UWB Research Overview

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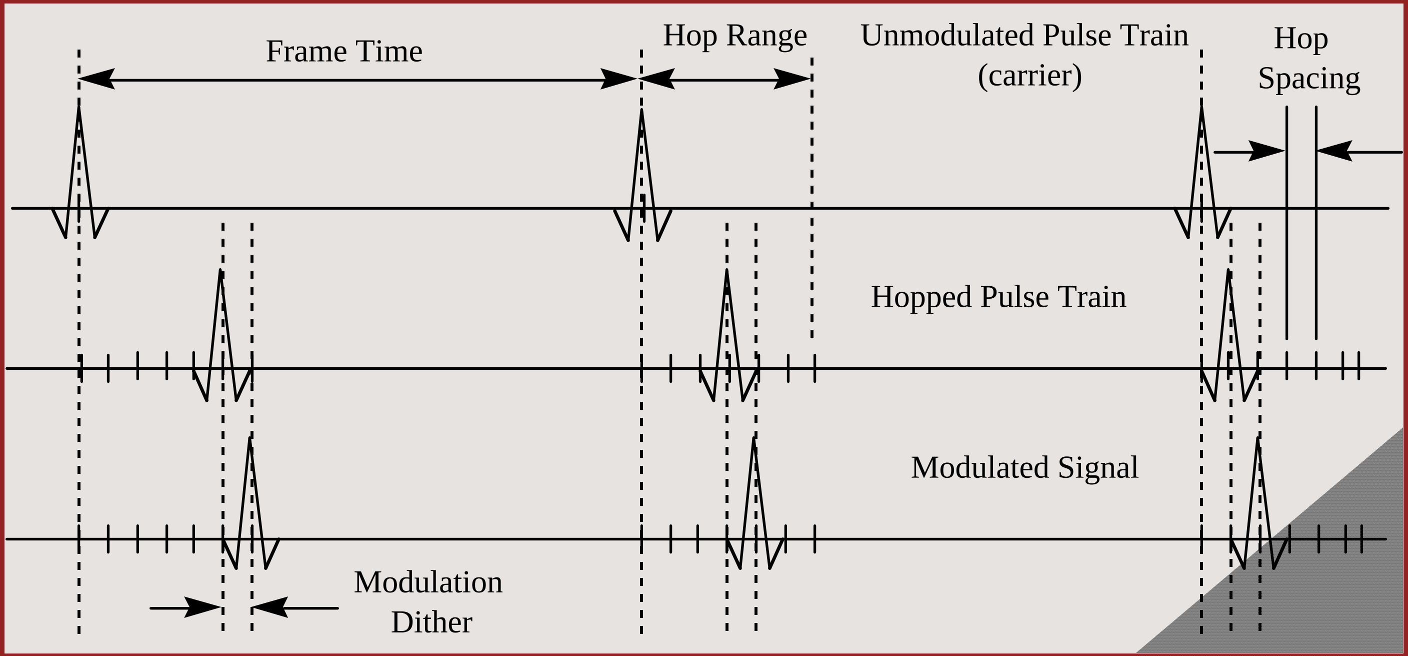
Overview

- 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)

