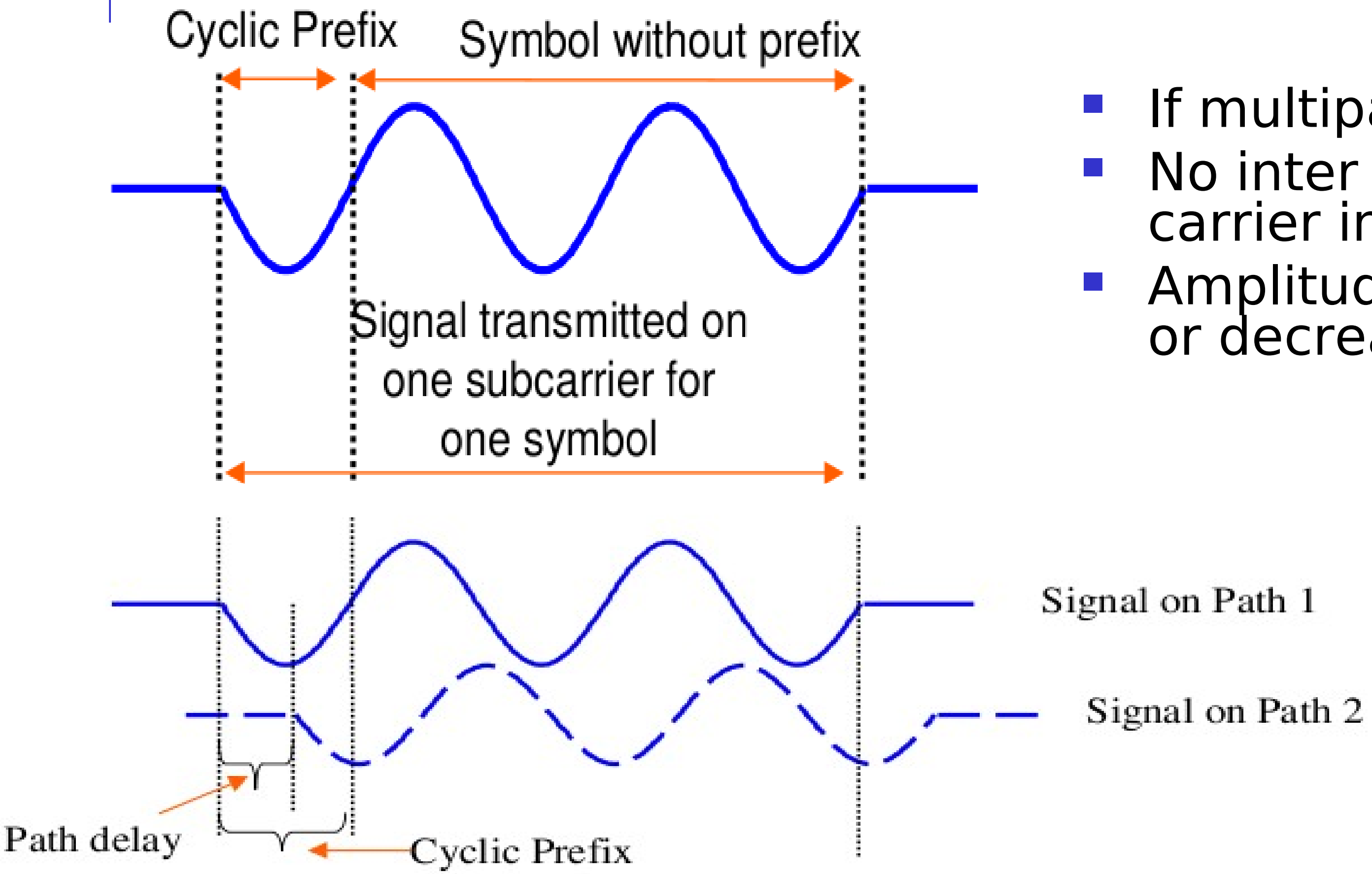


$$[\,y(0)\ y(1)\ \ldots\ldots\ y(N\text{-}1)\,] = [\,h(0)\ h(1)\ \ldots\ldots\ h(L\text{-}1)\,] * [\,x(0)\ x(1)\ \ldots\ldots\ x(N\text{-}1)\,]$$

$$Y(k) = H(k)\,.\,X(k)$$

- Loss in efficiency is the ratio of CP and total OFDM symbol

Cyclic Prefix



- If multipath delay < CP
- No inter symbol or inter carrier interference
- Amplitude may increases or decreases .

Peak to Average Power Ratio (PAPR)

- Crest Factor
- Single Carrier system
- OFDM
  - Base Band system
  - Band Pass system
  - PAPR is proportional to # of subcarriers
  - Characterized by CCDF

$$F_{PAPR}(x) = P\,(PAPR > x)$$

Distribution of PAPR

- Power Distribution

$$F(z) = 1 - e^{-z}$$

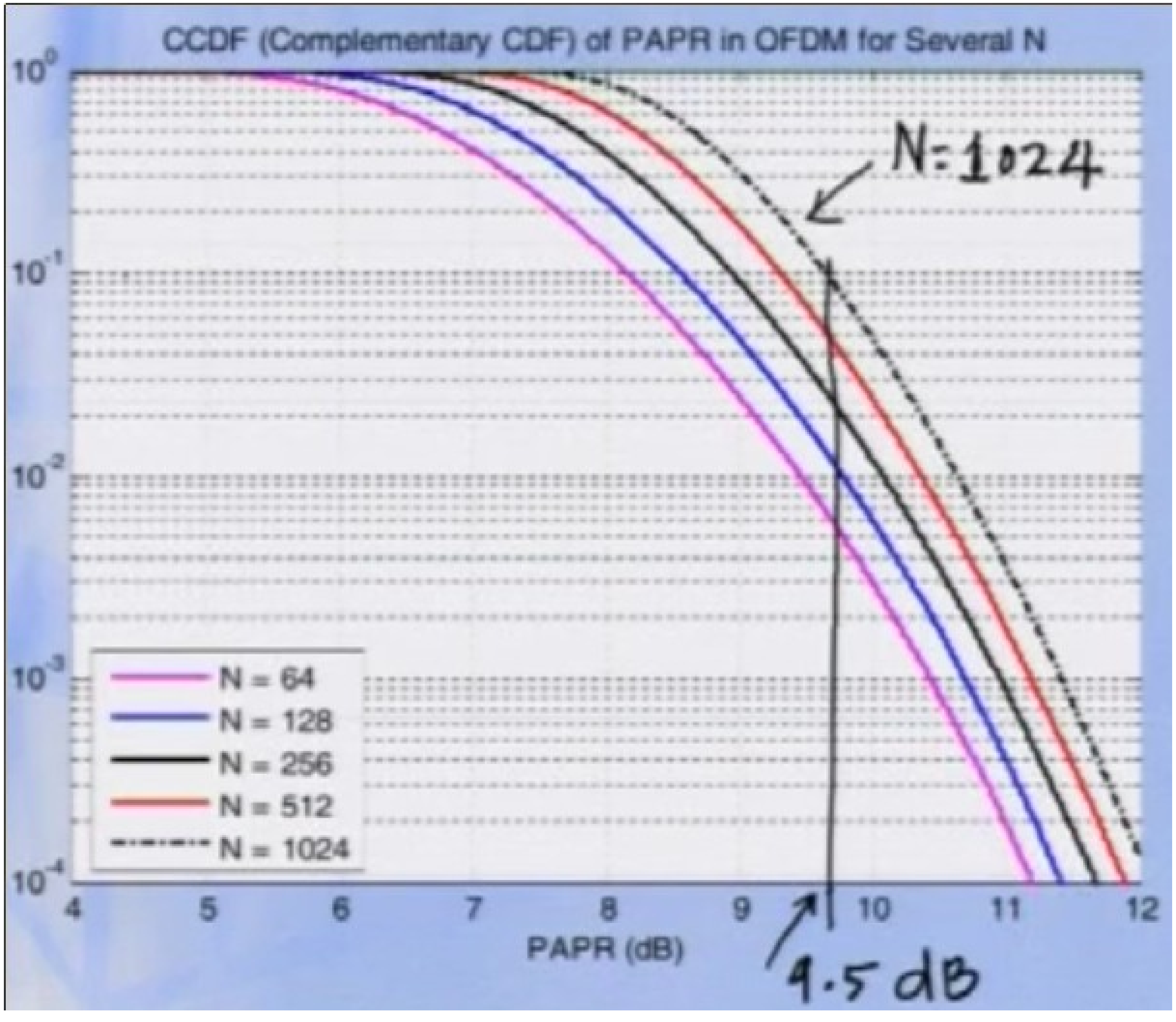
- Assuming all the samples are mutually uncorrelated
- Cumulative Distribution Function (CDF)

