Spectral monitoring and parameter estimation for ZP-OFDM signals

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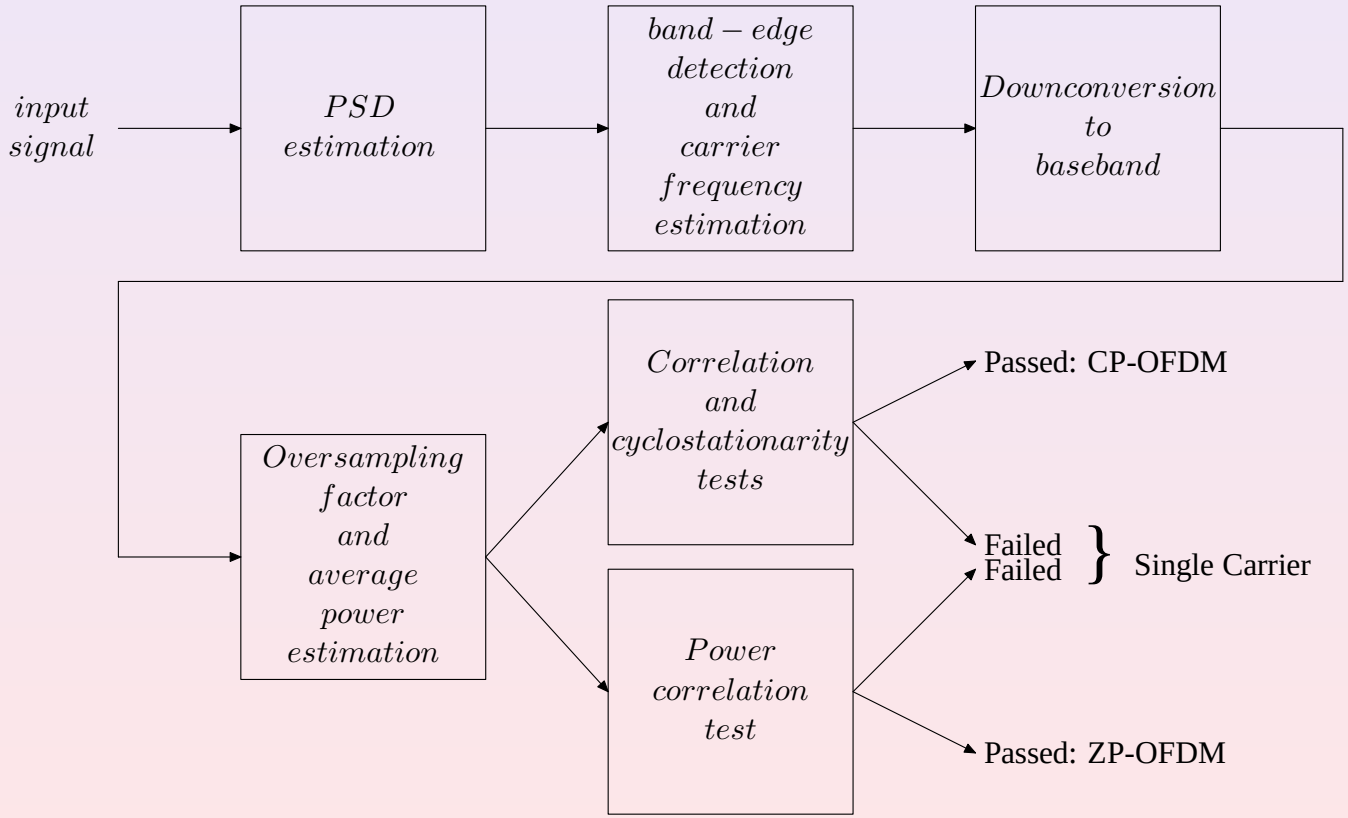
1. Introduction
2. Estimation of the spectral components
3. Parameter estimation for CP-OFDM (review)
4. Parameter estimation for ZP-OFDM
5. Conclusion

Introduction

- Aim: Spectral monitoring of multi-carrier modulations in frequency selective channels
- Estimation of the spectral components (carrier frequencies, bandwidths, powers)
  - Proposition of an iterative algorithm for the estimation of multiple spectral components
- Estimation of the parameters for CP-OFDM signals
  - Review of the autocorrelation and cyclostationarity features [Ishii05][Li06][Shi07][Dobre08]
- Estimation of the parameters for ZP-OFDM signals
  - Proposition of a power correlation feature

