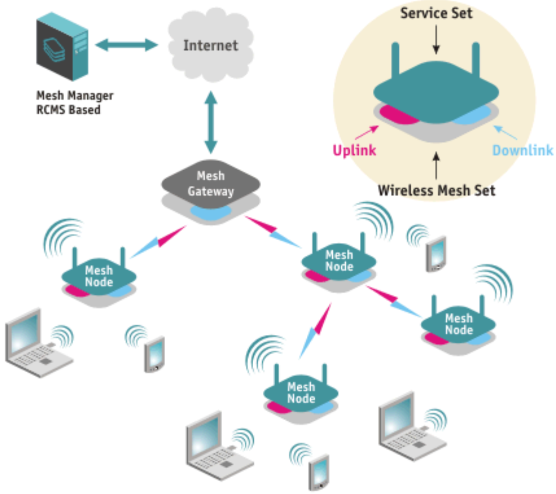
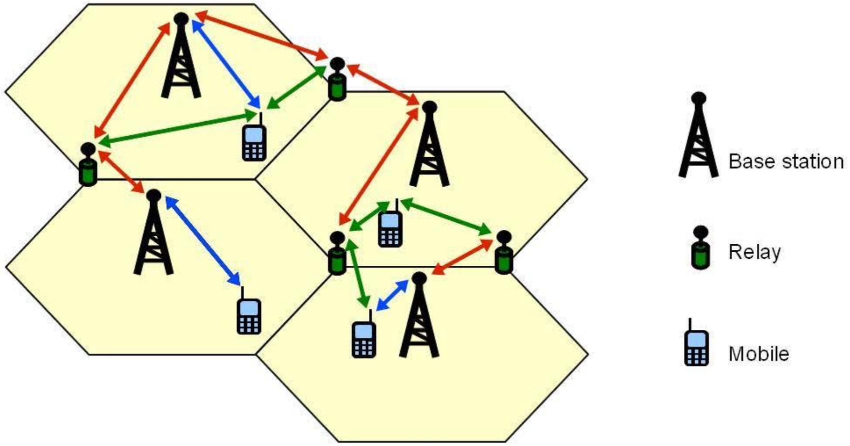
Communication Systems





Current and Future Trends in Communications Systems

- **Multiple antennas (MIMO)**
  4G standards, diversity vs. throughput, beamforming, channel feedback, novel antennas
- **Interference mitigation**
  more users, more data, pico- and femto-cells, wireless backhaul, fixed spectrum
- **Network cooperation**
  multi-cell transmission, relaying, network coding
- **Advanced receiver designs**
  ML-like (sphere) decoding, multi-user detection, advanced coding
- **Multimedia services**
  Delay and QoS constraints, protocols for multi-priority traffic
- **Cross-layer designs**
  Ad hoc networks, joint optimization of PHY, scheduling and routing
- **Wireless security**
  Eavesdropping, spoofing, jamming, other network attacks

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Advanced receivers
Network cooperation

Hamid Jafarkhani (Maryland '97)

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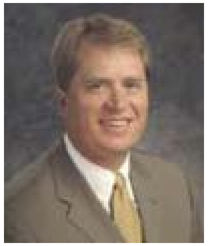

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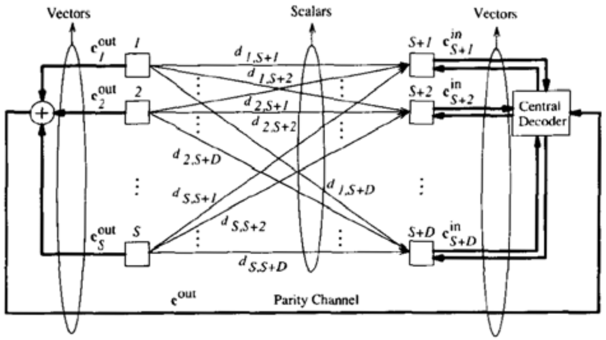
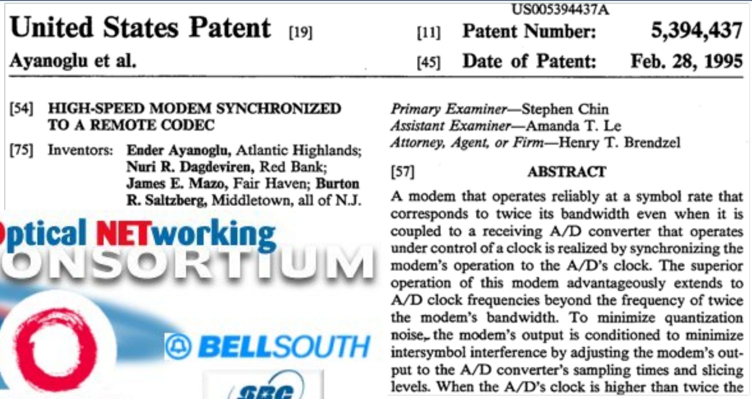
Past Research
Ender Ayanoglu




US005394437A

United States Patent [19] | [11] Patent Number: 5,394,437
Ayanoglu et al. | [45] Date of Patent: Feb. 28, 1995

[54] HIGH-SPEED MODEM SYNCHRONIZED TO A REMOTE CODEC

[75] Inventors: Ender Ayanoglu, Atlantic Highlands; Nuri R. Dagdeviren, Red Bank; James E. Mazo, Fair Haven; Burton R. Saltzberg, Middletown, all of N.J.