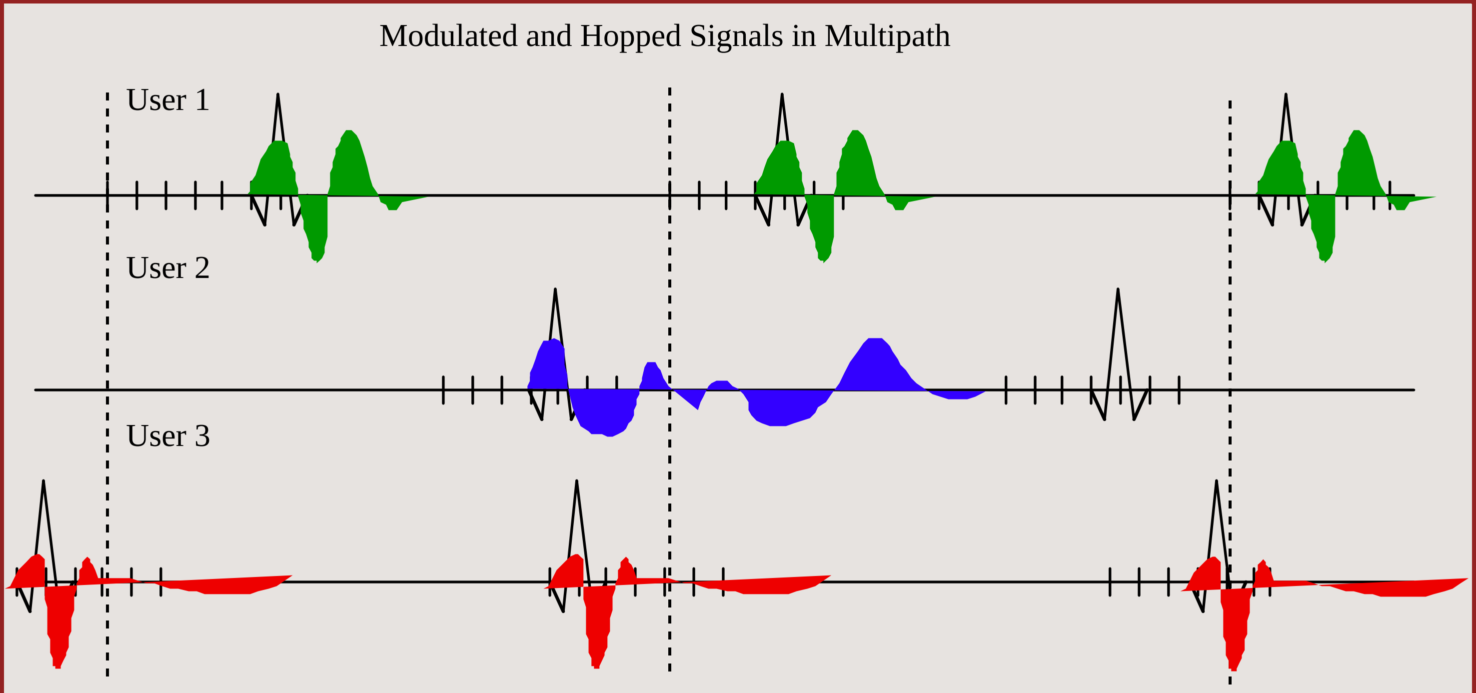


- Much of the multipath work based on this
- Other work is more general

Multipath Effects on TH UWB

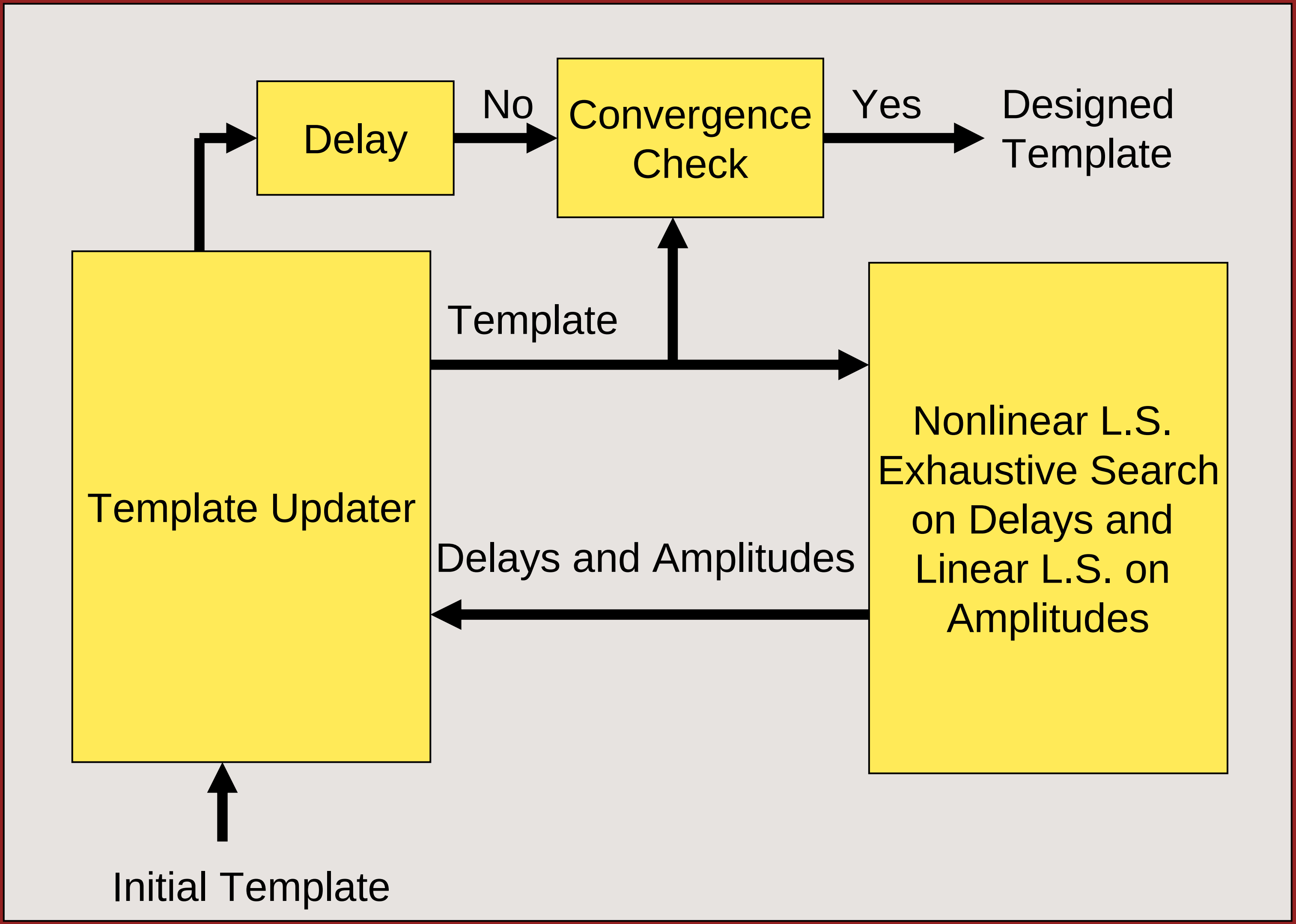
- Energy Capture
  - Design a simple correlator template to collect substantial energy? (No!)
  - Then, how much is gained by optimization of narrow pulse correlation template?
- Multiple Access
  - How does delay spread impact MAI?
  - What are the trade-offs in design choices and MAI?

