Cooperative Communications

S-72.4210 PG Course in Radio Communications
Wideband Radio Communications

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Outline

- Introduction.
- Historical Background.
- Cooperative Communications:
  - cellular and ad-hoc networks.
  - relay channel.
  - performance evaluation.
- Functions at the relay.
- Relay Channel: Distributed Turbo Coded Diversity.
- Conclusions

Introduction

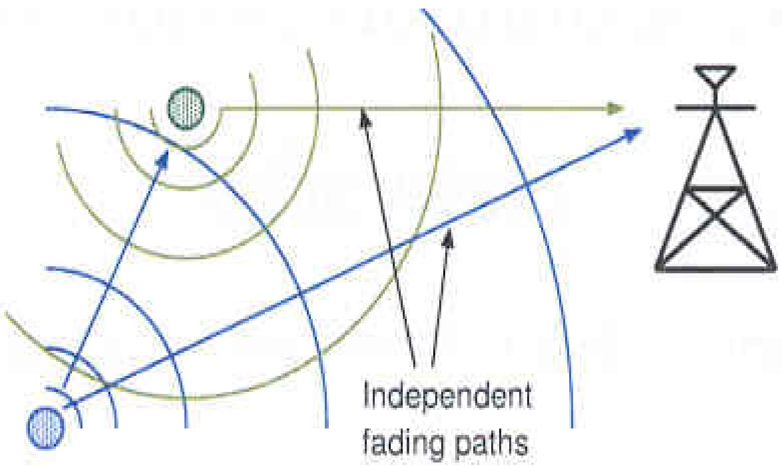
- Transmit diversity generally requires more than one antenna at the transmitter.
- However, many wireless devices are limited by size, costs and hardware complexity.
- By using cooperative communication, multiple virtual-antenna transmitter can be considered, e.g. in a cellular networks.
- Distributed diversity can be implemented by the use of relaying, e.g. in ad-hoc networks such as wireless sensor networks.
- A relay channel is a three terminal network consisting of a source, a relay, and a destination. However, this concept can be widely extended to larger network configurations.

Historical Background

- The idea of Cooperative Relay Networks was introduced in 1971, see ref.[1].
- In 1979 the ideal of cooperative communication for degraded relay channel was presented, see ref.[2].
- Isolated works in the 80's and 90's.
- In the last 3 years, cooperative communication networks have got new interest.

"Cooperative" Communications

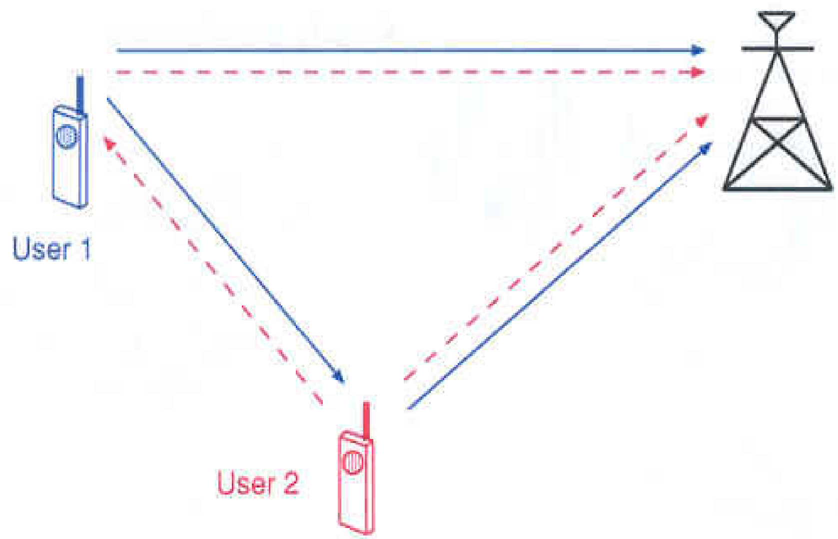
- Question: Why should cooperative communication networks being of interest?
  - They allow single-antenna mobiles to reap some of the benefits of MIMO systems.
  - Transmit Diversity (mitigate fading) and Coding Gain (lower BER).



- In Coop. Wireless Comm., the wireless agents (users) may increase their effective quality of service (BER, Outage probability,…) via cooperation.

Cellular Cooperative Communication Systems

- In CCCS each wireless user is assumed to transmit data as well as act as a cooperative agent for another user.
- ➢ Trade-offs in code rates and transmit power arise.

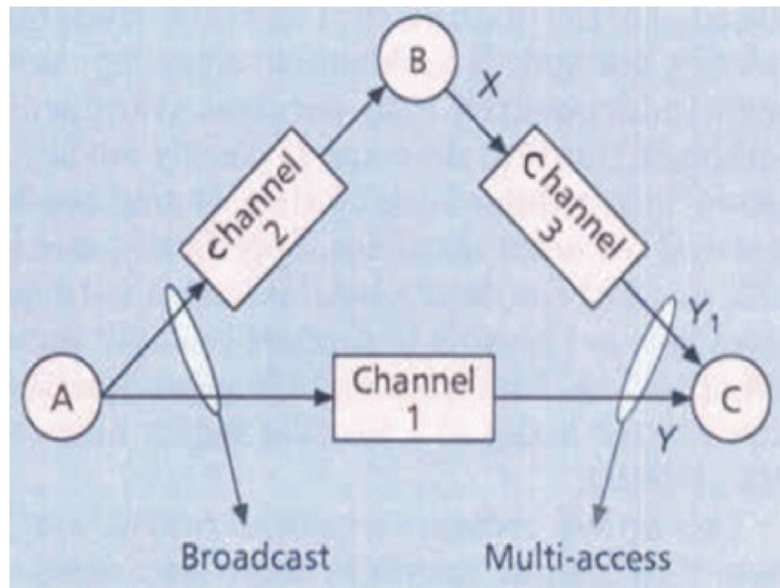


- More power is needed because each user is transmitting for both users, however
  - ➢ the baseline transmit power for both users may be reduced because of diversity gain.
- A user transmit both the own bits as well as some information for the partner, but
  - ➢ the spectral efficiency of each user improves because due to cooperation diversity the channel code rate can be increased.

