Channel Estimation for UWB Single and Multiple Antenna Receivers

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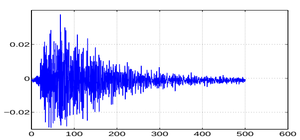
UWB CHANNEL ESTIMATION

UWB features (due to large bandwidths):
- potential for significant multipath capture
- fine time resolution
- high number of multipath components



To exploit channel diversity, channel parameters need to be accurately estimated

Applications requiring accurate channel estimation : localization and tracking, channel sounding, beamforming, etc.

MOTIVATION

Existing work on antenna arrays:
- relies on narrowband assumptions *[Krim/Viberg, '96]*
- not easily extended to UWB Impulse Radio

GOAL:
Assess whether multiple antenna receivers have an edge over single antenna receivers *independent of the array gain*

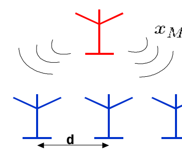
Versus *[Hussain '03, Abreu '05, Yang/Giannakis '04]*, our focus is on joint estimation and detection for UWB Rake receivers

HOW ? - Cramer Rao lower bounds for parameter estimation
- Performance analysis of 'conventional' ML estimators
- BER and SNR analysis of 'realistic' Rake receivers

SIGNAL MODEL

SIMO (uniform linear array)

To be estimated



$$x_M(t,n) = \sum_{l=1}^{L_p} \alpha_l p(t + \xi_l^n - \tau_l) + v_M(t,n)$$

amplitudes, DOA's, delays, AWGN

$$\xi_l^n = (n-1)\frac{d}{c}\sin(\theta_l)$$

NO ARRAY GAIN

'Narrowband' Model

$$x_M(t,n) = \sum_{l=1}^{L_p} \alpha_l p(t - \tau_l) e^{\xi_l^n \omega_c t} + v_M(t,n)$$

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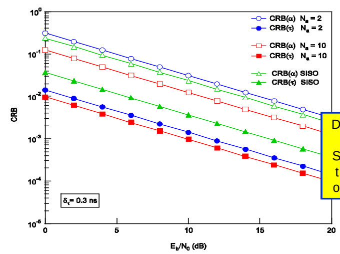
CRB FOR CHANNEL PARAMETERS

UWB channels and interpulse interference **(IPI):** Correlation among echoes cannot be neglected



Due to the additional shift given by the angle, the SIMO is more robust than the SISO in the presence of interpulse interference

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'SPACE-TIME' ML ESTIMATOR

Maximum Likelihood estimator (ignoring correlation among echoes) *[Lottici/Mengali '02, Win/Scholtz, '02]*

$$(\hat{\tau}_l, \hat{\theta}_l) = \arg\max_{(\tilde{\tau}_l, \tilde{\theta}_l)} \left[\sum_{k=0}^{K-1} \sum_{n=1}^{N_a} \int_0^{KT_s} x_M(t,n) p(t + \tilde{\xi}_l^n - \tilde{\tau}_l - kT_s) dt\right]^2$$

$$\hat{\alpha}_l = \frac{1}{E_p K N_a} \sum_{k=0}^{K-1} \sum_{n=1}^{N_a} \int_0^{KT_s} x_M(t,n) p(t + \hat{\xi}_l^n - \hat{\tau}_l - kT_s) dt$$

No IPI:
- the delays estimates are unbiased and asymptotically efficient
- the amplitude estimates are also asymptotically unbiased and efficient

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ML ESTIMATOR & IPI

$$E[\hat{\tau}_l] = \tau_l$$

Unbiased estimator

$$Var[\hat{\tau}_l] \geq \frac{1}{\frac{E_p}{2N_0}\sigma_\alpha^2 R_{pp''}(0)}$$

CRB for the delays when IPI is ignored

In the presence of IPI the estimator is biased

$$E\{\hat{\tau}_l\} = \tau_l - \frac{2\sigma_\alpha^2 \sum_{k \neq l} R_{pp'}(\Delta_{l,k}) R_{pp}(\Delta_{l,k})}{E\{\Gamma(\tau_l)''\}}$$

$$2\sigma_\alpha^2 \sum_{k \neq l} R_{pp'}(\Delta_{l,k}) R_{pp}(\Delta_{l,k}) \rightarrow \neq 0$$

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ML ESTIMATOR & SNR

Why using this suboptimal estimator?
- Low complexity (L_R parallel one-dimensional searches Vs one L_R-dimensional search)
- Ensure that the SNR (i.e. BER) conditioned on the channel is maximum in the presence of IPI

$$SNR = \frac{\sum_{l=1}^{L_R} (\alpha_l D_l + I_l)^2}{\frac{\sigma_S^2}{E_p} + \frac{\sigma_S^2}{E_p K} + \frac{\sigma_S^4 L_R}{E_p^2 K \boxed{\sum_{l=1}^{L_R} (\alpha_l D_l + I_l)^2}}}$$

We are doing 'the best we could do' in the presence of overlapping echoes

Function maximized by ML estimates

$$\sum_{l=1}^{L_R} \left[\sum_{k=0}^{K-1} \sum_{n=1}^{N_a} \int_0^{KT_s} x_M(t,n) p(t + \xi^n(\tilde{\theta}_l) - \tilde{\tau}_l - kT_s) dt\right]^2 \Bigg|_{\tilde{\tau}_l = \hat{\tau}_l, \tilde{\theta}_l = \hat{\theta}_l}$$

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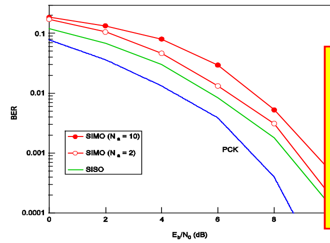
BER & ENERGY CAPTURE

Selective Rake receiver employing (suboptimal) ML estimates

- the SISO outperforms the SIMO with Na = 2, 10



Why?

Two close paths: the SISO SRake is still be able to capture enough energy from the remaining fingers

the effect of the lower accuracy of the SISO on the BER is not significant (CRB more sensitive to IPI).

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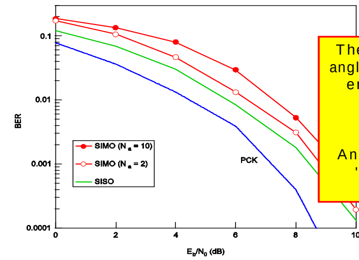
BER & ESTIMATION ERROR

Selective Rake receiver employing (suboptimal) ML estimates

- the SISO outperforms the SIMO with Na = 2, 10



Why?

The estimation error on the angles results in an additional error on the delay of the Rake fingers.

An error of few degrees is 'magnified' by a factor Na=2,10

$$\xi_l^n = (n-1)\frac{d}{c}\sin(\theta_l)$$

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