Primary Examiner—Stephen Chin
Assistant Examiner—Amanda T. Le
Attorney, Agent, or Firm—Henry T. Brendzel

[57] ABSTRACT

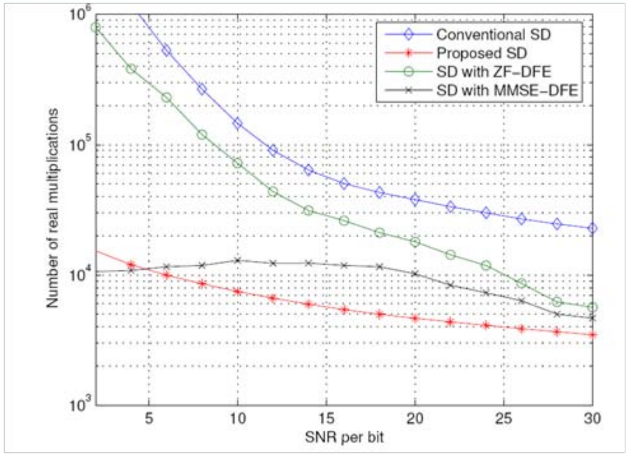
A modem that operates reliably at a symbol rate that corresponds to twice its bandwidth even when it is coupled to a receiving A/D converter that operates under control of a clock is realized by synchronizing the modem's operation to the A/D's clock. The superior operation of this modem advantageously extends to A/D clock frequencies beyond the frequency of twice the modem's bandwidth. To minimize quantization noise, the modem's output is conditioned to minimize intersymbol interference by adjusting the modem's output to the A/D converter's sampling times and slicing levels. When the A/D's clock is higher than twice the

- Diversity coding
- 56K modems
- Wavelength division multiplexing
- Wireless packet transmission

Current Research
Ender Ayanoglu

TABLE I
Comparison of the Maximum Number of VoIP Connections

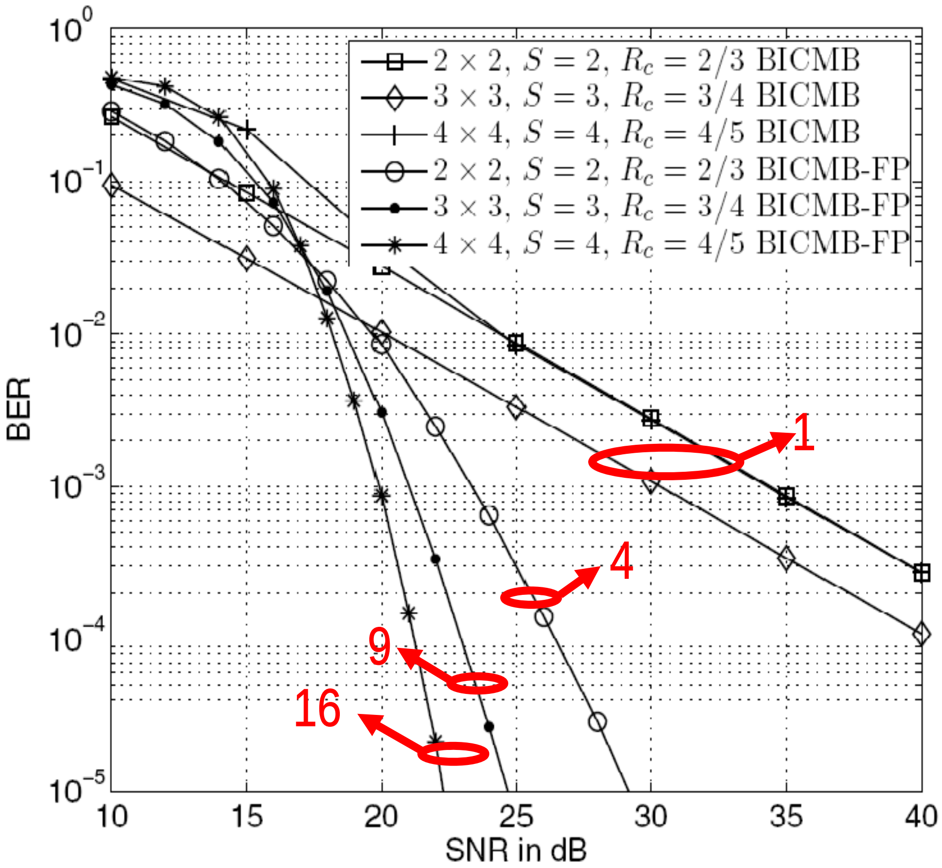
Sample Period	G.711				G.729			
	Proposed/Simulation	[22]	[32]	[39]	Proposed/Simulation	[22]	[32]	[39]
10 ms	27/27	29	21	26	29/29	30	22	27
20 ms	49/49	52	38	46	56/56	59	43	53
30 ms	70/70	74	53	68	85/85	88	65	82
40 ms	87/87	92	67	84	112/112	117	85	110
50 ms	102/102	108	79	99	139/139	145	106	136
60 ms	115/115	121	89	111	166/166	173	128	162



- **Recent work**
  - **Analysis and design of beamforming techniques for maximum throughput and maximum diversity in multi-input multi-output wireless networks**
  - **Reduced complexity sphere decoding, orthogonal and quasi-orthogonal space-time block decoding**
  - **Analysis of 802.11e Medium Access Control algorithm**
  - **Quality-of-Service scheduling in 802.11e**
  - **Network coding for network restoration**

Maximum Throughput with Maximum Diversity

Constellation Precoded Bit-Interleaved Coded Multiple Beamforming



16-QAM, 64-state punctured convolutional code

Related Poster Presentations

"Golden Coded Multiple Beamforming"
Boyu Li and Ender Ayanoglu

"Hitless Recovery from Link Failures in Networks with Arbitrary Topology"
Serhat Nazim Avci, Xiaodan and Ender Ayanoglu