Introduction

- Proposed block scheme



Estimation of the spectral components

- Spectrum estimated by the averaged periodogram (**s** the received signal divided into M blocks)

$$\mathbf{S}_{avg} = \frac{1}{M} \sum_{m=0}^{M-1} |FFT(\mathbf{s}_m)|^2 \quad (1)$$

- Iterative algorithm based on a rectangular window search in the frequency domain (LSE criterion)
  - Detection of the band edges B_{low} and B_{high}
  - Estimation of the carrier frequency $f_c = \frac{B_{low}+B_{high}}{2}$
  - Estimation of the average power in the bandwidth of interest

Estimation of the spectral components

- Example with two OFDM signals, one narrowband signal around 5 GHz and one wideband signal around 2.5 GHz.

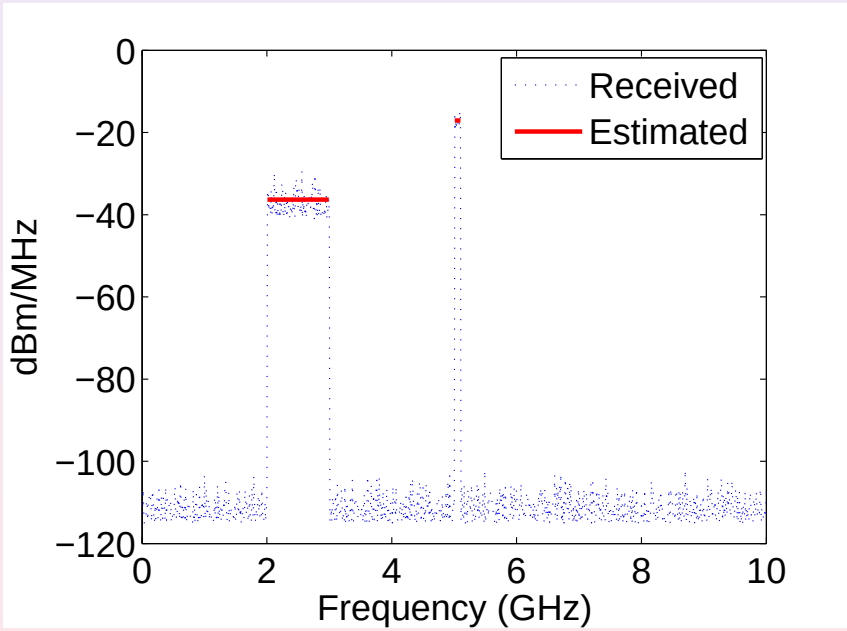
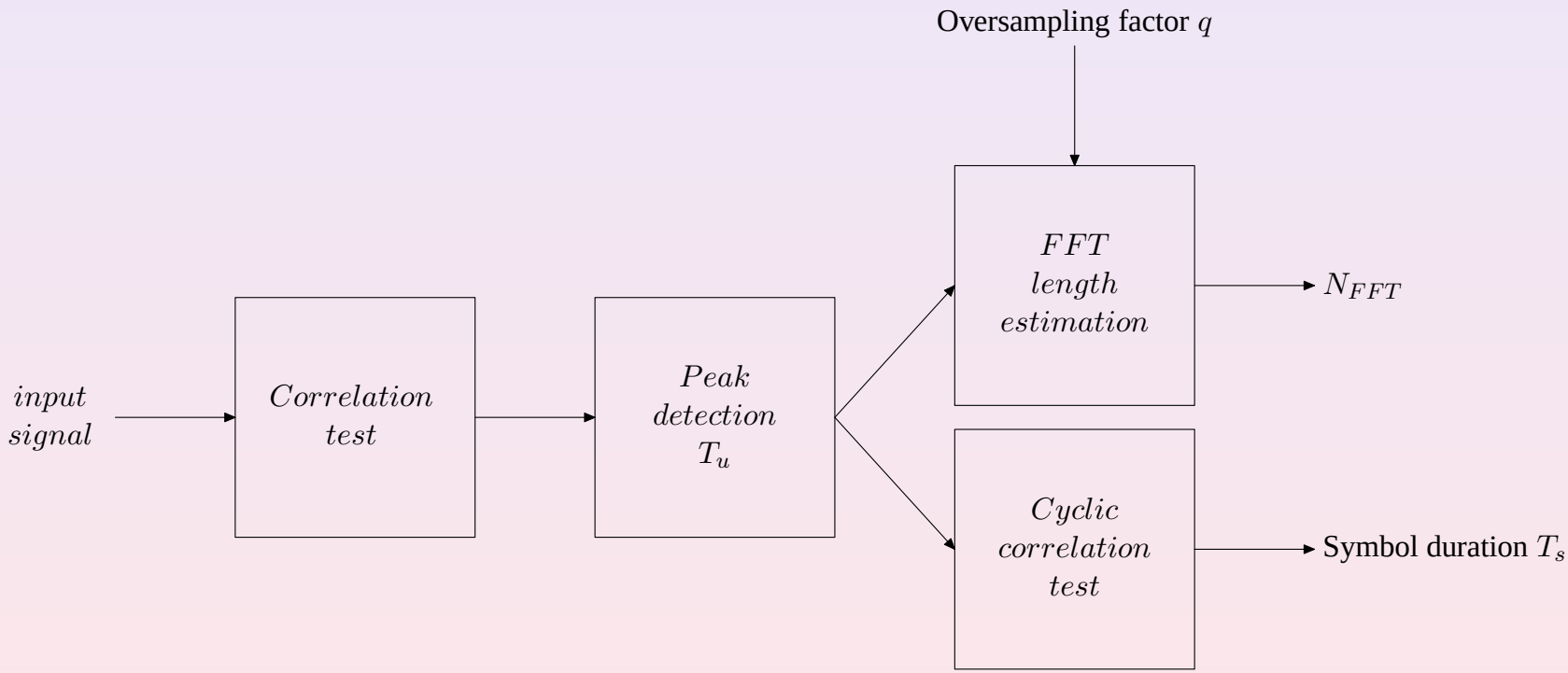


