UWB Research Overview
(MURI Annual Review)

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Overview

- **Multipath (Ali Taha)**
  - Energy Capture
  - Multiple Access Interference (“Capacity”)
- **FEC (Durai Thirupathi)**
  - Very Low-rate Turbo-Like Codes
- **Rapid PN Acquisition (Mingrui Zhu)**
  - Sparse Graphical Modeling
  - Iterative (Message Passing) Detection
Basic Signal Format (typical)

- Much of the multipath work based on this
- Other work is more general
Multipath Effects on TH UWB

- **Energy Capture**
  - Design a simple correlator template to collect substantial energy? (No!)
  - Then, how much is gained by optimization of narrow pulse correlation template?

- **Multiple Access**
  - How does delay spread impact MAI?
  - What are the trade-offs in design choices and MAI?
Multipath Delay Spread

- Signal resolves many paths which need to be collected using multiple correlations (Rake)
- Multipath delay spread seems to cause more MAI
Iterative Correlator Template Extraction Algorithm

Template Updater

- Initial Template

Nonlinear L.S. Exhaustive Search on Delays and Linear L.S. on Amplitudes

- Delays and Amplitudes

Convergence Check

- No

Delay

- Yes

Designed Template

- Template
Typical Correlator Template Extracted

- ~ 0.9 dB improvement in energy capture for 3 correlators
- Suggests little gain in correlator optimization
- Can be useful for extracting a clean pulse from lab. data
Frame Length Variation in Multipath

- Channels are from lab. Measurements
- Basic Trade
  - longer frames yield fewer collisions
  - shorter frames yield more pulses per bit & better collision mitigation
Hopping Range Variation in Multipath

- Channels are from lab. Measurements
- Basic Trade
  - longer ranges yield more collisions
  - shorter ranges yield worse collision mitigation
Very Low Rate Turbo-like Code Design

• Motivation
  – Pure power-limited channel!
  – Very low rate codes can enhance the performance of the spread spectrum system with no additional penalty
  – Turbo-like codes (TLC) can be designed to approach capacity at any code rate
  – Existing low rate TLC designs require either
    - large number of iterations (or)
    - large number of states in constituent codes

• Goal
  – To construct very low rate turbo-like codes
    - with low complexity constituent codes
    - with fast convergence of the iterative decoder
Low Rate TLC Design Method

• Design Low Rate Constituent Convolutional Codes
  – Based on super-orthogonal designs
  – Key notion is to decouple the rate and the number of states
  – Results in "simple" super-orthogonal convolutional codes

• Use Such Codes as constituent codes for TLC
Example: Results - AWGN Channel

- Rate 1/3 parent code vs 1/63 low rate code constructed using our algorithm
- PCCC: Constituent codes have 16 states each
- 1024 bit interleaver
- 15 iterations
- Roughly about 1 dB additional coding gain is possible
Reminder: Coding Gain in a Spread System

- ‘Estimated’ multiple access capacity of low rate coded system vs conventionally coded and spread system
- Coding gain translates to multi-user capacity in heavily spread systems
Example Results - Fading Channel

- Fading amplitude constant over blocks of 63 coded symbols
- Independent fading among blocks
- 10 iterations
- About 2 dB gain possible
Synchronization for Low Duty Cycle UWB Signals

- Frame Synch
- Coarse PN Synch
- Fine PN Synch.

Traditional Direct Sequence

Low Duty Cycle UWB
Rapid PN Acquisition Using Iterative Detection Techniques

- UWB systems may require very fast coarse PN pattern synchronization
  - Many resolution bins to search and true epoch will vary with time
  - "chasing tail" situation may arise

- Fully Parallel Acquisition
  - ML detection of initial state of an FSM evolution
  - Very complex in general, but fast

- Iterative Message Passing Algorithms
  - Require graphical model for problem/signal structure
  - Sparse Loopy Graphs => near ML performance & significant complexity reduction
Rapid PN Acquisition Using Iterative Detection Techniques

- Represent good PN patterns using sparse graphical models (new PN structures or existing)
- Apply standard message-passing iterative detection to approximate full parallel search
M-sequence Example: r-stage shift register

- **Observation**: for M-sequences with long period, there are many sparse generator polynomials & these directly provide sparse loopy graphical models.
- **Example**
  - An 15-stage shift register with generating polynomial of $[180001]_{\text{oct}}$. And the period of this m-sequence is $2^{15}-1 = 32767$.
  - Sparse Connections!
Sparse Loopy Graphical Model of 15-stage shift register
Message Passing Algorithm
Preliminary Results for Iterative Rapid PN Acq.

- Observation is 1024 Chips
  - Only observation for parallel and MPA
  - Dwell time for the Serial Search

- Serial Search Mean Time to Acquire
  - $\sim 16,000$ dwells for Pfa=5e-5
  - $\sim 21,000$ dwells for Pfa=1e-8

- Complexity
  - MPA $\sim 1/30$ Full Search for this example
  - MPA Complexity is exponential only in number of nonzero feedback taps
Summary & Future Work

- **Multipath**
  - Compare LOS power in chamber vs. Multipath in Lab.
  - Link budget work & FCC guidelines

- **FEC**
  - Explore non-AWGN advantages more completely for UWB
  - Tie closer to the UCB prototype needs

- **PN Acquisition**
  - Integrate to a verification/restart procedure
  - Integrate with frame sych. & determine capabilities in drift