Simulation of OFDM Communication System

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Introduction

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    b. Statistical Model
2. OFDM Communication system
    a. Communication system structure
    b. Channel Equalization
    c. Channel Estimation: FD and TD
3. Synchronization
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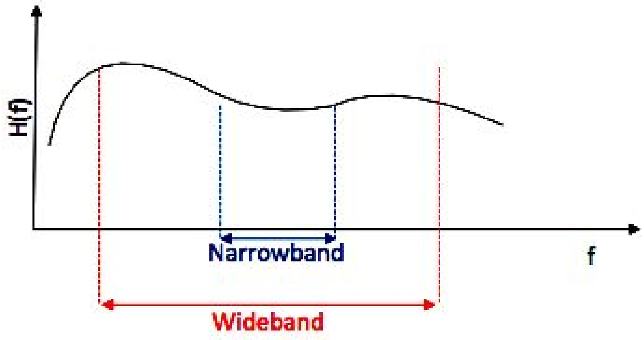
    b. Time shifting synchronization
4. SIMO
    a. Channel Modeling
    b. SIMO communicaiton system

Channel Modeling

Narrowband - Wideband

The first steps to define a channel models are:

- Comunication Sencenario
- Slow fading or Fast fading
    - coherenc bandwidth - symbol/frame duration
- **Narrowband or wideband model**
    - Coherence bandwidth - system bandwidth
    - Frequency domain -> flat fading / selective fading
    - Time domain -> MPC distinguishable



Channel Modeling - Narrowband

Interactive Objects (IOs) Definition:

$$h(\vec{r}) = \sum_{i=1}^{N} a_i e^{j\phi_i} e^{-j\vec{\beta}_i \vec{r}}$$

Statistical model

N-waves Model -> NLOS scenario -> Rayleigh distribution
1+N waves Model -> LOS scenario -> Rician distribution

K factor (Rician Distribution) = a_0^2 / Sum(a_i)^2
=> relative power of the LOS component compared to the mean power of MPC => fading decrease

Interference pattern for N-waves*

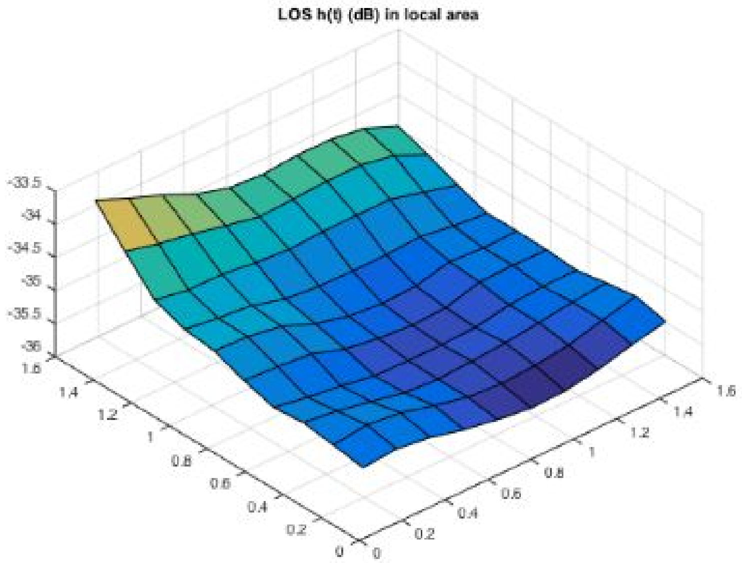


Figure 2: LOS $|h(t)|$ (dB) in XY plane

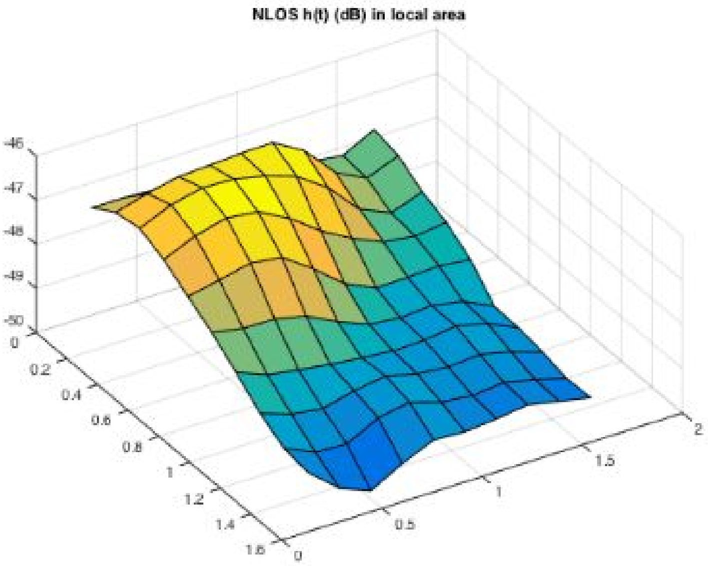


Figure 3: NLOS $|h(t)|$ (dB) in XY plane

Wideband Channel Model

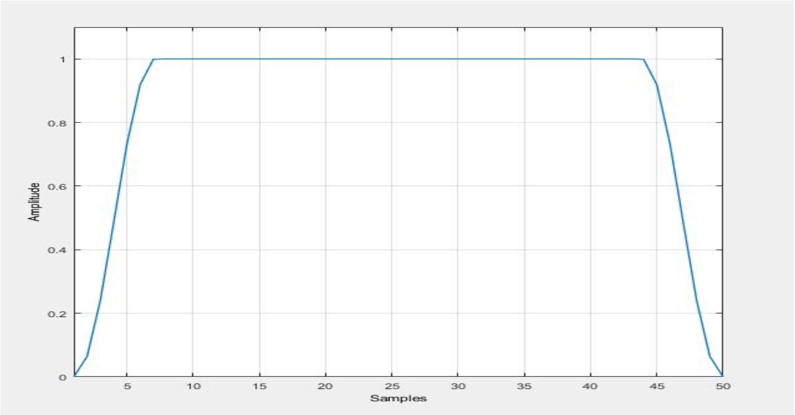
Frequency ⇔ Propagation Delay

Frequency Correlation ⇔ PDP(\tau)

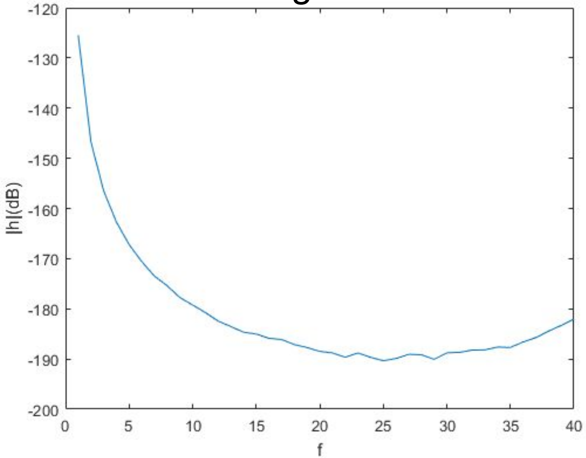
$$h(f) = \sum_{i=1}^{N} a_i \, e^{j\Phi_i} \, e^{-j2\pi f \, \tau_i}$$

Reduce bandwidth to 20MHz

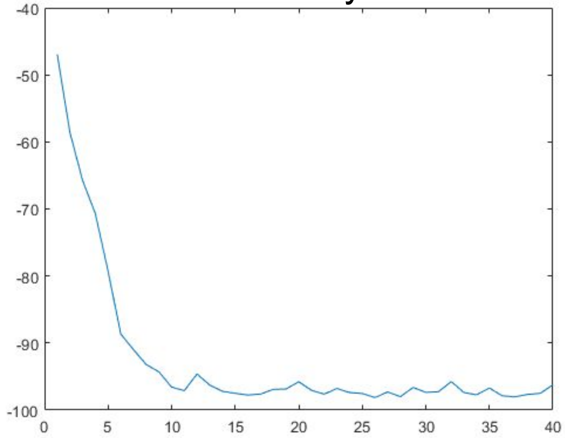
Applying Tuckey window instead of Rectangular window
=> Rect window -> causing discontinutiy in FD -> in TD (PDP) will show aliasing