Communication Systems Faculty

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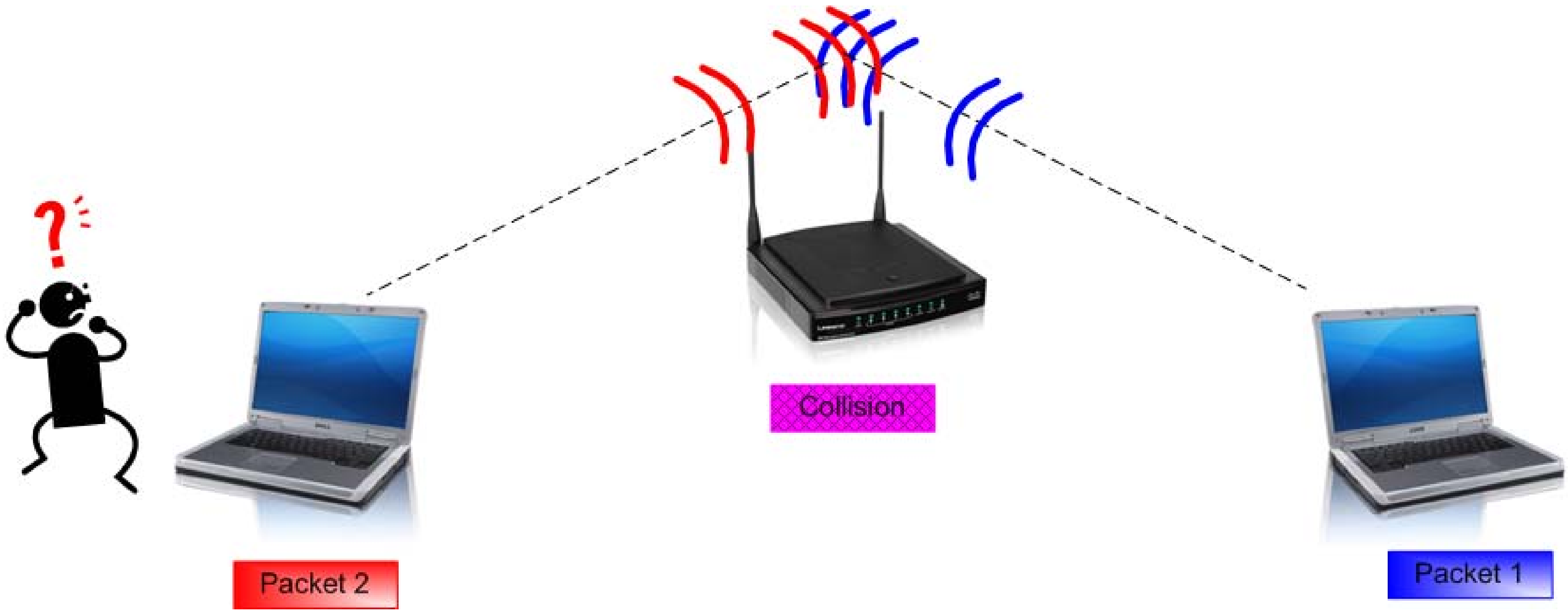
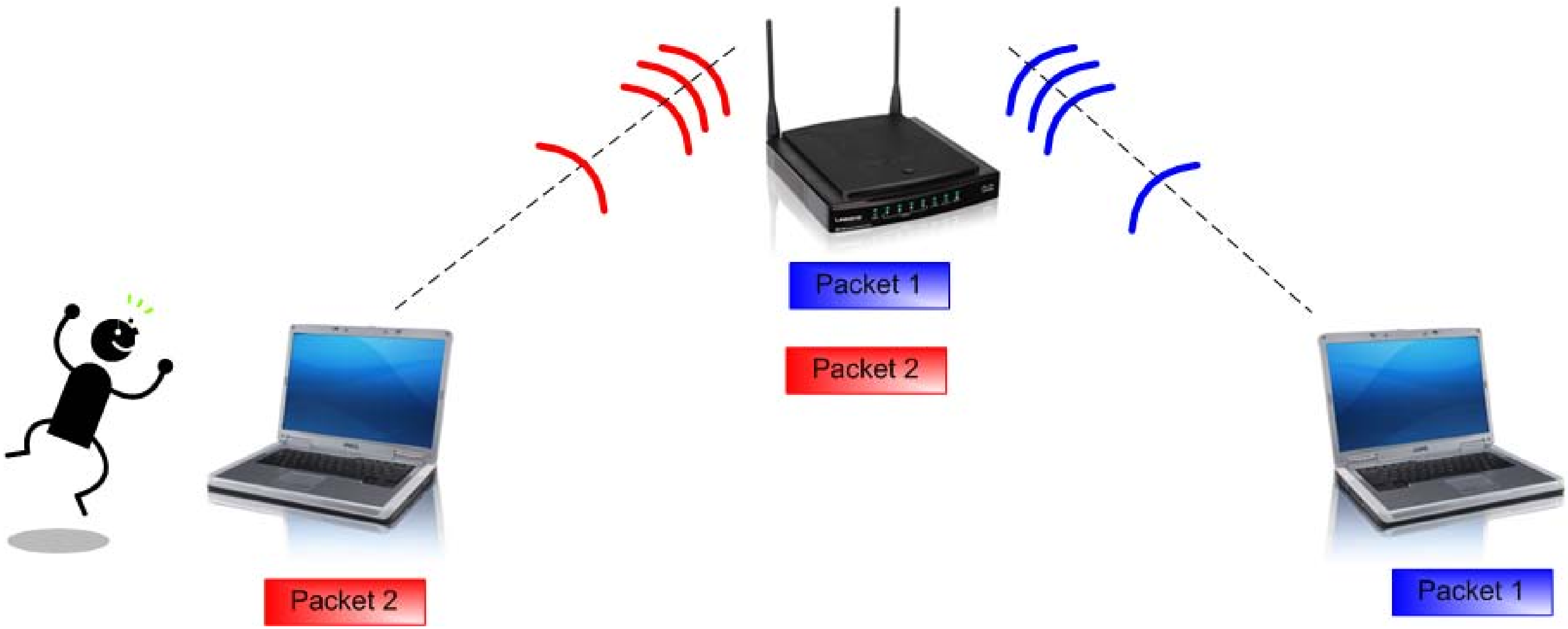
Multiuser Wireless Networks

Interference is the main challenge in multiuser wireless networks



Interference Mitigation

We have proposed different approaches to mitigate interference in the PHY instead of avoiding collisions in higher layers