$$p(PAPR \le z) = F(z)^N = (1 - e^{-z})^N$$

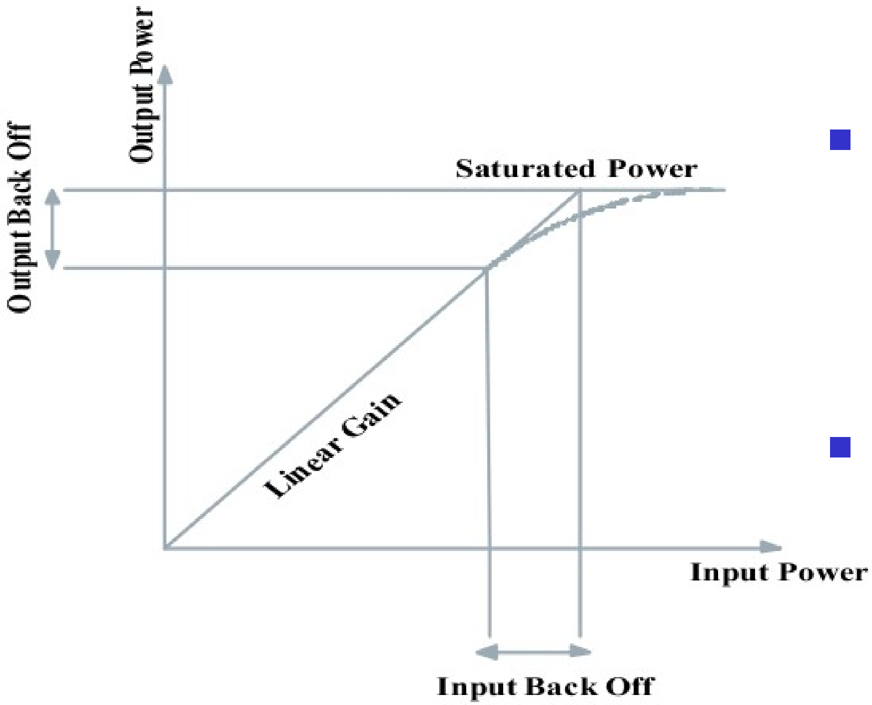
- Complementary Cumulative Distribution Function (CCDF)

$$p(PAPR > z) = 1 - (1 - e^{-z})^N$$

Complementary Cumulative Distribution Function(CCDF)



Effect of Peaks



- Large peaks cause saturation in power amplifiers, leading to intermodulation product among subcarriers.
- Loss of Orthogonality → ICI

Criteria for PAPR Reduction Method selection

- Side effects
- Avg power increase
- Implementation complexity
- No bandwidth Expansion
- Without additional power needed.

Distortion Techniques

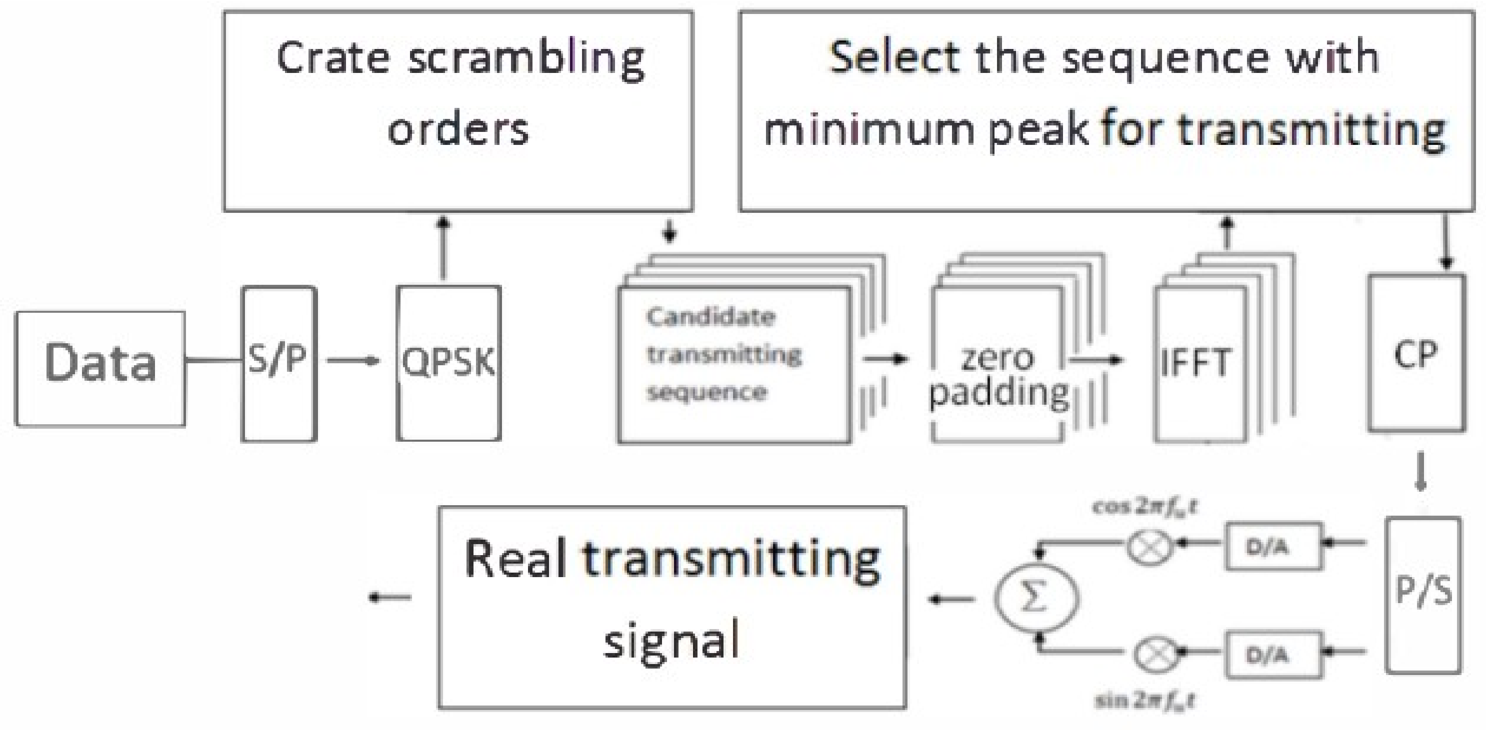
- Clipping
- Peak Windowing
- Peak Cancellation

