Detection of TR UWB signal in the presence of Narrowband Interference

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UWB4SN workshop Nov. 4, 2005, Lausanne, Switzerland
Introduction

System Model: UWB signal, NBI signal, AcR front end

Data model

Detection Schemes

Simulation Results

Conclusion and further outlook
Introduction

- **Tx System:**
  - Transmitted Reference (TR) Differential UWB

- **Receiver:**
  - TR AutoCorrelation Receiver (AcR)

- **Interferor:**
  - IEEE 802.11a WLAN Service
Introduction

► Why Interference could be adversary for UWB?
  ► unregulated spectrum
  ► should operate under -41.3dBm/MHz

► Why AcR is chosen as a victim receiver?
  ► Transmitted Reference
  ► Analog front end / Nonlinearity

► Why IEEE 802.11a WLAN is chosen as interferor?
  ► Common spectrum
  ► Deployment scenario
Figure 1: System Model

\[ D_j \]

\[ s(t) \]
\[ \beta(t) \]
\[ \hat{r}(t) \]

\( T_s \)
\( T_s \)
\( T_s \)

\[ \text{Integrate} \& \text{ damp} \]

\[ xW_1 \]
\[ xW_2 \]
\[ xW_{\text{extra}} \]

\[ Z \]
System Model: UWB signal

- UWB signal

\[
s(t) = \sum_{i=-\infty}^{\infty} \sum_{j=-0}^{N_p-1} a_{ij} \tilde{\omega}(t - t_{ij})
\]

- For differential TR scheme, \( a_{i,j} = a_{i,j-1} b_j d_i, \quad b, \quad d \in \{1, -1\} \)

- Received Signal:

\[
\hat{r}(t) = s(t) * h(t); \quad \hat{r}(t) = r(t) + \beta(t) + \nu(t)
\]

\[
\hat{r}(t) = [s(t) * h(t) * f_{rx}] + [\tilde{\beta}(t) * f_{rx}(t)] + [\tilde{\nu}(t) * f_{rx}(t)]
\]

\( f_{rx} \) is AcR front end filtering effect \((\approx 1)\)
NBI, IEEE802.11a OFDM passband signal

$$\beta(t) = Re\{x(t)e^{j(2\pi f_\beta t + \theta)}\}$$

Figure 2: Model of the narrowband interference

$$P_\beta(f) = \begin{cases} P_\beta & f_c - \frac{W_\beta}{2} < f_c < f_c + \frac{W_\beta}{2} \\ 0 & \text{otherwise} \end{cases}$$

$$\phi_\beta(\tau) = P_\beta W_\beta (\text{sinc} W_\beta \tau)(\cos 2\pi f_c \tau); \quad \mathcal{F}^{-1}\{P_\beta(f)\}$$
System Model: Received Signal

Correlator Output

\[ \hat{y}_j[i] = \int_{t_{ij}}^{t_{ij}+T_I} \hat{r}(t + D_j) \hat{r}(t) dt \]

Expanding further the correlator output equations:

\[ \hat{y}_j[i] = \int_{t_{ij}}^{t_{ij}+T_I} (r(t + D_j) + \beta(t + D_j) + v(t + D_j))(r(t) + \beta(t) + v(t)) dt \]

\[ y_j[i] = \int_{t_{ij}}^{t_{ij}+T_I} r(t + D_j)r(t) dt \]

\[ \beta_{1,j}[i] = \int_{t_{ij}}^{t_{ij}+T_I} r(t + D_j)\beta(t) dt \]

\[ \beta_{2,j}[i] = \int_{t_{ij}}^{t_{ij}+T_I} \beta(t + D_j)r(t) dt \]

\[ \beta_{3,j}[i] = \int_{t_{ij}}^{t_{ij}+T_I} \beta(t + D_j)\beta(t) dt \]
System Model: Correlators Output

- NBI by NBI product term in the data sample

\[
\beta_{3,j}[\hat{v}] = \int_{t_{ij}}^{t_{ij}+T_I} \beta(t + D_j)\beta(t)dt
\]

\[
\beta_{3,j}[\hat{v}] = \frac{1}{2} \int_{t_{ij}}^{t_{ij}+T_I} \text{Re}\{x(t + D_j)x(t)\}.\cos[2\pi f_\beta (2t + D_j) + 2\theta]dt
\]

\[
+ \frac{1}{2}\cos2\pi f_\beta D_j \int_{t_{ij}}^{t_{ij}+T_I} \text{Re}\{x(t + D_j)x^*(t)\}dt
\]

- First term can be neglected for \( T_I >> \frac{1}{2f_\beta} \)

- \( f_\beta \) is in GHz range and \( T_I \) is about 20\( ns \) for indoor propagation
Data Model

- Fixed phase sinusoid $\frac{1}{2} \cos 2\pi f_\beta D_j$ modulated by a Short time autocorrelation function of the baseband NBI signal $x(t)$

$$\phi_{x_j}[i] = \int_{t_{ij}}^{t_{ij} + T_I} \Re\{x(t + D_j)x^*(t)\} \, dt;$$

- Samples will be well correlated if $T_I << \frac{1}{B_\beta}$

- For IEEE 802.11a WLAN $\frac{1}{B_\beta} = 65.4 \, ns$, $T_I = 20 \, ns$

- NBI term can thus be written as:

$$c\phi_{x_j}[i]; \quad c \text{ is a sampled vector of } \cos(2\pi f_\beta D_j)$$
Where ISI is avoided (burst /LDC), a data model can be written as:

\[ y[i] = h d[i] + g + c\phi_x[i] + v \]

- \( h \) is due to the "data by data" term, and \( g \) is a bias term due to interference among pulses.