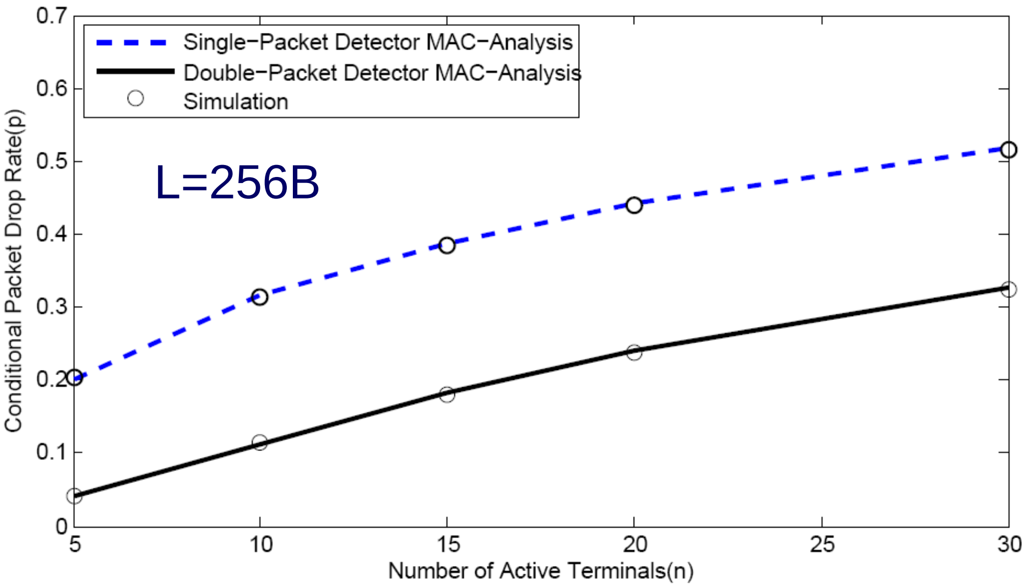


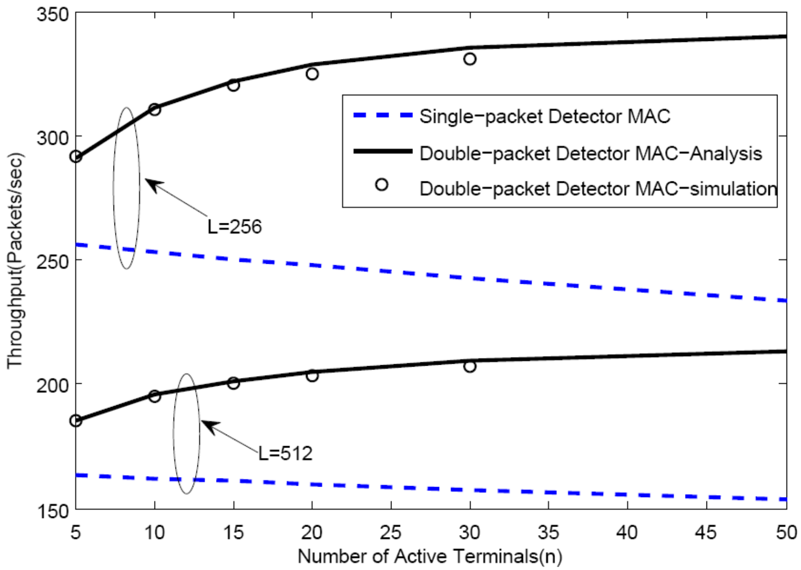
MPR = Multi-Packet Reception

Cross-Layer Interference Mitigation

- Designed a MAC layer to support the MIMO systems with PHY-layer interference cancellation
- Compared interference cancellation in the PHY layer with collision avoidance in the MAC layer
- Cross-Layer Design: Closed the PHY-MAC design loop by considering the effects of the MAC layer design on the PHY layer and handling the corresponding synchronization issues

- Results of NS-2 simulation
- No hidden terminal
- L=payload length
- Considerably higher saturation throughput for MPR, and throughput grows with number of active users
- Significantly lower packet drop rate for MPR





Channel Feedback

- **If feedback quality is low, beamforming schemes should gradually fall back to non-beamformed schemes.**

Perfect Channel Feedback → Beamforming

No Channel Feedback → Space-Time Coding

What about in-between cases?

How do we design beamformers for multiuser and cooperative networks?

Video Transmission over MANETs

- Transmitting video (H.264 bit stream) over wireless networks.
- The main challenges are
  - Protection against wireless channel noise, fading and packet erasure
  - Quality assessment
  - Real-time operation:
    - Delay
    - Computational Complexity

Related Poster Presentations

"MAC/PHY Cross-Layer Design with Asynchronous MIMO-MPR"
Sanaz Barghi, Hamid Jafarkhani and Homayoun Yosefi'zadeh

"Beamforming in Wireless Relay-Interference Networks with Quantized Feedback"
Erdem Koyoncu and Hamid Jafarkhani

"Performance of H.264 with Isolated Bit Error: Packet Decode or Discard?"
A. Murat Demirtas, Hamid Jafarkhani and Amy R. Reibman

"Cognitive MANETs Testbed and Protocols"
Homayoun Yousefi'zadeh and Hamid Jafarkhani

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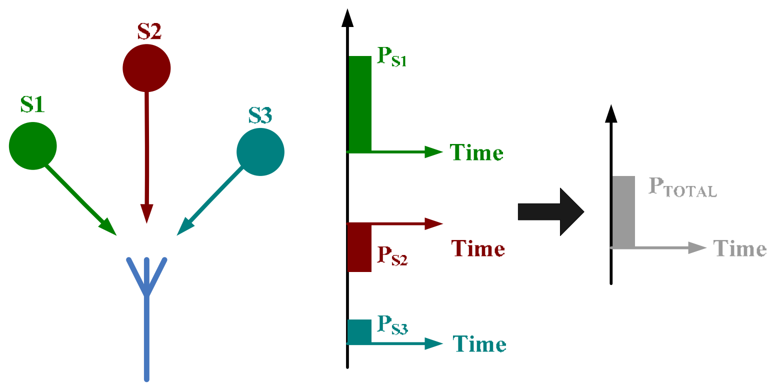
Summary of Active Projects