- Question: is cooperation worth?
  - – YES, as it will be later shown.

Relay Channels

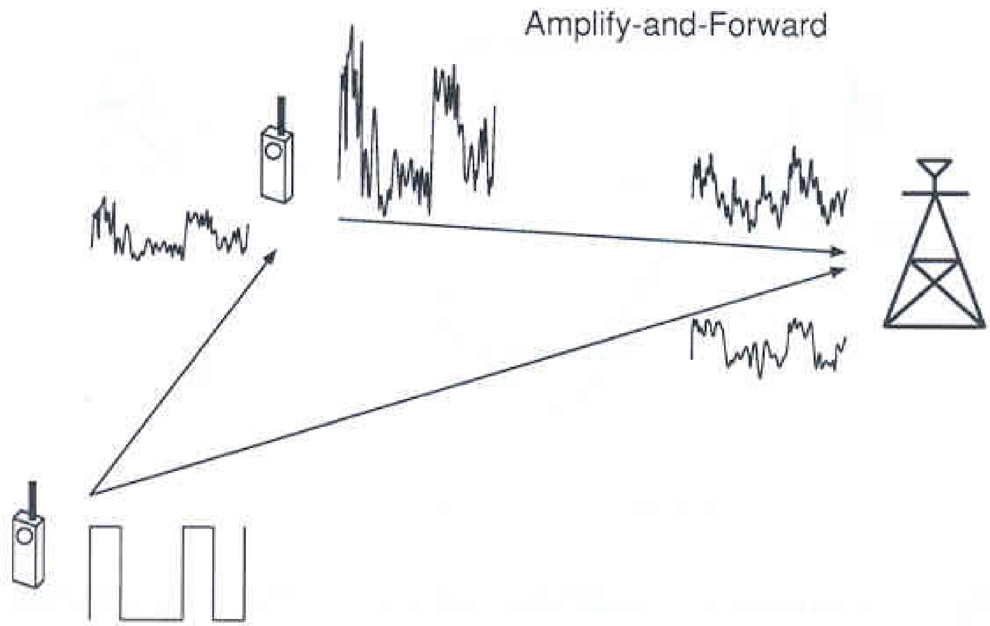
- A relay channel is a three-terminal network consisting of a source, a relay and a destination.
- The source broadcast to both relay and destination.
- Also, the relay forward the received message to the destination.
- Relay systems can achieve distributed spatial diversity in wireless networks of single-antenna devise transmitting over quasi-static fading channel.



- Relaying can be used to form a *virtual antenna array*.
- The strategy of cooperative diversity can be exploited by exchanging the role of source and relay.

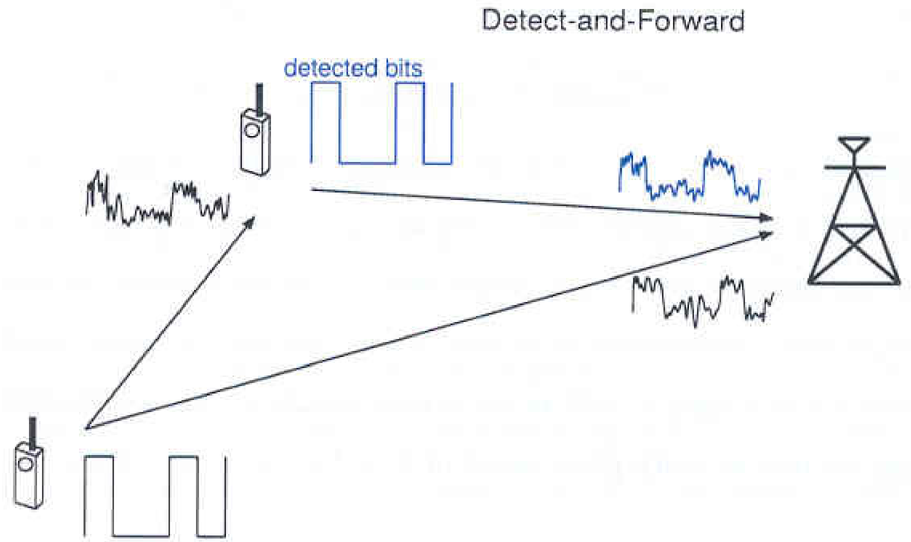
Amplify and Forward Method

- The user (relay) receives a noisy version of the signal transmitted by the partner (source).
- The noisy signal is simply amplified and retransmitted.



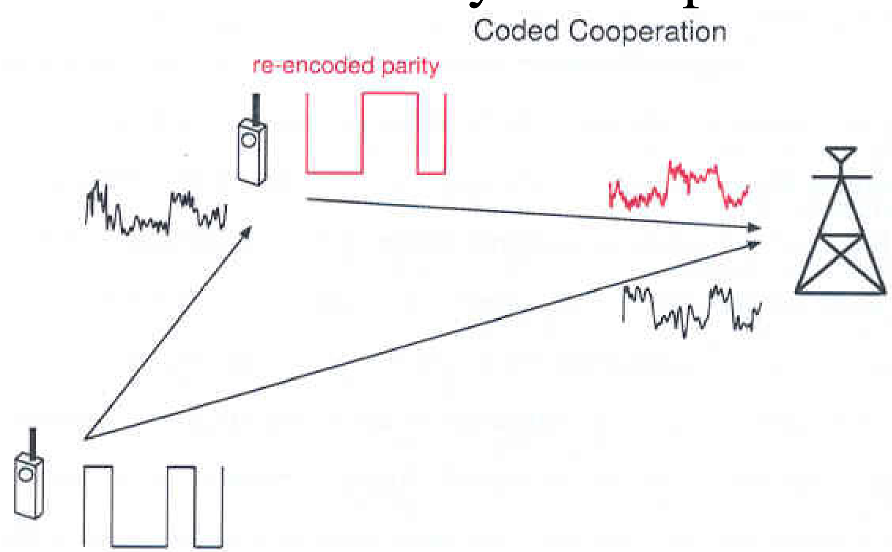
Detect and Forward Method

- The user (relay) attempts to detect the partner's bits (source) and then retransmits the detected bits.
- The partner has to be assigned mutually by the base station.
- Different partnership topologies may be used.

