SAND2006-0537P

Channel Modeling of Exo-Atmospheric Network and Cooperative Communication

presented by Ketan Mandke

August 10, 2005

Sandia National Laboratories

Outline

I. Exo-Atmospheric Network Channel Modeling
- Goals
- Features
- Animation
- Preliminary Results

II. Cooperative Communication
- Basic Idea
- Motivation
- Cooperative Strategies
- Relay Selection
- Specific Applications

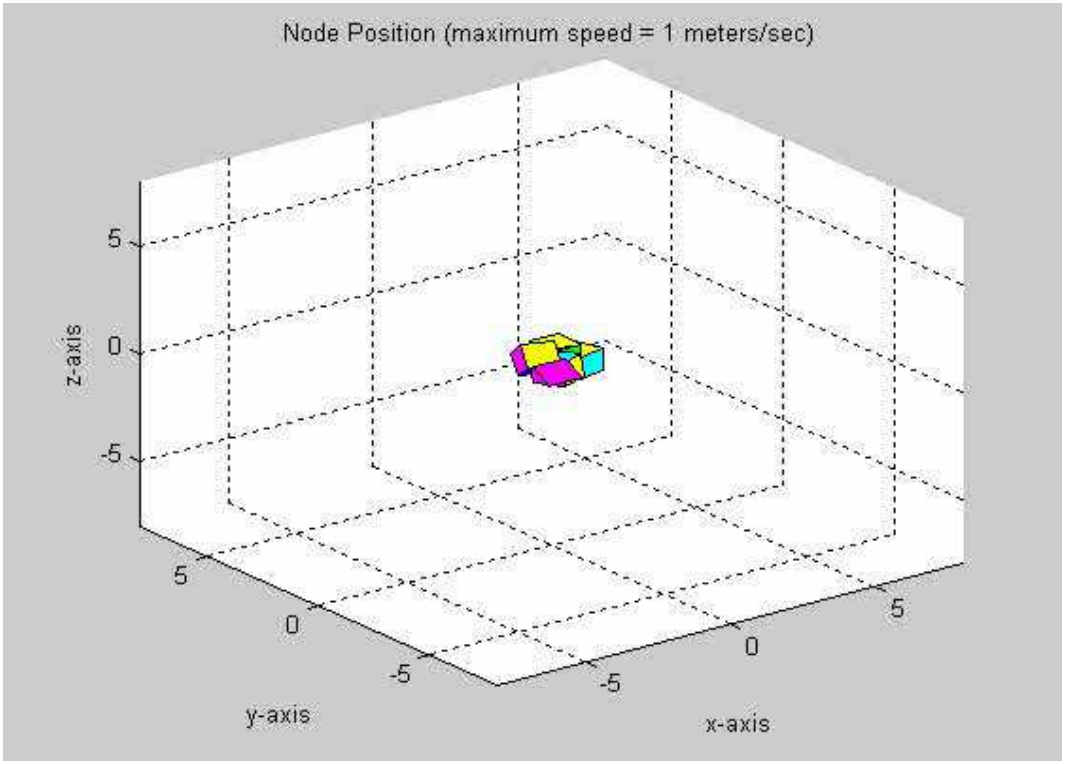
Part I: Exo-Atmospheric Network Modeling – Goals

- Develop tool for generating traces of wireless channel quality in exo-atmospheric scenario (i.e. realistic model for geometry and wireless behavior)
- Establish reasonable stochastic model for wireless channel between nodes (including some understanding of coherence time)
- Show preliminary results using modeling tool