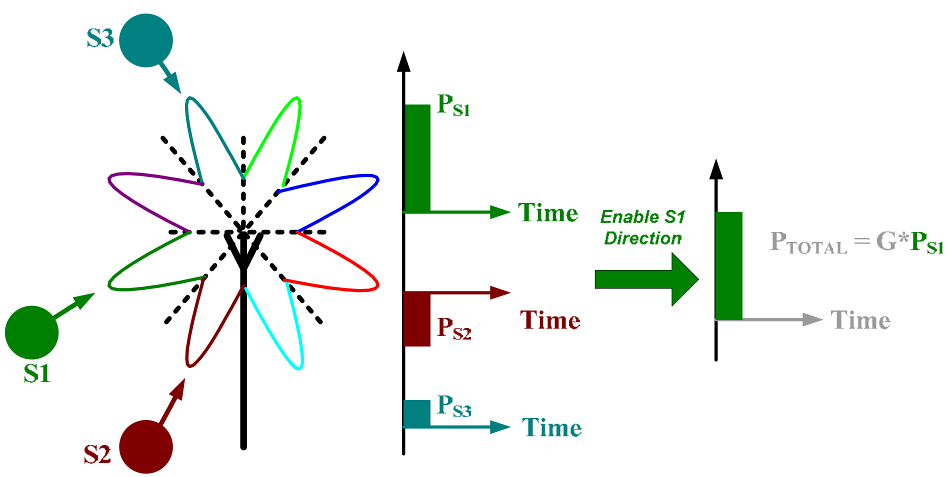
- **Relay and sensor networks**
  - Increasing range and possibly capacity of wireless systems via relays.
  - Sensor network design for applications such as smart grids.

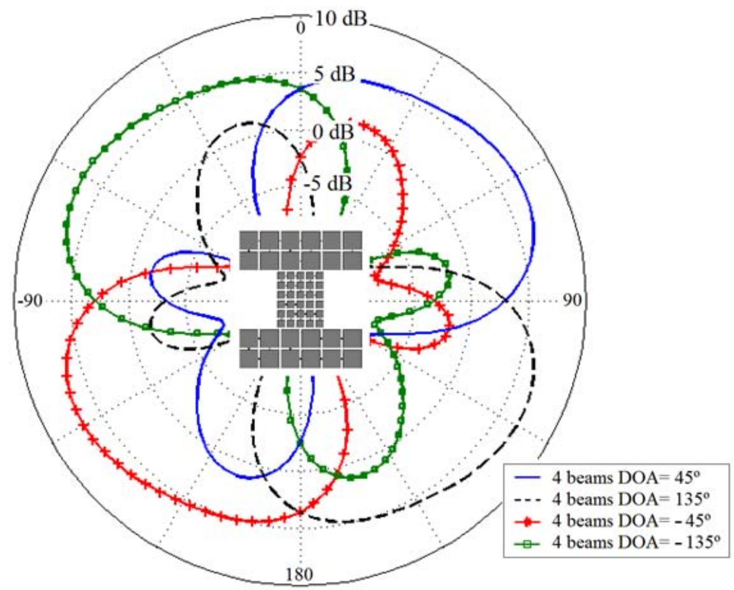
- **Efficient MIMO Systems**
  - Improving the capacity of wireless system via precoding and feedback.
  - Efficient architectures such as sphere decoders, FEC architectures, etc
  - Link performance improvement using directional antenna systems based on MEMS technologies

Omni vs. Directional Antennas



P_{s1}, P_{s2} and P_{s3} are received all the same time therefore irresolvable when received with an Omni-directional antenna