Scrambling Techniques

- Based on scrambling each OFDM symbol with different scrambling sequences.

- Scrambling Schemes
  - Adaptive Subcarrier Selection
  - Selective Mapping
  - Partial Transmit Sequence
  - Block Coding

Scrambling Techniques

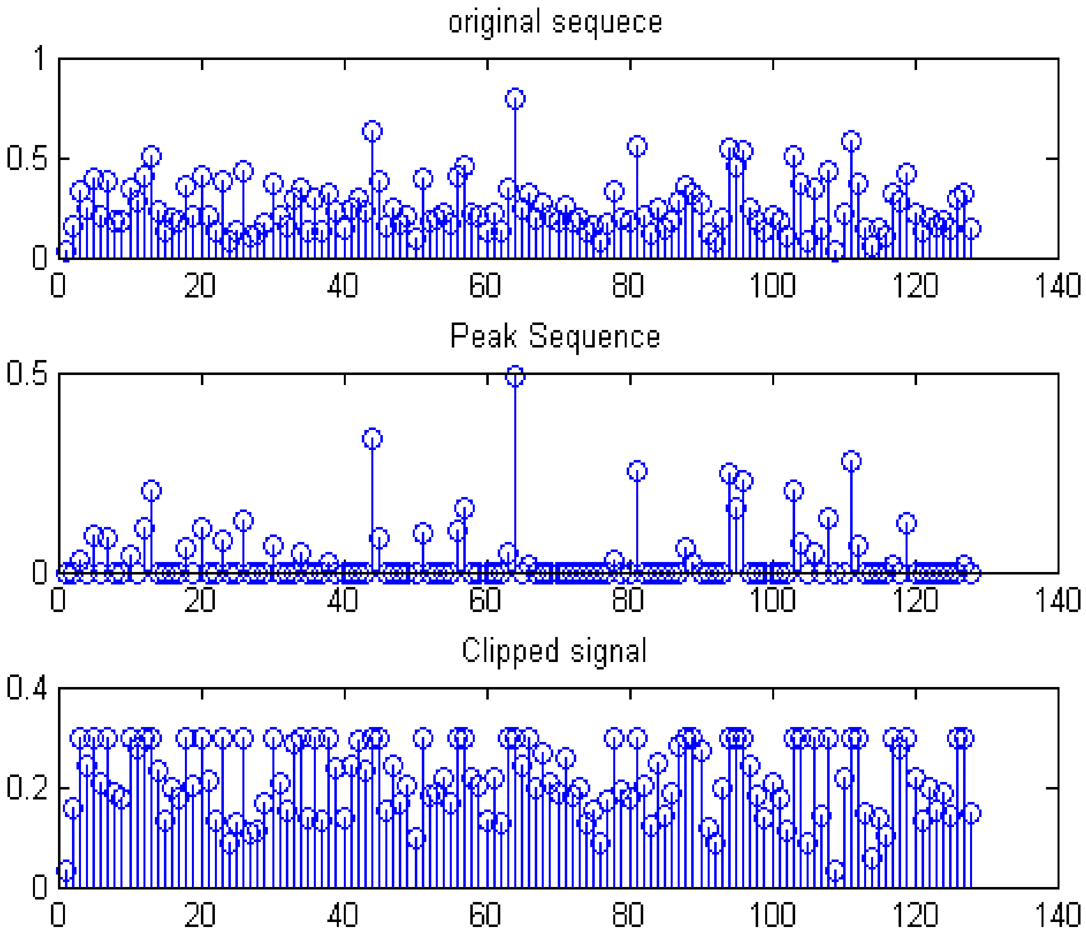


- Overhead increases at Tx and Rx

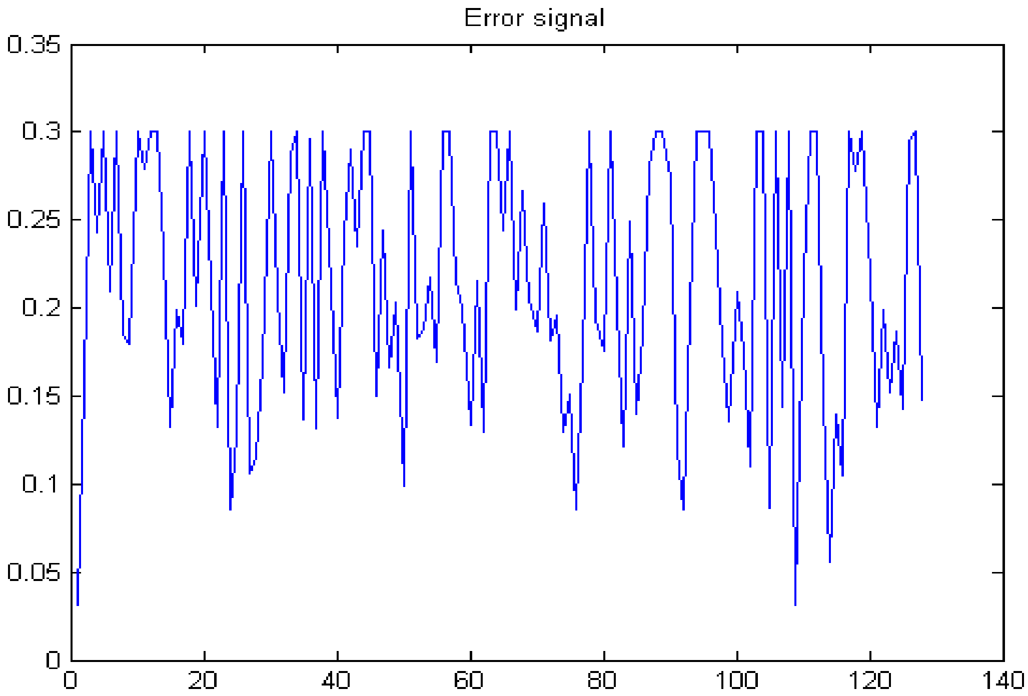
Clipping

- Non-Linear technique
- Simple & less expensive
- Can't get original signal
- MMSE(Minimum Mean Square Error)

