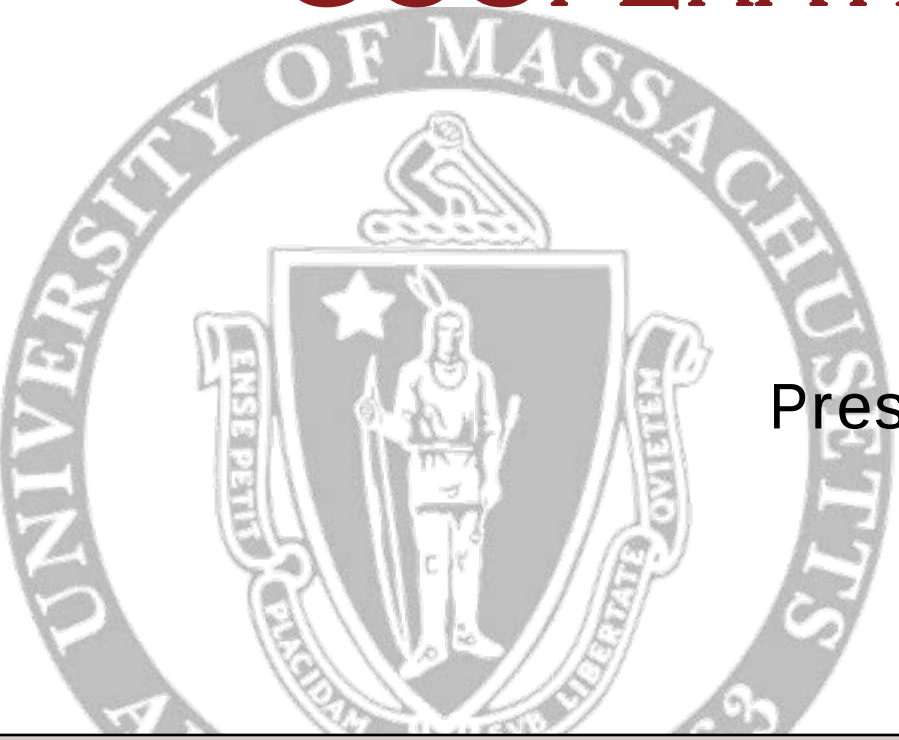
Introduction to Cooperative Diversity



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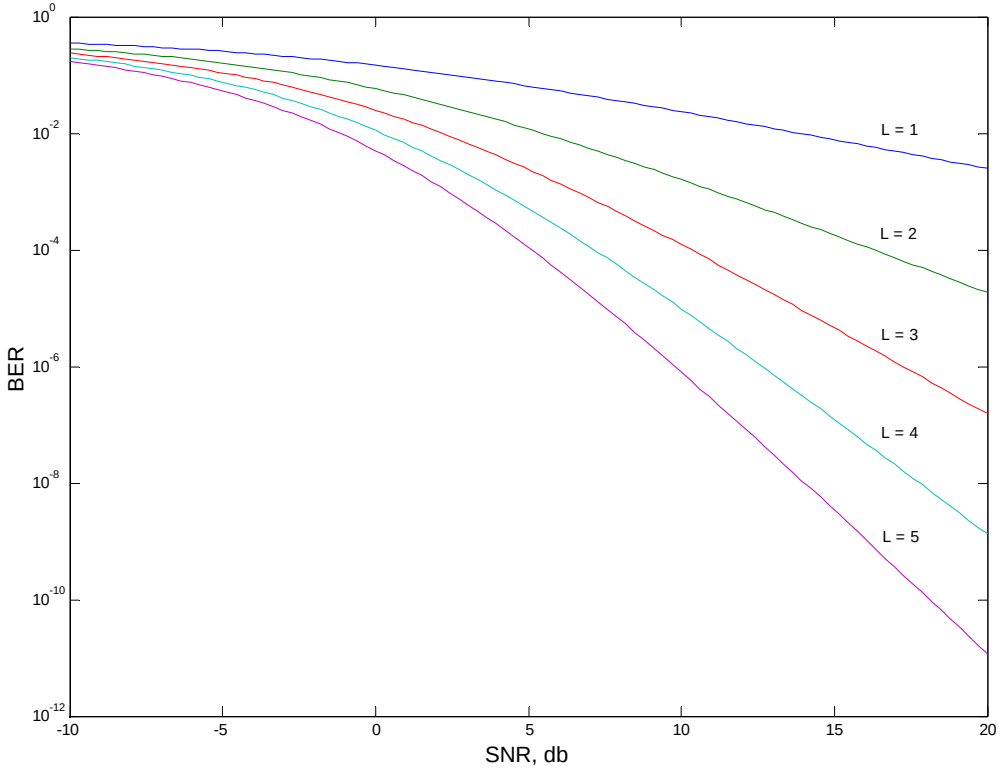
Outline