Model Features

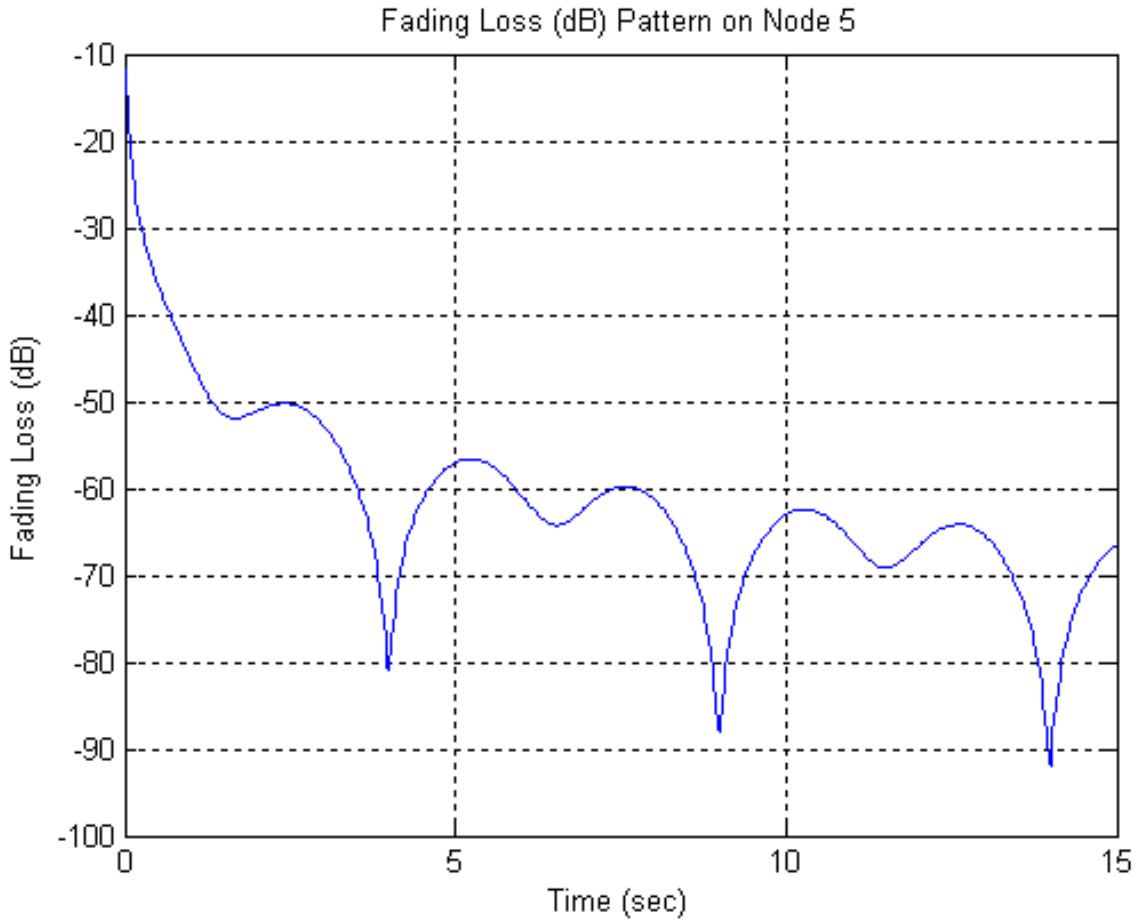
- Variable parameters
  - Antenna pattern – (e.g. ½ wavelength dipole)
  - Trajectory – direction + velocity
  - Rotation – axis of rotation + angular velocity
  - Orientation – axis of rotation + angular shift
- Static trajectory and rotation (i.e. no acceleration)
- Point Assumption
  - All nodes collapsed to a point
- Generates free space pathloss pattern (n=2)
- Generates fading pattern
  - result of rotation of antenna pattern
- Computes phase
  - based on antenna location offset and antenna spacing

Model Geometry



Sandia National Laboratories

Modeling – Example Trace



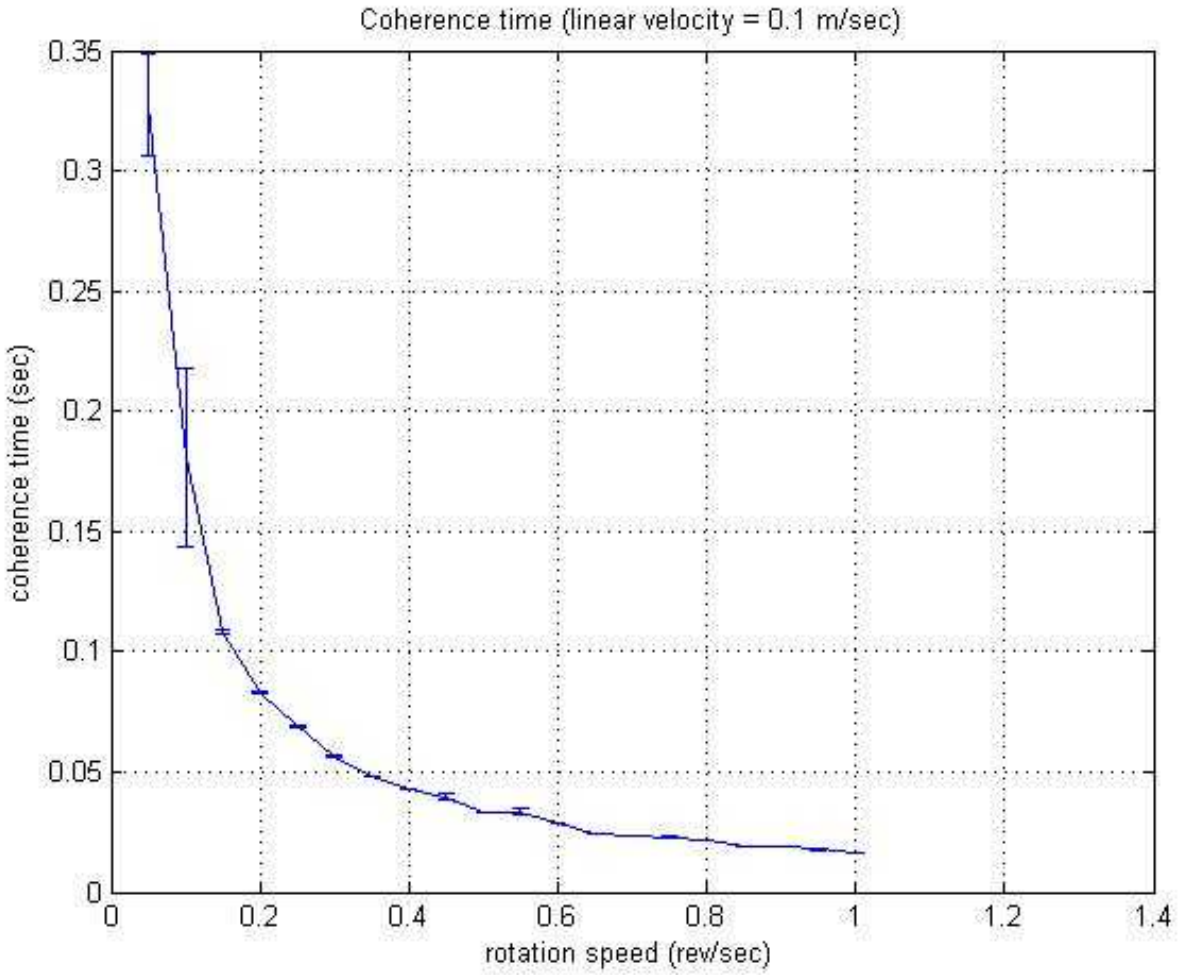
Velocity = 1.2719 m/sec, Angular Speed = 0.2 rev/sec