Results


original sequece
1
0.5
0
0
20
40
60
80
100
120
140
Peak Sequence
0.5
0
0
20
40
60
80
100
120
140
Clipped signal
0.4
0.2
0
0
20
40
60
80
100
120
140

Results



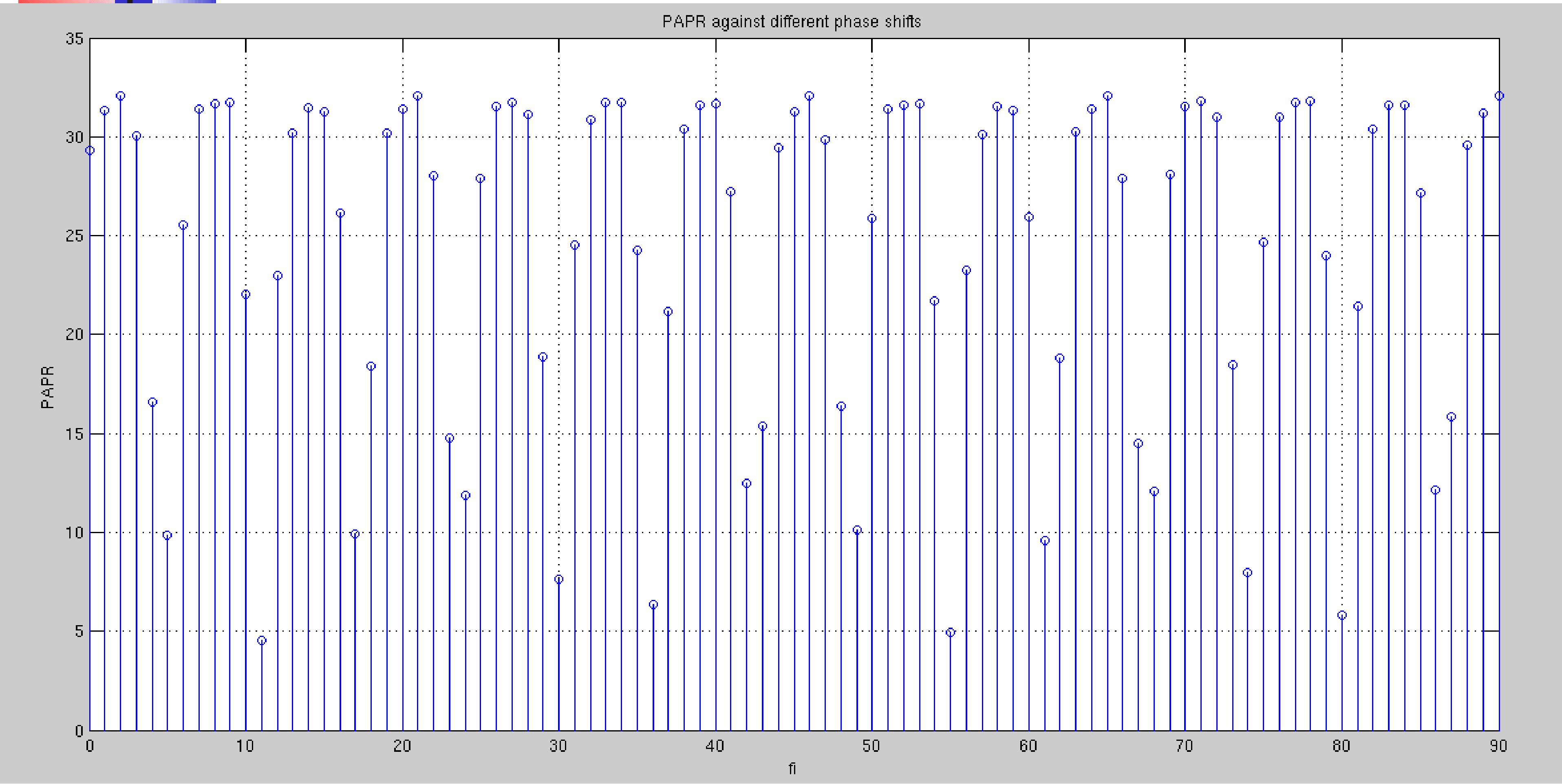
Sample Result:

PAPR of Original Signal in dB 20.6920
PAPR of Clipped Signal 5.63 dB
MMSE = 0.0070

Selective Mapping

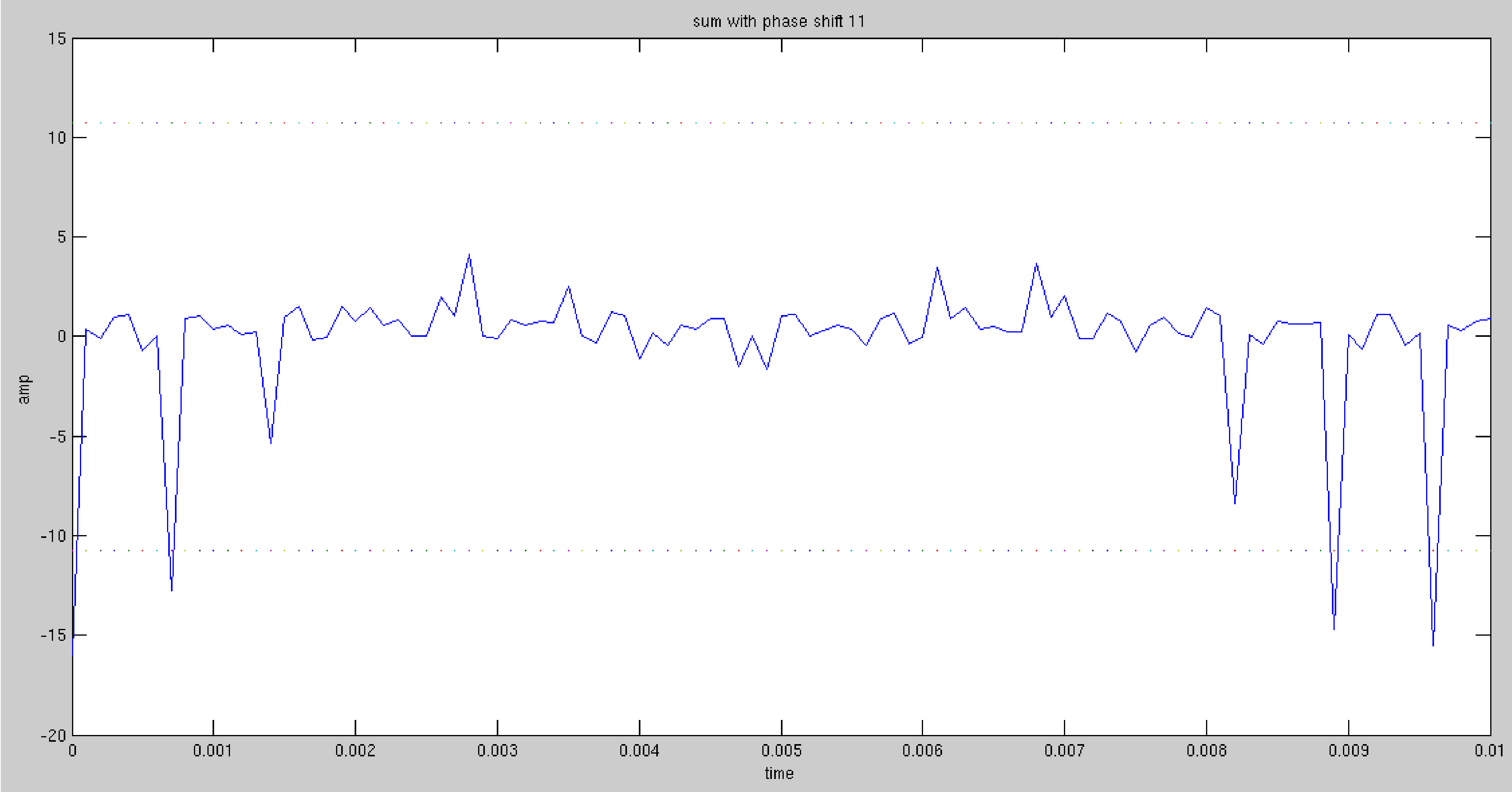
- Set of Signals with phase shifts
- Most favorable signal chosen
- Side information → Complexity
- Not removed peaks, but prevent it from frequently generation