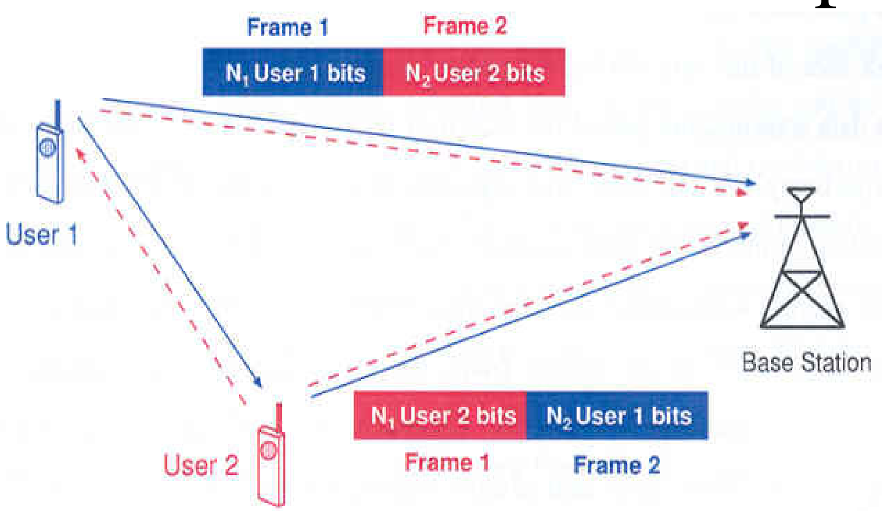


Coded Cooperation Method

- This method integrates cooperation into channel coding.
- It sends different portions of each user's code word via two independent fading paths.
- Each user tries to transmit incremental redundancy for its partner.
- Otherwise, the user revert to non-cooperative mode.
- No feedback between the users
  - managed automatically through code design.



Coded Cooperation Method

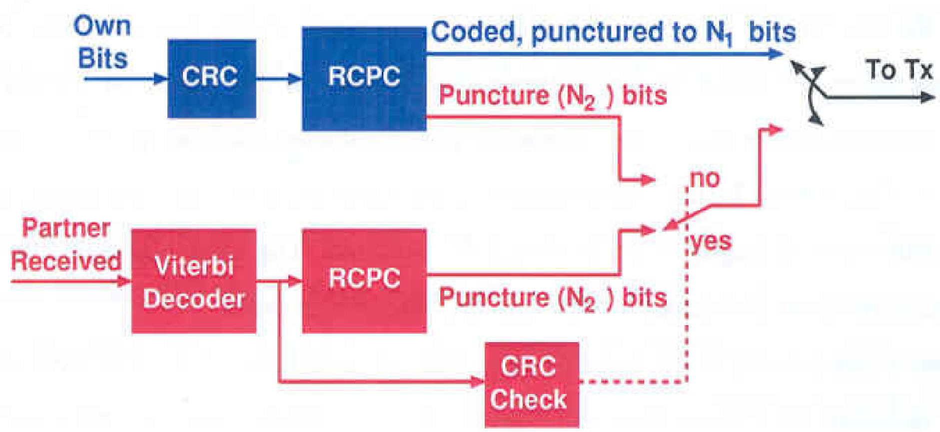


- Encode bits with CRC and RCPC code. Puncture and transmit N1 code bits.

  CRC: Cyclic Redundancy Check.

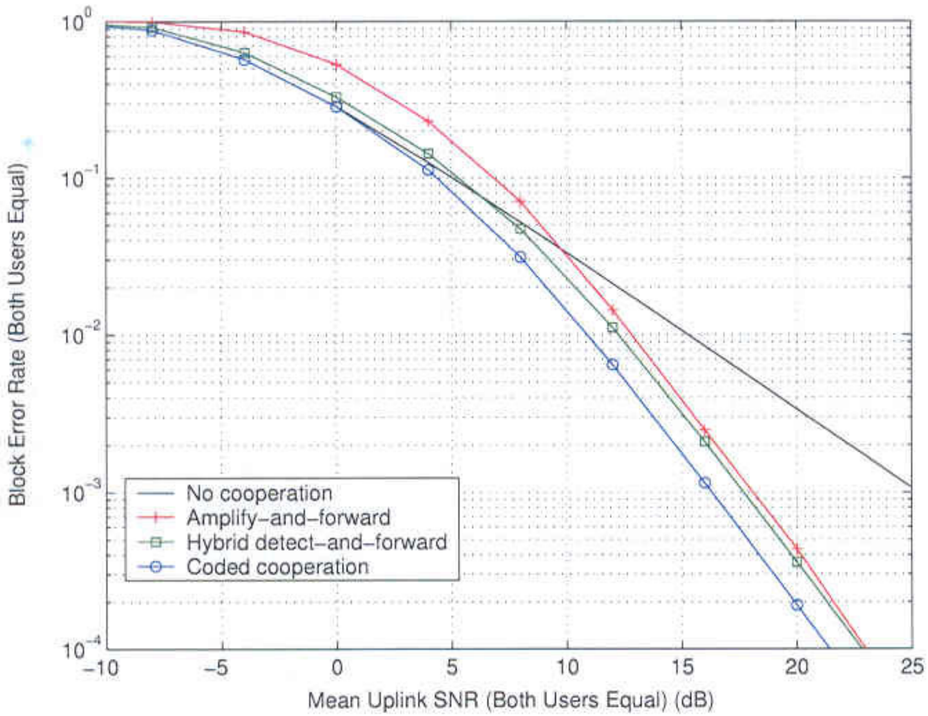
  RCPC: Rate-Compatible Punctured Convolutional.