Sandia National Laboratories

Preliminary Results - Modeling

- **Coherence time vs. angular rotation**
  - **Inverse relation supports intuition**
- **Relay channel**
  - **Shows potential for diversity gain (i.e. improvement in performance and reliability) through relaying**
- **Antenna Switching**
  - **Show theoretical performance bounds for various switching techniques**

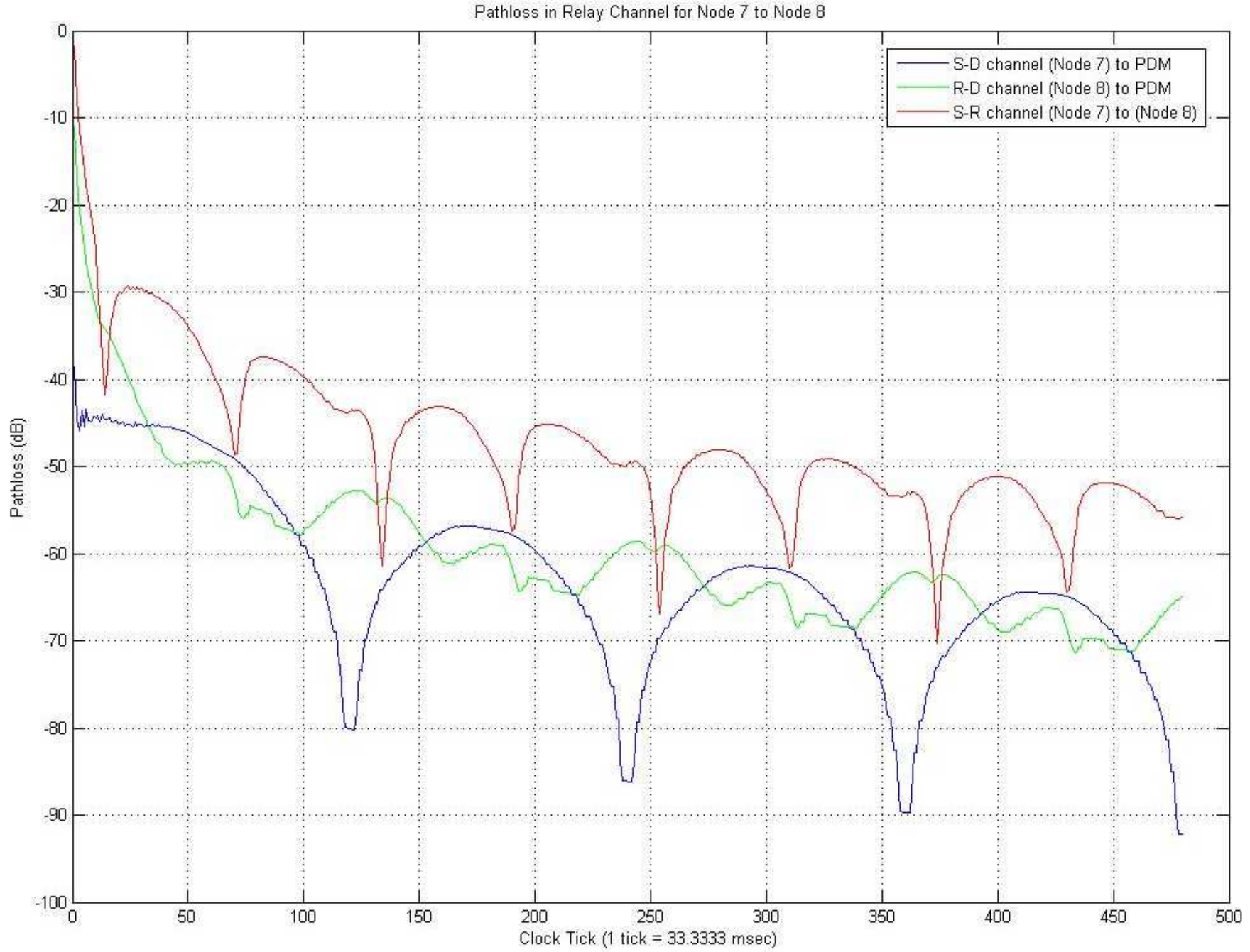
Coherence Time vs. Angular Rotation



Sandia National Laboratories

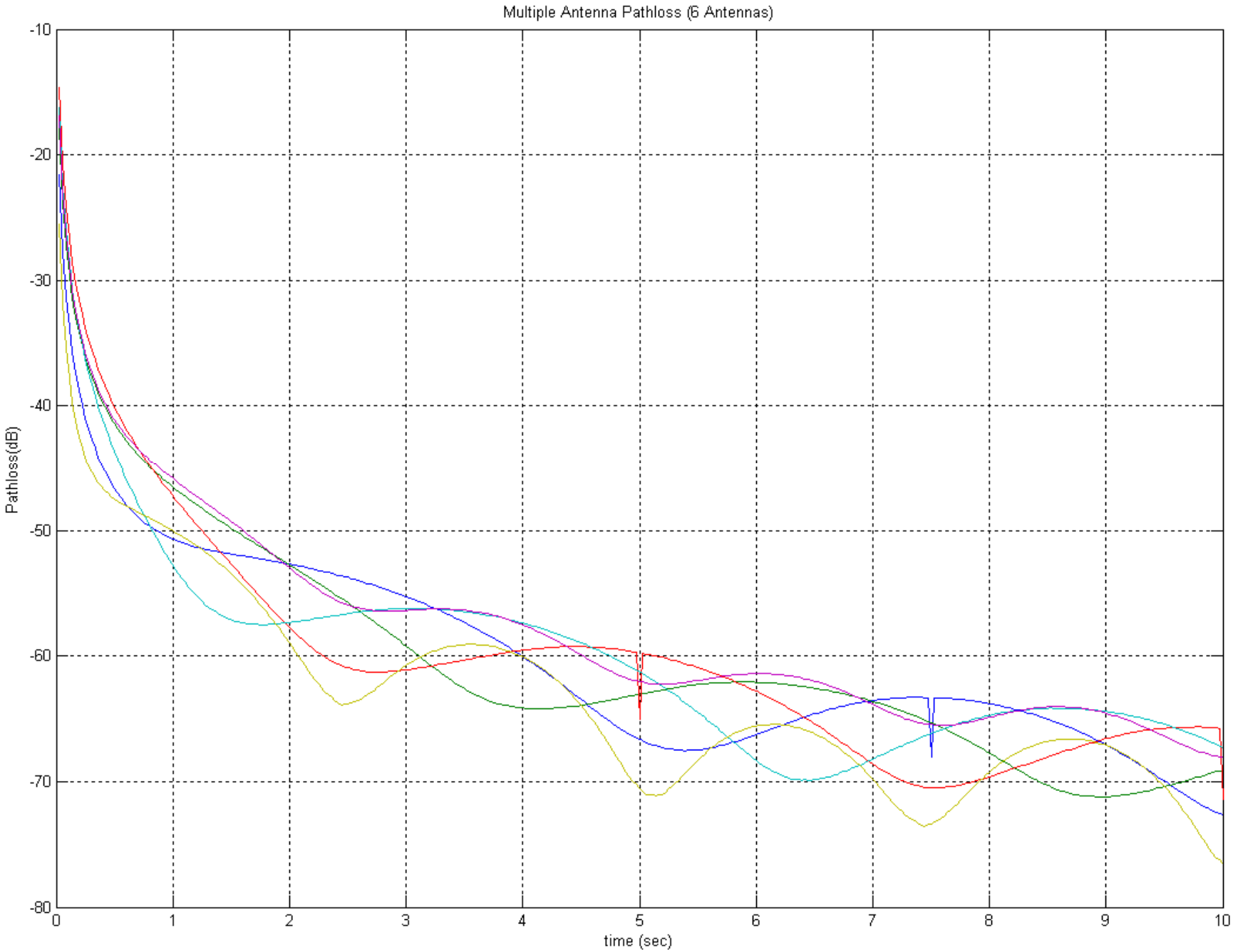
Preliminary Results - Modeling

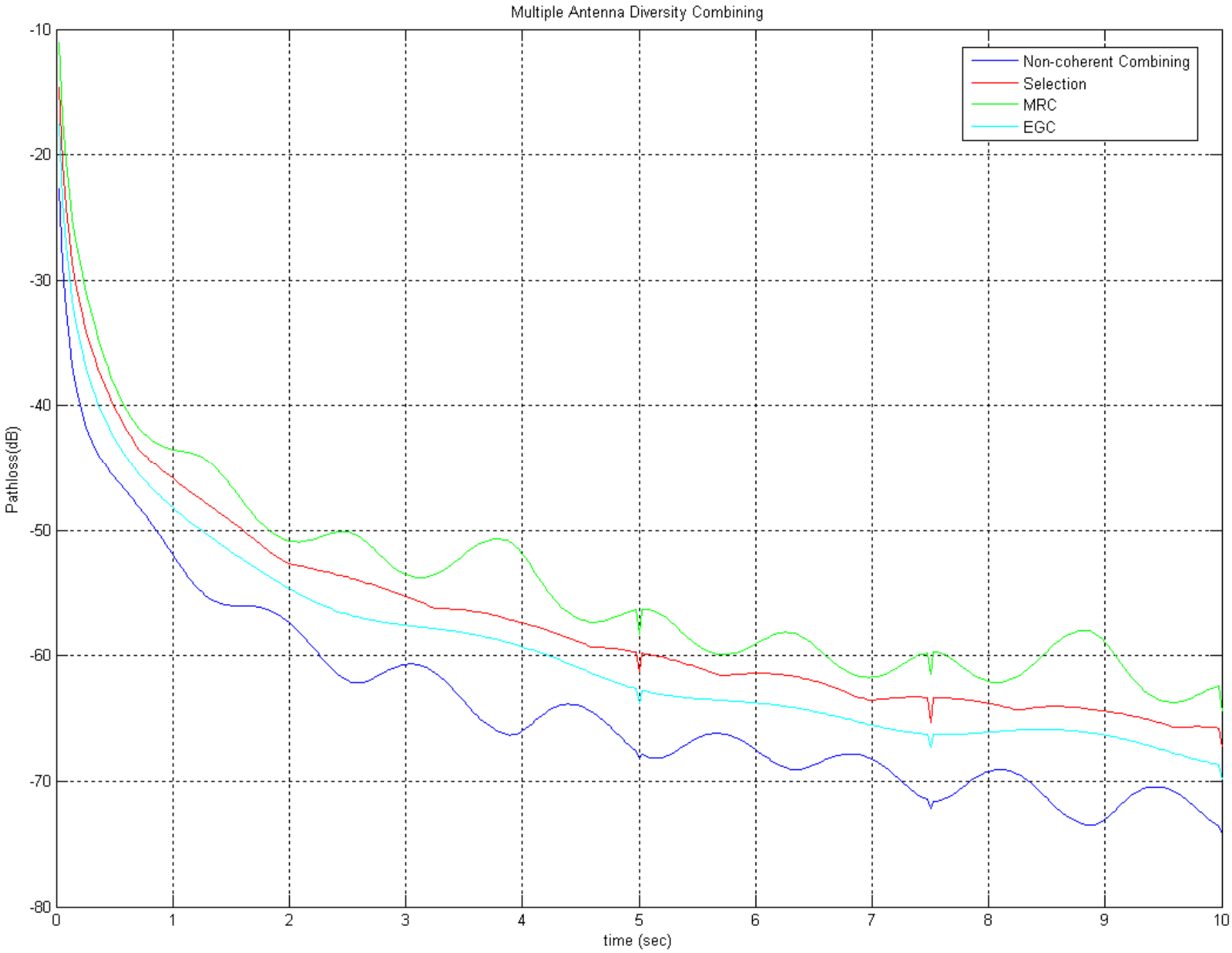
- Coherence time vs. angular rotation
  - Inverse relation supports intuition
- **Relay channel**