- Review of Previous Discussion
- Interference Modeling (Don's question)
- Introduction to Cooperative Diversity
- Algorithms
- Performance
- Challenges
- Future Research

Bit Error Rate vs SNR

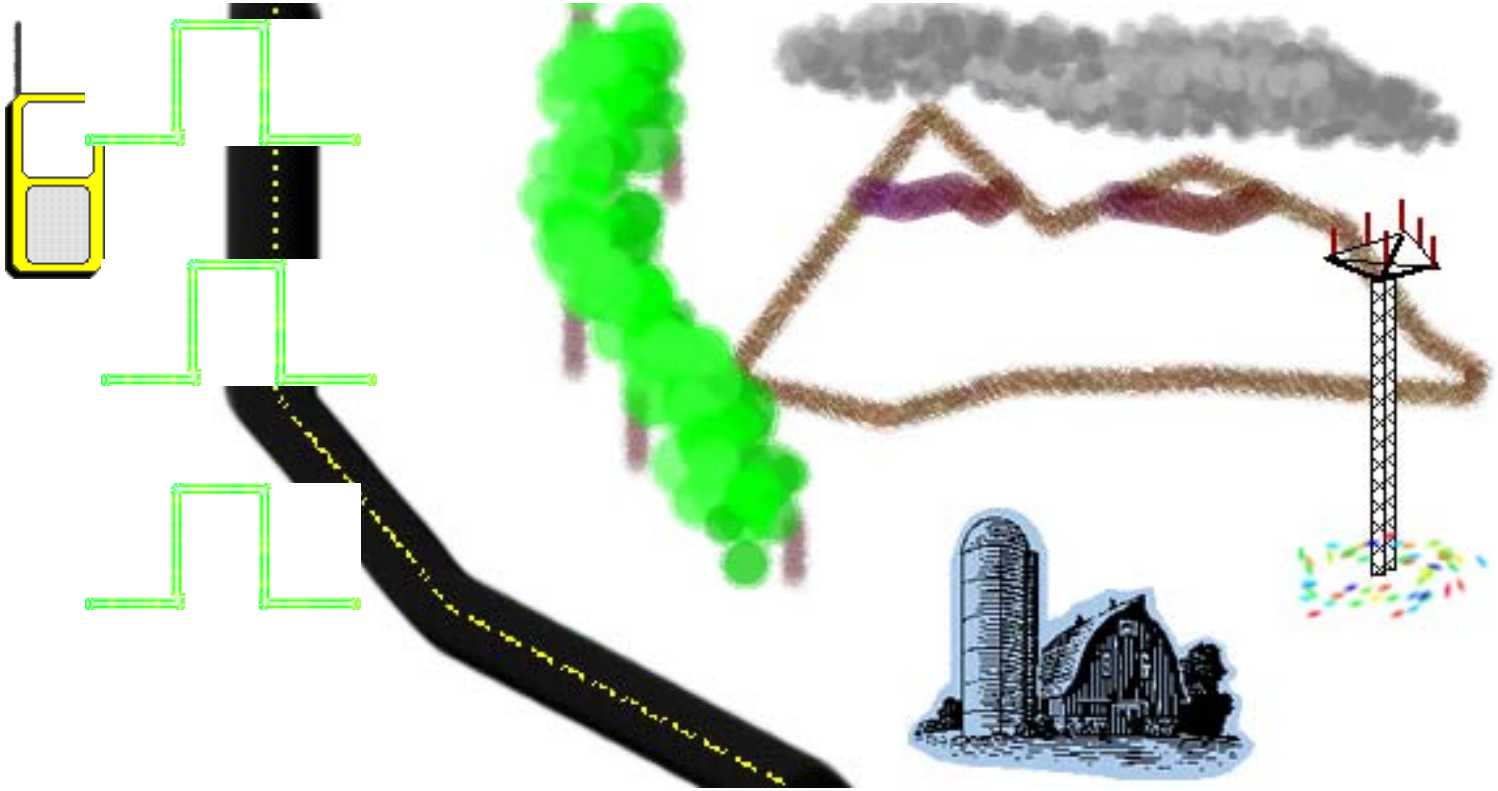


- P1 = 1/SNR
- P2 = 1/SNR^2
- P3 = 1/SNR^3
- P4 = 1/SNR^4
- P5 = 1/SNR^5

Jensen's Inequality

- Increasing SNR (i.e. increasing transmit power) doesn't buy much.
- Increasing the amount of diversity drastically improves the link's reliability.