Filter avec rectangular Window

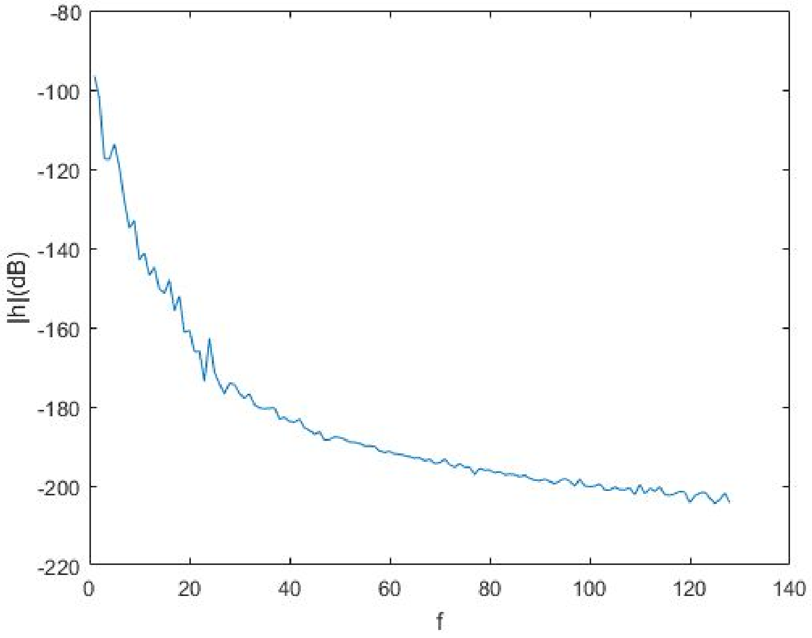


Filter avec Tuckey window

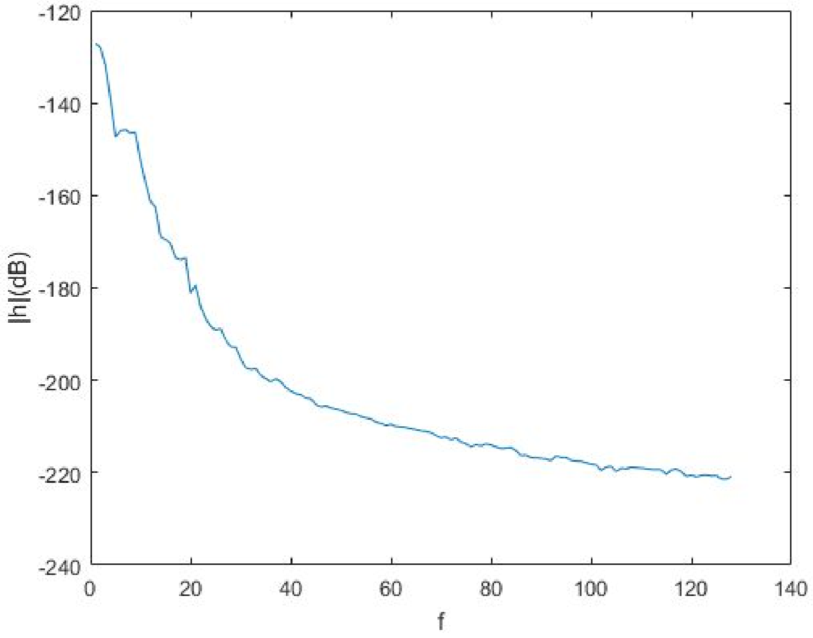


Power Delay Profile

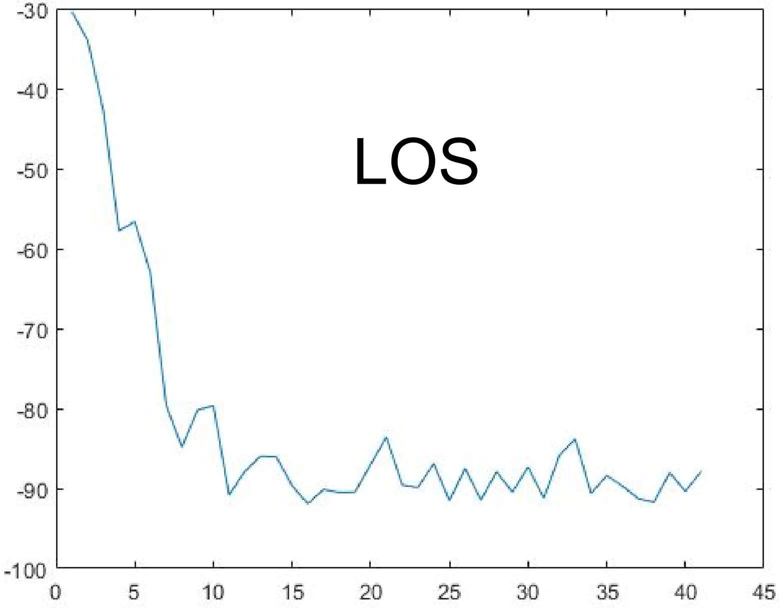
$$PDP(n) = \frac{1}{N}\sum_{i=1}^{N} |h_i(n)|^2$$



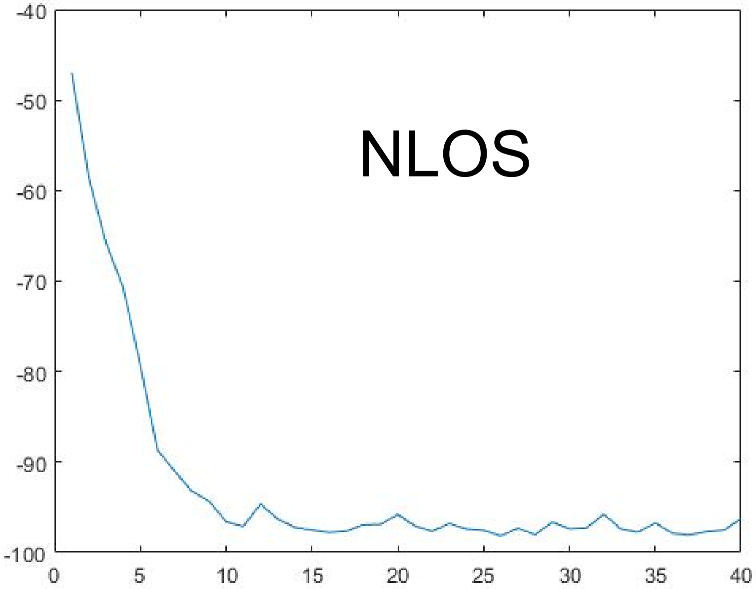
LOS



NLOS



LOS
-30
-40
-50
-60
-70
-80
-90
-100
0
5
10
15
20
25
30
35
40
45



NLOS
-40
-50
-60
-70
-80
-90
-100
0
5
10
15
20
25
30
35
40

Results

Modes	LOS	NLOS
σ_τ	1.4778e-8	2.0681e-8
Δf_c(Hz)	11088386.9204	7695686.3627

Table 1: the delay spread and coherence frequency for 200MHz

Modes	LOS(rec)	LOS(tuckey)	NLOS(rec)	NLOS(tuckey)
σ_τ	1.411e-7	3.0183e-08	1.7334e-07	2.8560e-08
$\Delta f_c(Hz)$	1127663.5984	5273077.7274	918154.0045	5572605.7692

Table 2: the delay spread and coherence frequency for filtered signal

Taps	1	2	3	4	5	6
K	4.0055	2.8696	1.1078	1.9071	1.1713	1.3041

Table 4: the Rice factor K in wideband

SIMO Channel

Beamforming

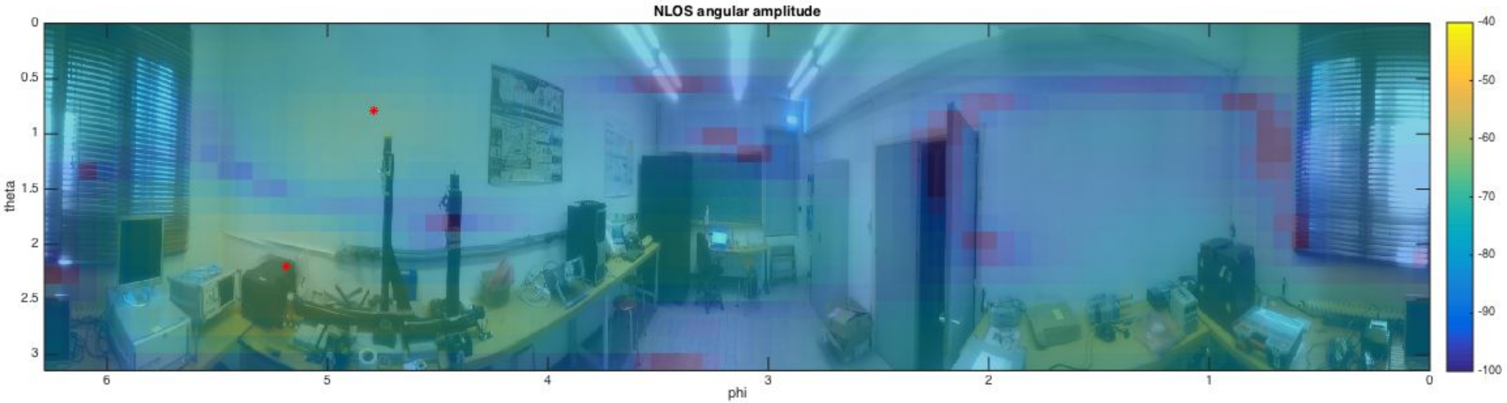
Measuring the angular distribution in 3D