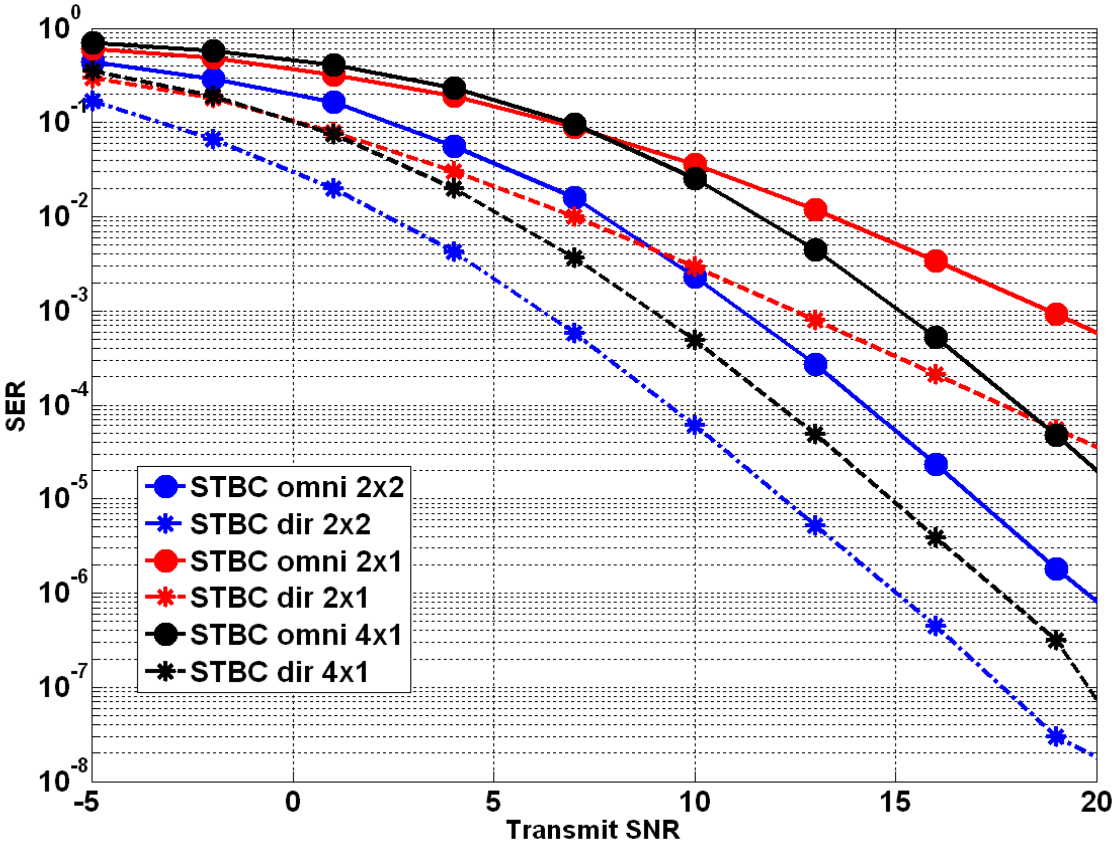




Extra antenna modalities require fast direction finding and training techniques.

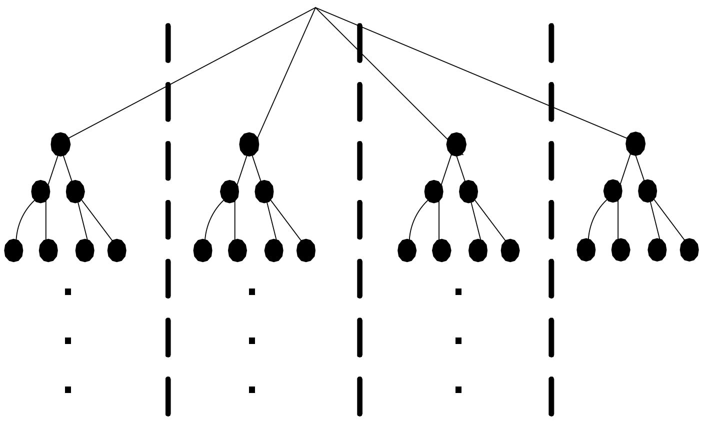
System Performance

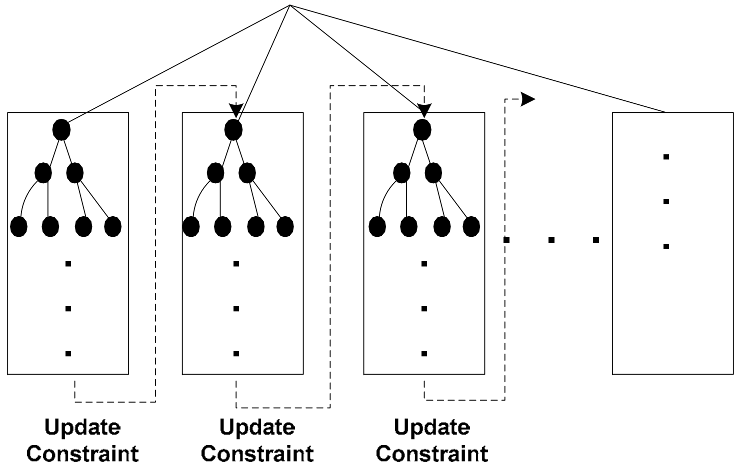
- **System Setup**
  - OFDM
  - 1024 Subcarriers
  - 50 Hz Doppler
- **MRA features:**
  - 8 beam directions
  - One beam active at a time
  - Constant antenna receive gain in the active beam



- Lower SER using directional antennas in all cases
- Better performance in low SNR for 2x1 STBC directional than 2x2 STBC Omni

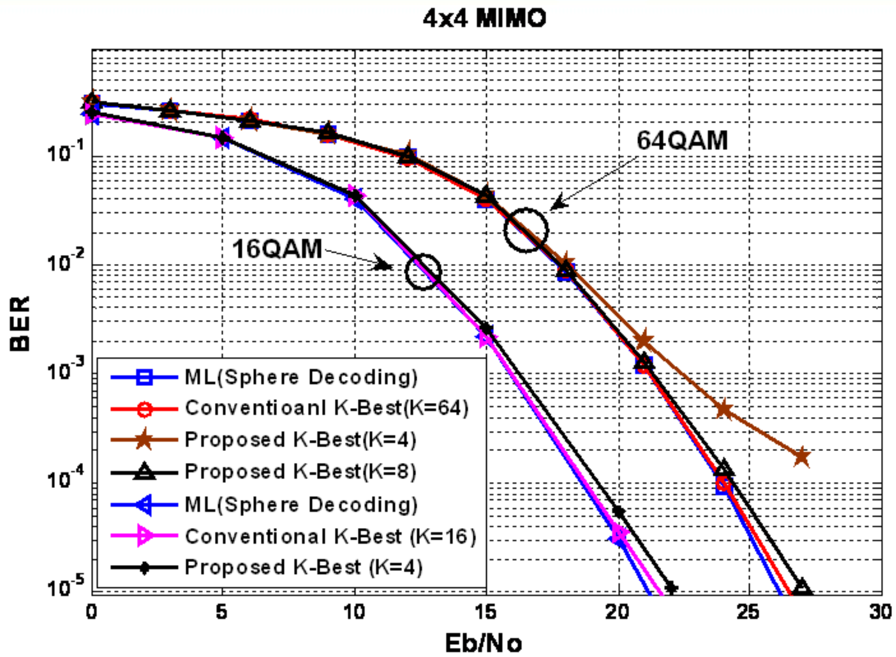
K-Best Decoder with Radius Shrinking and Early Termination

