Advanced Signal Processing for Wireless Communications

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MITRE Sponsored Research

Problem

- Infrastructureless Wireless Networks
  - Currently very unreliable and inefficient
  - Critical to Network Centric Warfare
  - Critical in both mobile and sensor networks
- Trend in commercial wireless is for smart nodes with sophisticated signal processing on soft information at the physical layer (802.11n, CDMA EV-DO, UMTS, 802.16)
  - Increased capacity, decreased latency

[picture taken from TAT briefing 2006]

- We are extending this trend to problems in wireless communication that are critical to the defense sector
  - Ad hoc networks: Grand Challenge of Communications and Networking
    - Create simple networks of smart nodes
    - Improve throughput and reliability of ad hoc networks

Background

NOW	EMERGING
Build in unnecessary excess link margin for unknown SNR	Rateless coding approaches capacity at any SNR
Link abstraction: Link is either On or Off, use ARQ in link-layer	Coherent combining of soft information ⇒ Hybrid ARQ, rateless coding
Shortest-path routing: - Determine single best route - Needs accurate tables	Cooperative Diversity – Fault tolerant – Multiple Routes – Treat stale routes as fades – Higher capacity Network Coding
Standards: 802.11abgn, 3G(UMTS, EV-DO)	802.11s, 802.16j, 802.16m, HSDPA, LTE

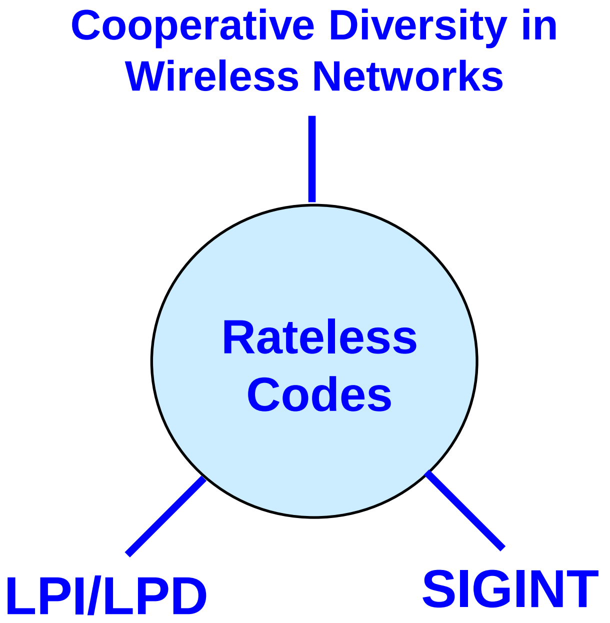
Objective

I. **Develop practical capacity approaching rateless coding solutions. If we can approach capacity at any rate, there is no cost to be rateless!**

II. **Combine rateless coding with cooperative diversity to achieve high performance wireless ad hoc networks**

III. **Combine rateless coding with low-probability-of-intercept/detection (LPI/LPD) techniques to produce a high throughput stealth waveform**

IV. **Investigate SIGINT exploitation of rateless coding and other opportunistic wireless approaches**

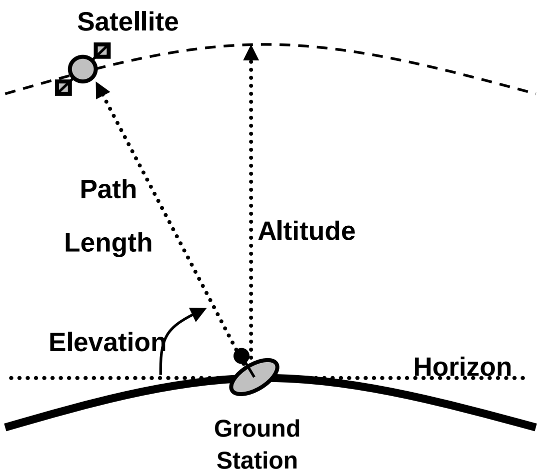


Rateless Codes are the Building Blocks!

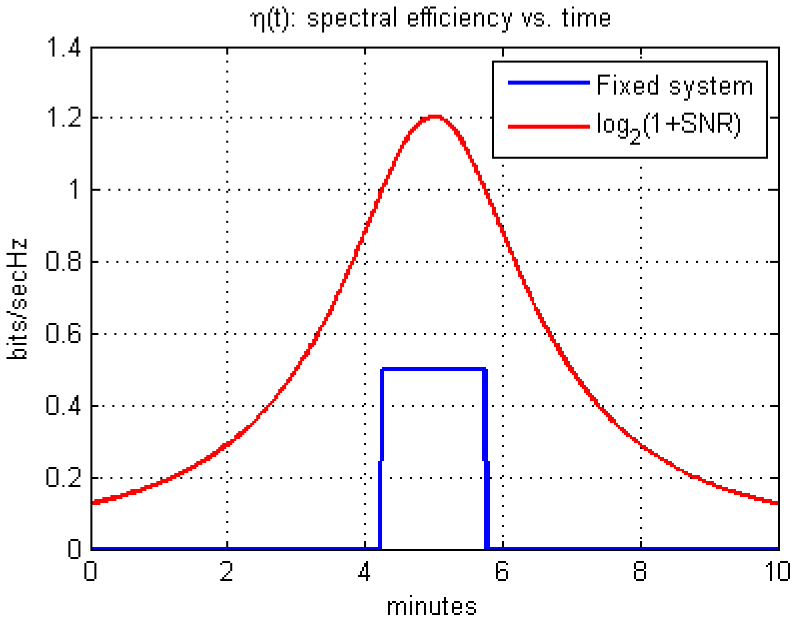
FY 2008 Research Activities

- Rateless Coding
  - Power Allocation for Rate Compatible Layered Codes
  - Bit Interleaved Coded Modulation
- LPI/LPD
  - LDPC, Raptor and Turbo based rateless codes for Low SNR
- Cooperative Diversity
  - Analysis and simulation of "OLT" Hierarchical Cooperation Scheme
  - Contributions to 802.16 standards on Cooperative Relays to enable OLT like features
- Practical Implementation
  - GNU radio: Inexpensive shareware radio platform
    - Open Source OFDM code
  - Cell Broadband Engine: Sony PS3 provides unprecedented GFLOPS/$