  - **Shows potential for diversity gain (i.e. improvement in performance and reliability) through relaying)**
- Antenna Switching
  - Show theoretical performance bounds for various switching techniques


Pathloss in Relay Channel for Node 7 to Node 8
S-D channel (Node 7) to PDM
R-D channel (Node 8) to PDM
S-R channel (Node 7) to (Node 8)
Pathloss (dB)
Clock Tick (1 tick = 33.3333 msec)
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
0
50
100
150
200
250
300
350
400
450
500

Preliminary Results - Modeling

- Coherence time vs. angular rotation
  - Inverse relation supports intuition
- Relay channel
  - Shows potential for diversity gain (i.e. improvement in performance and reliability) through relaying
- **Antenna Switching**
  - **Show theoretical performance bounds for various switching techniques**


Multiple Antenna Pathloss (6 Antennas)
Pathloss(dB)
-10
-20
-30
-40
-50
-60
-70
-80
0
1
2
3
4
5
6
7
8
9
10
time (sec)


Multiple Antenna Diversity Combining
Non-coherent Combining
Selection
MRC
EGC
Pathloss(dB)
time (sec)
-10
-20
-30
-40
-50
-60
-70
-80
0
1
2
3
4
5
6
7
8
9
10

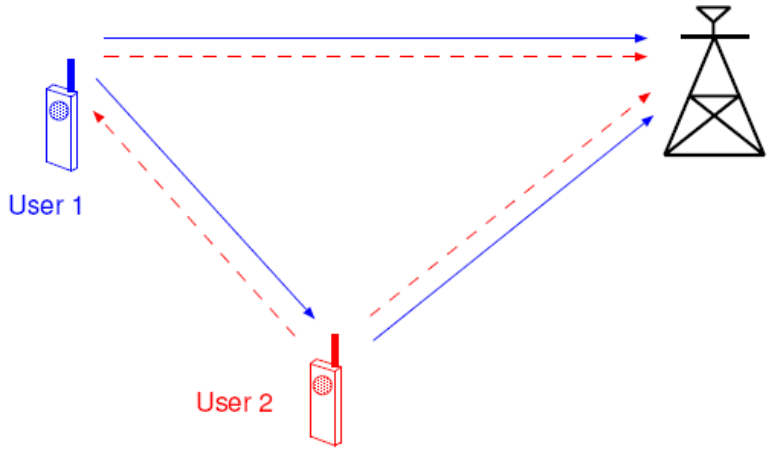
Modeling – Conclusions

- Developed tool for generating traces of wireless channel quality in exo-atmospheric application scenario
- Gathering sufficient statistics for all intra-user, downlink, and uplink channels is time consuming, so …
- Established method for fitting reasonable stochastic model to data collected from wireless channel traces
- Next Step – Incorporate results into network level simulations in OPNET