Figure: Spectral components estimation of multiple signals

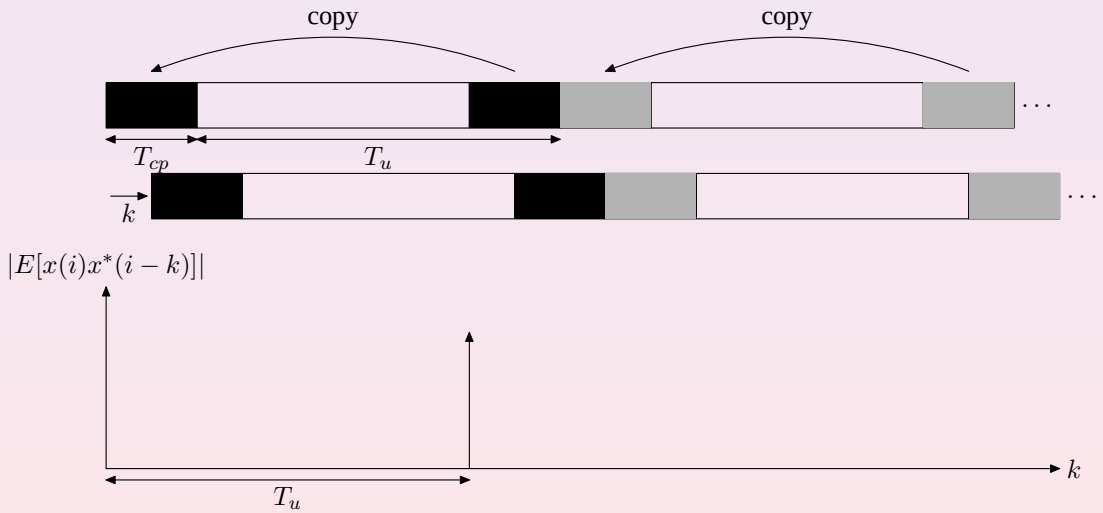
Parameter estimation for CP-OFDM (review)



Parameter estimation for CP-OFDM (review)

- Autocorrelation of the transmitted sequence

$$E[x(i)x^*(i-k)] = \frac{1}{N}\sum_{i=0}^{N-1} x(i)x^*(i-k) \quad k \in [0 \dots N-1] \qquad (2)$$



- A peak observed at delay T_u corresponding to the useful symbol duration.