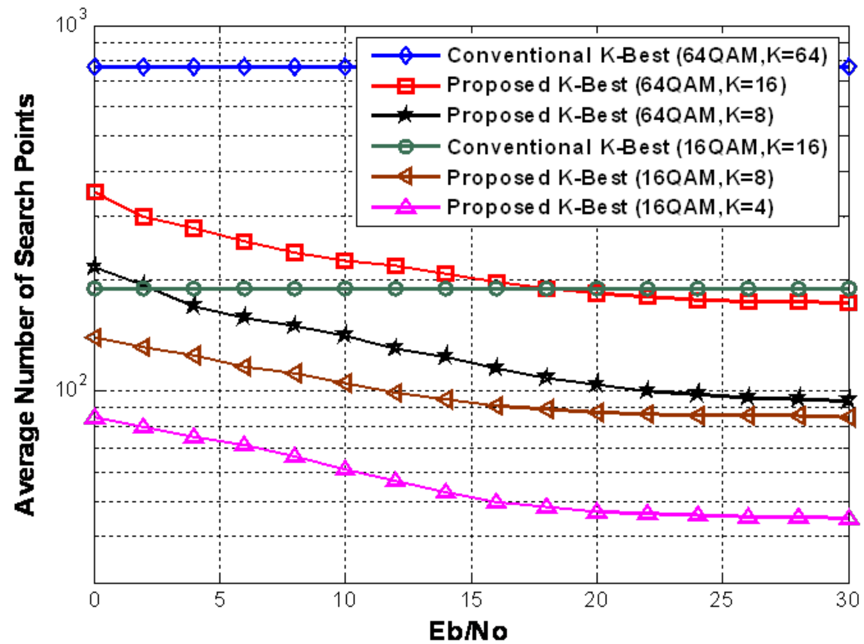




- A tree can be decomposed into individual sub-branches
- Each sub-tree searched by a K-Best decoder with reduced K (Reduced Dimensionality)
  - Decrease complexity for the computational units and storage spaces.
- Aggressive branch pruning based on radius update
  - Early termination is possible

Simulation Results: BER & Complexity





QAM	Approach/Parameter	Away from ML at BER = 10^{-3}	Away from ML at BER = 10^{-4}
64	K-Best with K = 64	< 0.1 dB	0.1 dB
	Proposed with K′ = 8	0.1 dB	0.6 dB
	Proposed with K′ = 4	1 dB	> 3 dB
16	K-Best with K = 16	< 0.1 dB	0.1 dB
	Proposed with K′ = 4	0.2 dB	0.7 dB

Related Poster Presentations

"MIMO Decoder Based on Tree-Search Approaches: Algorithm and VLSI Architecture"
Chung-An Shen and Ahmed M. Eltawil

"Cognitive Low Power Wireless Communication Systems"
Muhammad Khairy, Amin Khajeh, Fadi Kurdahi and Ahmed Eltawil

"Agile, Multi-Antenna Capable SDR Platform for Advanced Public Safety Communications"
Chitaranjan Pelur Sukumar, Hamid Eslami, Gaurav Patel, Fadi Kurdahi and Ahmed Eltawil

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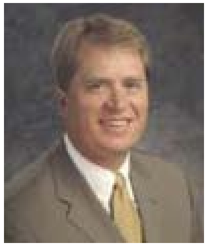

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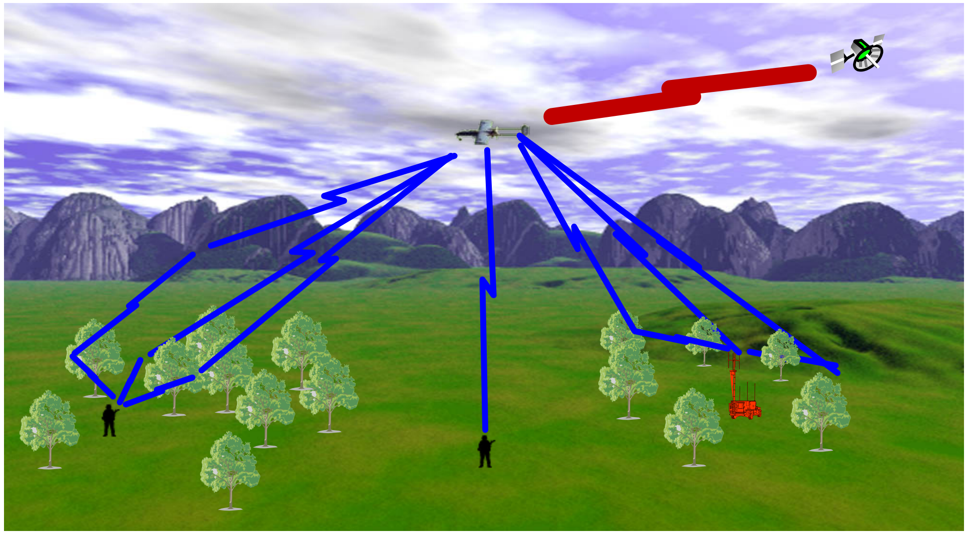
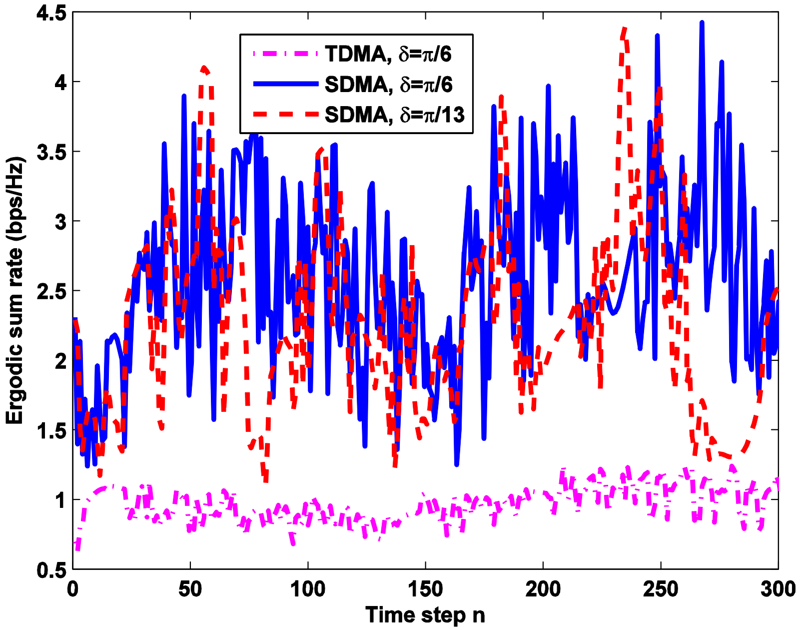
UAV Positioning for Ground-to-Air Uplink