Part II – Cooperative Communication

Definition:

Class of communication schemes in which nodes (i.e. mobile units, wireless terminals, etc.) are willing to *cooperate* (i.e. allocate some portion of their resources) to aid in the communication between some source and destination pair.

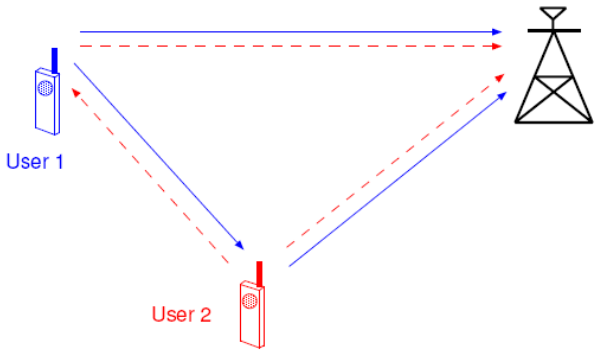


Sandia National Laboratories

Motivation – A Simple Example

Scenario:

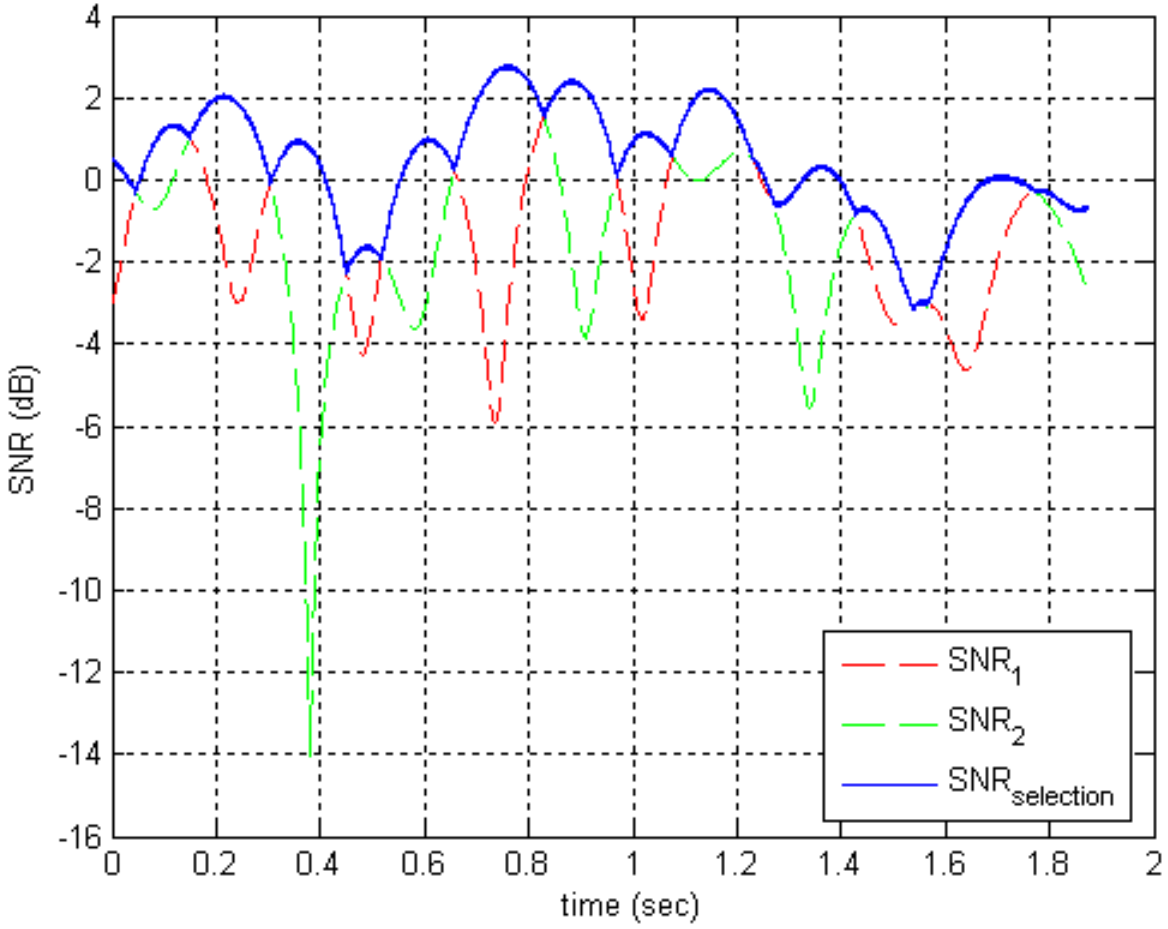
- **Two nodes transmitting the same data stream to a destination over independently fading paths (over two orthogonal slots, e.g. time, frequency, etc.)**