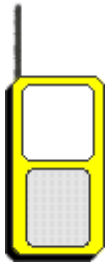
Space Diversity

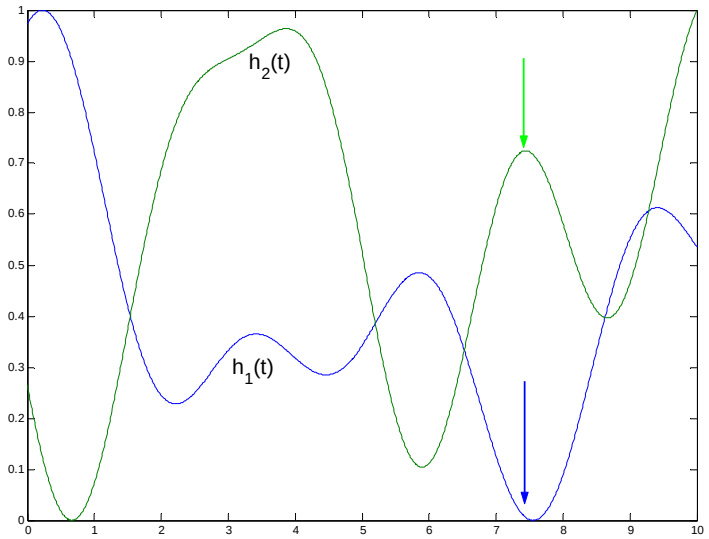


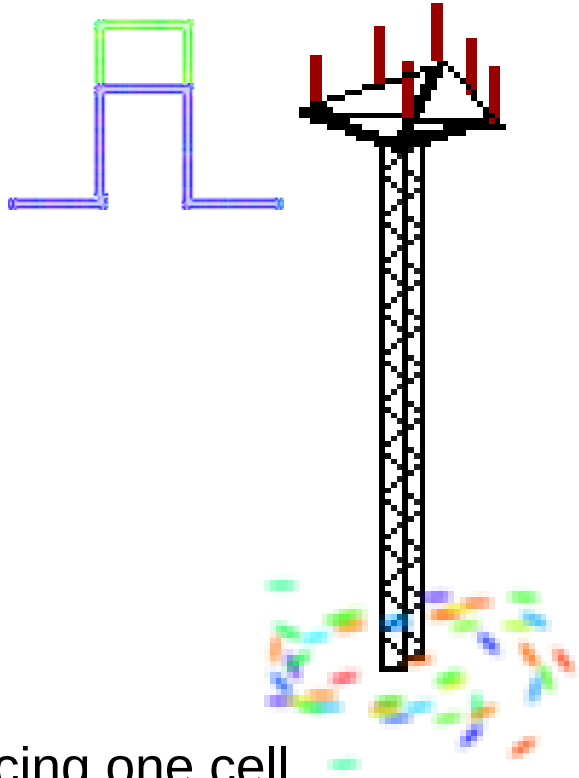
- The channel gain is not only a function of time, but also of position, h(t, r).
- The transmitter must far enough so that it sees a different channel. What's far enough?
  - This is the same as coherence time for time diversity.

Space Diversity

Far Enough = λ/2



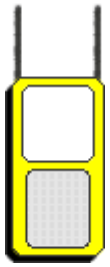


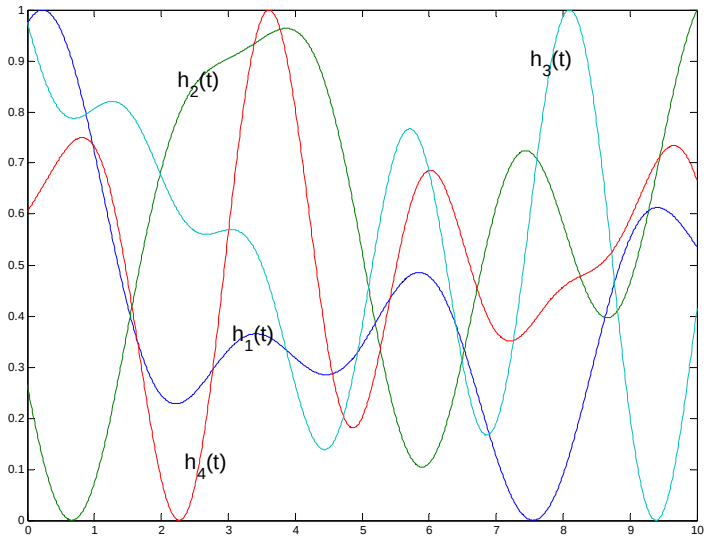


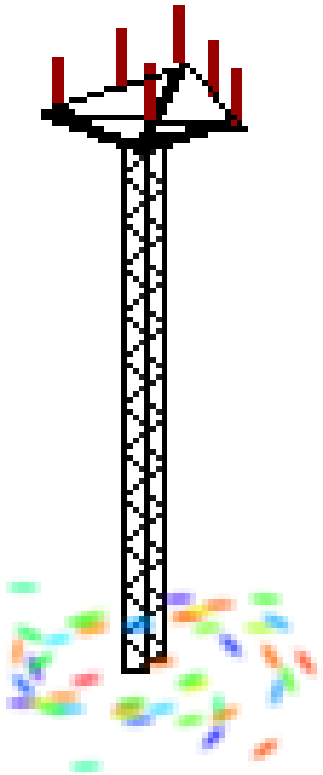
- Most cell towers have multiple transmit cells servicing one cell.
- On the down link channel, the system is a MISO system.
- The antennas must be spaced at least λ/2 apart to see "independent" channels.