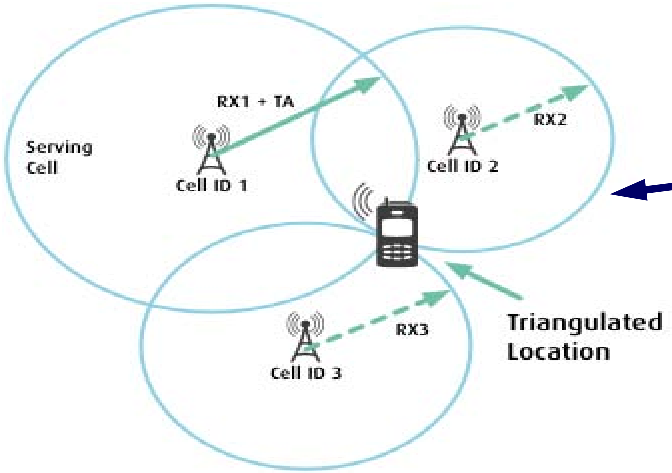
- UAVs already widely used for surveillance and "ordnance delivery"
- Smaller agile platforms also considered for tactical communications (relaying, downlink broadcasting, etc.)
- UAVs under consideration: large enough for multiple antennas, payload must be lightweight, energy consumption is important, algorithm complexity is thus a key issue

- We have developed low complexity algorithms for adaptively positioning non-hover UAV for optimal uplink communications
- Studied various trade-offs: TDMA vs. SDMA, throughput vs. fairness



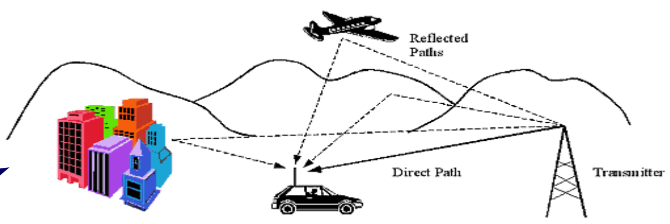
OFDM Signal Design for Positioning & Communications

- **Project Goal:** design OFDM signal optimized for both positioning and high-rate communications
- **Benefits:** allows for single-receiver architecture, less expensive devices, lower power convergence of GPS and cellular => positioning indoors or dense urban canyons



key is accurate time-delay estimation

but "multipath" is a big complication

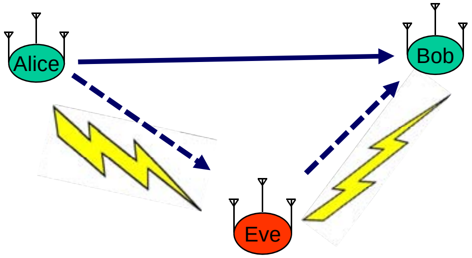


- Derived optimal pilot distribution, with adjustable accuracy for time-delay and channel estimates
- Pilot energy not uniformly distributed (prior work) – pushed to band edges for time-delay accuracy
- Surprising outcome: optimal pilot distribution is sparse *without being constrained to be so*

Physical Layer Security in Wireless Networks

- Security typically handled by cryptographic techniques implemented at higher layers
- Key distribution and management is complicated and has a high overhead
- Vulnerabilities also exist in *ad hoc* networks with no central infrastructure and where nodes randomly join and leave the network
- Physical layer methods exist to achieve security when encryption is not possible
- Even if encryption is available, PHY-layer techniques can be used to augment security

- **Project Goal:** Investigate PHY-layer security techniques for multiple-antenna networks, employing beamforming and jamming



- **Scenarios Considered:**
  - simple wiretap channel
  - interference channel
  - cooperative jammers (helpers)
  - broadcast channel
  - two-hop relay channels
  - two-player eavesdrop/jamming games

Related Poster Presentations

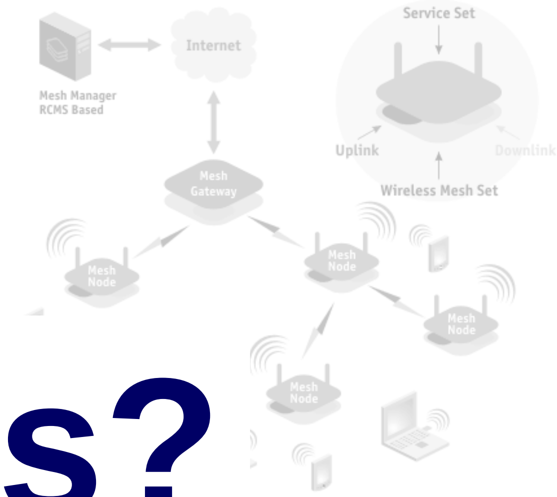
"Dynamic UAV Positioning for the Ground-to-Air Uplink"
Feng Jiang and A. Lee Swindlehurst

"Signal Design for Combined Positioning and Communication Systems"
A. Lee Swindlehurst and Gonzalo Seco-Granados

"Physical Layer Security for Wireless Networks"
Ali Fakoorian, Jing Huang, Amitav Mukherjee and A. Lee Swindlehurst

"Closed Loop Tracking Using Multi-Modal RF/EO Sensors"
Sean O'Rourke and A. Lee Swindlehurst

Communication Systems



Questions?