Multipath Delay Spread

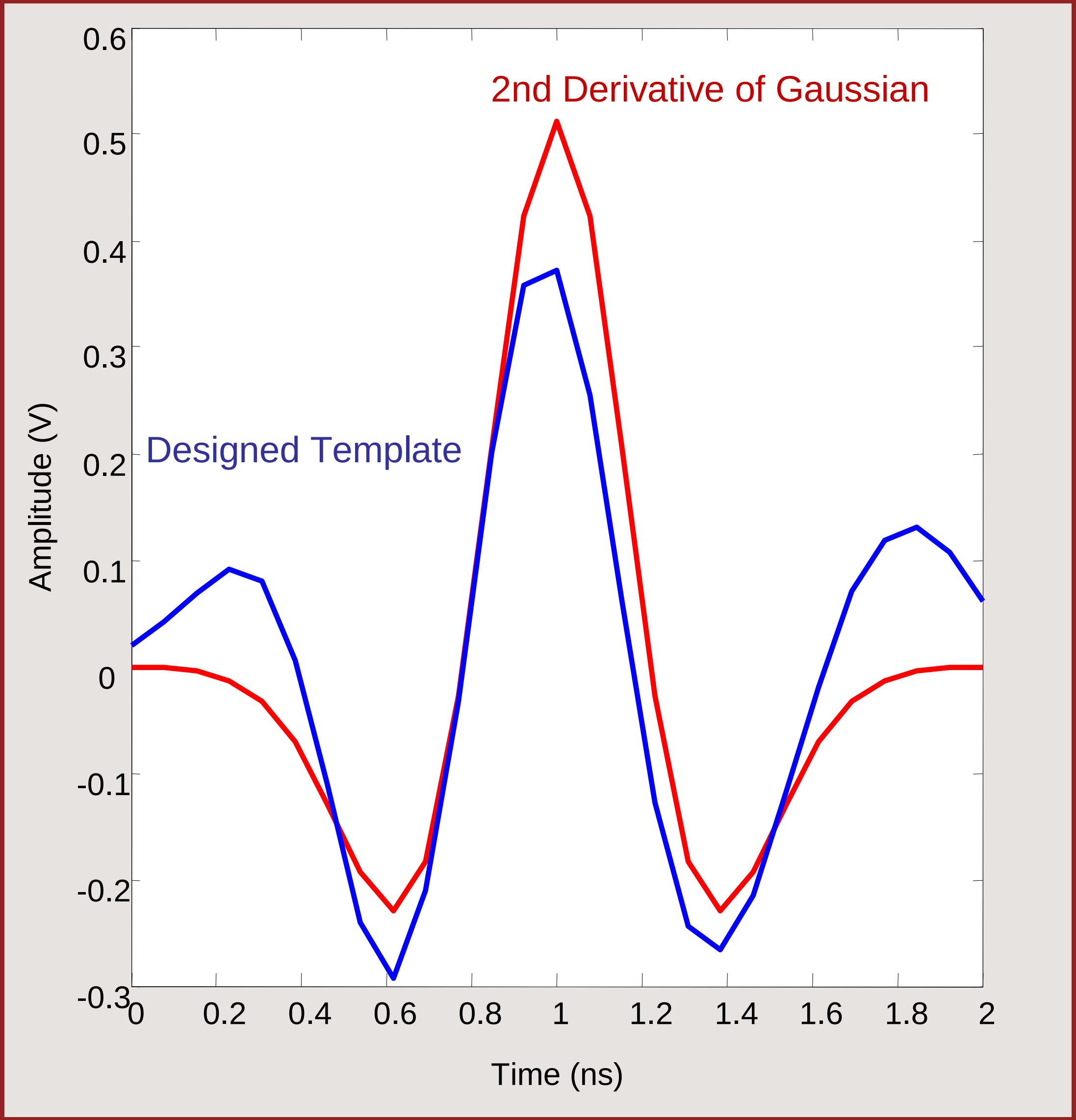


- Signal resolves many paths which need to be collected using multiple correlations (Rake)
- Multipath delay spread seems to cause more MAI