- Receive and decode partner. If CRC checks, transmit partner's N2 puncture bits. Otherwise, transmit own N2 puncture bits.



Performance Evaluation: scenario #1

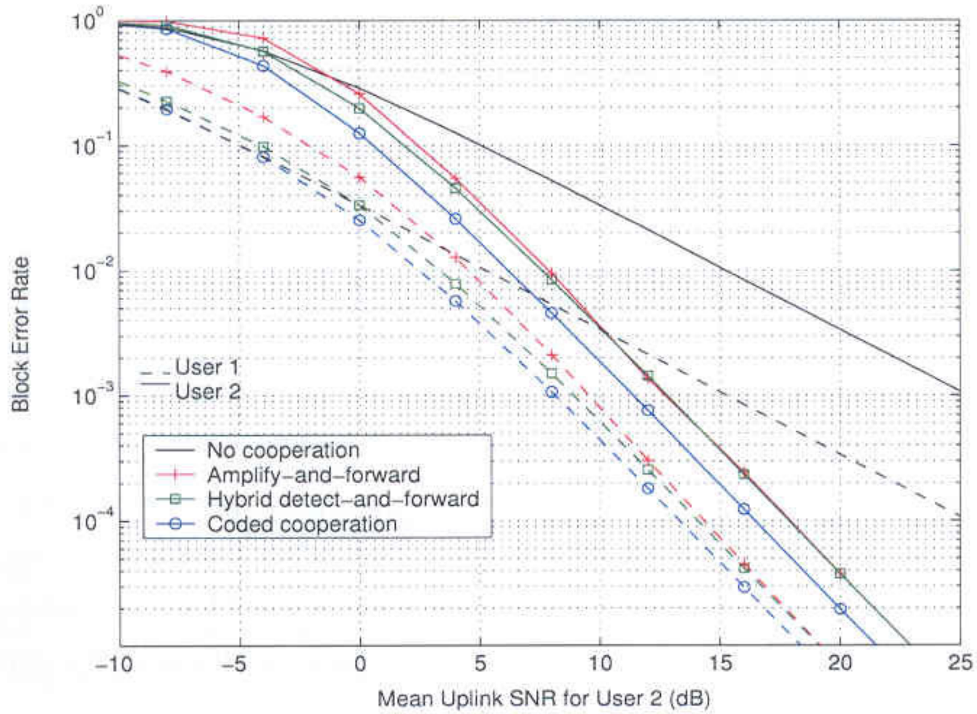
- The user channels is the same in uplink (to the base station).
- The inter-user channel is 10 dB below that of the uplink channel.



- The slope indicates a diversity order 2 due to the cooperation of the 2 users.
- To cooperate is worth even though the inter-user channel has a poorer quality than the uplink channel.

Performance Evaluation: scenario #2

- The mean uplink SNR for user 1 is 10 dB higher than that of 2.
- The inter-user SNR is equal to the uplink channel for user 2.



- For a strong user is still worth to cooperate with a user having a poor quality uplink channel.
- The difference in performance between the two users are reduced.

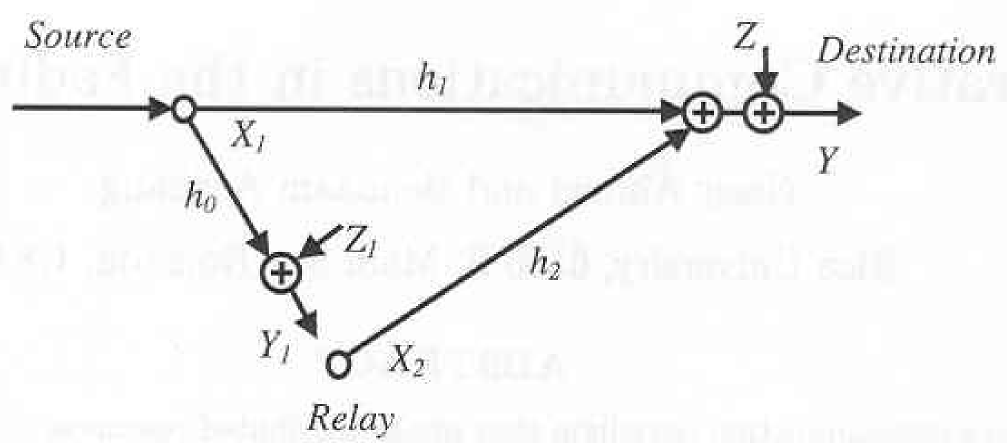
Cooperative Communication in Fading Channel

- Each link i is attenuated by fading coefficients:

$$h_i \text{ where } i \in \{0, 1, 2\}$$

- The magnitude of the coefficients is Rayleigh distributed.
- At the relay: $y_1 = h_0 x_1 + z_1$
- At the destination: $y = h_1 x_1 + h_2 x_2 + z$
- Link power:

$$\gamma_0 = |h_0|^2$$
$$\gamma_1 = |h_1|^2$$
$$\gamma_2 = |h_2|^2$$



Network Coding Protocols: achievable rates

- Amplify and Forward (AF) technique

$$R_{AF}(\gamma, P_s, P_r) = \frac{1}{2}\log\left(1 + 2\gamma_1 P_s + \frac{4\gamma_2 P_s \gamma_0 P_r}{1 + 2P_s\gamma_0 + 2P_r\gamma_2}\right)$$