- In the absence of NBI and noise, detection could be accomplished by:

\[ \hat{z}[i] = \sum_{j=0}^{N_p-1} b_j (y_j[i] - g); \quad \hat{d}[i] = \text{sign}(\hat{z}[i]) \]
NBI Mitigation: Least Square Solution

- Sampled output for \( N - 1 \) symbols

\[
Y = [y[0] \ y[1] \ y[2] \ \ldots \ y[N - 1]]^T
\]

\[
z = Yw
\]

- Find an estimate of \( \hat{w} \) that minimizes the following norm

\[
\min_w \|d - Yw\|
\]

- Setting the derivative of the cost function to zero

\[
J(w) = \|d - Yw\|, \quad \hat{w} = ((Y^T Y)^{-1})^T Y^T d
\]

- Implementation requires pilot symbols
NBI Mitigation: Detection based on SVD

- $Y$ can be factored as:

$$Y^T = U \Sigma V^T$$

Where $Y^T$ is $m \times n$ data matrix $U$ is $m \times m$ unitary matrix and $V$ is $n \times n$ unitary matrix

$$\Sigma = diag(\sigma_1, \sigma_2, \ldots, \sigma_p), \quad \text{where} \quad p = min(m, n)$$

- Correlation of the code vector $b$ and the column containing the data from unitary matrix $U$ is used for separation.
NBI Mitigation: Adaptive Constant Modulus Algorithm

- Constant amplitude \(\{R = 1\}\) of binary antipodal symbols \(d_i \in \{-1, 1\}\) are transmitted.

\[
J_{CM} = \sum_{i=1}^{N} (z_i^2 - R)^2
\]

- The adaptation equation can be written as:

\[
w[n]^T = w[n-1]^T - \mu \sum_{i=1}^{N} (z_i^2 - R) z[n]^T y
\]
The nearest minimum rank Matrix $Y$ will be:

$$Y_{\text{rank}<r} = [U_1, U_2] \begin{bmatrix} \Sigma_1 & 0 \\ 0 & 0 \end{bmatrix} [V_1, V_2]^T$$

$Y$ will be reconstructed by 0 substitution or nulling the smaller singular values.
Detection Error

\[ e_i = d_i - z_i; \quad z = w^T y \]

\[ \sigma_e^2 = E\{e^2\}; \quad \sigma_d^2 = E\{(d - w^T y)^2\} \]

\[ = E\{(d - w^T [hd + g + c\phi_x + v])^2\} \]

Optimum combiner that minimizes \( \sigma_e^2 \) assuming \( \sigma_d^2 = 1 \) and noise is uncorrelated with the NBI and UWB signal, will be;

\[ w = [hh^T + R]^{-1} h; \quad R = E\{(g + c\phi_x + v)^2\} \]

Computing \( R \) requires knowledge of the model parameters.
Simulation Results: Parameters

NBI:
- signaling: OFDM
- carrier frequency: 5.125GHz
- no of carriers: 48
- baseband: QPSK

UWB:
- Tr: Differential-TR
- No of pulses/sym: 9
- Symbol Period: 100ns
- Delay: 0.2ns

Figure 3: UWB (LDC), NBI and Noise at the front end
Simulation Results: SVD Decomposition (low SIR)

Figure 4: Sampled output of the correlators (symbol axis)

Figure 5: Sampled output of the correlators (correlators axis)
Simulation Results: SVD Decomposition (high SIR)

Figure 6: Sampled output of the correlators (symbol axis)

Figure 7: Sampled output of the correlators (correlators axis)
Simulation Results: SVD, LS BER

Figure 8: BER plots for conventional threshold detector vs SVD

Figure 9: BER plots for LS solution and Adaptive CMA (initialization with code vector)
Simulation Results: CMA BER

Figure 10: BER plots for 35dB SNR and SIR

Figure 11: BER plots for -10dB SIR and SNR axis (model parameters used for initialization)
We presented the analysis of the narrowband interference for frame differential TR-UWB system and LDC scheme.

A data model has been derived for LDC schemes which could provide us a better understanding and insight for possible interference cancellation.

In the presence of NBI the conventional/threshold detector performs poorly.

Detection based on SVD of the data matrix is found promising for strong interference (as compared to the conventional detector), however it gets unstable for higher SIR.
Conclusion

- Detection based on LS solution showed much more improved performance than the conventional detector.
- Detection based on adaptive CMA is shown to provide comparable performance as that of the LS (no pilot symbols are used). During simulation it was observed that initialization vector is highly critical for the performance.
- This fact is attributed to the existence of multiple local minima and the CMA fails to attain a global minimum point.
- Further improvement of the mitigation schemes performance might need tuning of the model to include nonlinear terms.