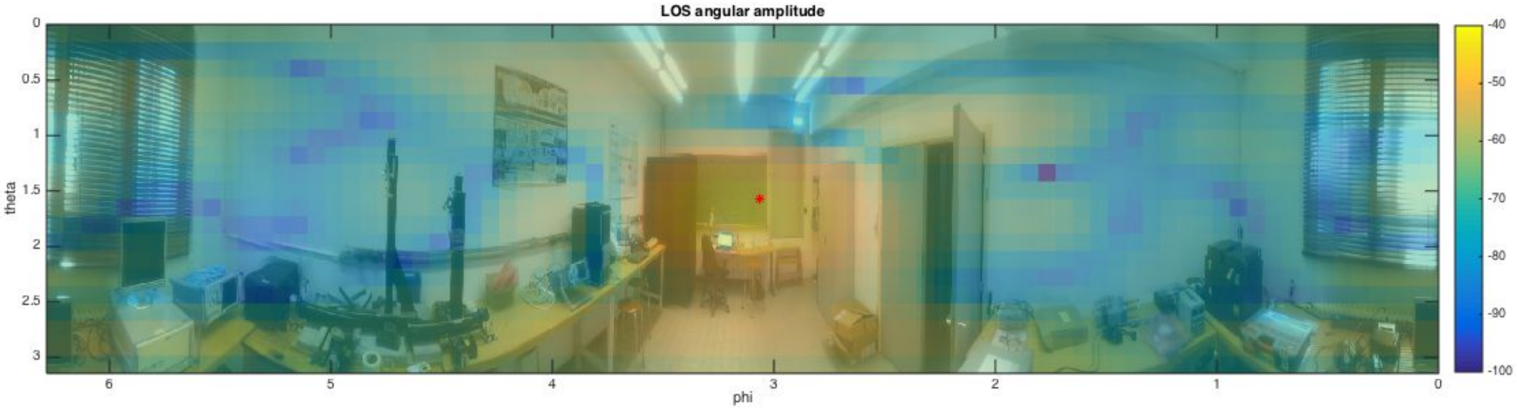
$$h_i(n) = \sum_k a_k e^{j(\phi_k - \vec{\beta}_k \vec{r}_i)}$$

$$B_i(\theta, \varphi) = e^{-j\vec{\beta}_{(\theta,\varphi)}\vec{r}_i}$$

$$a_n(\theta, \varphi) = \frac{\sum_i h_i(n) B_i^*(\theta,\varphi)}{\sum_i |B_i(\theta,\varphi)|^2}$$

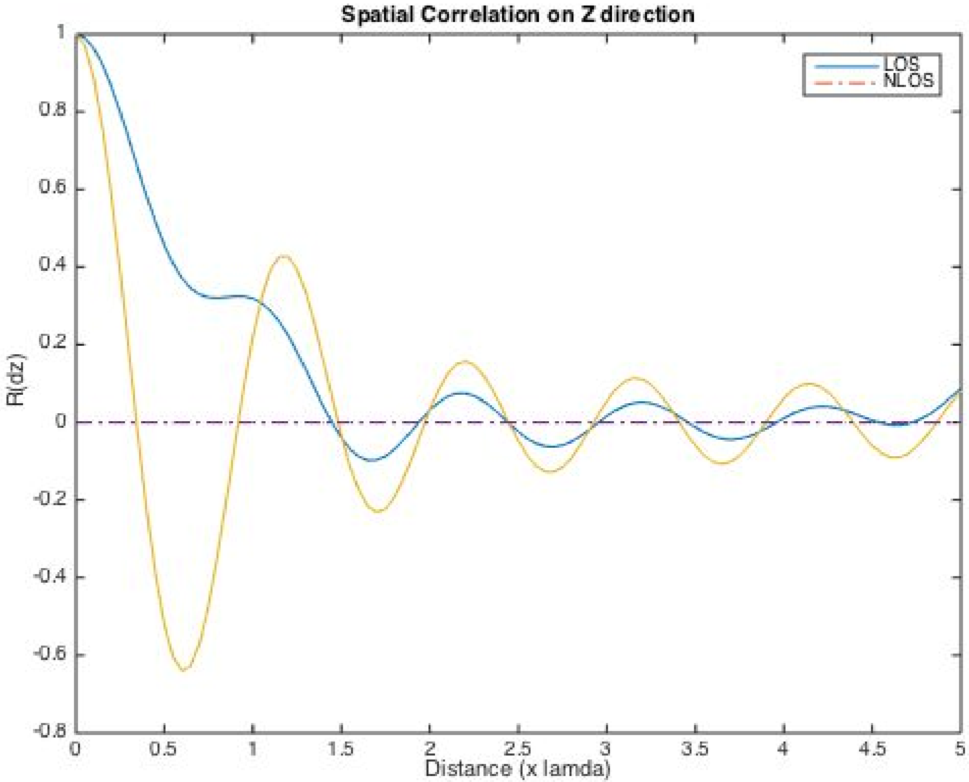
LOS and NLOS a(\theta, \phi)



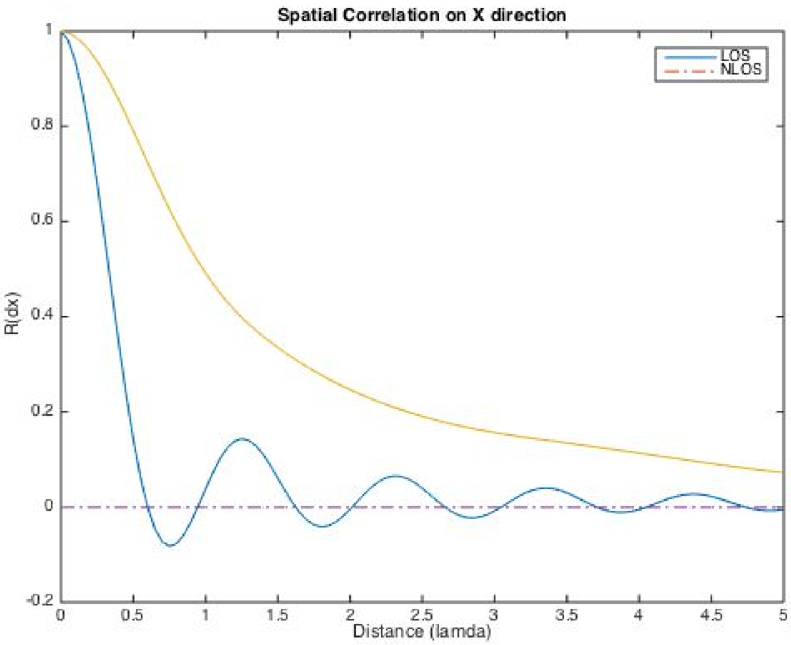


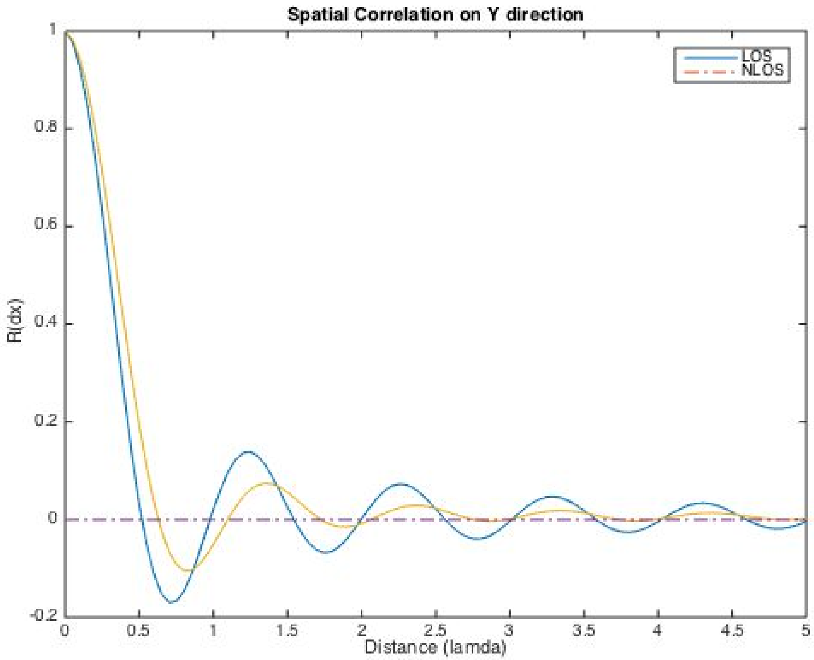
Spatial Correlation

- Spatial Correlation and angular spectrum are a pair of FT transform
- In N-waves model, R(dz) ~ Bessel(lamda)
  - Clarke model: coherece distance ~ 0.5 lamda