Results



Results obtained in SLM technique: Minimum @11 degrees

OFDM Signal with minimum PAPR for 11'o Phase shift

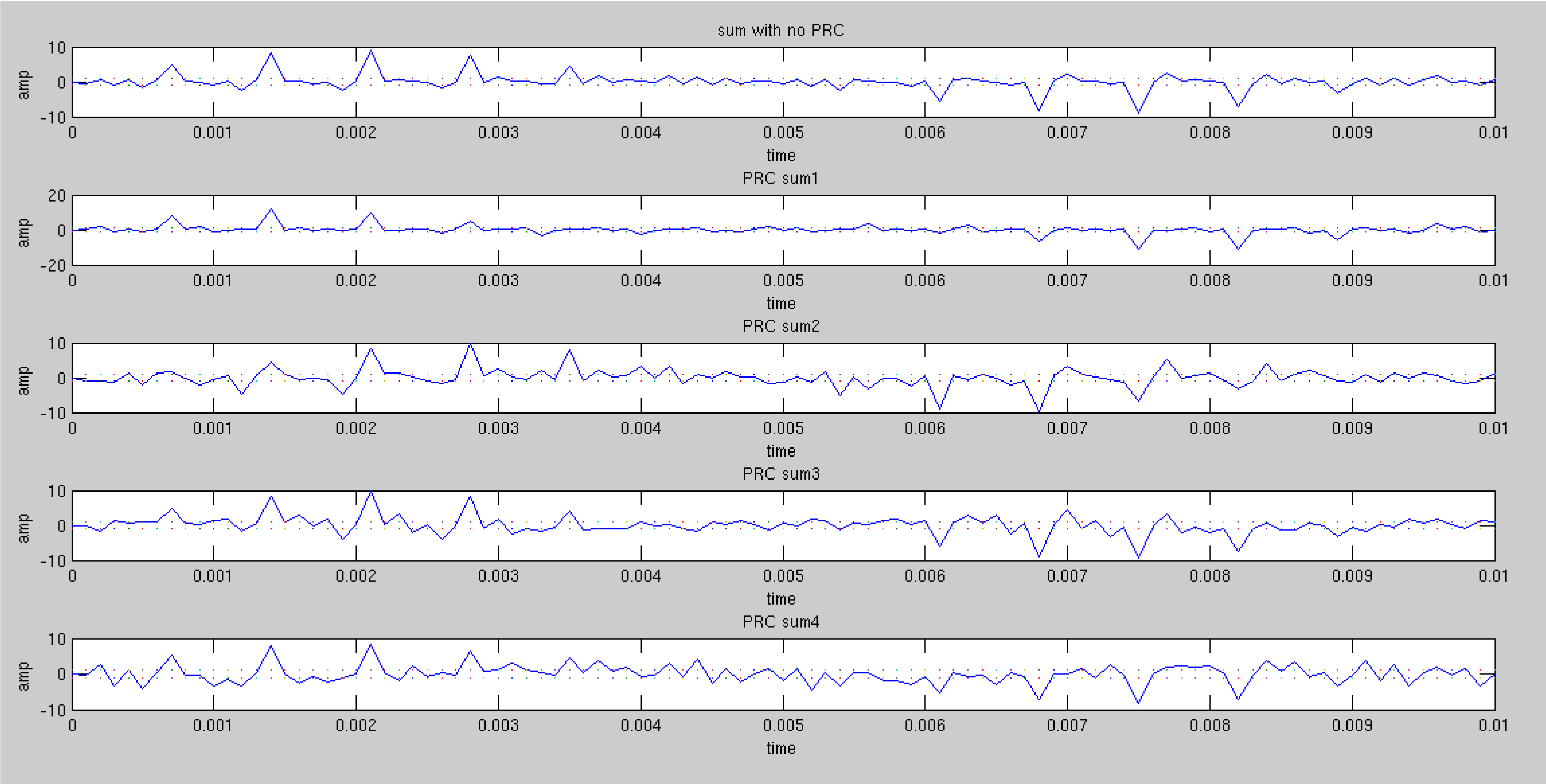


Tone Reservation

- Includes set of peak reduction carriers
- Combination of reserved tones → Creation of anti peaks
- Amount of complexity
- #of tones small → less peak reduction