Parameter estimation for CP-OFDM (review)

- In frequency selective channels, the digital baseband signal can then be modeled as:

$$y(i) = e^{j(2\pi\epsilon i+\phi)} \sum_{l=\theta}^{L-1+\theta} h(l-\theta)x(i-l) + n(i) \tag{3}$$

- Autocorrelation of the received sequence

$$r(k) = \frac{1}{N}\sum_{i=0}^{N-1} y(i)y^*(i-k) = \begin{cases} \sum_{l=0}^{L-1} |h(l)|^2\sigma_x^2 + \sigma_n^2 & k = 0 \\ e^{j2\pi\epsilon T_u} \sum_{l=0}^{L-1} |h(l)|^2 \frac{T_{cp}}{T_s}\sigma_x^2 & k = T_u \\ e^{j2\pi\epsilon k} \sum_{l=0}^{L-1} h(l+k)h^*(l)\sigma_x^2 & k = 1,\ldots,L-1 \\ e^{j2\pi\epsilon k} \sum_{l=0}^{L-1} h(l+k-T_u)h^*(l)\frac{T_{cp}}{T_s}\sigma_x^2 & k = T_u + (1,\ldots,L-1) \\ 0 & \textit{otherwise} \end{cases} \tag{4}$$

Parameter estimation for CP-OFDM (review)

- Estimation of T_u [Ishii05][Li06][Shi07]:

$$T_u = k_{opt} = \max_{k > \tau_{max}} |r(k)| \tag{5}$$

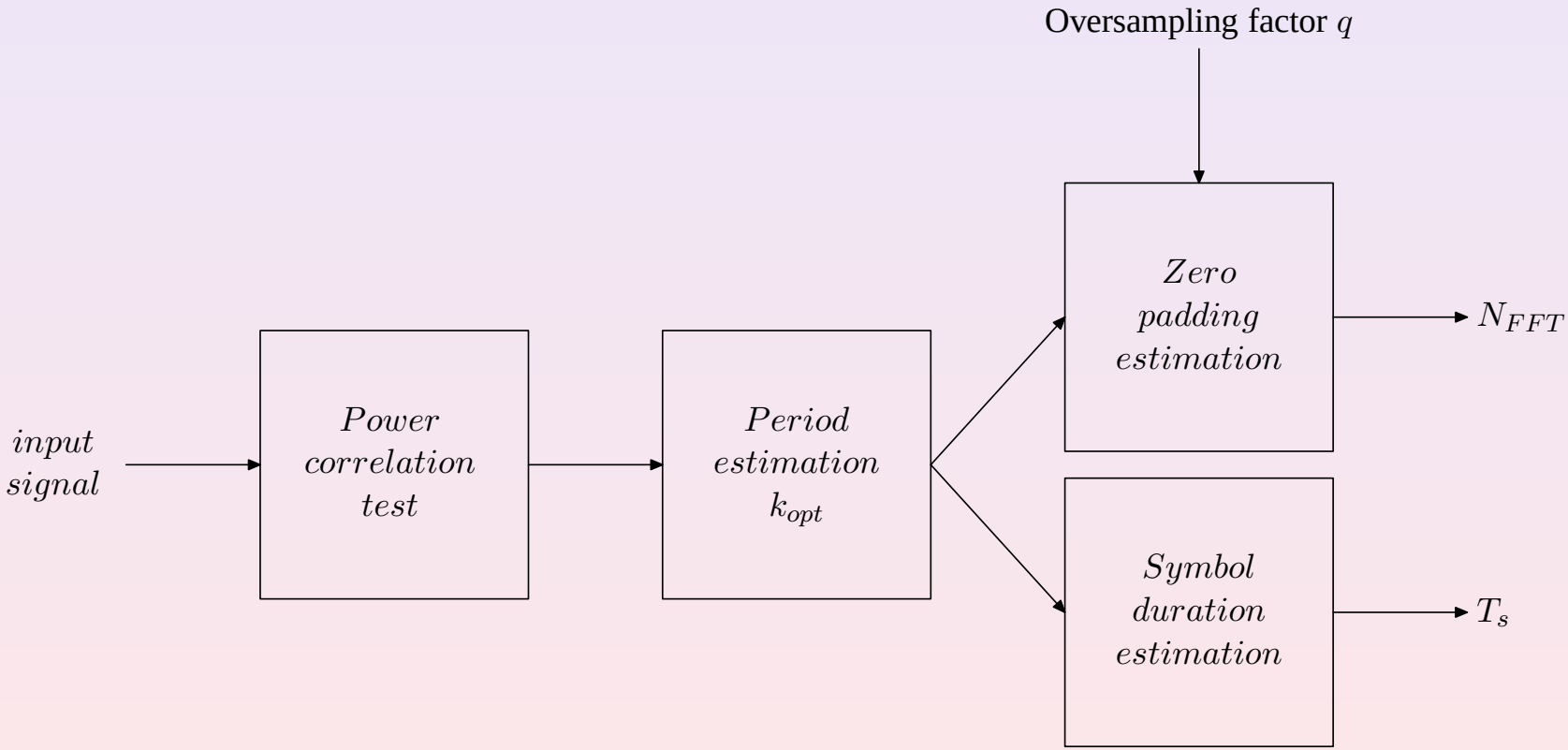
- Estimation of T_s (cyclic autocorrelation) [Li06][Shi07]:

$$\beta_{opt} = \max_{\beta \neq 0} |c^{\beta}(T_u)|^2 \tag{6}$$

with

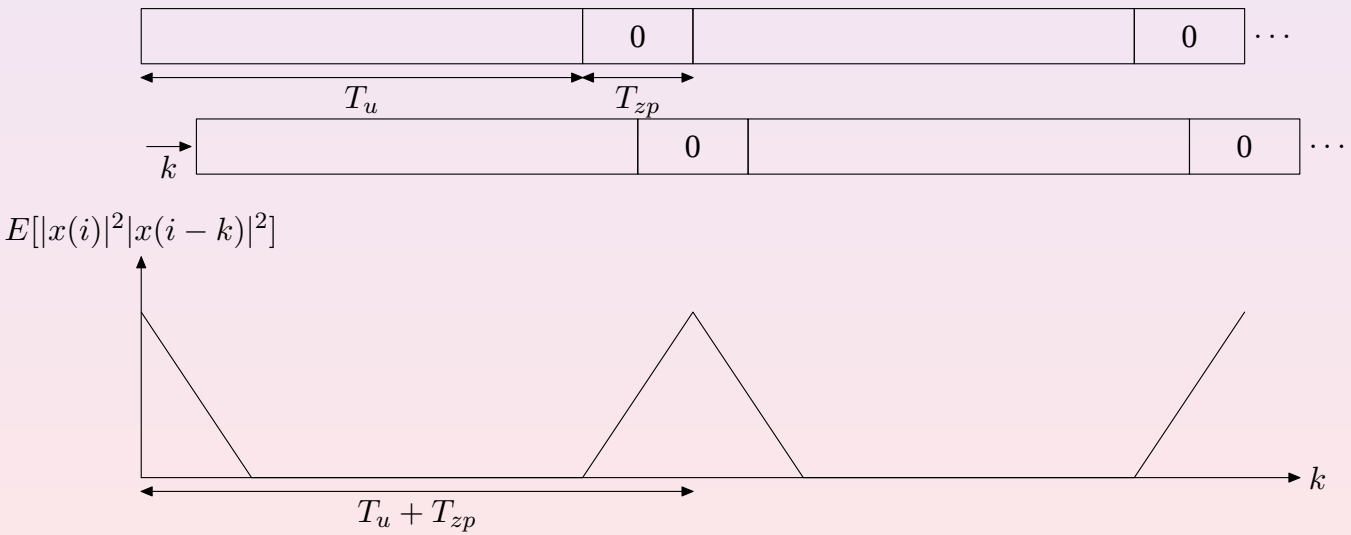
$$c^{\beta}(T_u) = \frac{1}{N} \sum_{i=0}^{N-1} y(i) y^*(i - T_u) e^{-2\pi j \beta i / N} \tag{7}$$

Parameter extraction for ZP-OFDM



Parameter estimation for ZP-OFDM

- Proposition of the power correlation of the transmitted sequence $E[|x(i)|^2|x(i-k)|^2] = \frac{1}{N}\sum_{i=0}^{N-1}|x(i)|^2|x(i-k)|^2$



Parameter estimation for ZP-OFDM

- Power correlation of the received sequence

$$d(k) \triangleq \frac{1}{N} \sum_{i=0}^{N-1} |y(i)|^2 |y(i-k)|^2 \tag{8}$$

$$d(k) = \begin{cases} \frac{T_u}{T_s}\left(\sum_{l=0}^{L-1} |h(l)|^4 \mu_x^4 + 4\sigma_x^2\sigma_n^2 + \mu_n^4\right) & \\ + \frac{T_{zp}}{T_s}\mu_n^4 & k, t = 0 \\ \frac{T_u - c}{T_s}\left(\sum_{l=0}^{L-1} |h(l)|^2\sigma_x^2 + \sigma_n^2\right)^2 & \\ + \frac{2c}{T_s}\sigma_n^2\left(\sum_{l=0}^{L-1} |h(l)|^2\sigma_x^2 + \sigma_n^2\right) & 0 < c < T_{zp} \\ + \frac{T_{zp} - c}{T_s}\sigma_n^4 & \forall t \neq 0 \\ \frac{T_u - T_{zp}}{T_s}\left(\sum_{l=0}^{L-1} |h(l)|^2\sigma_x^2 + \sigma_n^2\right)^2 & \\ + \frac{2T_{zp}}{T_s}\sigma_n^2\left(\sum_{l=0}^{L-1} |h(l)|^2\sigma_x^2 + \sigma_n^2\right) & otherwise \end{cases} \tag{9}$$

