Blind ZP-OFDM Parameter Estimation in Frequency Selective Channels

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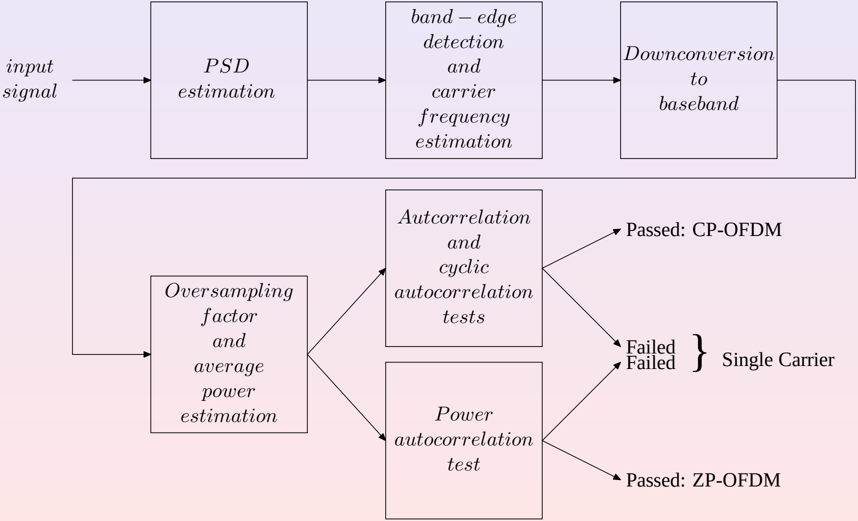
Introduction

- Aim: Blind parameter estimation of multi-carrier modulations in frequency selective channels with phase and frequency offsets
- State of the art:
  - Single-carrier modulations [Dobre07]
  - Orthogonal Frequency Division Multiple Access with a Cyclic Prefix (CP-OFDM) time guard interval (Wifi, WiMax)
    - Mixed moments [Wang05]
    - 4th order cumulants [Akmouche99][Grimaldi07]
    - Autocorrelation and cyclic autocorrelation [Bolcskei01][Punchihewa07][Ishii05][Li06][Shi07]
- Orthogonal Frequency Division Multiple Access with a Zero Padding (ZP-OFDM) time guard interval (WiMedia)
  - Original contribution: Proposition of the power autocorrelation feature in frequency selective channels with phase and frequency offsets

Introduction

- Proposed block scheme



Introduction

- Estimation of the carrier frequencies f_c^i, $i = 0 \ldots N_s - 1$ with N_s the number of signals present in the observed spectrum
  - Non-parametric approach based on a Fast Fourier Transform (FFT) [Yucek06]
  $$\mathbf{S} = |FFT(\mathbf{s})|^2 \tag{1}$$
  with $\mathbf{s}$ the received sampled data stream $\mathbf{s} = [s(0) \ldots s(N-1)]^T$ and $\mathbf{S}$ the Power Spectral Density (PSD)
  - The band-edges B_{low}^i and B_{high}^i, $\forall i = 0 \ldots N_s - 1$ are detected with a threshold between the noise level and the signal level driven by the sensitivity of the receiver.
  - The carrier frequencies are then estimated as:
  $$f_c^i = \frac{B_{low}^i + B_{high}^i}{2} \quad i \in [0 \ldots N_s - 1] \tag{2}$$

Introduction

- Assuming that the carrier frequencies f_c^i, $i = 0 \ldots N_s - 1$ have been estimated, then each individual signal of interest is downconverted to baseband.The digital baseband signal can then be modeled as a received sequence $\mathbf{y} = [y(0) \ldots y(N-1)]^T$ of length N such that:

$$y(i) = e^{j(2\pi\epsilon i+\phi)} \sum_{l=0}^{L-1} h(l)x(i-l) + n(i) \quad i \in [0 \ldots N-1] \tag{3}$$

where $\mathbf{x} = [x(0) \ldots x(N-1)]^T$ is the vector of N transmitted symbols which have been oversampled by a factor q, h_l's are the oversampled multipath channel coefficients with L the number of channel taps, $\mathbf{n} = [n(0) \ldots n(N-1)]^T$ is the vector of Additive White Gaussian Noise (AWGN), ϕ the phase offset, and ϵ the frequency offset.