Space Diversity

The probability that all four channels are in deep fade is much smaller than the probability that any one channel is in a deep fade.

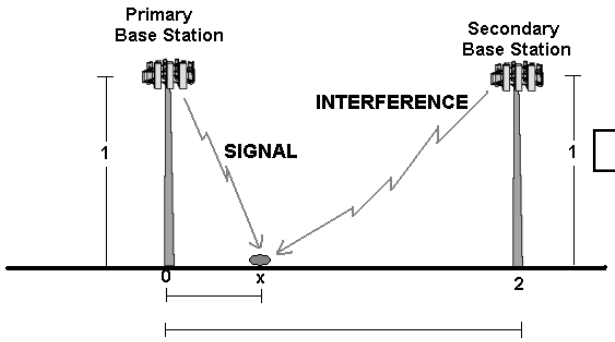




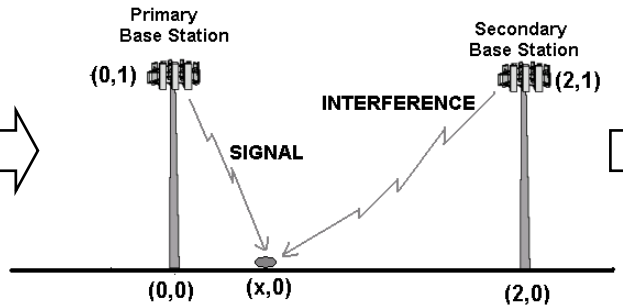


- Multiple antennas at phone and at base station, this is a MIMO system.
- The cost is receiver/transmitter complexity.
- The benefit is that the BER is approximately 1/SNR^L.

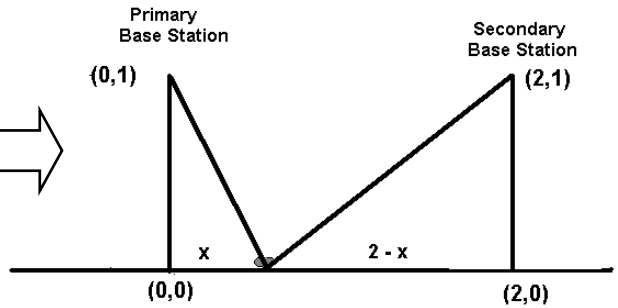
Interference: Signal to Interference Noise Ratio – SINR



A portion of a simplified cellular network.



Coordinates on the simplified cellular network.



Definition 1.

$$\text{Power of the received signal} = \frac{1}{(\text{distance from the phone to the antenna})^2}$$

Definition 2.

$$\text{Signal-to-interference ratio} = \frac{\text{Power of received signal from primary station}}{\text{Power of received signal from secondary station}}$$

$$\text{Power of Primary Signal} = \frac{1}{x^2+1}$$

$$\text{Power of Secondary Signal} = \frac{1}{(x-2)^2+1}$$

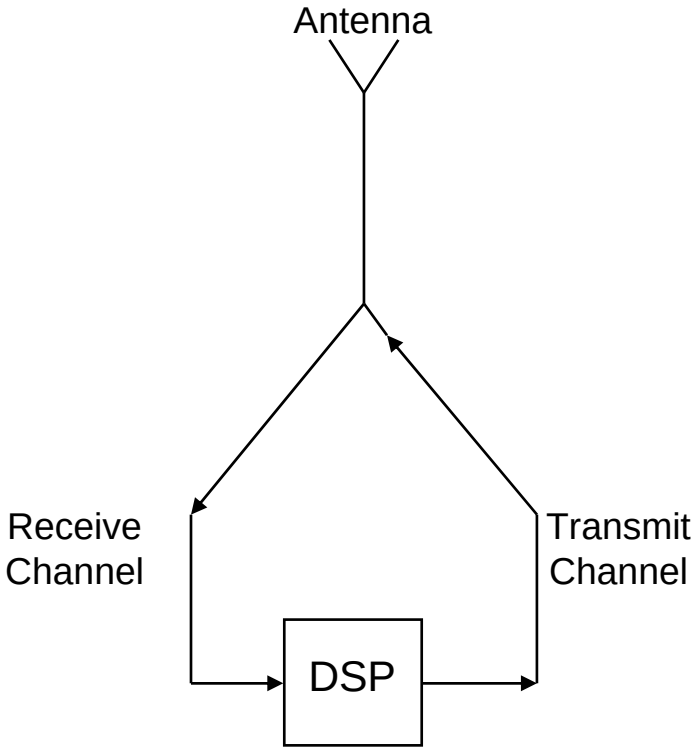
$$f(x) = \text{Signal-to-Interference Ratio} = \frac{\frac{1}{x^2+1}}{\frac{1}{(x-2)^2+1}} = \frac{(x-2)^2+1}{x^2+1}$$