Parameter estimation for ZP-OFDM

- Estimation of T_s by finding the largest harmonic of $\mathbf{D} = FFT(\mathbf{d})$:

$$k_{opt} = \max_{k \neq 0} |\mathbf{D}(k)|^2 \tag{10}$$

- Estimation of T_{zp} by searching the closest triangular function:

$$i_{opt} = \min_{i} (\mathbf{d}^{shifted} - \mathbf{d}_i^{target})^2 \tag{11}$$

with

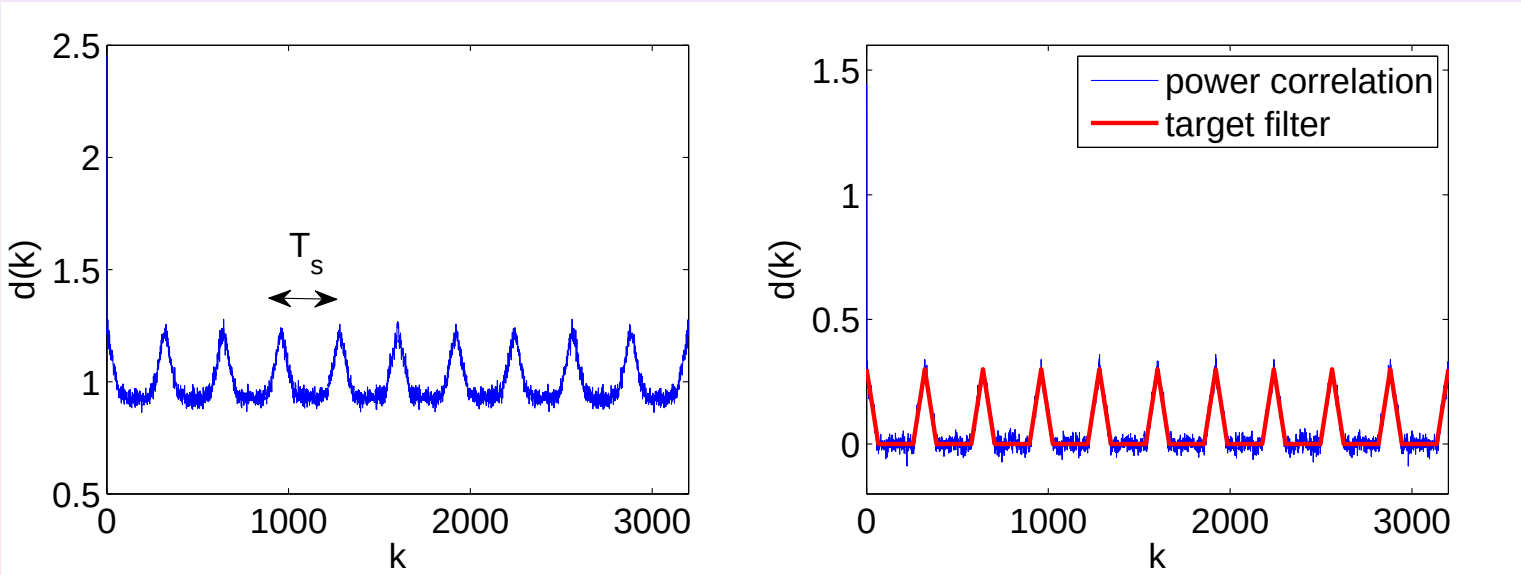
$$\mathbf{d}_i^{target} = [\frac{A_i}{ik_{opt}}(ones(i) - dec), zeros(\frac{N}{k_{opt}} - 2i), \frac{A_i}{ik_{opt}}(ones(i) - decr)]^T \times k_{opt} \tag{12}$$

and

$$A_i = sum\left(\mathbf{d}^{norm} - T_s \frac{T_s - 2i}{(T_s - i)^2}\right) \tag{13}$$