- Decode and Forward (DF) technique

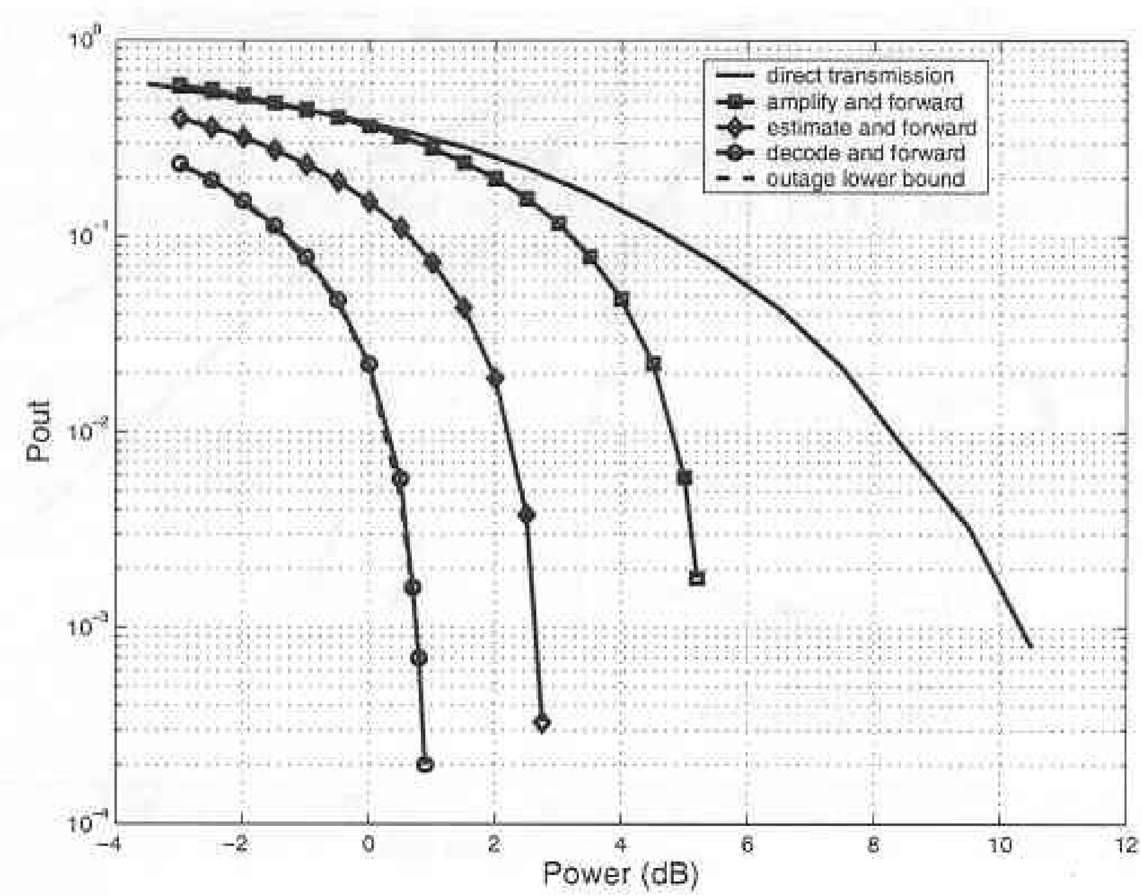
$$R_{DF}(\gamma, P_s, P_r) = \max_{0 \le \rho \le 1} \min\left\{\log\left(1 + (1-\rho^2)\gamma_0 P_s\right), \log\left(1 + \gamma_1 P_s + \gamma_2 P_r + 2\rho\sqrt{\gamma_1\gamma_2 P_s P_r}\right)\right\}$$

where ρ controls the correlation between the signal transmitted by the source and the relay.

- Estimate and Forward (EF) technique

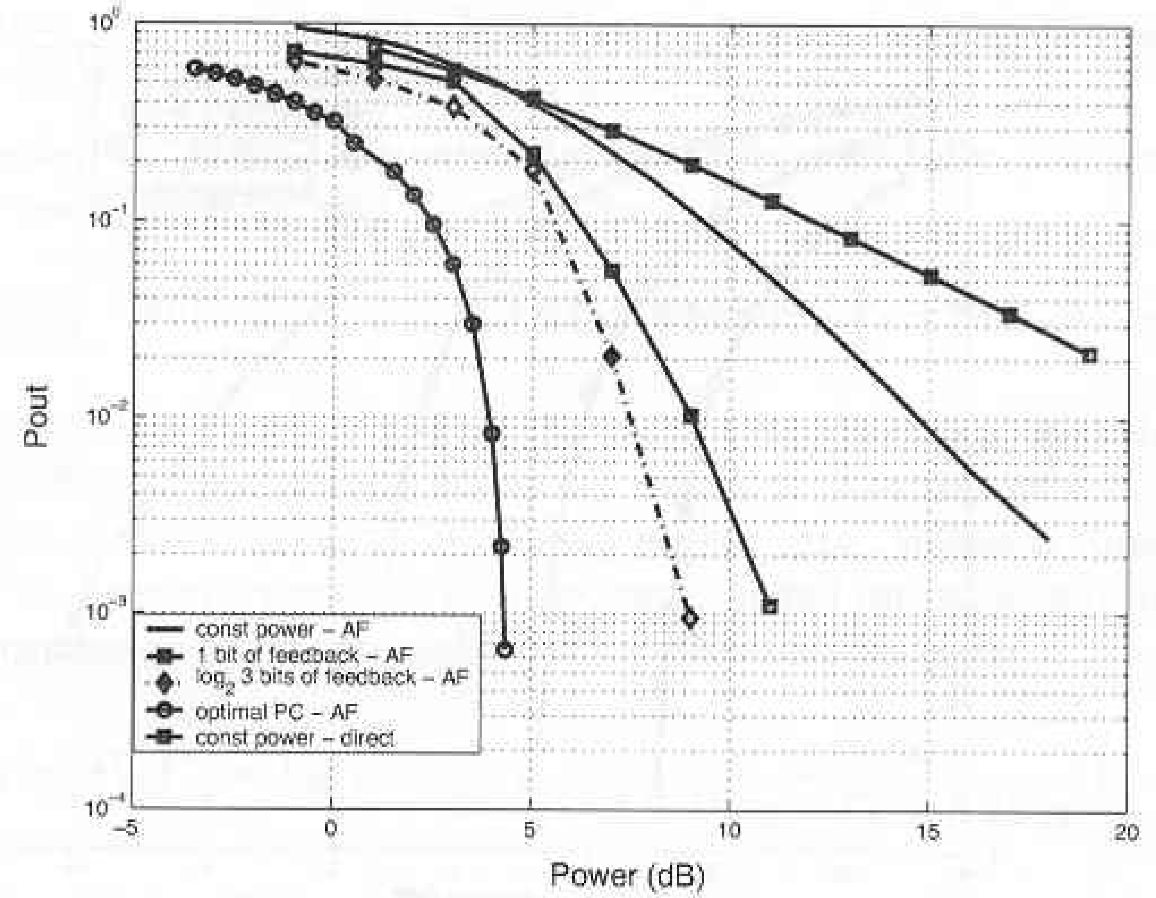
$$R_{EF}(\gamma, P_s, P_r) = \log\left(1 + \gamma_1 P_s + \frac{\gamma_2 P_s \gamma_0 P_r}{1 + P_s\gamma_0 + P_s\gamma_1 + P_r\gamma_2}\right)$$