Source: http://mathdemos.gcsu.edu/mathdemos/cellsir/cellsir.html

Radio Assumptions

- Half duplex: transmit or receive one at a time.
- Fading coefficients are known at receivers.
- Isolation
  - Small receive signal power & Large transmit signal power.
  - Signal Isolation: No signal interference at the antenna; antenna is able to properly differentiate between transmit and receive signals.

Isolation Diagram:



Metrics

- Ergodic / Shannon Capacity: takes the average rate of transmission over time.
  - If rate is above threshold, link is good.
  - If rate is below threshold, link is not good.
  - Equation:

$$R = \log_2\left(1+\alpha^2 SNR\right)$$

- Outage Probability: the probability that a mutual information random variable falls below some fixed rate ahead of time.
  - More concerned with the probability that the link can sustain a given rate
  - Equation:

$$SNR \geq \mathrm{T} : R = R_0$$

$$SNR < \mathrm{T} : R = 0$$

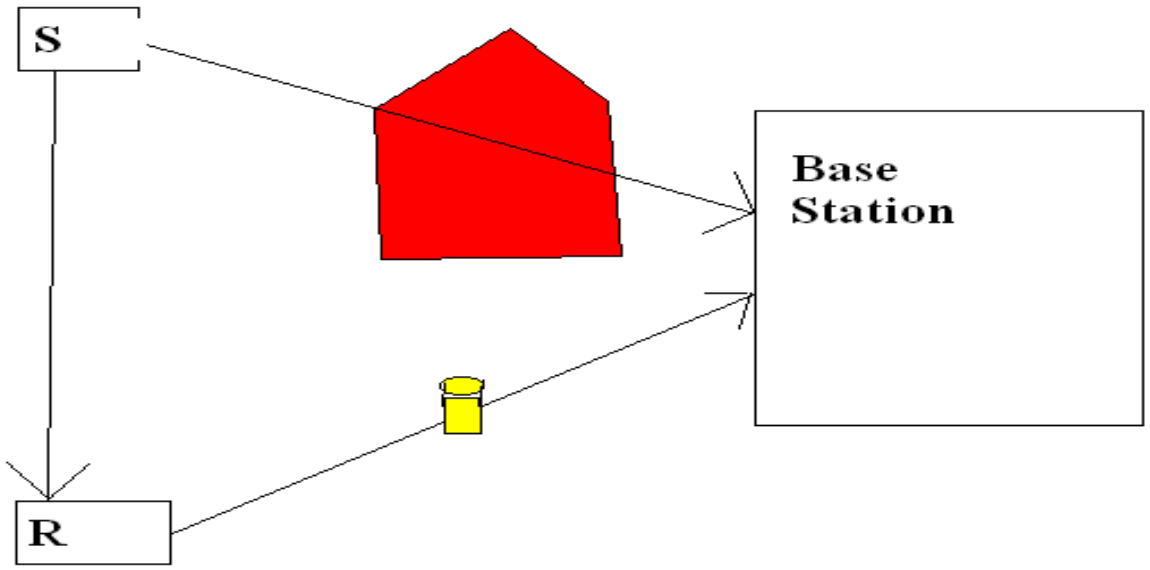
Definition

- $A_{r,s}$: fading coefficients, in this case between the relay and source
  - Important to note that fading coefficients are assumed to be known at the receivers
- Relay: performs transmission and receiving of information.
- Spatial Diversity: using two or more antennas separated in space so that they provide more paths to/from a source or destination.