Iterative Correlator Template Extraction Algorithm

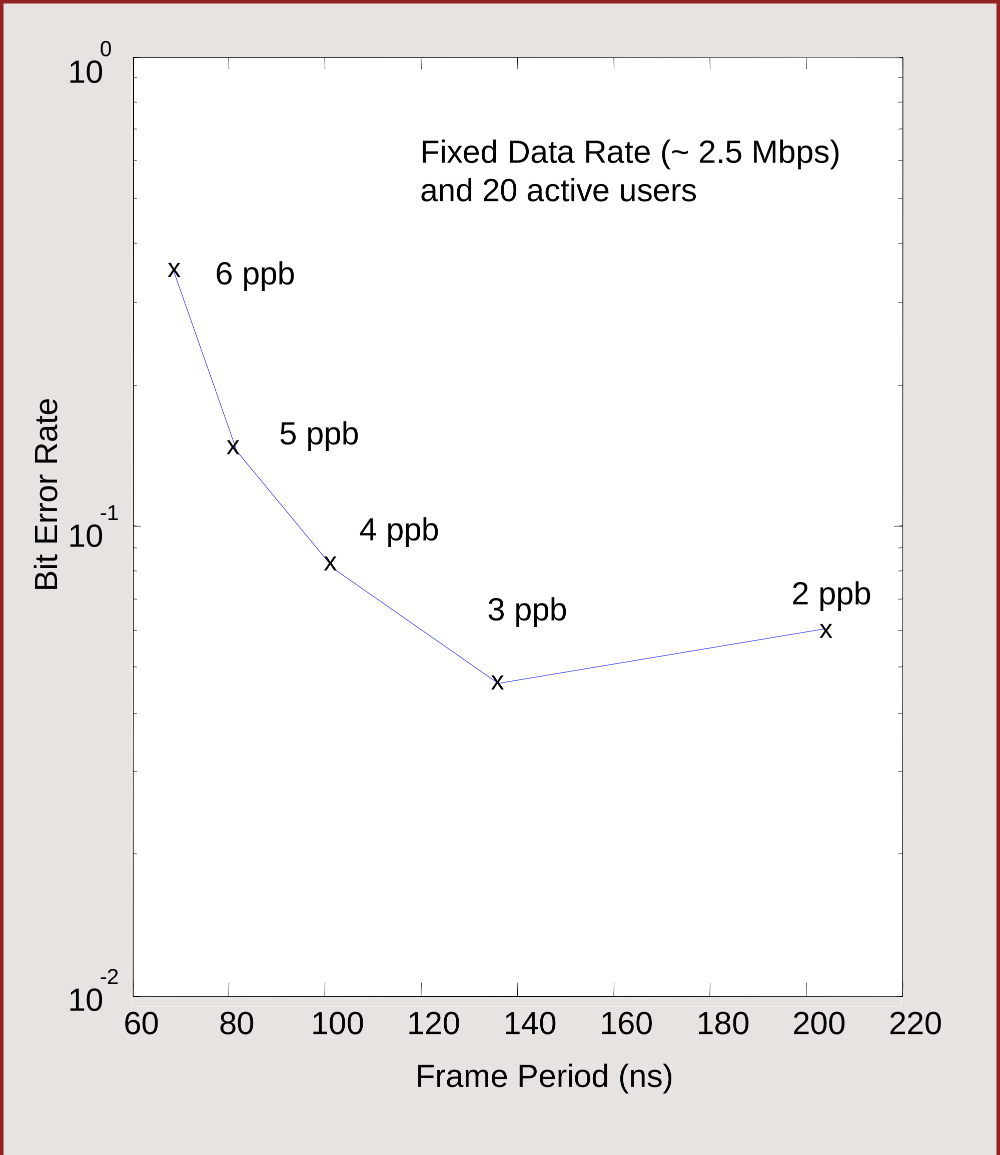


Typical Correlator Template Extracted



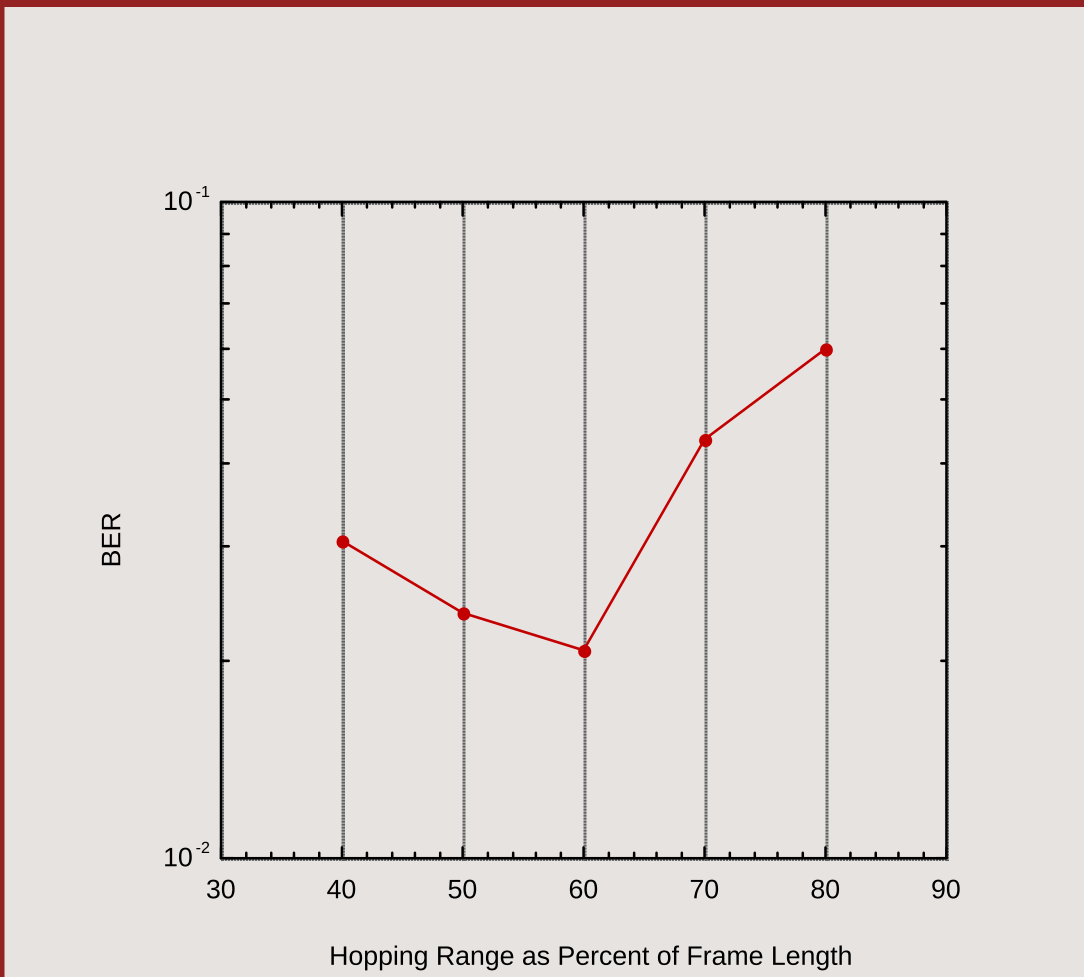
- ~ 0.9 dB improvement in energy capture for 3 correlators
- Suggests little gain in correlator optimization
- Can be useful for extracting a clean pulse from lab. data