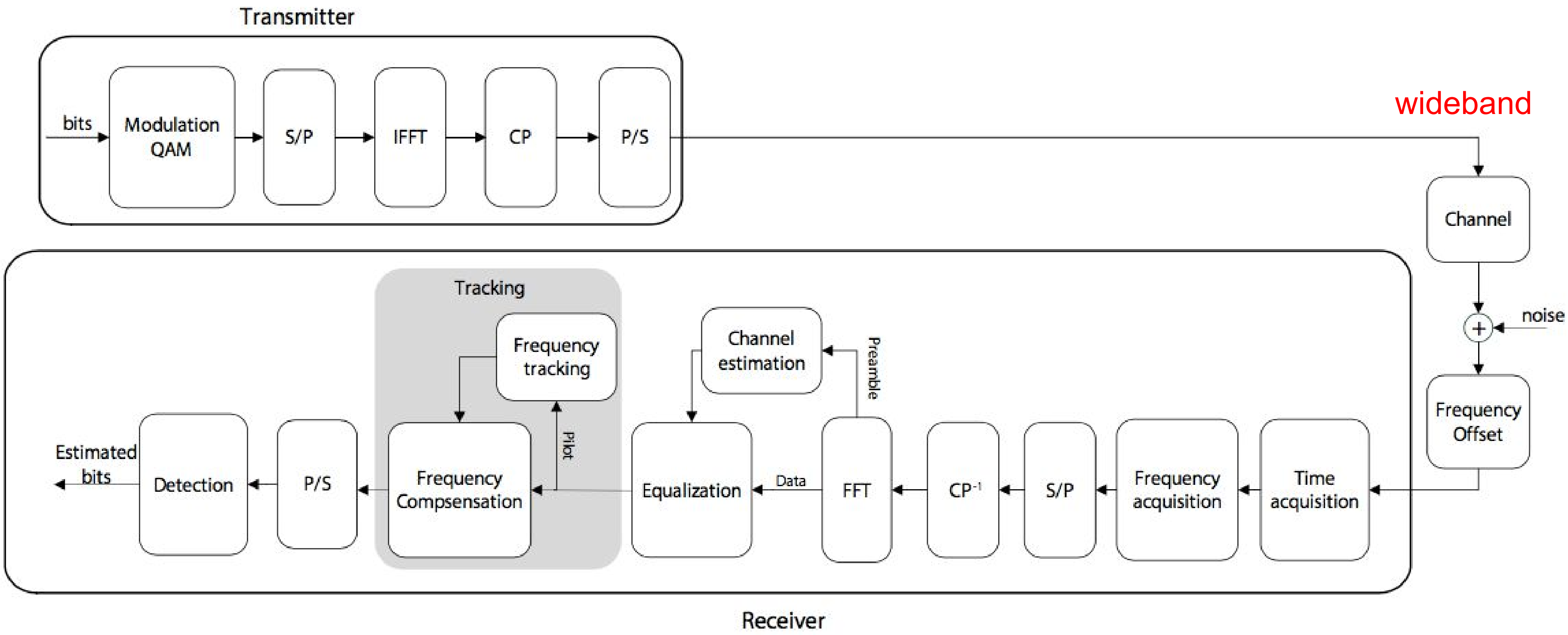
Spatial correlation for narrowband model





OFDM Communicatin System

System Structure

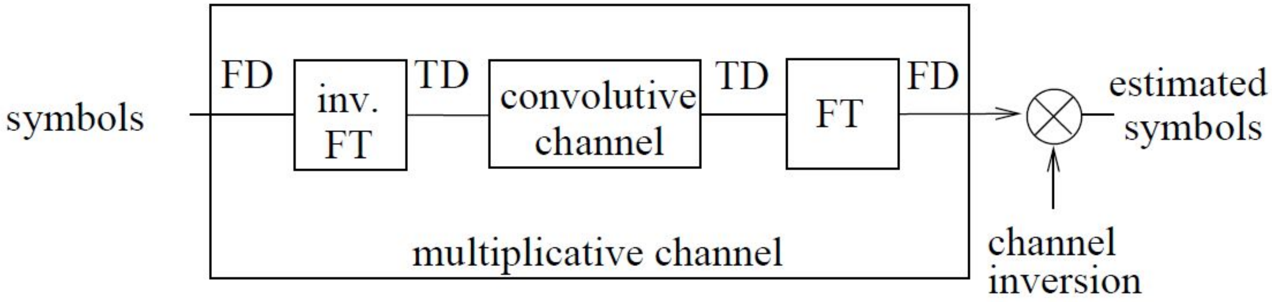


Equalization-----compensate ISI

Zero-forcing equalizer:

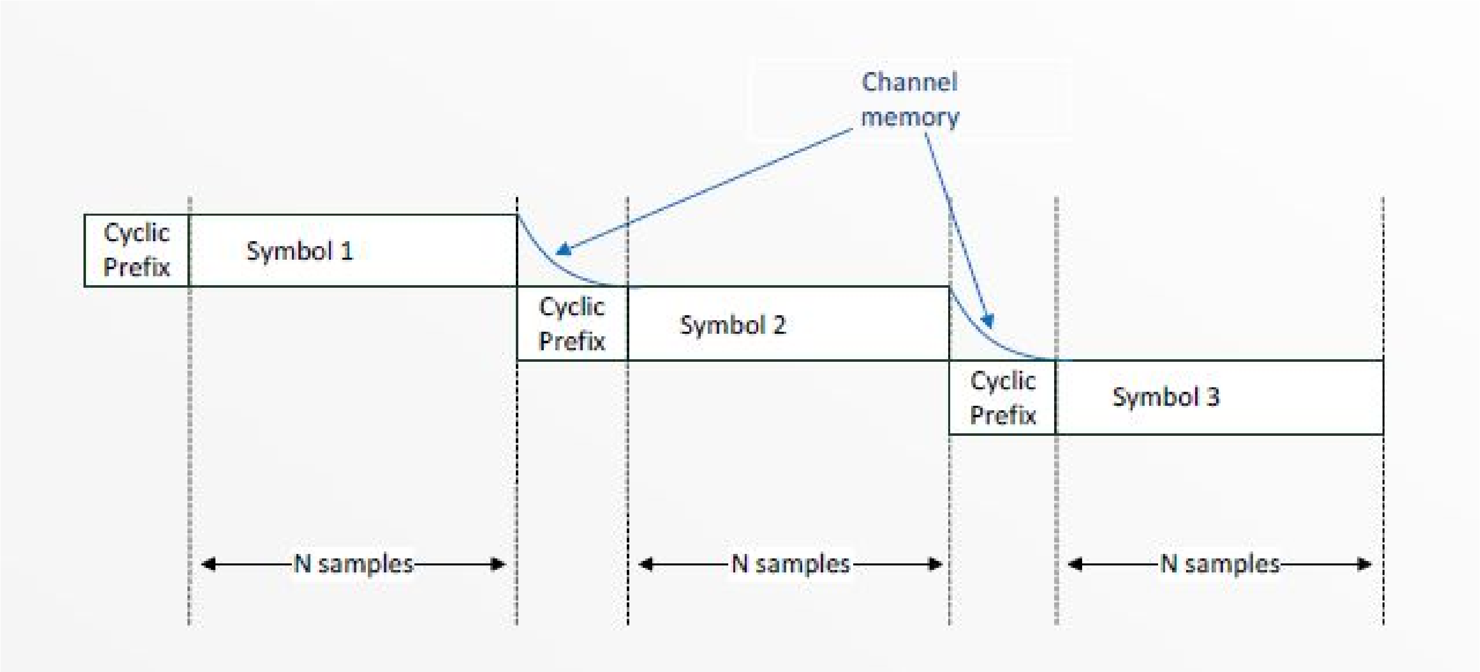
$$F_{ZF} = (H^H \cdot H)^{-1} \cdot H^H$$

Orthogonal Frequency Division Multiplexing (OFDM) :



Periodic signal is needed.