- **Receiver uses selection combining to improve performance**

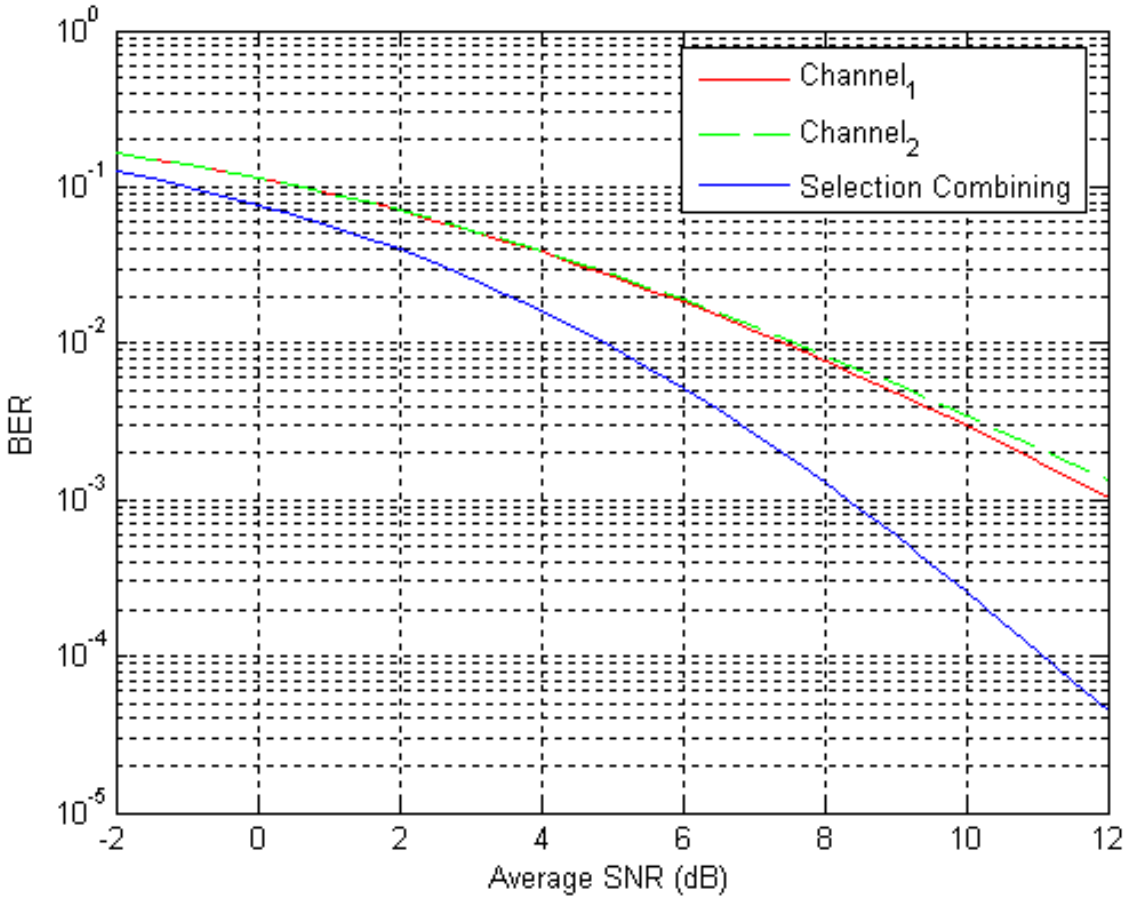
Motivation – A Simple Example (cont.)