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

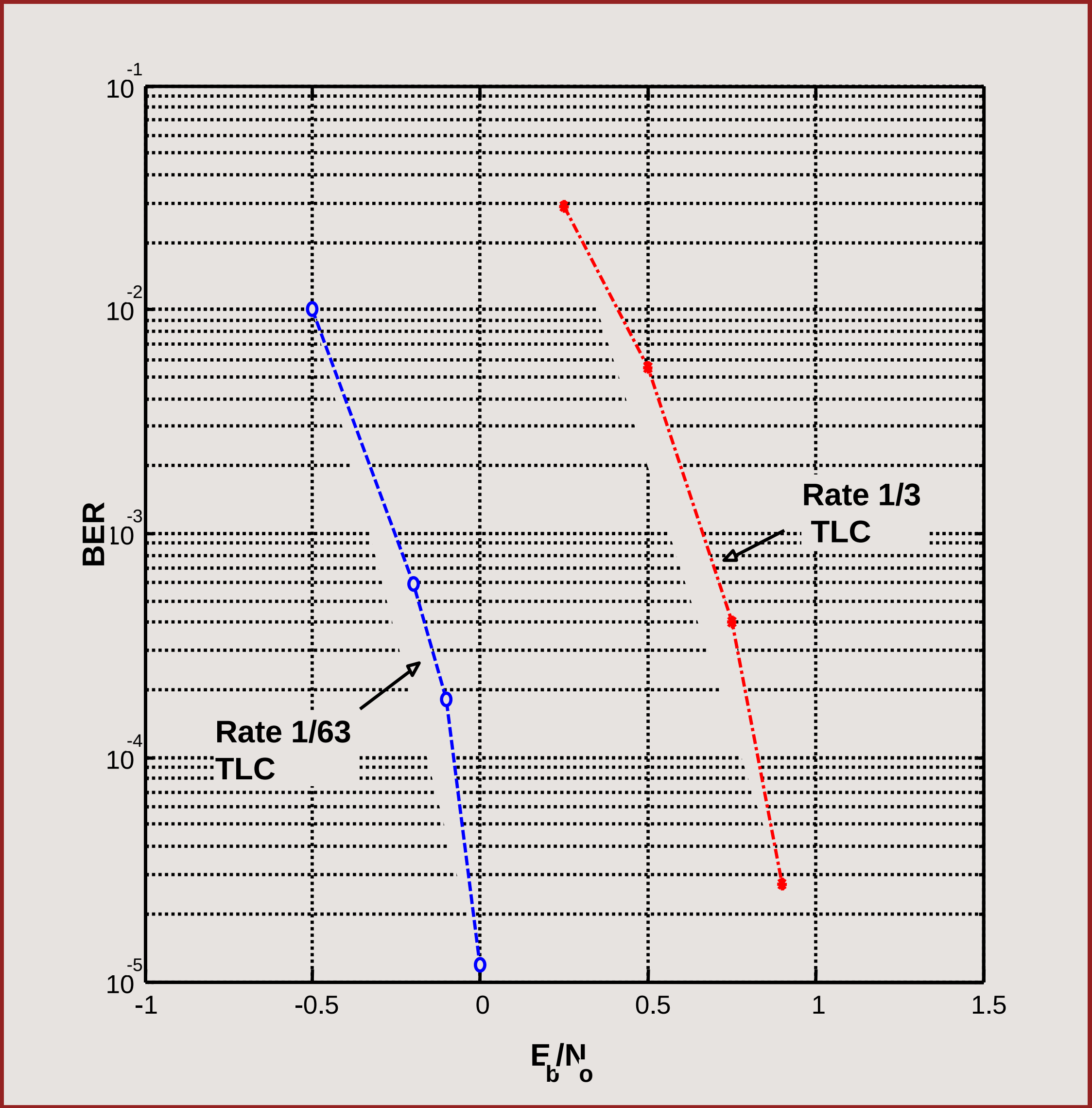
Very Low Rate Turbo-like Code Design

- 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

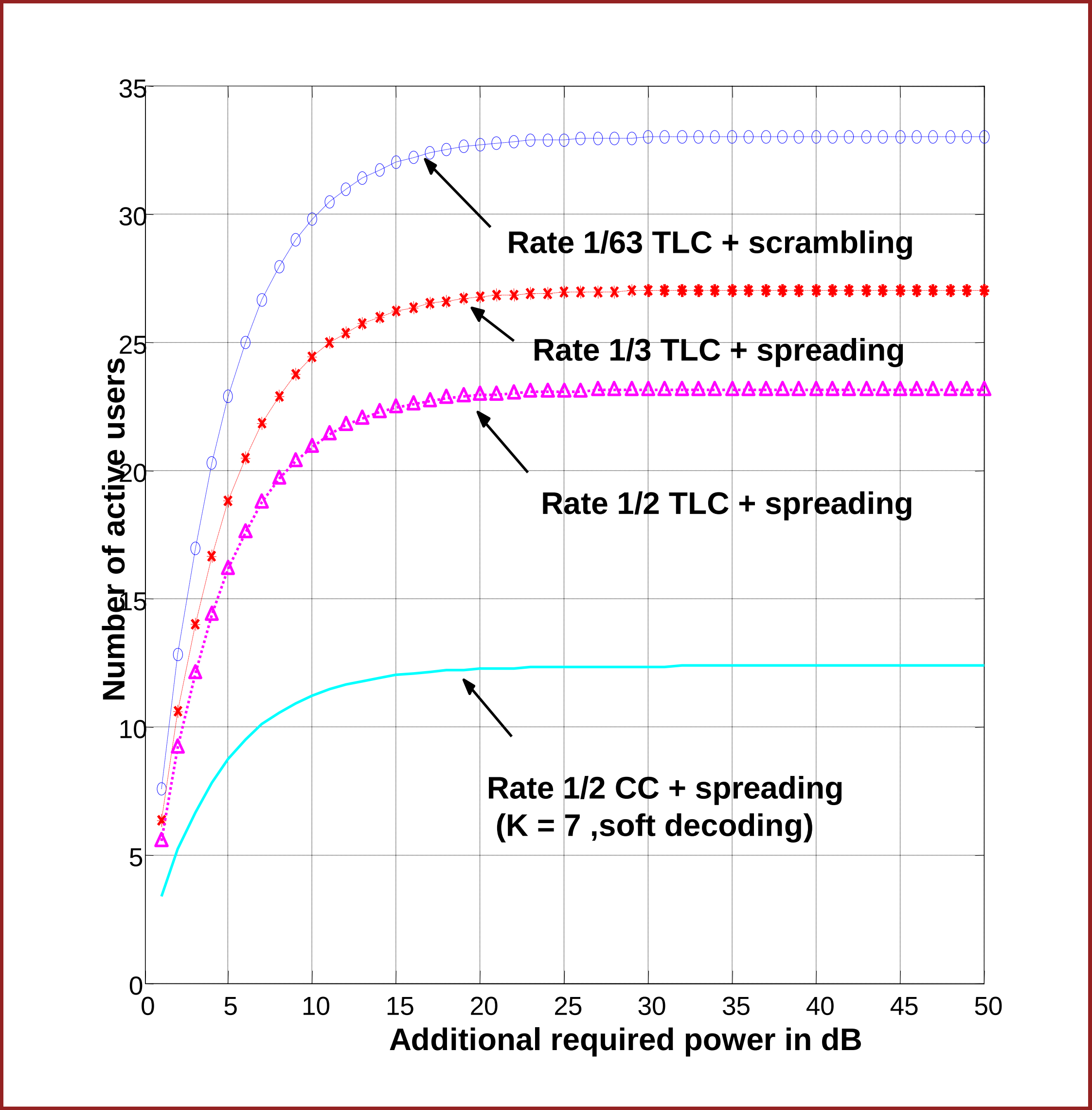
- Design Low Rate Constituent Convolutional Codes
  - Based on super-orthogonal designs
  - Key notion is to decouple the rate and the number of states
  - Results in “simple” super-orthogonal convolutional codes
- Use Such Codes as constituent codes for TLC