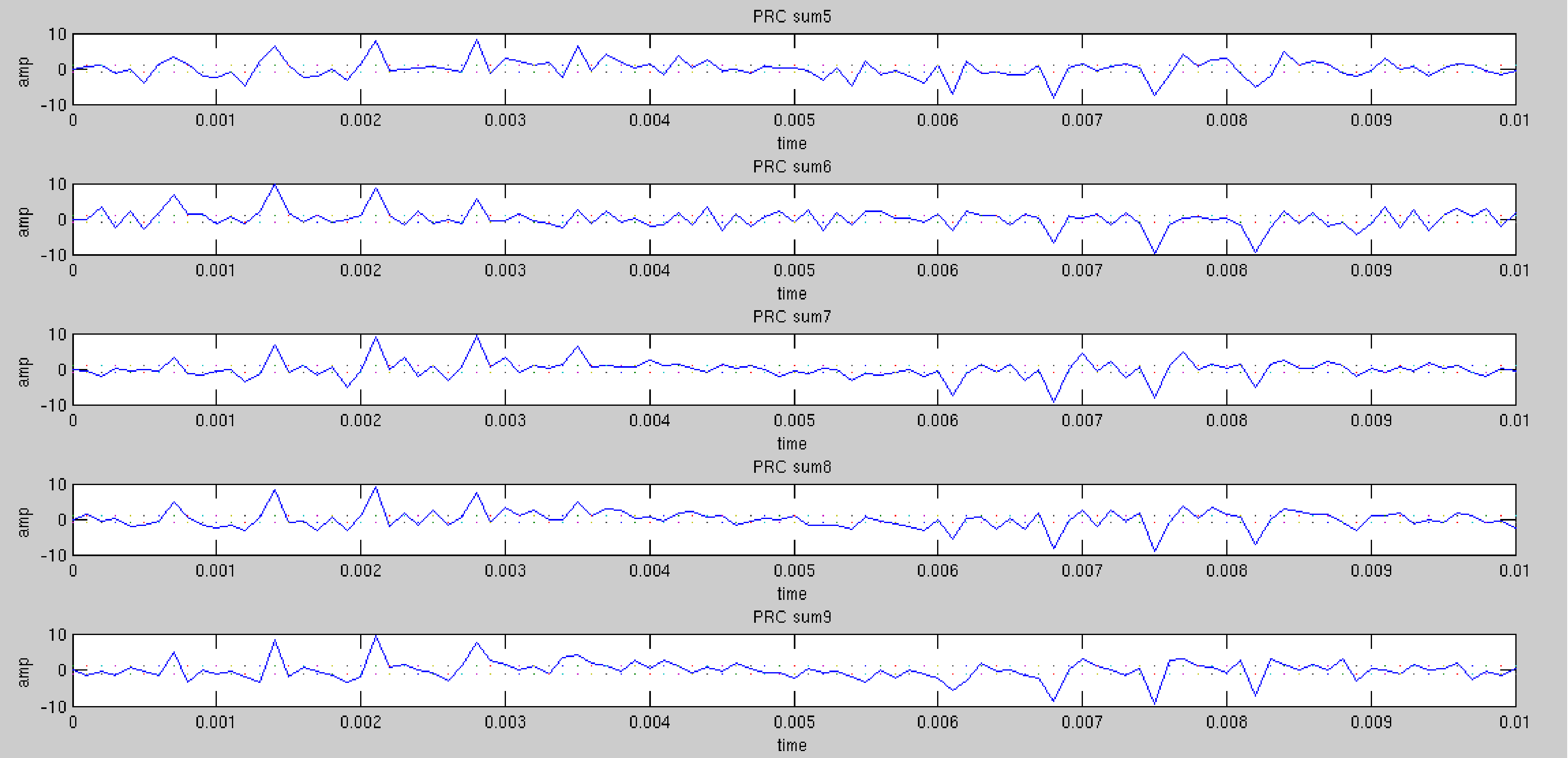
  → less usage of BW

Results



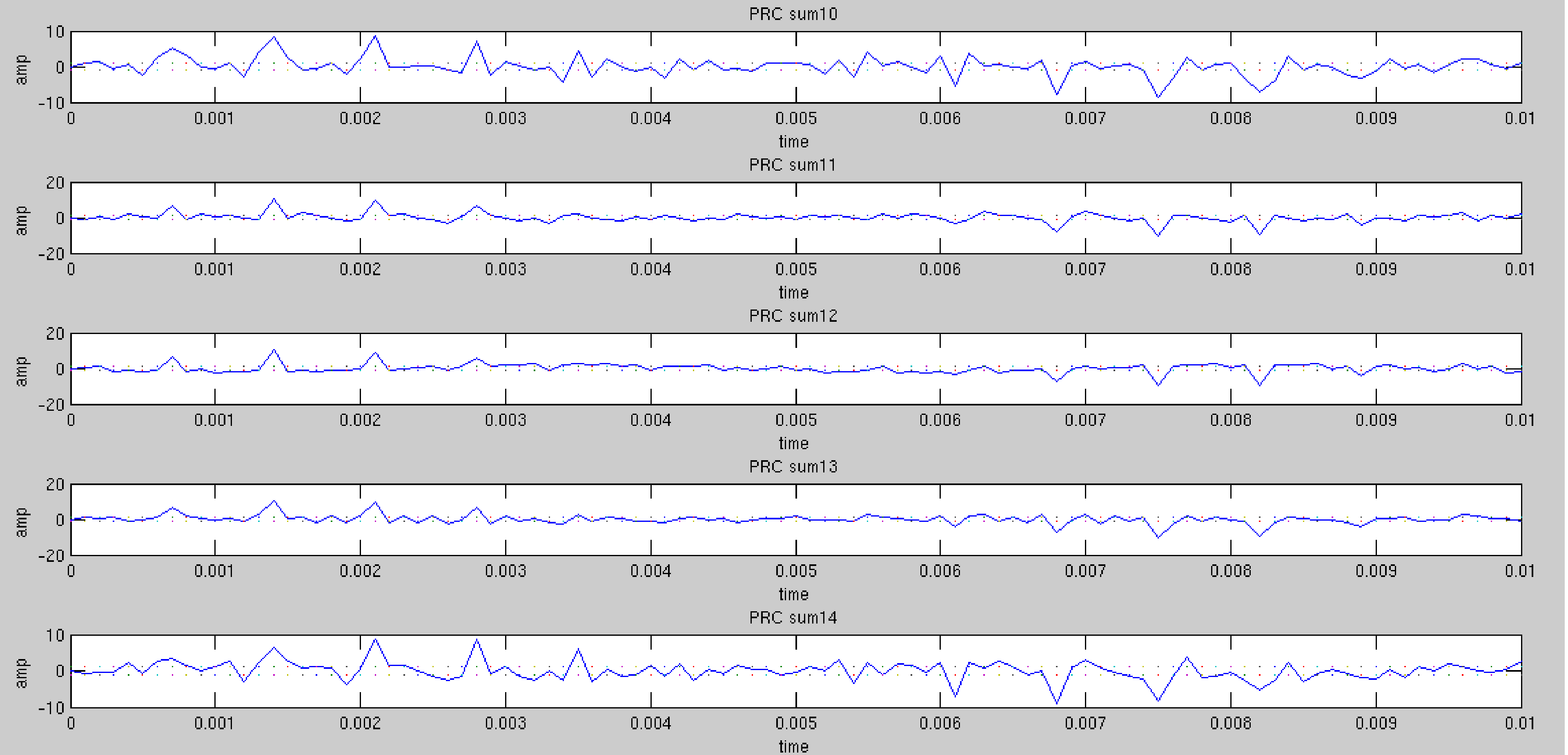
sum with no PRC
10
0
-10
amp
0
0.001
0.002
0.003
0.004
0.005
0.006
0.007
0.008
0.009
0.01
time
PRC sum1
20
0
-20
amp
time
PRC sum2
10
0
-10
amp
time
PRC sum3
10
0
-10
amp
time
PRC sum4
10
0
-10
amp
time