Introduction

- Estimation of the oversampling factor q (corresponds to the ratio between the sampling rate of the receiver and the sampling rate of the transmitter) and the signal power p:
  - PSD of the desired signal also by FFT [Shi07]

$$\mathbf{Y} = |FFT(\mathbf{y})|^2 \tag{4}$$

  - We design a target filter (with the total energy $A = sum(\mathbf{Y})$) as:

$$\mathbf{Y}_i^{target} = [A/(2*i)*ones(i), zeros(N-2*i), A/(2*i)*ones(i)] \tag{5}$$

  - Exhaustive search on the following optimization problem:

$$\min_i(\mathbf{Y} - \mathbf{Y}_i^{target})^2 \tag{6}$$

  - The upsampling factor q is defined as:

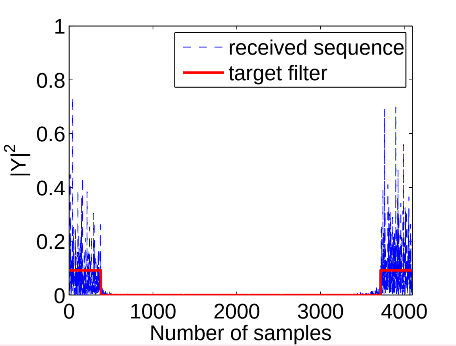
$$q = \frac{N}{2i_{opt}} \tag{7}$$

  - The estimated signal power p is defined as:

$$p = \frac{A}{2i_{opt}} \tag{8}$$

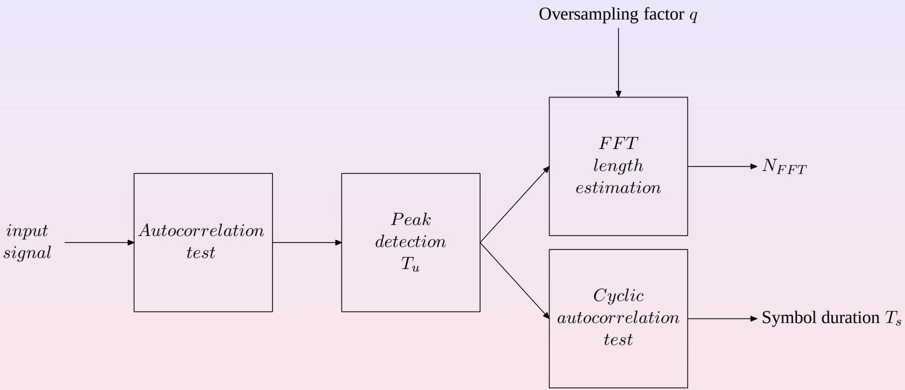
Introduction

- Example using real measured data



- The estimated upsampling factor is $q = 5.39$
- The estimated PSD is $p = 0.0916$

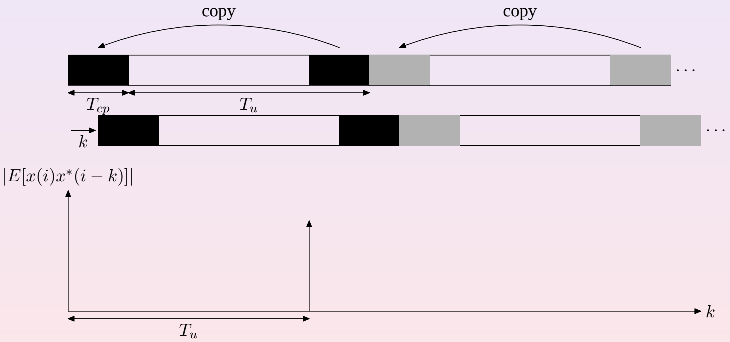
Blind Parameter Estimation of CP-OFDM



Blind Parameter Estimation of CP-OFDM

- Autocorrelation of the transmitted sequence

$$E[x(i)x^*(i-k)] = \frac{1}{N}\sum_{i=0}^{N-1} x(i)x^*(i-k) \quad k \in [0 \ldots N-1] \tag{9}$$



- A peak in the autocorrelation function can be observed at delay T_u corresponding to the useful symbol duration.

Blind Parameter Estimation of CP-OFDM

- Autocorrelation of the received sequence

$$r(k) = \frac{1}{N}\sum_{i=0}^{N-1} y(i)y^*(i-k) \quad k \in [0 \dots N-1] \tag{10}$$

$$r(k) = \begin{cases} \sum_{l=0}^{L-1} |h(l)|^2\sigma_x^2 + \sigma_n^2 & k = 0 \\ e^{j2\pi\epsilon T_u}\sum_{l=0}^{L-1} |h(l)|^2\frac{T_{cp}}{T_s}\sigma_x^2 & k = T_u \\ e^{j2\pi\epsilon k}\sum_{l=0}^{L-1} h(l+k)h^*(l)\sigma_x^2 & k = 1, \dots, L-1 \\ e^{j2\pi\epsilon k}\sum_{l=0}^{L-1} h(l+k-T_u)h^*(l)\frac{T_{cp}}{T_s}\sigma_x^2 & k = T_u + (1, \dots, L-1) \\ 0 & otherwise \end{cases} \tag{11}$$