Example: Results - AWGN Channel



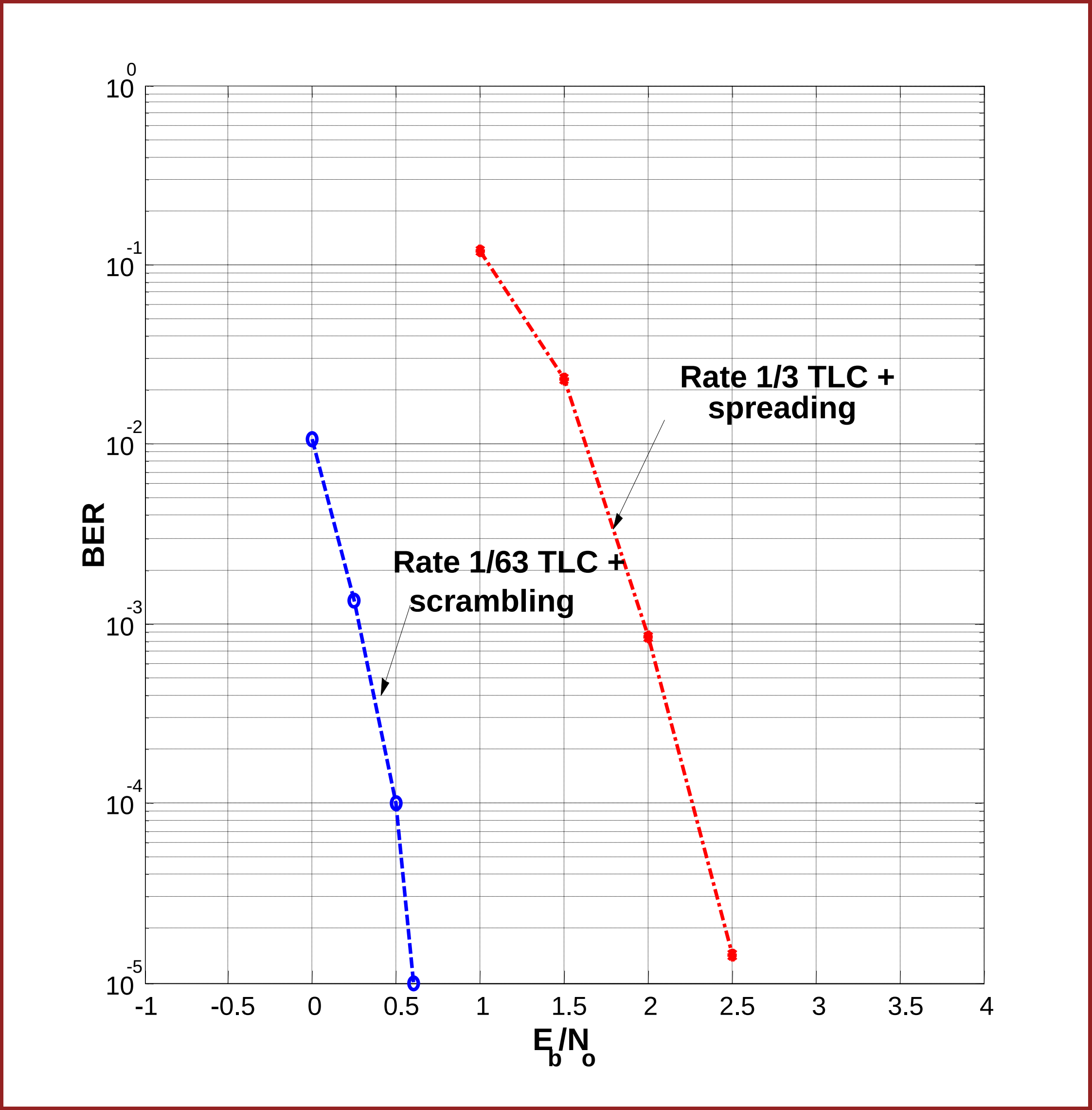
- Rate 1/3 parent code vs 1/63 low rate code constructed using our algorithm
- PCCC: Constituent codes have 16 states each
- 1024 bit interleaver
- 15 iterations
- Roughly about 1 dB additional coding gain is possible

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

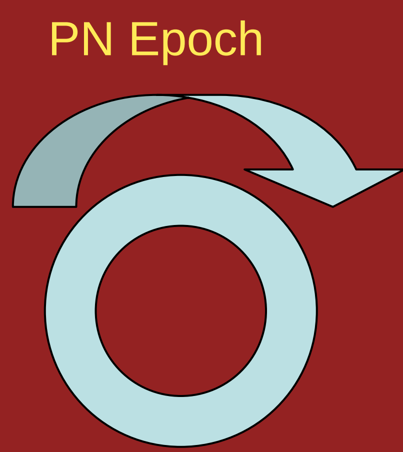
Example Results - Fading Channel



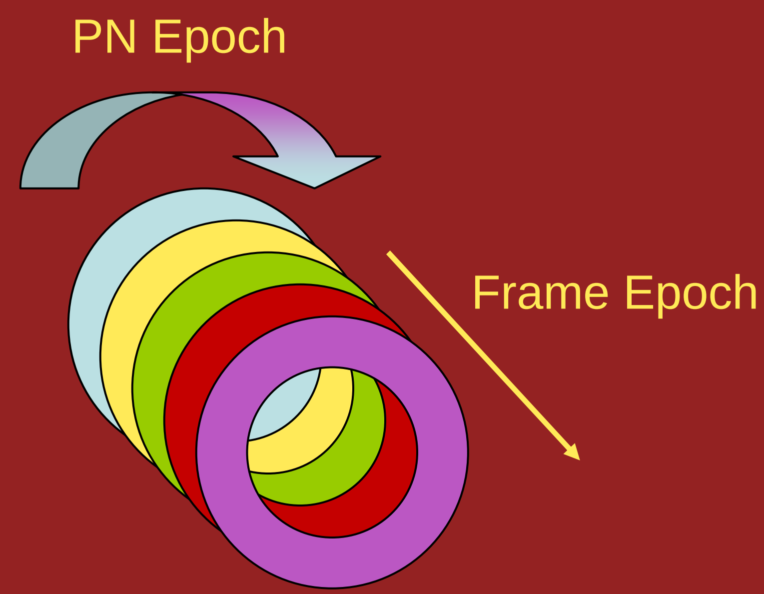
- Fading amplitude constant over blocks of 63 coded symbols
- Independent fading among blocks
- 10 iterations
- About 2 dB gain possible

Sychronization for Low Duty Cycle UWB Signals

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



Traditional Direct Sequence



Low Duty Cycle UWB

Rapid PN Acquisition Using Iterative Detection Techniques

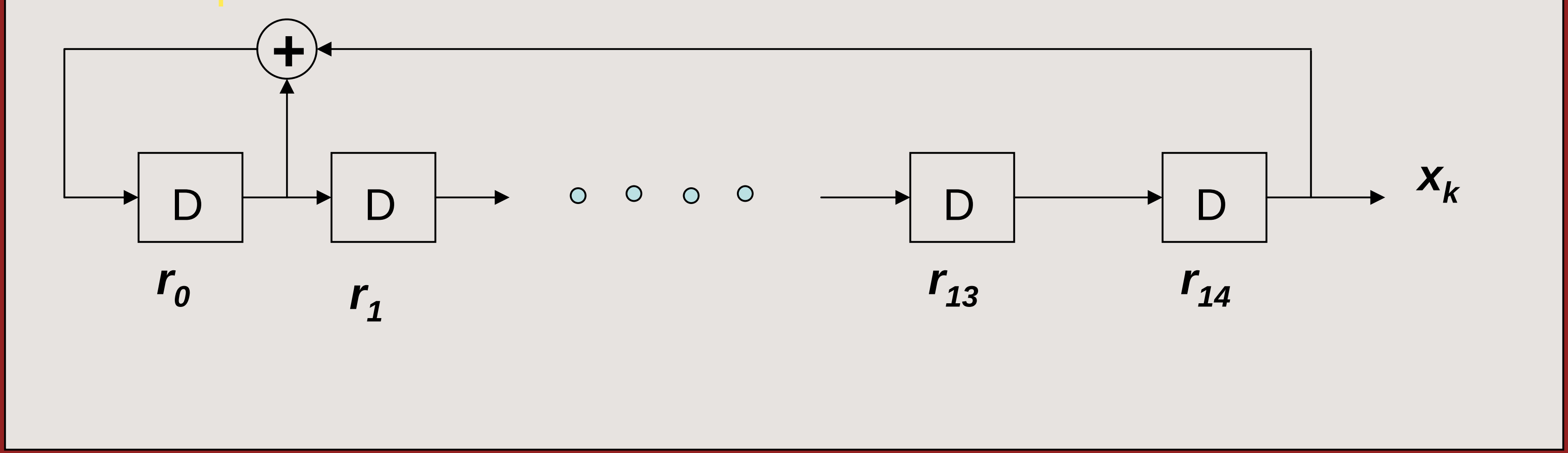
- UWB systems may require very fast coarse PN pattern synchronization
  - Many resolution bins to search and true epoch will vary with time
  - "chasing tail" situation may arise
- Fully Parallel Acquisition
  - ML detection of initial state of an FSM evolution
  - Very complex in general, but fast
- 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