What is Cooperative Diversity

- Cooperative - working or acting together willingly for a common purpose or benefit.
- Diversity - variety; multiformity
- Cooperative Diversity
  - Relay
  - Fading Channel
  - Spatial Diversity

Cooperative Diversity



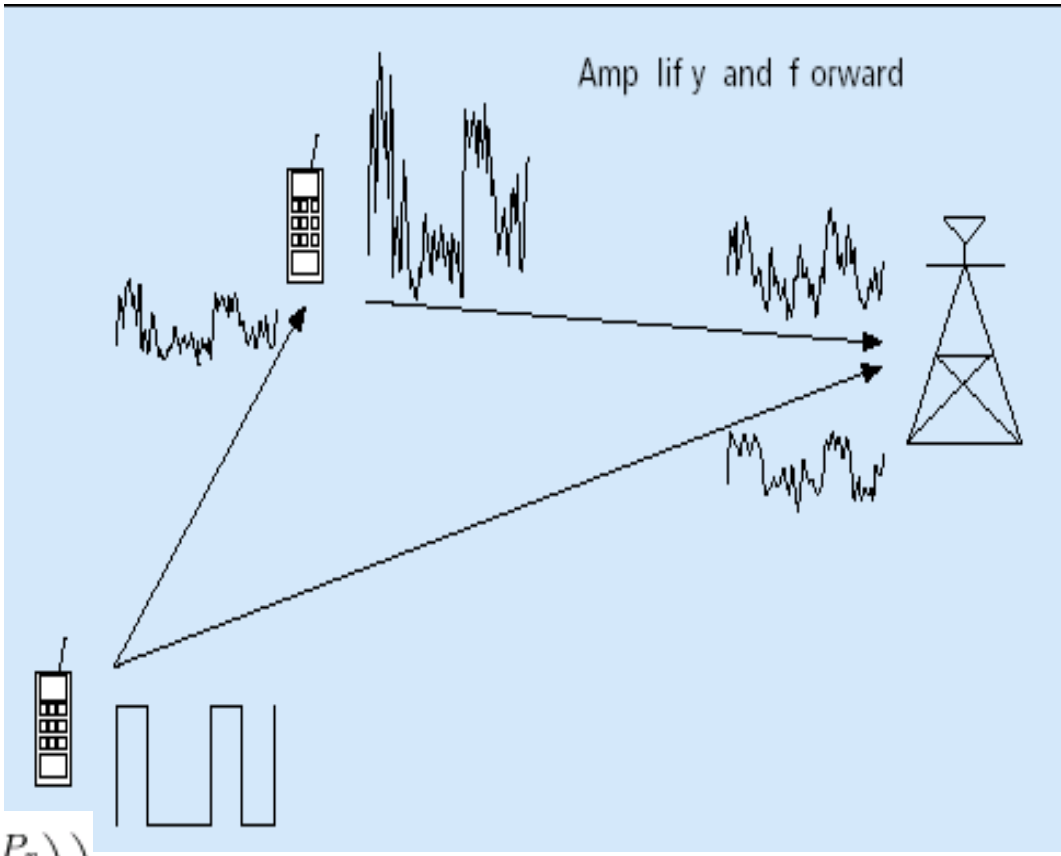
- One Source and another source which acts as a relay and a base station

Relay Algorithms

- Amplify and Forward
- Decode and Forward
- Selection and Dynamic Relaying
- Incremental Relaying

Amplify and Forward

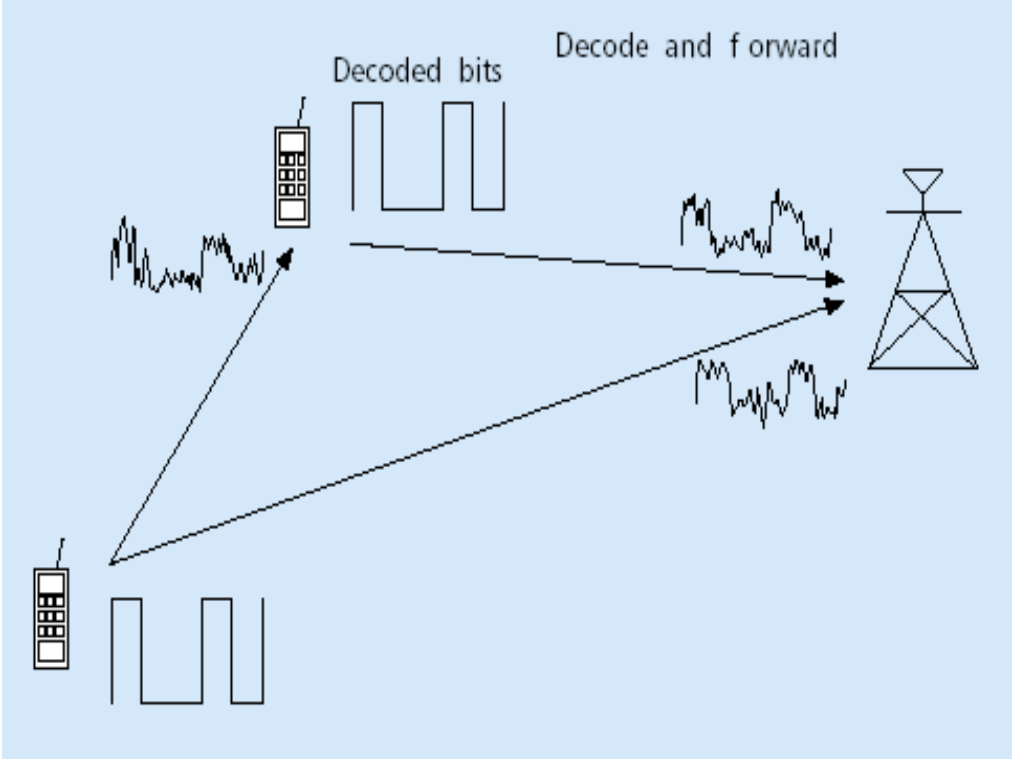
- Relay performs amplification of received signal
- Benefits
  - Greater Diversity
  - Low complexity
- Faults
  - Decrease Bandwidth Efficiency
  - Scheduling
- Equation:



$$I_{\mathrm{AF}} = \frac{1}{2}\log\left(1 + 2\frac{|A_{d,s}|^2 P_s}{N_0} + f\left(2\frac{|A_{r,s}|^2 P_s}{N_0}, 2\frac{|A_{d,r}|^2 P_r}{N_0}\right)\right)$$

Decode and Forward

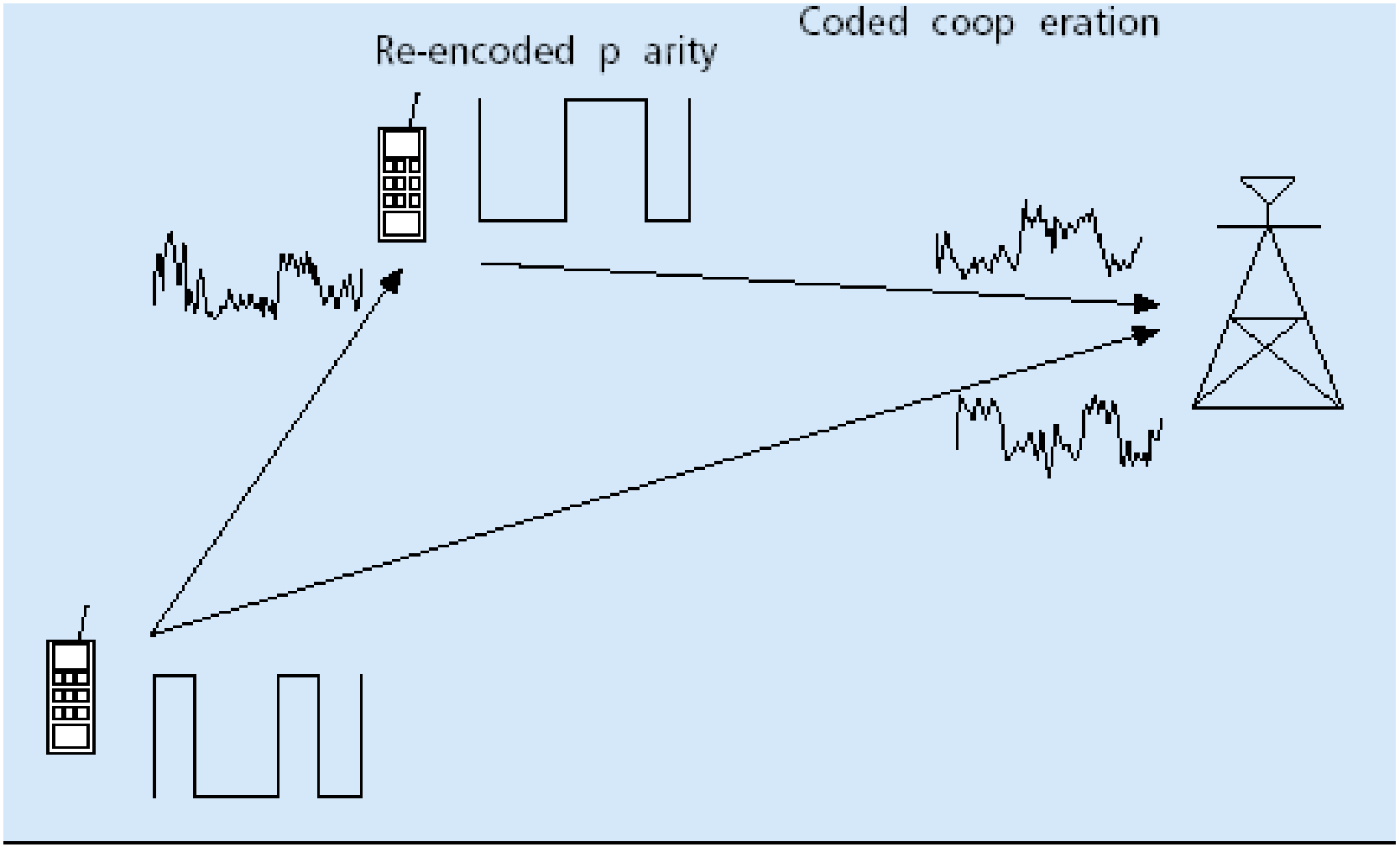
- Relay partitions its own bits and source bits into two separate frames.
- Benefits and Disadvantages similar to Amplify and Forward