Power Control with Perfect Feedback



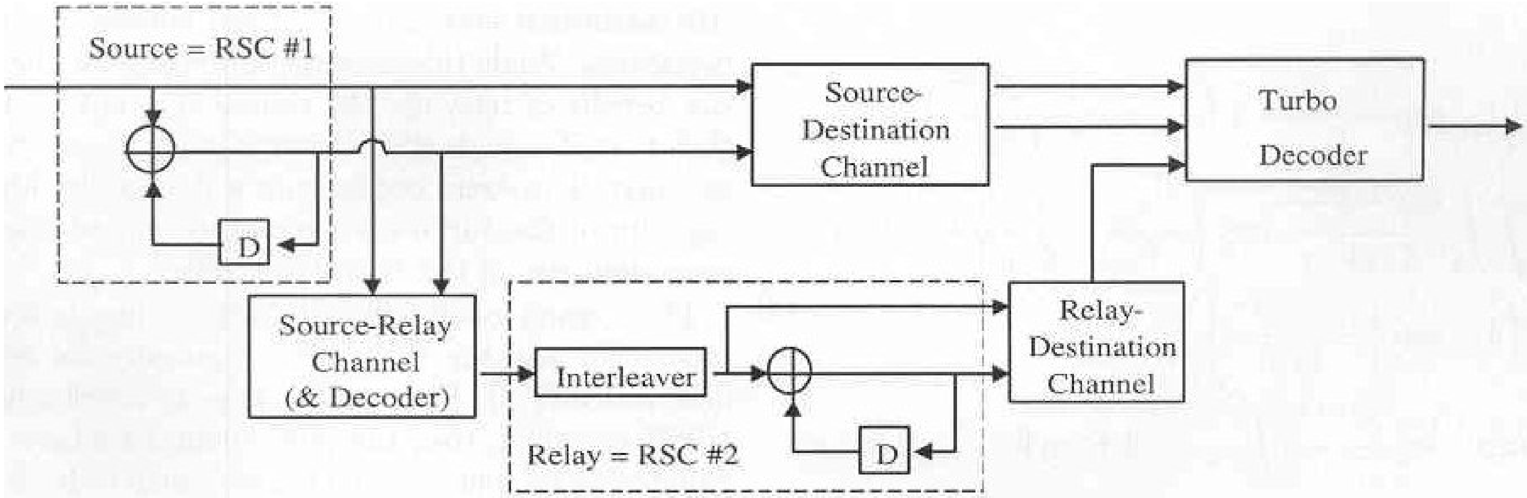
- The network channel state is measured by the destination.
- And, it is perfectly available at both the source and the relay.
- Probability of outage vs. network power.

Power Control with Finite Rate Feedback



- The rate of the feedback link is limited.
- The power control is done by using a quantized version of the network channel state.
- Effect of more feedback bits on outage performance.