Results

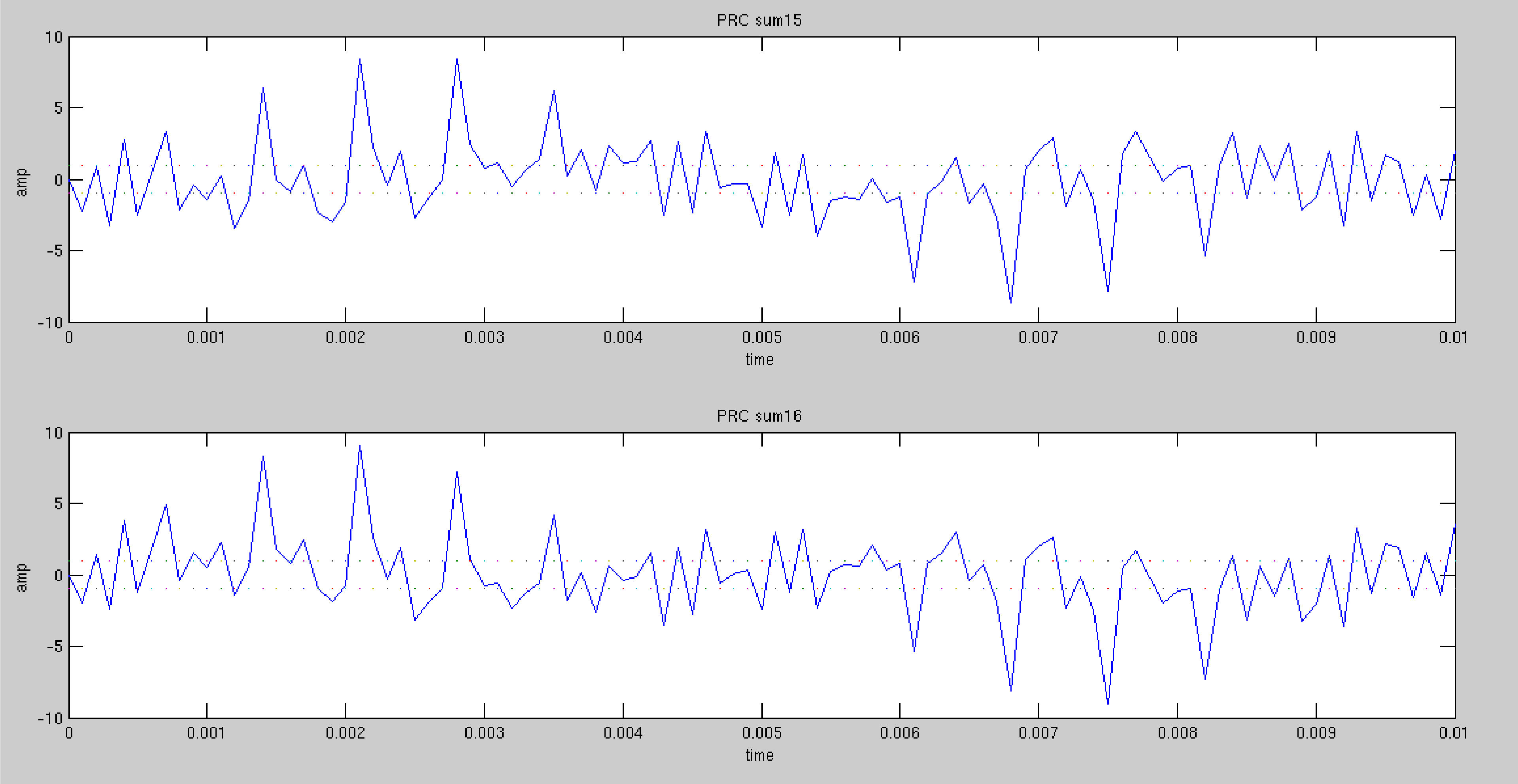


PRC sum5
PRC sum6
PRC sum7
PRC sum8
PRC sum9
amp
time
10
0
-10
0
0.001
0.002
0.003
0.004
0.005
0.006
0.007
0.008
0.009
0.01

Results


PRC sum10
PRC sum11
PRC sum12
PRC sum13
PRC sum14
amp
time
10
0
-10
20
-20
0.001
0.002
0.003
0.004
0.005
0.006
0.007
0.008
0.009
0.01