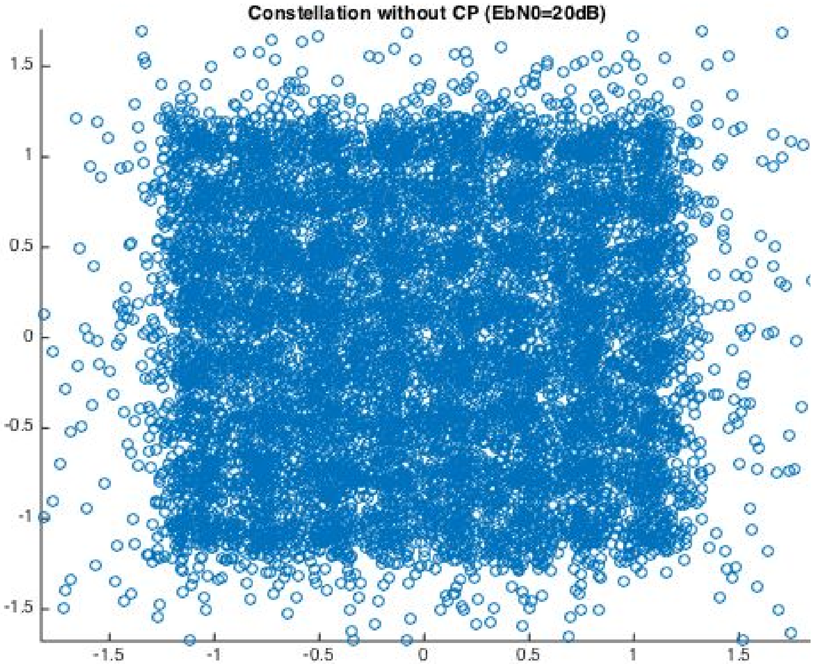
Cyclic Prefix

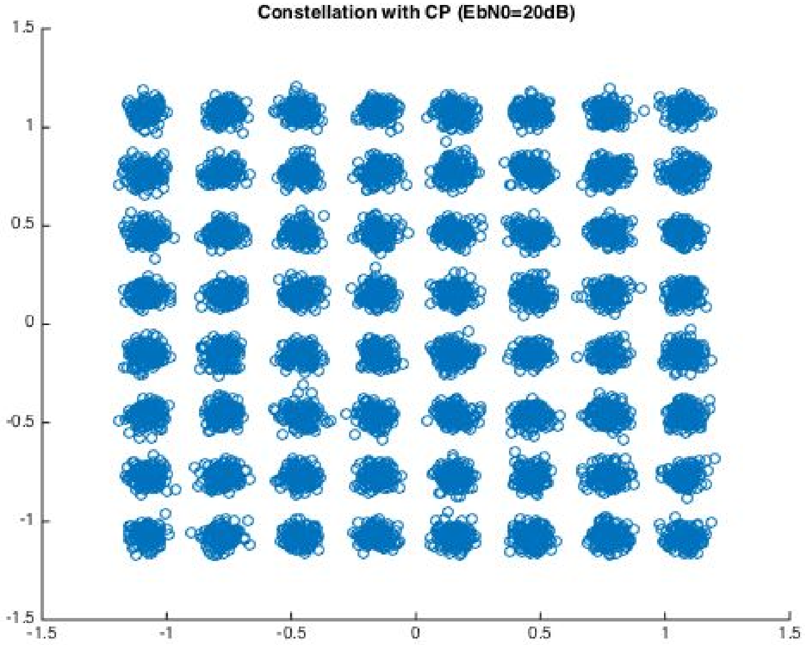


Making the block periodic which ensures the orthogonality

Mitigation the channel memory corruption

Cyclic Prefix





Constellation with/without CP

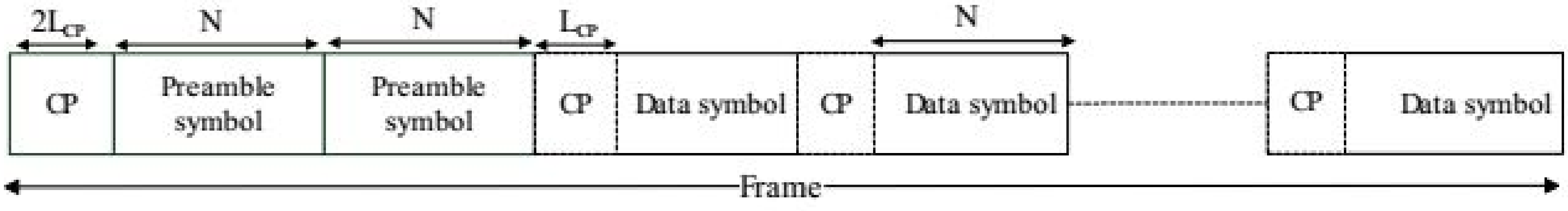
The procedure of equlization

Equalizer

Equalization

H ?

Preamble!!!



Channel Estimation - Freq Domain

Channel estimation:

$$\widehat{H}(k) = \frac{R'(k)}{S'(k)} = H(k) + \frac{W(k)}{S'(k)}$$

Accuracy assessment:

$$NMSE = \frac{\sum_k |\widehat{H}(k) - H(k)|^2}{\sum_k |H(k)|^2}$$

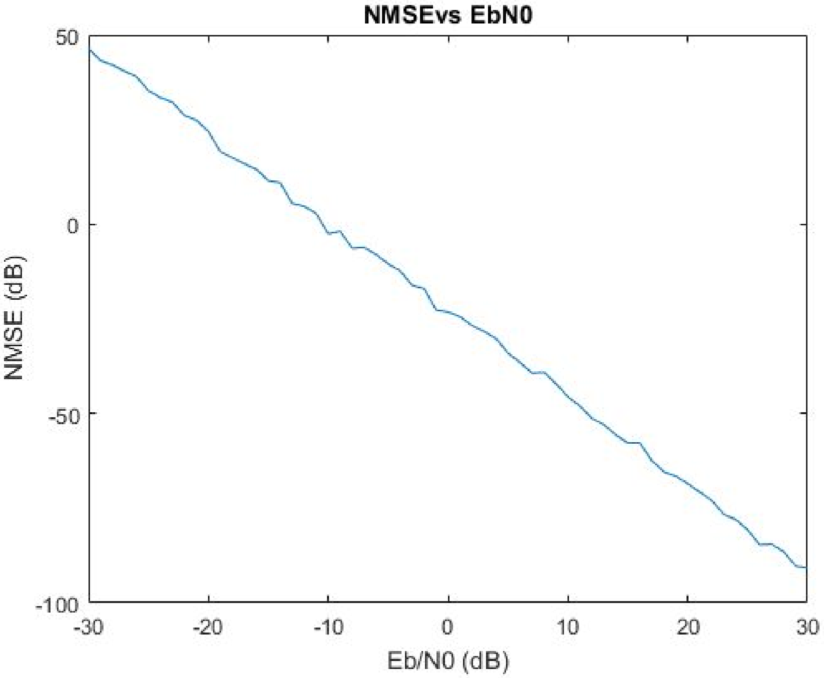
ZF estimator limitation

$$F_{ZF} = (H^H \cdot H)^{-1} \cdot H^H$$

$$\begin{aligned}\underline{\underline{R}}_{\epsilon} &= E\left[(\underline{I} - \hat{\underline{I}}_{ZF}) \cdot (\underline{I} - \hat{\underline{I}}_{ZF})^H\right] \\ &= 2N_0 \left(\underline{\underline{H}}^H \cdot \underline{\underline{H}}\right)^{-1}\end{aligned}$$

Amplifies the noise significantly at the frequencies where the channel attenuation is high