Blind Parameter Estimation of CP-OFDM

- Knowing the oversampling factor q and the useful symbol duration T_u, we can determine the FFT size

$$N_{FFT} = \frac{T_u}{q} \tag{12}$$

- Knowing the useful symbol duration, we can then determine the symbol period T_s by the cyclic autocorrelation [Bolcskei01]

$$C^{\beta}(T_u) = \frac{1}{N} \sum_{i=0}^{N-1} y(i) y^*(i - T_u) e^{-2\pi j \beta i / N} \quad \beta \in [0 \ldots N-1] \tag{13}$$

- We perform an exhaustive search on the following optimization problem :

$$\max_{\beta \neq 0} |C^{\beta}(T_u)|^2 \tag{14}$$

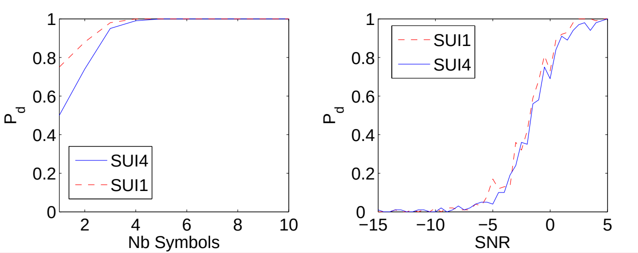
- The estimated overall symbol duration is defined as:

$$T_s = T_u + T_{cp} = \frac{N}{\beta_{opt}} \tag{15}$$

Blind Parameter Estimation of CP-OFDM

- Simulation results of WiMAX (Bandwidth=10 MHz, Nb tones=256 and Cyclic prefix= 64 (25 %)) on the Stanford University Interim (SUI) channel models for fixed wireless applications [SUI03]

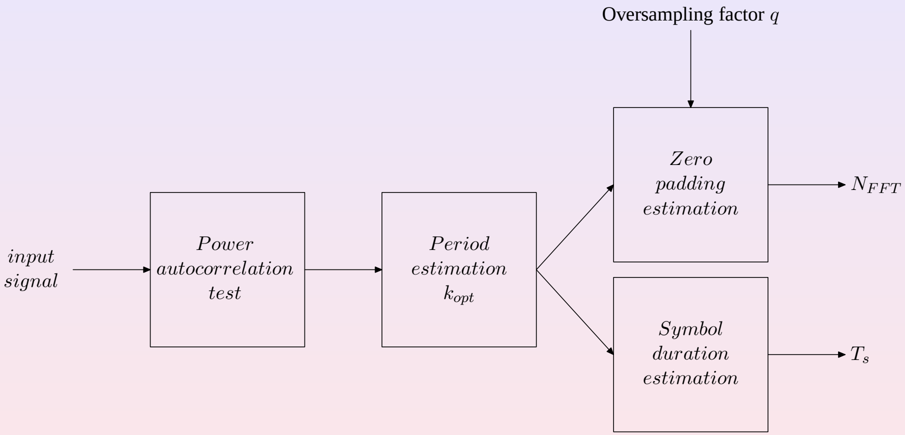
SUI 1 channel				SUI 4 channel			
	Tap 1	Tap 2	Tap 3		Tap 1	Tap 2	Tap 3
Delay (μs)	0	0.4	0.9	Delay (μs)	0	1.5	4
Power (dB)	0	-15	-20	Power (dB)	0	-4	-8
K factor	4	0	0	K factor	0	0	0
Doppler (Hz)	0.4	0.3	0.5	Doppler (Hz)	0.2	0.15	0.25



(a) SNR=5 dB (b) Nb symbols=5

Figure: Probability of correct detection for a WiMax signal through SUI-4 channels models

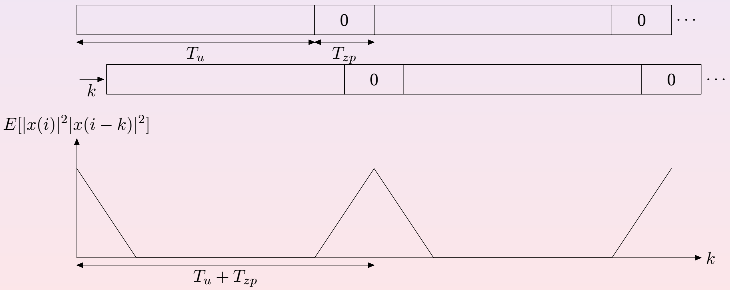
Blind Parameter Estimation of ZP-OFDM



Blind Parameter Estimation of ZP-OFDM

- We cannot use autocorrelation nor cyclic autocorrelation for ZP-OFDM (WiMedia)
- Power autocorrelation of the transmitted sequence

