UWB Communication using Compressed Sensing

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Theoretical Background

Motivation

Ultra-wideband (UWB) wireless technology advantages:
- High data rate
- Frequency diversity can be exploited
- FCC Unlicensed commercial deployment due to low transmitted spectral power density [dBm/Hz]

Restrictions: Short range and High rate ADC is needed

We propose sub-Nyquist hardware implementation for channel estimation and data detection, by exploiting the sparse nature of the channel response

Nyquist Channel Estimation

- Transmitter uses a trinary (-1, 0, 1) direct sequence (DS) \(a_{DS}[n]\) which is N=511 chips length to spread spectrum data symbols ~1Mbps known training sequence (for channel estimation) or data (for data detection) is multiplied by the direct sequence and sent in 500MHz DAC

- Transmitted signal is: \(x(t) = \sum_{n=0}^{N-1} a_{DS}[n] s(t-n T_s - m T_D) = \sum_{n=0}^{N-1} a_{DS}[n] s(t-n T_s) - m T_D\)

- Complying Nyquist sampling rate requires a high rate ADC

- For channel estimation, an accumulator is used to estimate the channel

- For data detection, rake receiver uses estimated channel

Sub-Nyquist Channel Estimation

- We want to sample less bands (q time slower than Nyquist), yet maintain the frequency selectivity to some degree
- Transmitter uses signal whose frequency support is a subset \(L\) of the full bandwidth
- The transmitter will transmit only on M FFT coefficients that are selected by masking DS

\[
\begin{align*}
B_{DS} &= \text{IFFT}_N\{\text{FFT}_M\{a_{DS}[k]\}|k \in L\} \\
\text{Sampling} &= \text{performed by a low rate ADC}
\end{align*}
\]

- Use sparse recovery (e.g. OMP) to reconstruct the sparse signal

System Implementation

- The demo system illustrates the application of sub-Nyquist sampling to QPSK UWB signals
- In the system ~250kops data rate is applied, which spreads to 125 MHz bandwidth
- 2 channels are active for I and Q in both AWG and sampler
- The channel response and noise are modeled before the packet transmitted through AWG
- The system implemented on NI PXIe chassis with signal generator – NI PXIe-5451 AWG and receiver – NI 5761 digitizer samples the signals directly at 125/64/32 Msps to achieve down to 1/8 of the Nyquist rate

Simulation Results

- Matlab simulation compare results for Nyquist, Foldable and *Direct sample methods

**Direct FFT Sampling:** Randomly select M coefficients to sample from full rate (not feasible)
- Measuring performance using energy capture and RMS error
- Performance of data detection through Error Vector Magnitude (EVM):

\[
\text{EVM}(s,k) = 1 - \frac{1}{M} \sum_{t=1}^{M} |a_t - \hat{a}_t|^2
\]

Conclusions:

Analog acquisition using a low rate ADC and standard front-end can be performed to detect data in multipath channels
For q=8, only 12% of the energy is dropped at estimation and EVM raised by factor 2 only at Eb/N0 of 0dB at data detection stage

Demo system

- Foldable generated constellation
- Transmitted signal with channel response and noise
- Aliased signal as sampled by 1/q Nyquist rate
- QPSK detected constellation
- EVM calculation

References


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