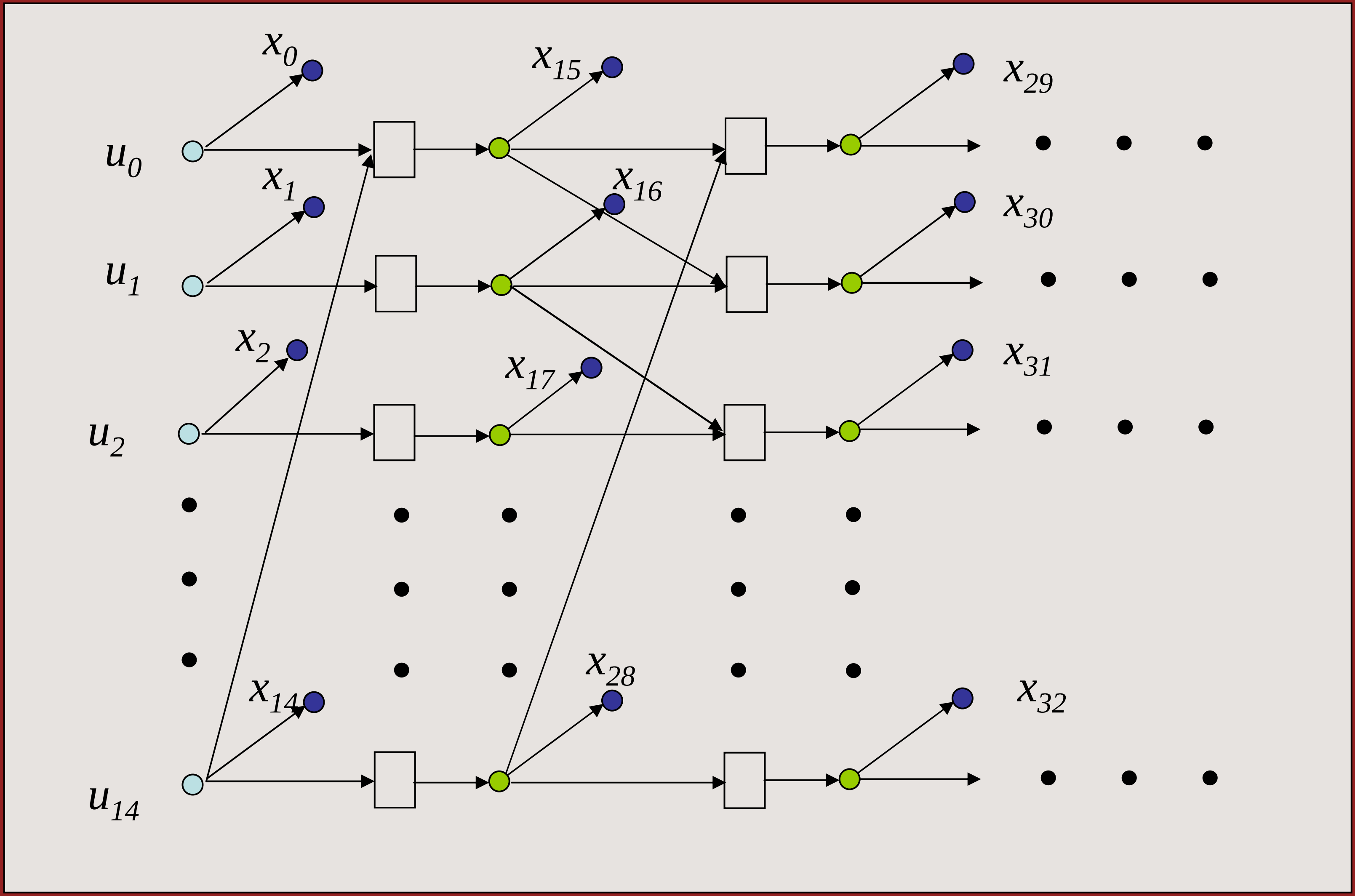
- Represent good PN patterns using sparse graphical models (new PN structures or existing)
- Apply standard message-passing iterative detection to approximate full parallel search