Channel Estimation - Freq Domain



NMSE vs EbN0

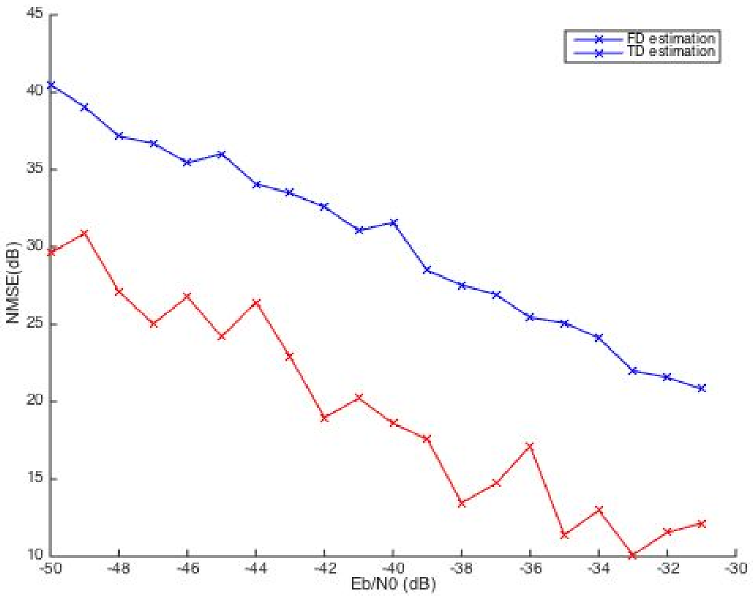
BER vs EbN0

Channel Estimation - Time Domain

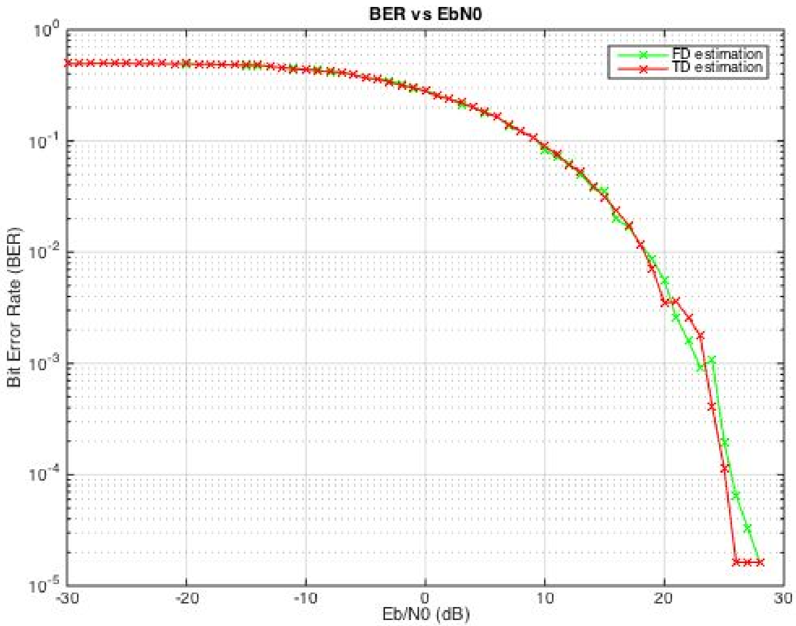
$$\hat{h} = r \backslash s$$

$$s = \begin{bmatrix} s_0 & \cdots & s_{L-1} \\ \vdots & \ddots & \vdots \\ s_{N-1} & \cdots & s_{N+L-1} \end{bmatrix}$$

Channel Estimation - Time Domain



NMSE vs EbN0



BER vs EbN0

Time domain channel estimation

When the channel is estimated in the frequency domain, Q channel coefficients are estimated independently based on the observation of a vector of size Q

However the channel frequency response is fully determined by the $L << Q$ time domain channel coefficients:

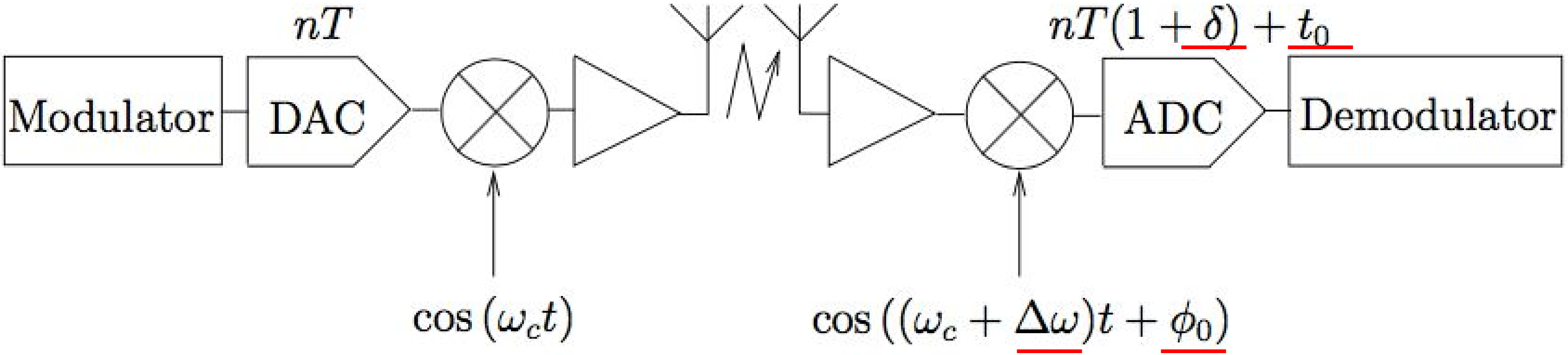
$$\underline{h}^F = \sqrt{Q}\,\underline{\underline{\bar{F}}}_Q \cdot \underline{h}$$

Therefore it is more efficient to estimate directly the channel in the time domain because the corresponding system benefits from the redundancy in the received vector

Ref: lecture notes

Synchronization

Synchronization challenges



Frequency synchronization: phase shift, carrier frequency offset (CFO)

Time synchronization: sample clock offset (SCO), time shift

Frequency synchronization

$$r_p = \sum_{q=-Q/2}^{Q/2-1} I_q^F h_q^f \gamma_q^0 \gamma_{p,q} + z_p^F$$

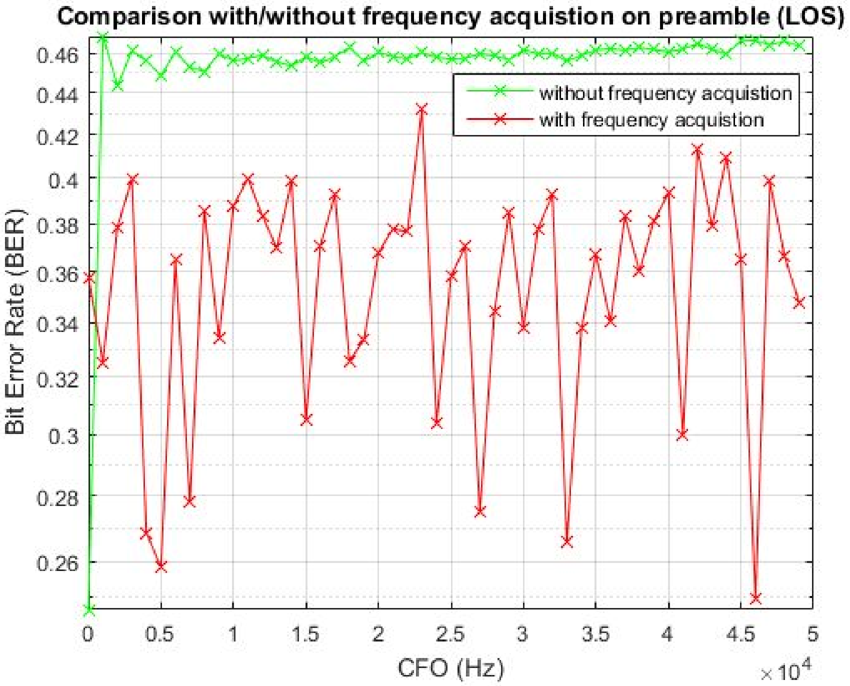
CFO acquisition based on preamble:

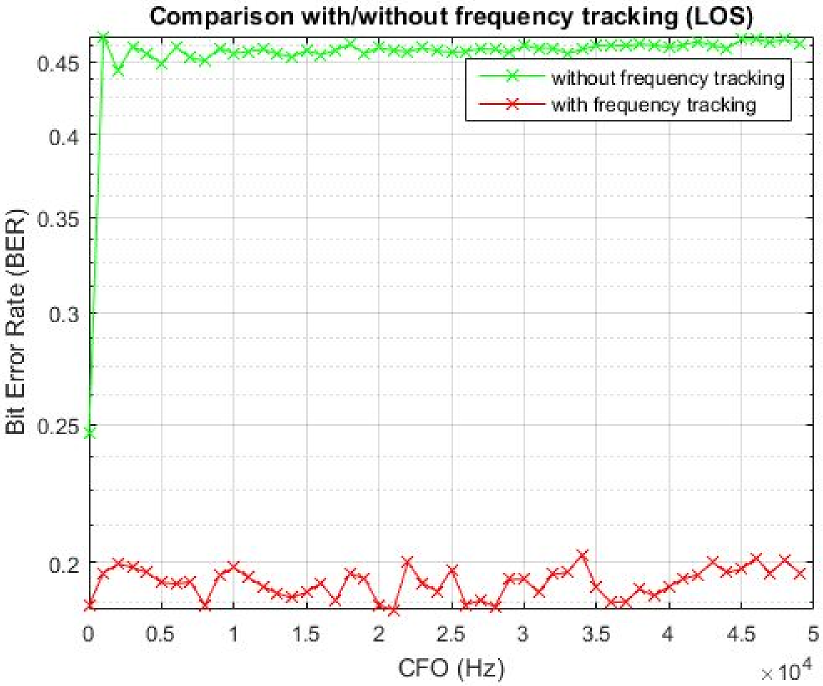
Rough estimation, $[-\frac{1}{2NT}, \frac{1}{2NT}]$

Phase tracking based on pilot sub-carriers:

4 pilot subcarrier {-21 ; -7 ; 7 ; 21}

Frequency synchronization

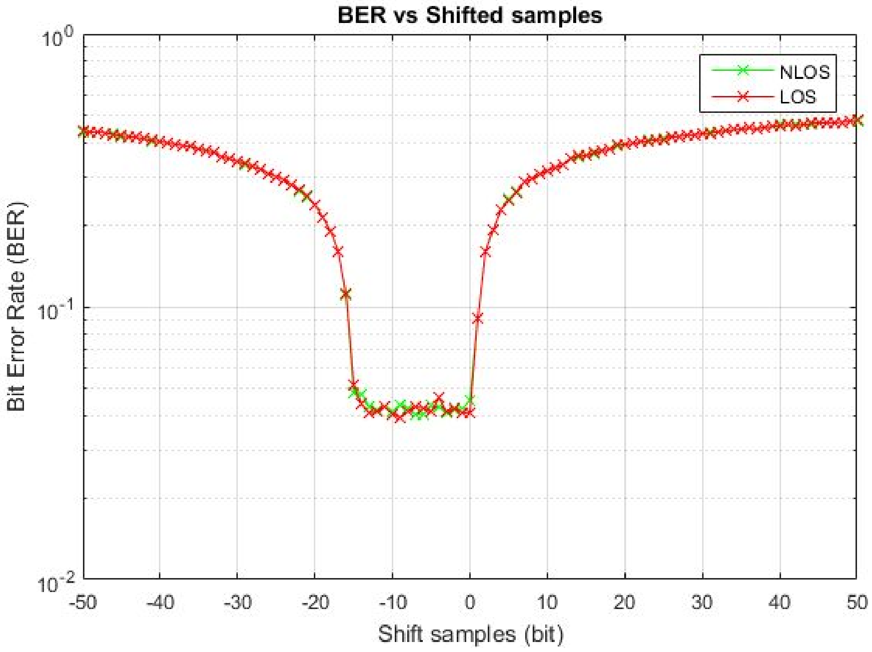




BER vs CFO

Time synchronization

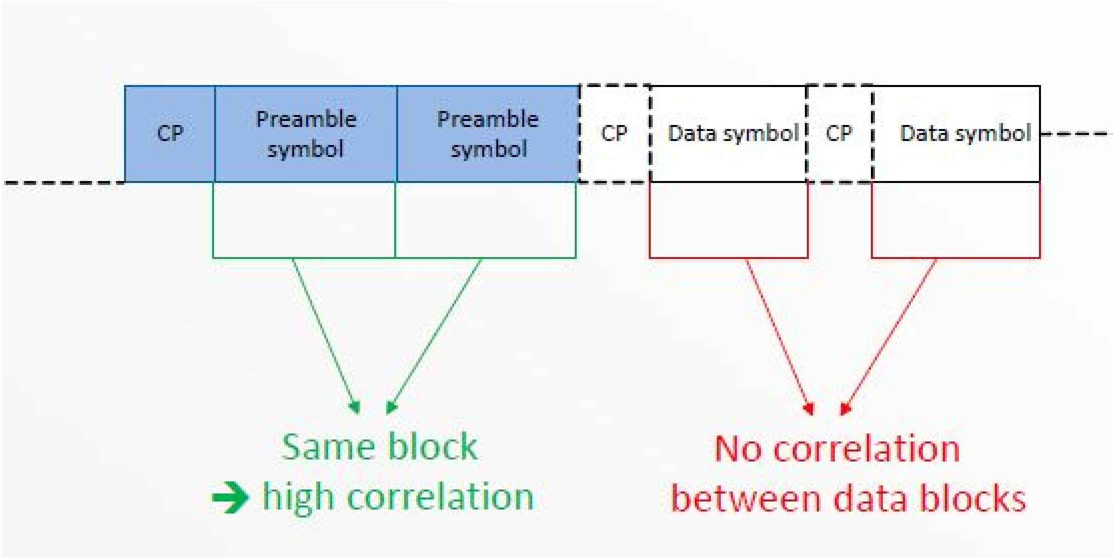
$$r_p = \sum_{q=-Q/2}^{Q/2-1} I_q^F h_q^f \gamma_q^0 \gamma_{p,q} + z_p^F$$



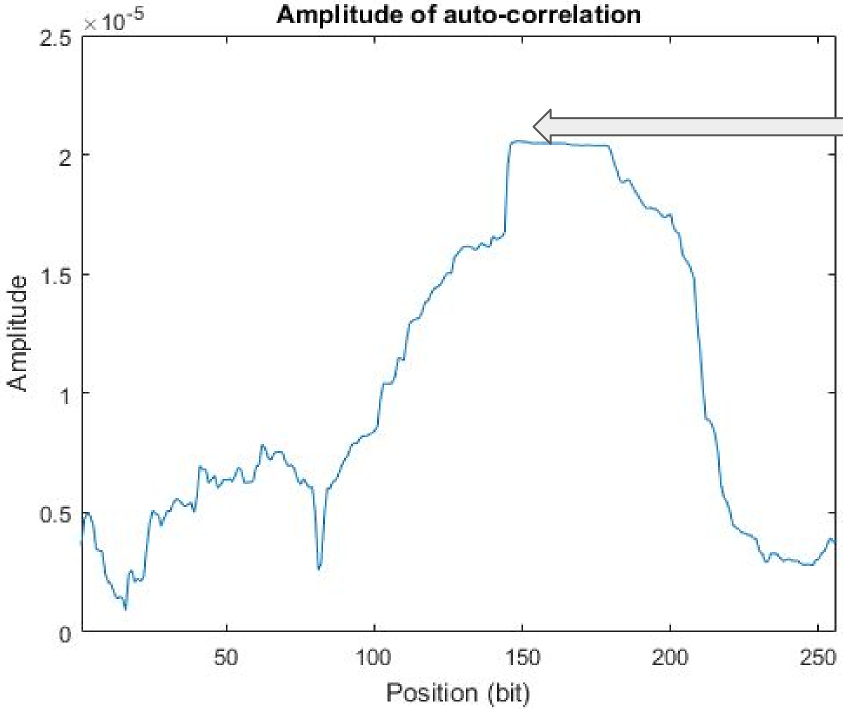
Auto-correlation:

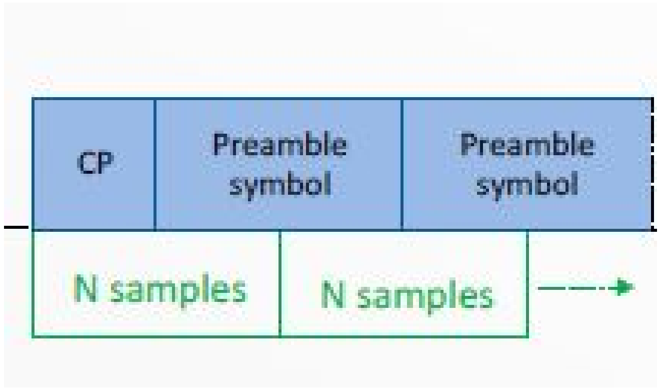
$$\hat{n} = \max_{n} p(r_{n+N} | r_n, x_{n+N} = x_n)$$

is applied to estimate the time of arrival.