Relay Channel: Distributed Turbo Coded Diversity

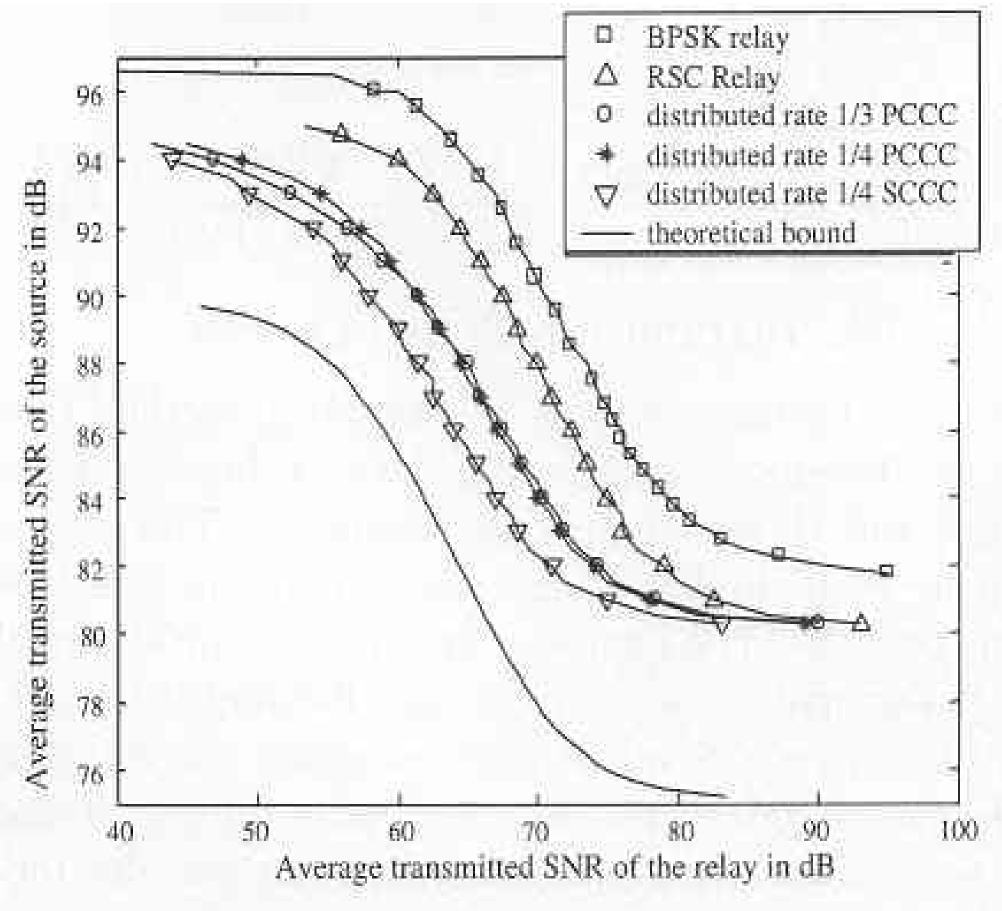


- The source: broadcasts a recursive convolutional code to both relay and destination.
- The relay: detects, interleaves and re-codes the received signal before forwarding it to the destination.
- The destination: receives both codes in parallel, a distributed turbo code is embedded in the relay channel.

Relay Channel: Distributed Turbo Coded Diversity

- The system is assumed to be half-duplex → the relay may not simultaneously receive and transmit.
- The relay channel operates in a time division duplex mode.
- First time slot: the source broadcasts to the relay and destination.
- Second time slot: just the relay transmits to the destination.
- The source and the relay may not transmit coherently.
- Both source and relay generate a very simple code; a two-state rate ½ recursive systematic convolutional code (RSC).
- The relay operates the decode-and-forward technique.
- At the destination there will arrive two versions of the transmitted message, one from the source and one from relay.

Distributed Turbo Code: Performance



- Minimum transmitted SNR at source and relay required to achieve an end-to-end FER of 10^{-2} when the relay is halfway between the source and the destination.

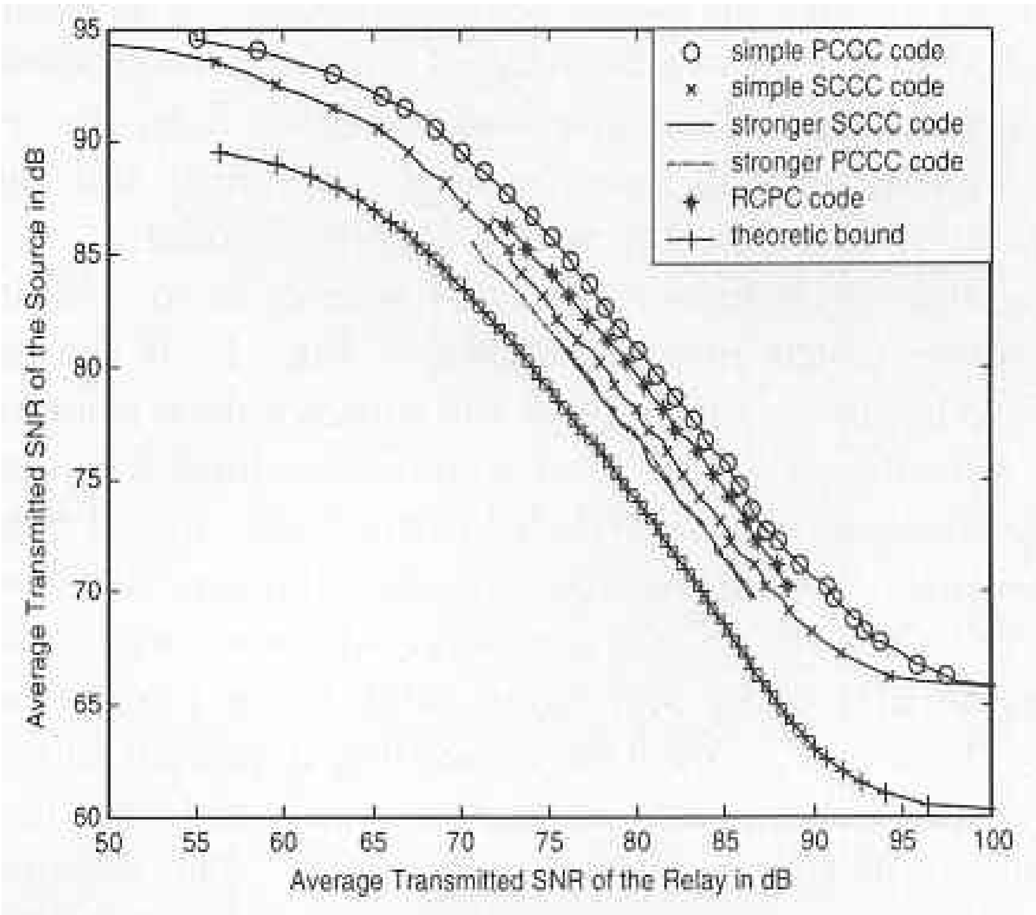
BPSK: Binary Phase Shift Key.

RSC: Recursive Systematic Convolutional.

PCCC: Parallel Concatenated Convolutional Code (Turbo Code).

SCCC: Serial Concatenated Convolutional Code.