M-sequence Example: r-stage shift register

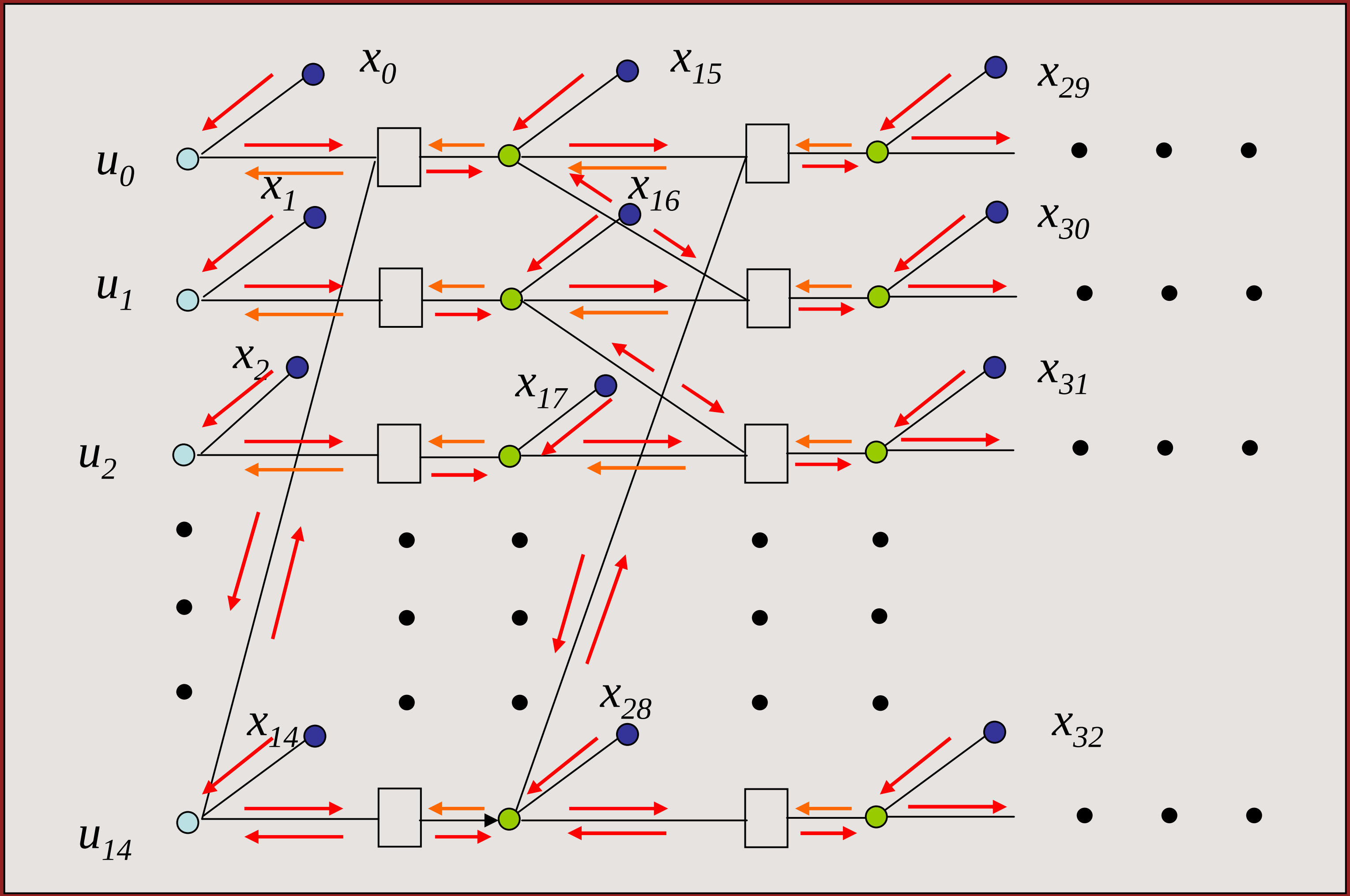
- **Observation:** for M-sequences with long period, there are many sparse generator polynomials & these directly provide sparse loopy graphical models.
- Example
  - An 15-stage shift register with generating polynomial of $[180001]_{oct}$. And the period of this m-sequence is 2^{15}-1 = 32767.
  -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



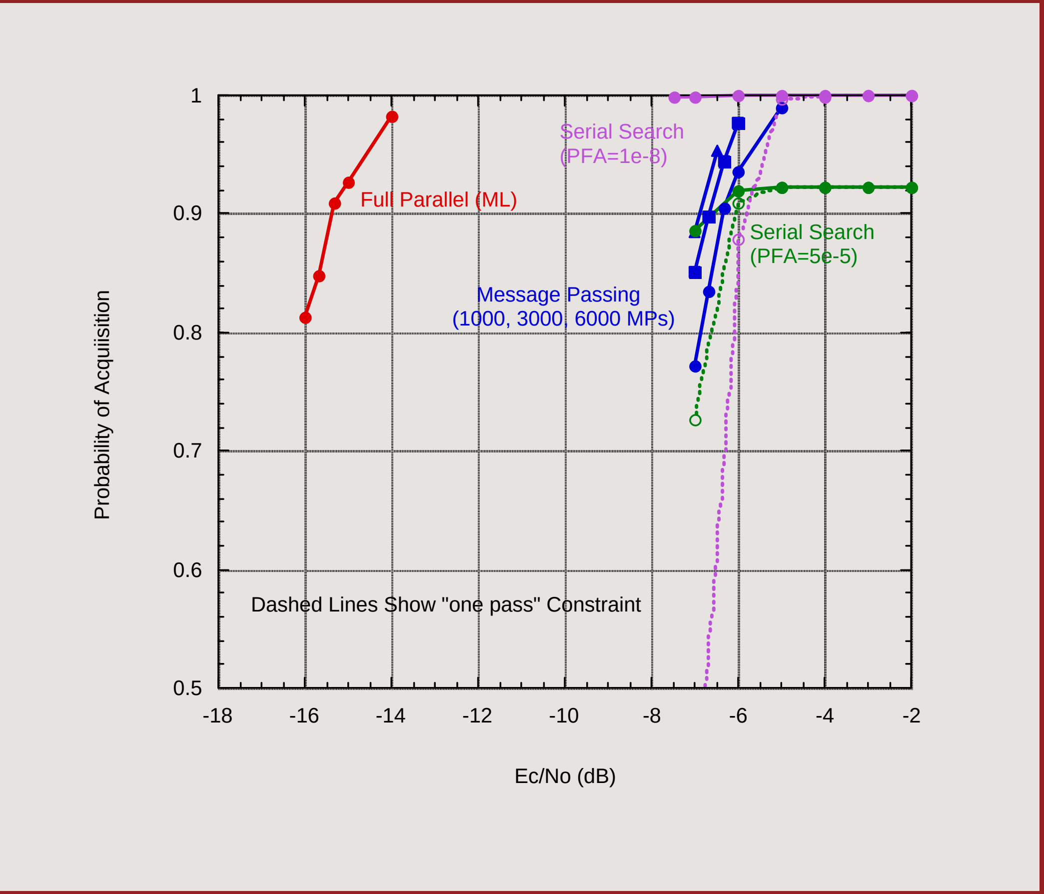
Sparse Loopy Graphical Model of 15-stage shift register



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
  - ~ 16,000 dwells for Pfa=5e-5
  - ~ 21,000 dwells for Pfa=1e-8
- Complexity
  - MPA ~ 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