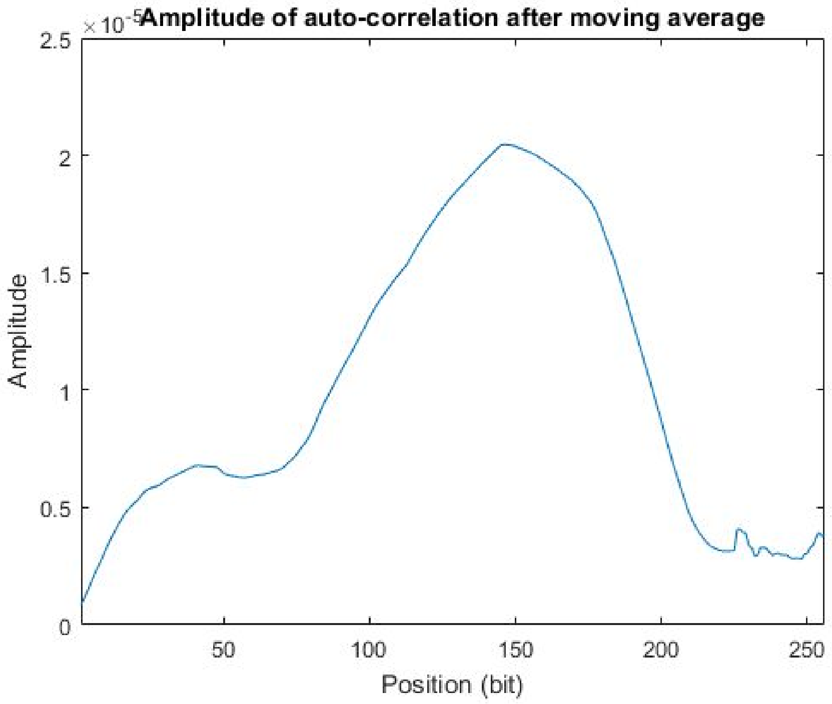
Time synchronization



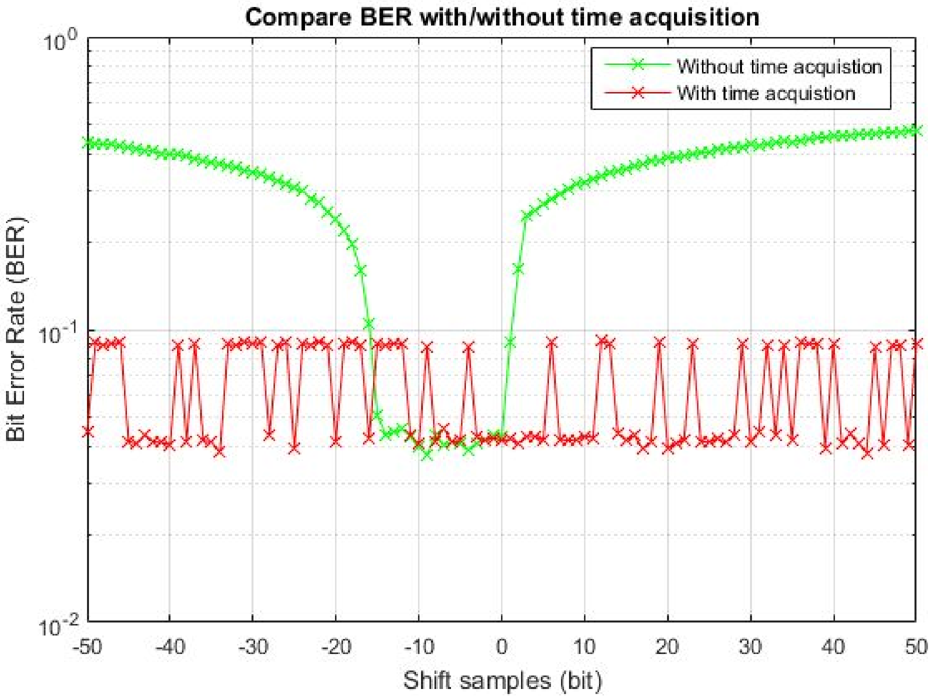


Amplitude of auto-correlation

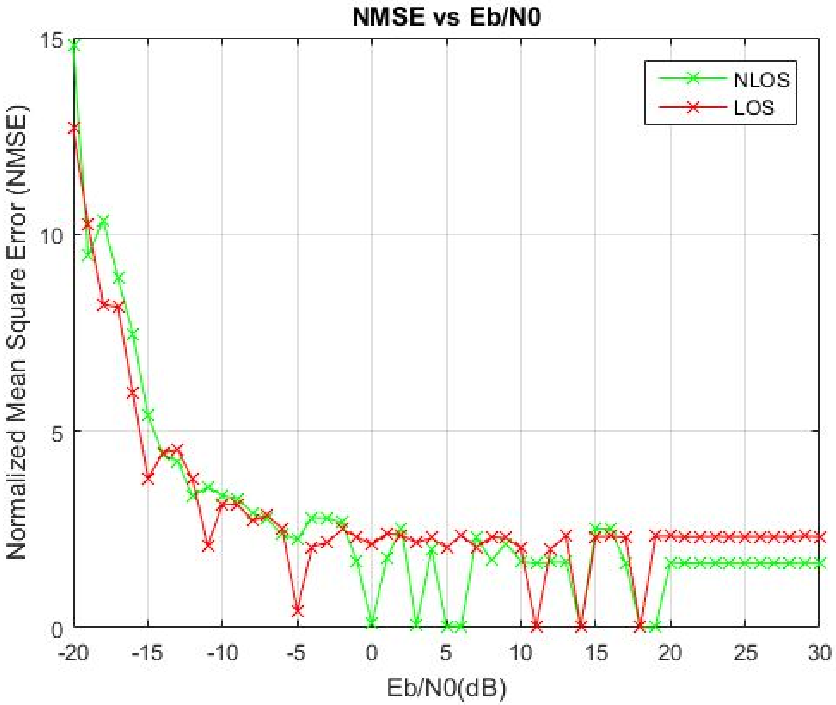
Modified Auto-correlation



Time synchronization



BER with/without time acquisition



NMSE vs EbN0

SIMO Communication System

SIMO System

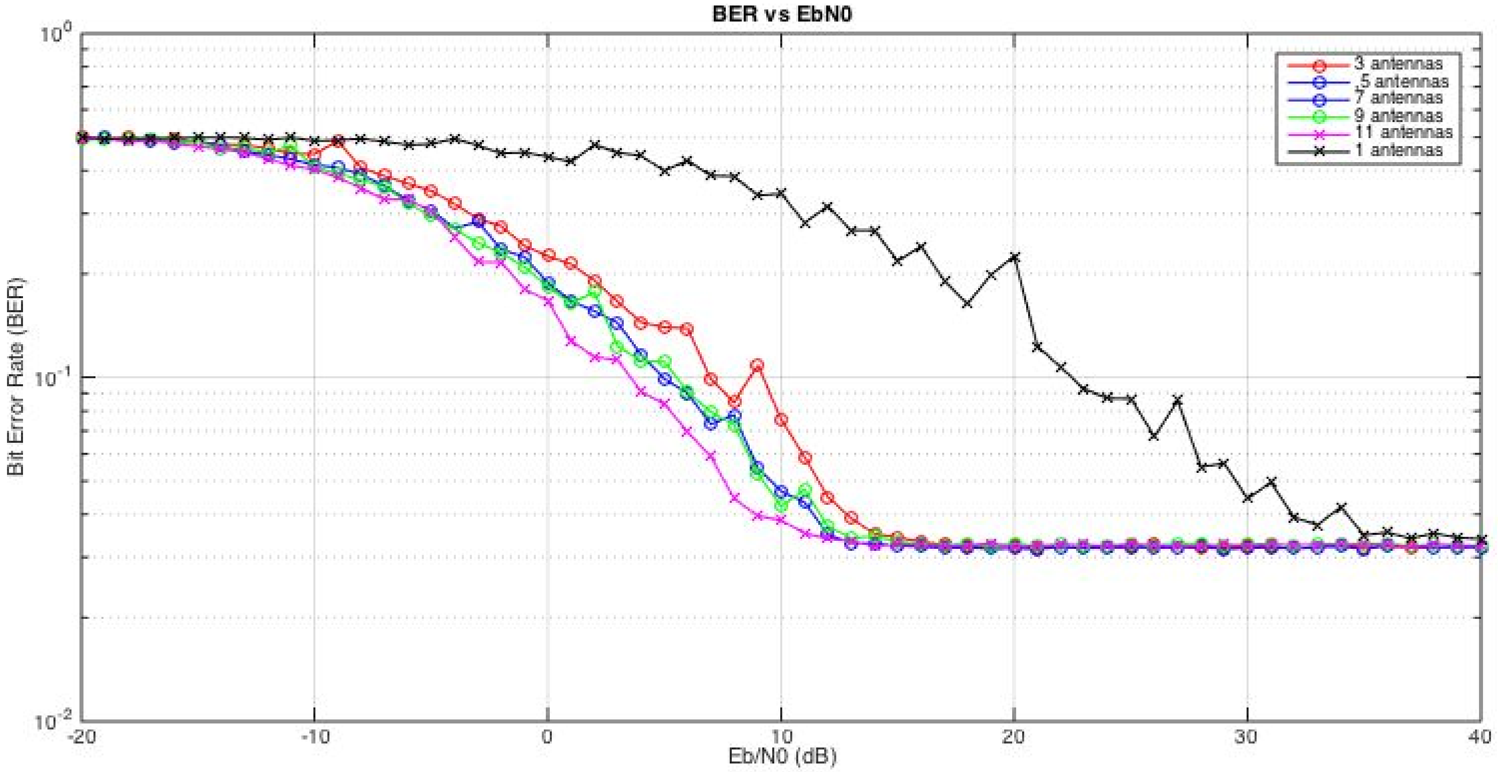
Maxiumu Ration Combination: $$\hat{\mathbf{s}}(q) = \sum_{i=1}^{N_{\mathrm{rx}}} \frac{\mathbf{h}_i^{F*}(q)\mathbf{r}_i^F(q)}{\sum_{j=1}^{N_{\mathrm{rx}}} |\mathbf{h}_j^F(q)|^2} \qquad q = 1, 2, ..., N$$

Notes:

1. MRC is maximum the SNR compared with the equal weighted combination or simply pick the best SNR signal. (Proof (Cauchy-Schwarz) available on the report)

2. CFO and TOA is the same for each received signal, since the receiver is synchronized by one local oscillator

Performance Comparison



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Extra Slides