$$E[|x(i)|^2|x(i-k)|^2] = \frac{1}{N}\sum_{i=0}^{N-1} |x(i)|^2|x(i-k)|^2$$



Blind Parameter Estimation of ZP-OFDM

- Power autocorrelation of the received sequence

$$d(k) = \frac{1}{N}\sum_{i=0}^{N-1} |y(i)|^2|y(i-k)|^2 \quad k \in [0\dots N-1] \tag{16}$$

$$d(k) = \begin{cases} \sum_{l=0}^{L-1} |h(l)|^4\mu_x^4 + 4\sigma_x^2\sigma_n^2 + \mu_n^4 & k,t=0 \\ \hline \frac{T_u - c}{T_s}\left(\sum_{l=0}^{L-1} |h(l)|^2\sigma_x^2 + \sigma_n^2\right)^2 & \\ + \frac{2c}{T_s}\sigma_n^2\left(\sum_{l=0}^{L-1} |h(l)|^2\sigma_x^2 + \sigma_n^2\right) + \frac{T_{zp}-c}{T_s}\sigma_n^4 & \\ 0 < c = |k - tT_s| < T_{zp} & \forall t \neq 0 \\ \hline \frac{T_u - T_{zp}}{T_s}\left(\sum_{l=0}^{L-1} |h(l)|^2\sigma_x^2 + \sigma_n^2\right)^2 & \\ + \frac{2T_{zp}}{T_s}\sigma_n^2\left(\sum_{l=0}^{L-1} |h(l)|^2\sigma_x^2 + \sigma_n^2\right) & otherwise \end{cases} \tag{17}$$

Blind Parameter Estimation of ZP-OFDM

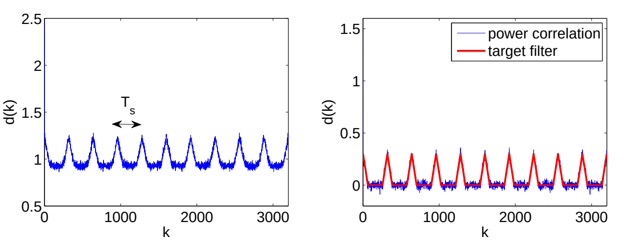
- In order to find the number of periods in the power autocorrelation function, we have:

$$\max_{k\neq 0} |[FFT(\mathbf{d})](k)|^2 \tag{18}$$

- The estimated symbol duration is:

$$T_s = \frac{N}{k_{opt}} \tag{19}$$

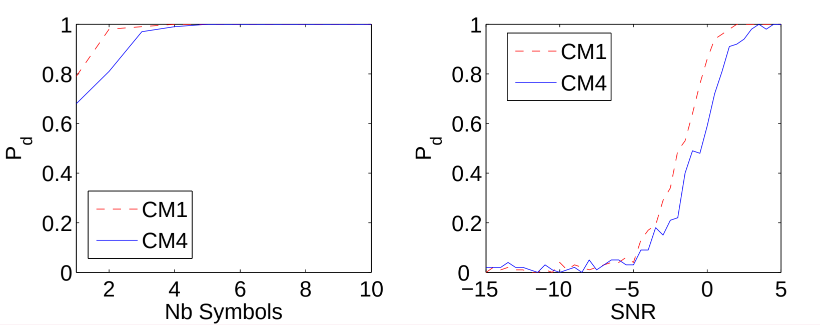
- Filter design for the estimation of the zero padding duration



(a) SNR=20 dB (b) SNR=20 dB

Blind Parameter Estimation of ZP-OFDM

- Simulation results of WiMedia (Bandwidth=528 MHz, Nb tones=128 and Zero Padding=37 (29 %)) with IEEE 802.15.4a channel models CM1 to CM4 (Saleh Valenzuela channel models)



(c) SNR=5 dB (d) Nb symbols=5

Figure: Probability of correct detection for a WiMedia signal through CM1-4 channels models

Conclusion

- Blind parameter estimation of CP-OFDM (Wifi and WiMax) and ZP-OFDM (WiMedia) using autocorrelation, cyclic autocorrelation and power autocorrelation features
- 5 OFDM symbols are necessary at 5 dB to correctly estimate the parameters of a CP-OFDM (WiMax) signal on generic SUI channel models or a ZP-OFDM signal (WiMedia) on generic IEEE 802.15.4a channel models.
- Applications:
    - Monitoring WiMedia (Bluetooth 3.0)
    - Adequate power control strategies (Detect And Avoid (DAA), Dynamic Spectrum Management (DSM),...).