Parameter estimation for ZP-OFDM

- Filter design for the estimation of the zero padding duration

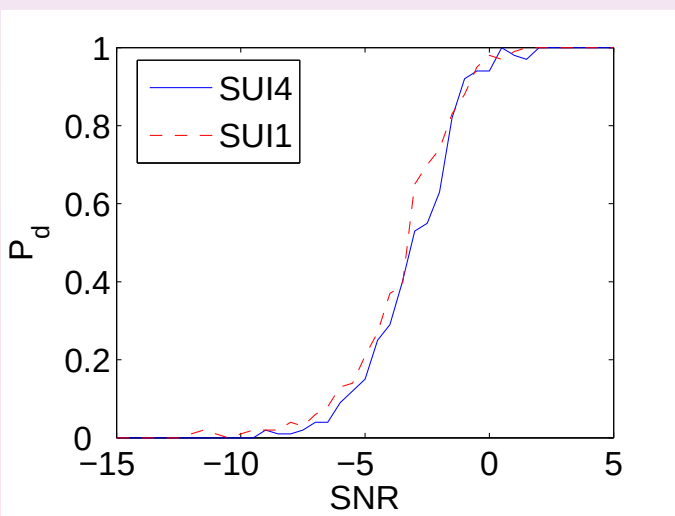


(a) SNR=20 dB

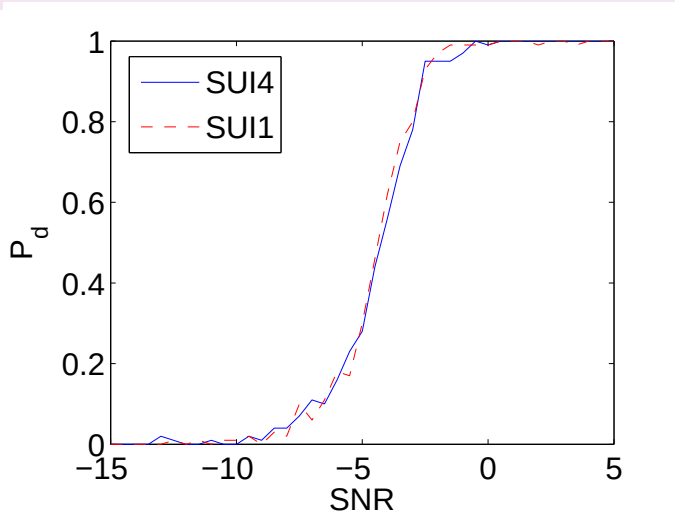
(b) SNR=20 dB

Simulation results

- Simulation results are performed on the Stanford University Interim (SUI) channel models for fixed wireless applications [SUI03]
- WiMAX parameters for CP-OFDM and ZP-OFDM signals (10 MHz, 256 tones, cyclic prefix (25 %), 10 received symbols)