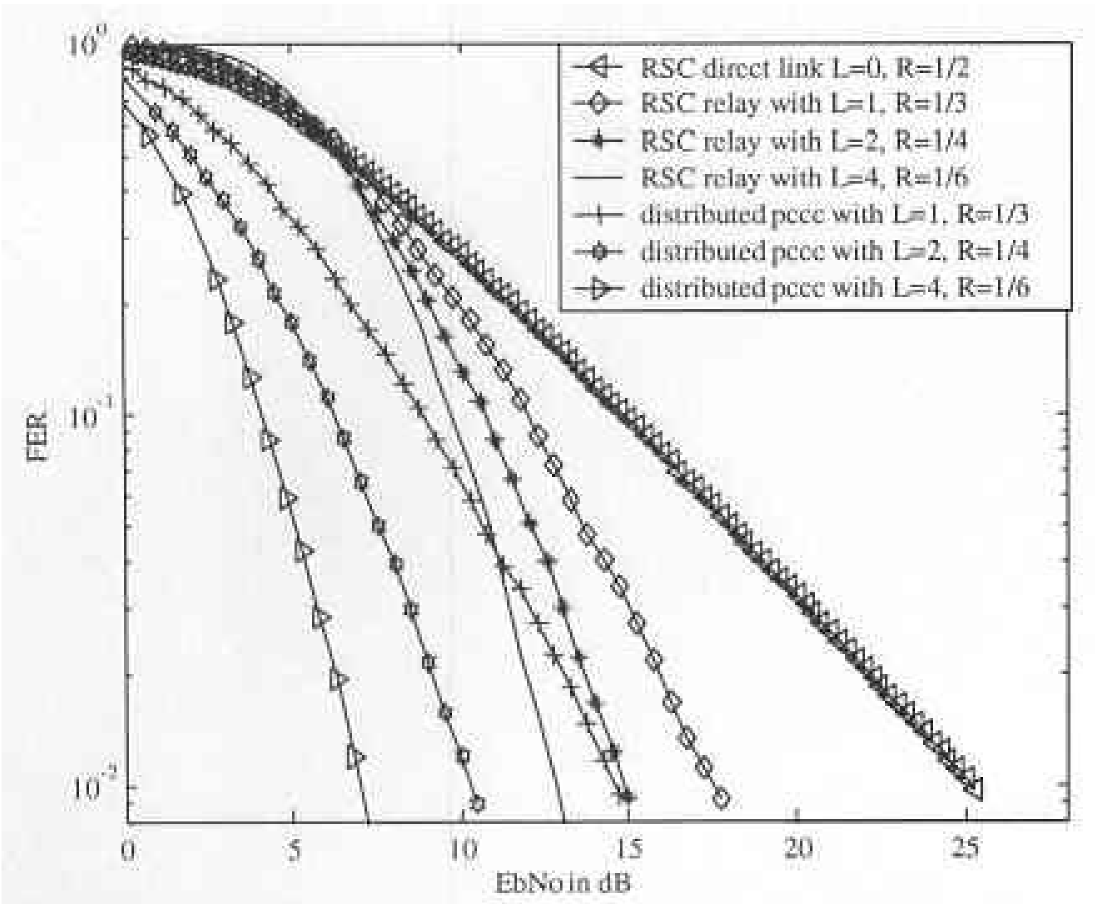
Distributed Turbo Code: Performance



- Minimum transmit SNR at source and relay required to achieve an end-to-end FER of 10^{-2} when the relay is 1 m away from the source and 9 m away from the destination.

RCPC: Rate Compatible Convolutional Codes.

Distributed Turbo Code: Performance



- FER for distributed multiple turbo codes over the multiple relay channel under the assumption of perfect source-relay links.

L= # of relays

R=code rate

Conclusions

- The idea of cooperative communications has been presented.
- The main relay functions have been addressed.
- Examples of cellular and sensor networks have been discussed.
- The cooperation between users is generally worth.
- Several benefits may be gained whenever the network resources are shared between the users in an optimal and controlled manner.
- Performance improvements due to user cooperation have also been shown.

References

[1] Van Der Meulen, E.C.; “Three-terminal communication channels”, Adv. Appl. Prob. 3, 1971.

[2] Cover, T.; Gamal, A.E.; “Capacity Theorems for Relay Channel”, IEEE Transactions on Information Theory, Vol. 25, Issue 5, Sep, 1979, Page(s): 572-584.

[3] Nosratinia, A.; Hunter, T.E.; Hedayat, A.; “Cooperative Communication in Wireless Networks”, IEEE Communications Magazine, Vol. 42, Issue 10, Oct. 2004, Page(s): 74-80.

[4] http://cmc.rice.edu/docs/docs/Ahm2005Mar5Cooperativ.pdf

[5] Ahmed, N.; Khojastepour, M.A.; Aazhang, B.; “Outage Minimization and Optimal Power Control for the Fading Relay Channel”, IEEE Information Theory Workshop, 24-29 Oct. 2004, Page(s): 458-462.

[6] Zhao, B.; Valenti, M.C.; “Distributed turbo coded diversity for relay channel”, Electronic Letters, Vol. 39, Issue 10, 15 May 2003, Page(s): 786-787.

[7] Valenti, M.C.; Zhao, B.; “Distributed turbo codes: toward the capacity of the relay channel”, IEEE 58th Vehicular Technology Conference, VTC-Fall, Vol. 1, 6-9 Oct. 2003, pp: 322–326.

[8] Laneman, J.N.; Tse, D.N.C.; Wornell, G.W.; “Cooperative Diversity in Wireless Networks: Efficient Protocols and Outage Behaviour”, IEEE Transactions on Information Theory, Vol.50, Issue 12, December 2004, Page(s): 3062-3080.

Homework

- Why cooperative communications may be considered as an interesting strategy for wireless communication?
- In the blocks diagram of page 18, why is a turbo decoder employed there?