Selection Combining Over Two Independently Fading Rayleigh Channels



Sandia National Laboratories

Motivation – A Simple Example



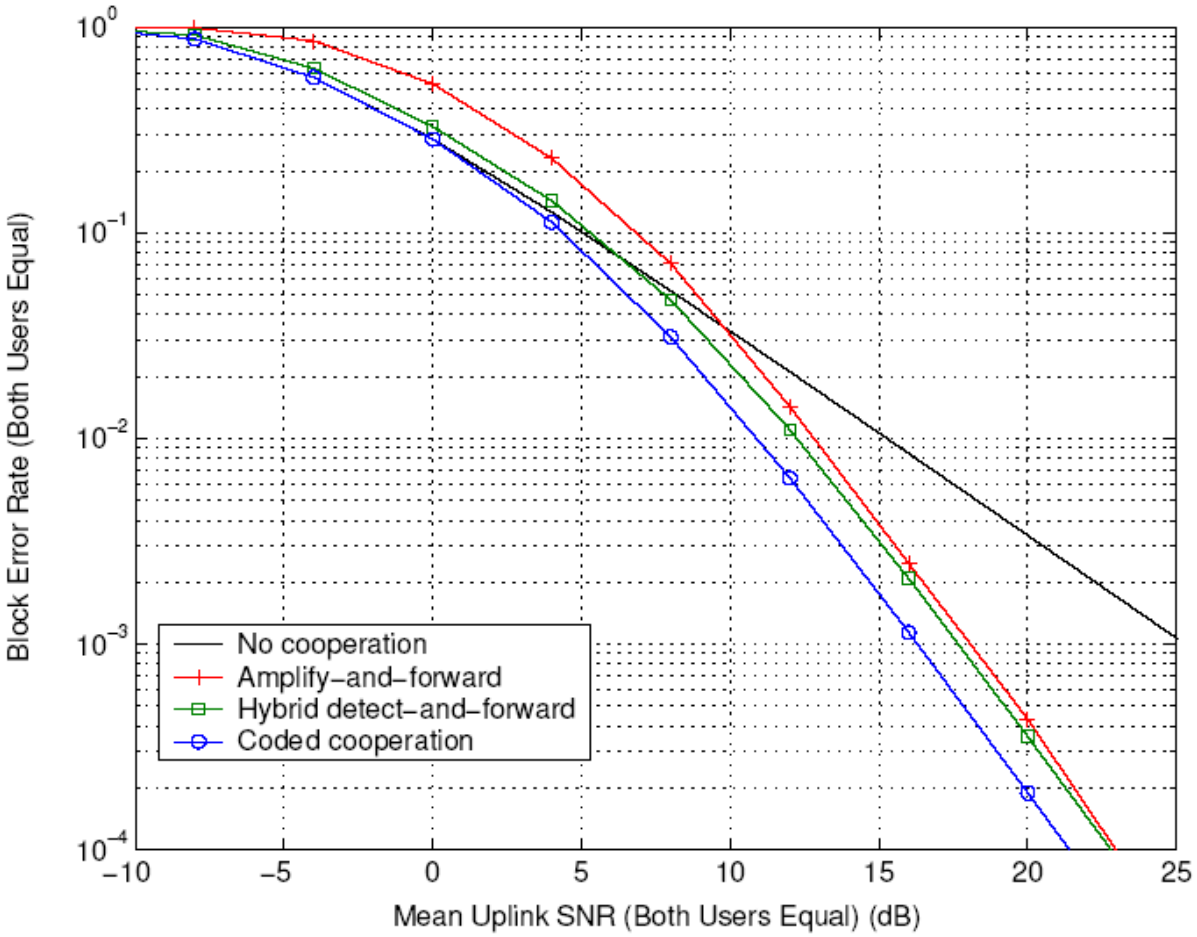
Bit Error Rate vs. Average SNR – Both channels undergo Rayleigh fading. BPSK modulation is assumed (without loss of generality).

Sandia National Laboratories

Cooperative Strategies

	Amplify-and-Forward (AF)	Decode-and-Forward (DF)	Coded Cooperation (CC)
Advantages	• Outperforms other techniques when intra-user channel is “good”	• Performs as well as AF in most scenarios • Does not require full-duplex communication • Can take advantage of error-detection	• Combines advantages of coding gain with diversity • Able to apply network coding or distributed coding
Disadvantages	• Assumes full-duplex communication • May be technologically non-trivial •Amplifies noise in intra-user channel	• With sufficient temporal diversity, DF is equivalent to retransmission	• No unifying network theory (i.e. no notion of achievability) • “Good” code construction is difficult

Cooperative Strategies – Performance



Both users have statistically symmetric uplink channels, and the intra-user channel has mean SNR 10dB below the uplink channels.

Sandia National Laboratories

Relay Selection Policies

Relay Selection Policy	Description
Geographic	Relay nodes closest to the destination have higher priority in relay contention
Minimal distance	Choose a nearby relay to improve the reliability of communication between source and relay, which affects end-to-end reliability
Minimal load	Balance load among relays by choosing relays which are not congested
Minimal interference	Choose relays which will generate the minimum level of interference to their local regions
Parallel-Relay	Allow all or a subset of relays to transmit simultaneously
Reciprocity-based	Relay nodes participate in a contention process wherein the relay node with the best channel to the destination is selected as the winner

Target Application 1

Exo-atmospheric network

- Characteristics
  - Centralized traffic and control model
  - Requires high throughput and reliability
- Distributed Spatial Diversity Model
  - Static relay selection
  - Flexible cooperation
  - Utilizes centralized protocols
  - Able to collect more information (due to traffic patterns) without additional overhead

Target Application 2

Unattended Ground Sensors

- Characteristics
  - Distributed traffic and control model
  - Designed for throughput, reliability, network lifetime
  - Need for scalability and robustness to failure
- Relay Network Model
  - Dynamic relay selection
  - Less flexibility in cooperative strategy
  - Utilizes more spatial diversity
  - Requires distributed protocols

Cooperative Communication – Conclusion

- Inspired by MIMO systems, spatio-temporal diversity techniques, relay channel, and information theory
- Promising new paradigm for network communication (e.g. eliminate adversarial or greedy point-to-point medium access)
- Development of practical protocols is still in its infancy

Questions?

Sandia National Laboratories