Selection and Dynamic Relaying

- Similar to decode and forward but implements a Decision Region algorithm
  - Fading coefficient falls below threshold then we transmit using non-cooperative techniques
  - Fading coefficient falls above threshold then we transmit using cooperative techniques like decode and forward and amplify and forward
- Two of the fading coefficients have to be low for information lost

Coded Cooperation

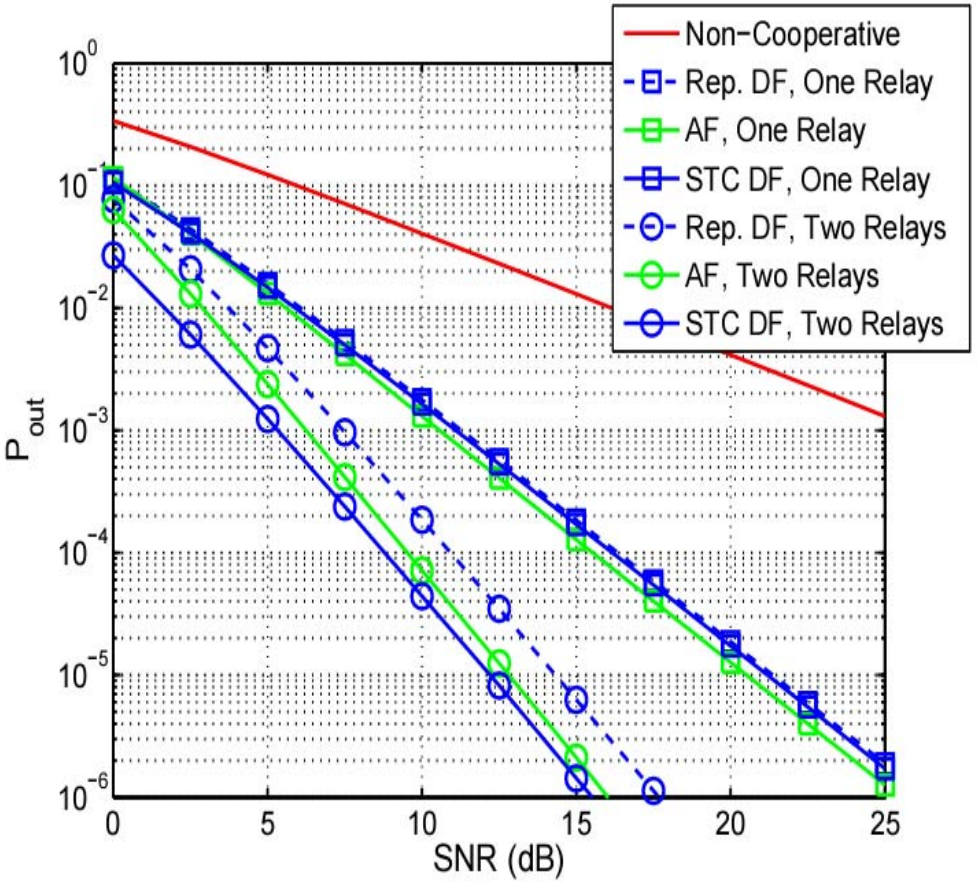


Incremental Relaying

- Send an acknowledgment bit to indicate whether the message was received correctly
- If a positive acknowledgment is made at the destination then do nothing
- If provided a negative acknowledgment then a request is made to transmit via relay
  - Relay uses amplify and forward algorithm
- Benefits
  - Bandwidth
- Disadvantages
  - Time delay

Performance

- Decode and Forward offers better diversity than Amplify and Forward regardless of the quality of the source-relay link
- Generally, the more relays you have the better the diversity.



COOPERATIVE DIVERSITY Models, Algorithms, and Architectures *Cooperation in Wireless Networks: Principles and Applications Real Egoistic Behavior is to Cooperate!* Fitzek, Frank H.P.; Katz, Marcos D. (Eds.) Springer, 2006.

Challenges

- Obvious Challenges: Higher Layer Protocols and mechanisms.
- Development of Hardware Testbeds to demonstrate functionality.
- Overhead in transmitting network metrics across source-relay-destination nodes.
- Power/Energy conservation.

Future Research

- Management of multi-user networks.
- Link interaction in complicated network architecture.
- Development of power control mechanisms for cooperative transmissions
- Enhanced coding scheme for cooperative communication.