Illustrative Rateless Coding Example



Initial Elevation	Flyover Duration	Data of Fixed System	Available Capacity
6 deg	10.1 min	6.0 Gb	27.8 Gb
15 deg	7.0 min	4.2 Gb	16.9 Gb
30 deg	4.1 min	2.4 Gb	7.8 Gb



Potential with rateless modulation/coding approach

$$\#\,\text{bits} = \text{BW} \cdot \int_0^T \eta(t)\,dt$$

Rateless Coding Technology

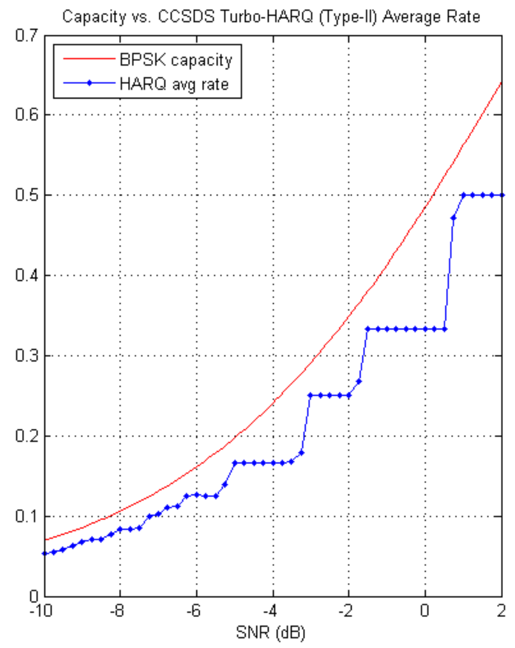
	Power-Limited (Status Quo)	BW-limited (Emerging)
Retransmission of transformed codewords	■ Repeat codes with Chase combining ■ Constellation remapping	Layered codes with dither [Erez, Wornell], [Shapiro, Barron, Wornell]. Around 2dB from Capacity
Rate compatible codes ■ Punctured mother codes ■ Raptor codes	■ Binary signaling ■ Far from capacity in many regimes of operations	■ Bit-interleaved coded modulation ■ Layered codes with optimal power allocation Promise of 1-1.5 dB from Capacity
Regime	■ Binary signaling ■ Low SNR ■ Limited range of throughputs ■ Low spectral efficiency	■ Spectrally efficient signaling ■ Near capacity in all regimes of operations (at all SNR)
Gains	■ 2-3 dB over conventional ARQ	■Several dB gain possible ■ All throughputs attainable

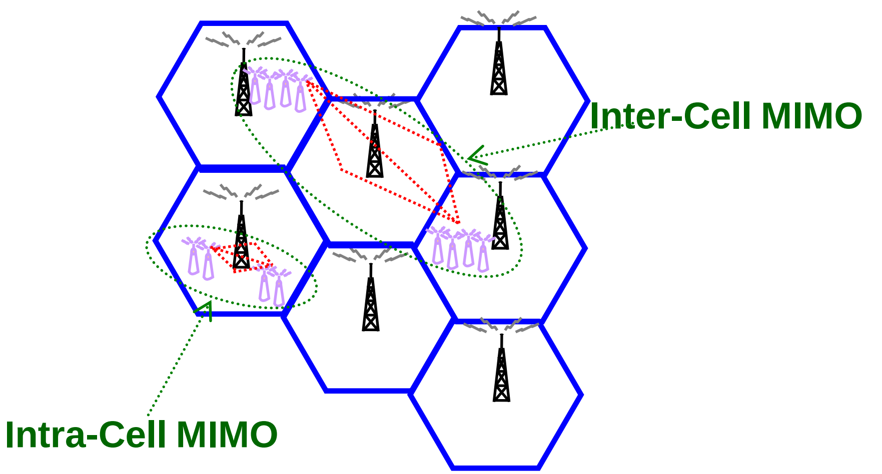
Technologies

MSR Focus

Impacts

- **Robust Point-to-Point Links**
- **Wireless Ad Hoc Networks**
- **Current and future communications waveforms**
- **Contributions to Standards**
  - **IEEE 802.11s (Mesh Networking)**
  - **IEEE 802.16j (Mobile Multihop Relay)**
  - **IEEE 802.16m (Advanced Air Interface)**
- **Publications, conference presentations, patents, etc.**





Future Plans

- Rateless Coding Demonstration on GNU Radio on Cell Broadband Engine
- Rateless Coding
  - Parallel Channels (MIMO/Multicarrier)
  - Cooperative Diversity
    - Analysis of Scalable Protocols
  - Mobile Ad Hoc Networks
    - Infrastructureless MAC/Network layer protocols
- LPD/LPI Communication
  - Waveform Design
  - Exploitation