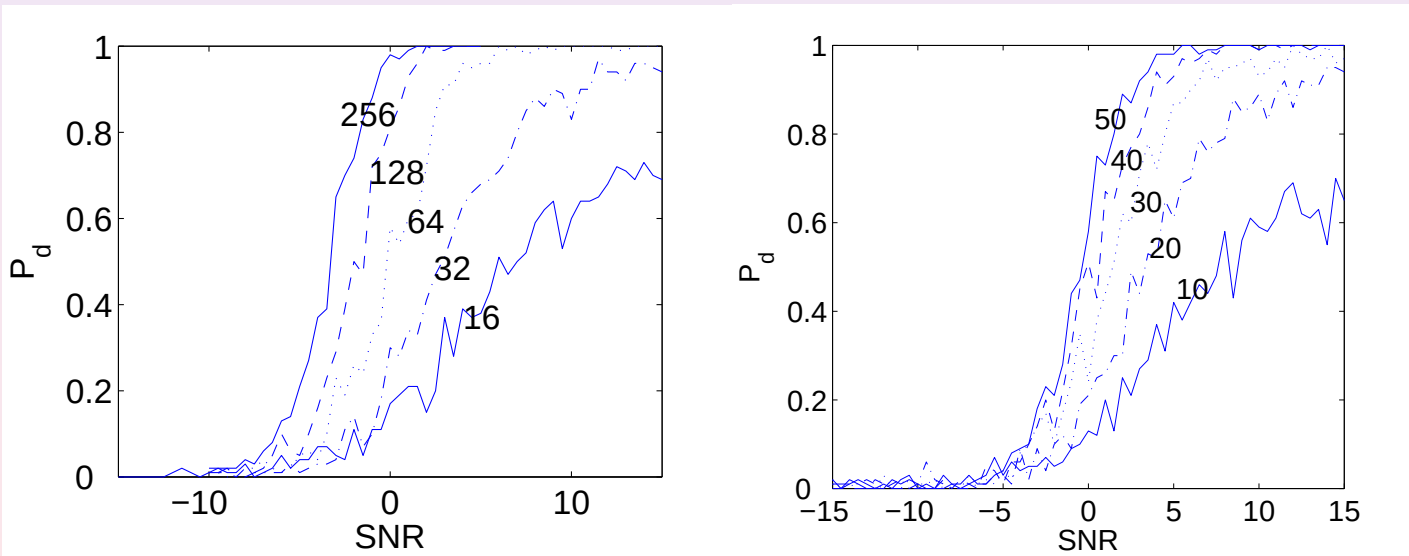
(a) CP-OFDM



(b) ZP-OFDM

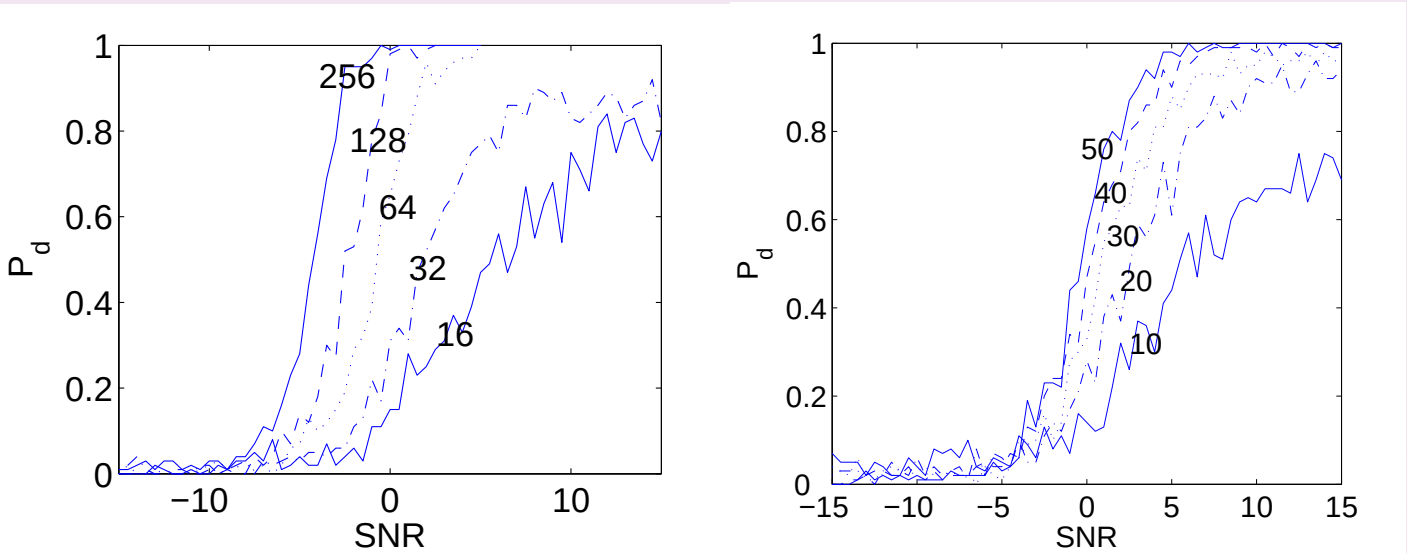
Simulation results

- Influence of the number of tones (left) and the number of symbols (16-tones) for CP-OFDM signals on SUI-1 channel



Simulation results

- Influence of the number of tones (left) and the number of symbols (16-tones) for ZP-OFDM signals on SUI-4 channel



Conclusion

- Spectral monitoring of multi-carrier modulations in frequency selective channels
  - Iterative algorithm for the estimation of multiple spectral components
  - Autocorrelation and cyclic autocorrelation features to estimate T_u and T_s for CP-OFDM signals
  - Power autocorrelation feature to estimate T_s and T_{zp} for ZP-OFDM signals
- With WiMAX parameters for CP-OFDM or ZP-OFDM signals, as low as 5 dB received power for good performance results with 10 OFDM symbols.
- Number of recorded symbols to be adjusted with the number of subcarriers and the cyclic prefix (or zero padding) length