Results



Results

PAPR = 26.6393

PAPR1 = 29.29

PAPR2 = 25.8413

PAPR3 = 25.4080

PAPR4 = 21.6240

PAPR5 = 21.7348

PAPR6 = 25.4585

PAPR7 = 24.3934

PAPR8 = 23.6455

PAPR9 = 24.5452

PAPR10 = 22.8342

PAPR11 = 26.31

PAPR12 = 25.7989

PAPR13 = 26.0764

PAPR14 = 23.2783

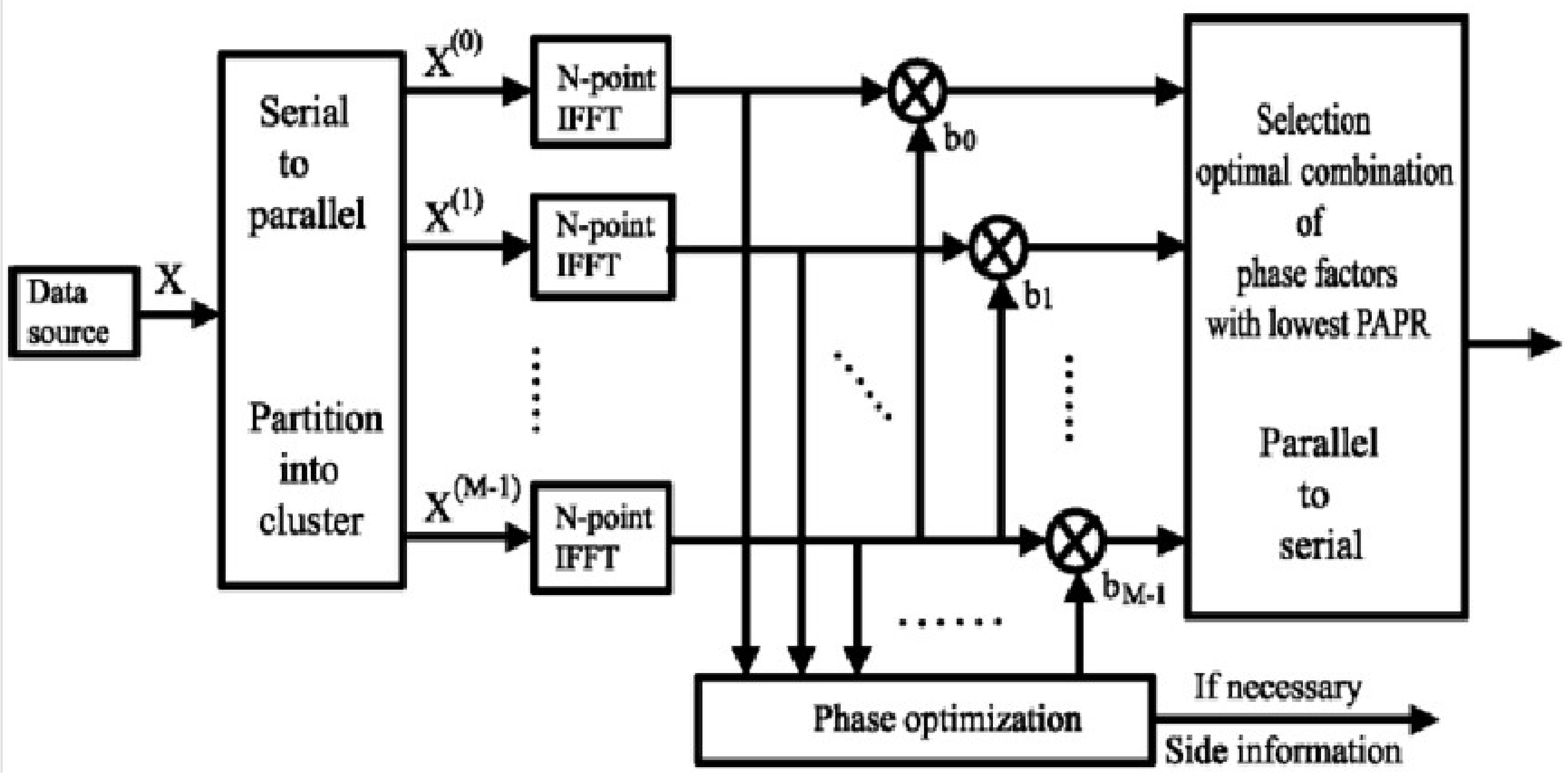
PAPR15 = 22.1395

PAPR16 = 23.4401

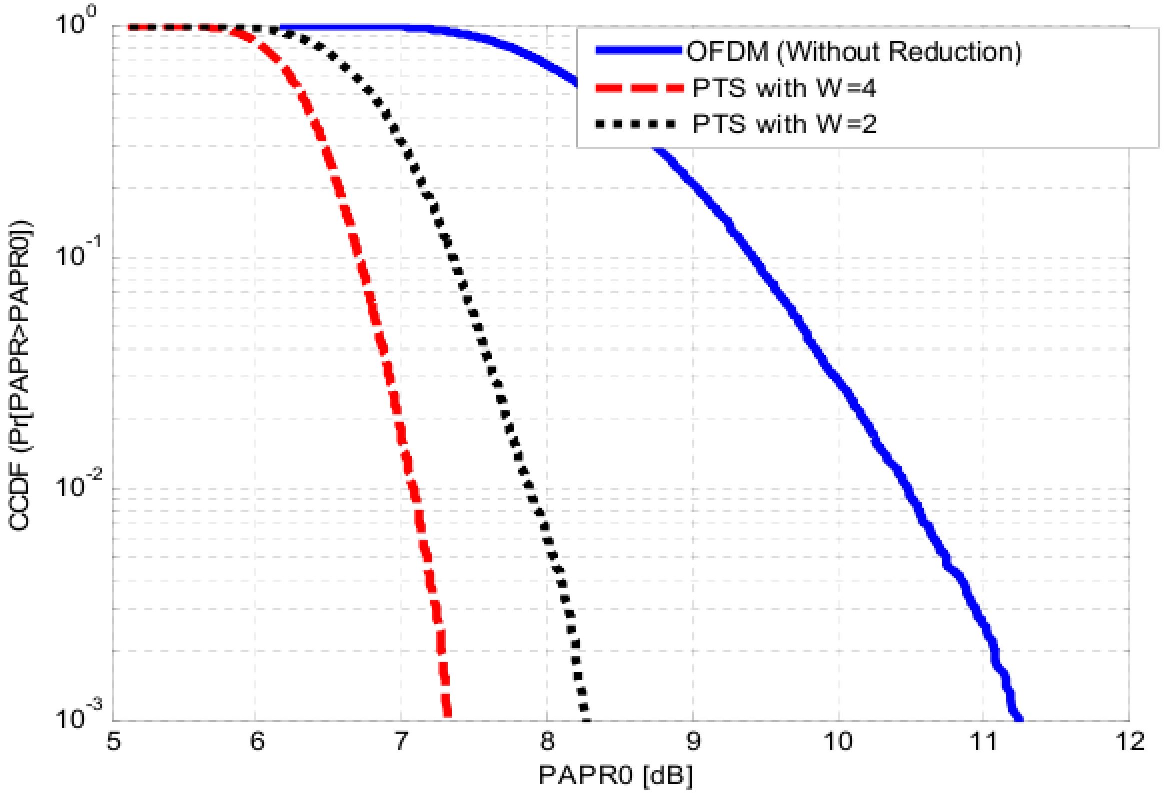
Partial Transmit Sequences

- Probabilistic based ← SLM
- Divide into Non-Overlapping sub block
- Sub carriers in each sub-block are weighted by phase factor for that sub-block
- Interleaved partition, adjacent partition, random partition
- No need to transmit SI → better performance

Block Diagram of PTS



Results



OFDM (Without Reduction)
PTS with W=4
PTS with W=2
CCDF (Pr[PAPR>PAPR0])
PAPR0 [dB]
10^0
10^{-1}
10^{-2}
10^{-3}
5
6
7
8
9
10
11
12

Conclusions

- Multi Carrier System – High Data Rate
- Effective Digital Modulation for wireless communications
- Major challenges – PAPR and ICI
- Optimum technique for PAPR Reduction
- Loss in data rate, transmit signal power, BER, Computational complexity – Major factors

References

[1] Arun Gangwar, Manushree Bhardwaj *An Overview: Peak to Average Power Ratio in OFDM system & its Effect*"International Journal of Communication and Computer Technologies, Vol 01-No.2, Issue:02 Sept 2012.

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[3] Ahmad R. S. Bahai, Burton R. Saltzberg, *Multi-carrier digital communications Theory and applications of OFDM*, Kluwer Academic / Plenum Publishers New York, Boston, Dordrecht, London, Moscow 1999.

[4] Nicola Marchetti, Muhammad Imadur Rahman, Sanjay Kumar, Ramjee Prasad, Chapter2. *OFDM: Principles and Challenges*.

[5] Dov Wulich, Lev Goldfeld, Gill R. Tsouri, *Peak to Average Power Ratio in Digital Communications.* IEEE Trasn. pp 779-782.