Cooperative Wireless Communication

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Motivation

- The mobile wireless channel suffers from fading,
  Coping mechanism $\Longrightarrow$ generate diversity by sending independent copies of the same signal
- Multiple antenna is required for transmit diversity
- Wireless devices are limited by size or hardware complexity to one antenna
- Wireless antennas are omnidirectional
- In case of Ad-hoc wireless com., no fixed infrastructure

Cooperative Communication - Background

- Each wireless user is assumed to act as cooperative agent for another user
- Allow single-antenna mobiles to reap some of the benefits of MIMO systems
- Possible improvement both in throughput and transmit power

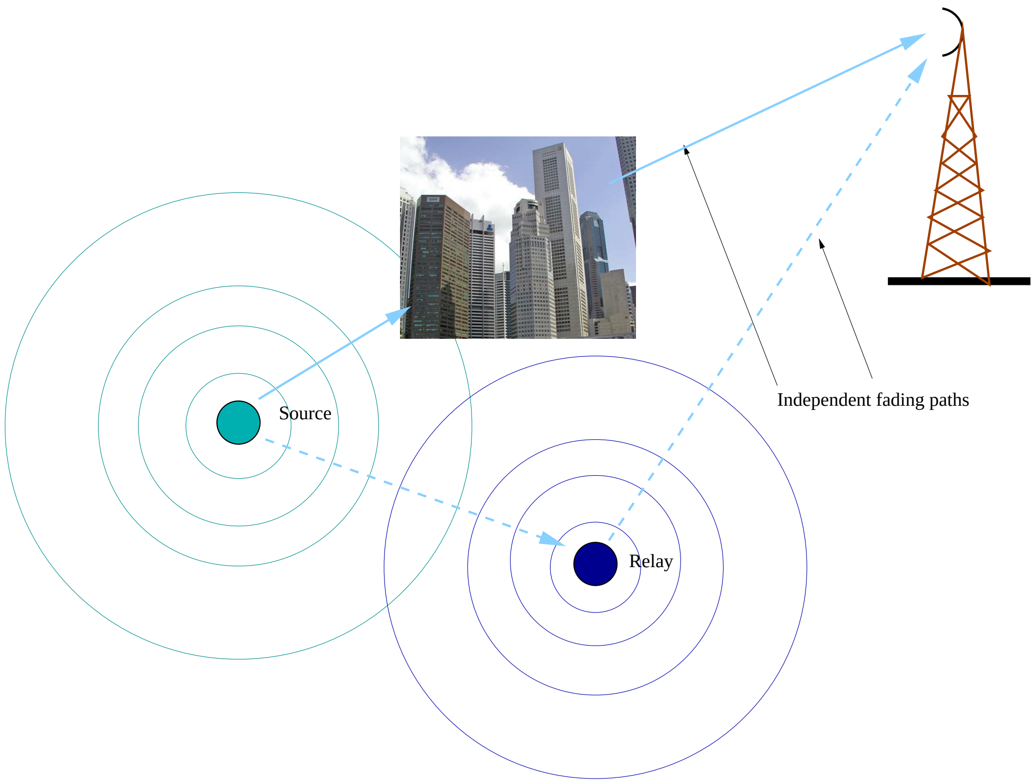

Figure 1: Cooperative communication

Background cont'd

- Basic idea originally by van der Meulen (1969), Cover and El Gamal (1979)
  - Capacity of AWGN degraded relay channel (achievable rate)
  - $Y_1 = X_1 + Z_1,\ z_1 \sim N(0, \sigma_1)$, and $Y = (X_2 + Z_2) + Y_1,\ z_2 \sim N(0, \sigma_2)$
  - $C^* = \max_{0 \leq \alpha \leq 1} \min\{C(\frac{P_1+P_2+2\sqrt{\overline{\alpha} P_1 P_2}}{N_1+N_2}), C(\frac{\alpha P_1}{N_1})\}$ where $\overline{\alpha} = 1 - \alpha$ and $C(x) = \frac{1}{2}\log(1+x)$.
- Cooperative scheme
  - Diversity and fading channel
  - Fixed total system resource

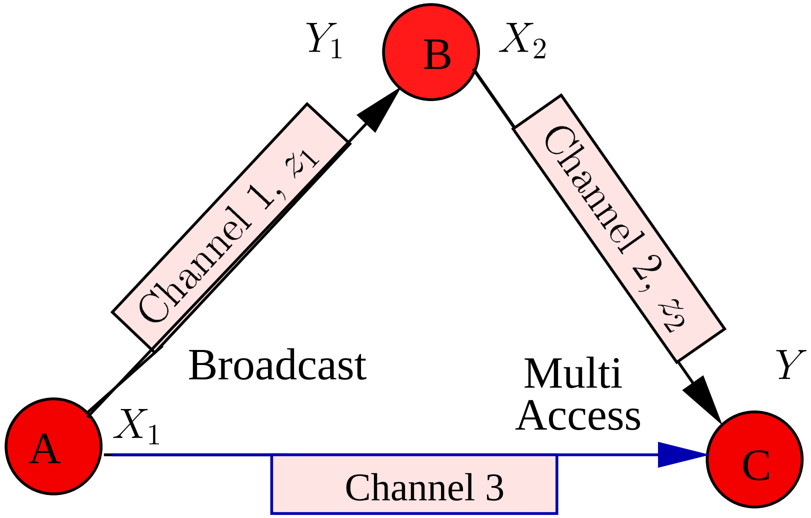

Figure 2: The relay channel

Amplify-And-Forward

- How it works
  - Amplify and retransmit
  - Decision is made at the base station
- Two independently faded versions of same signal, leading to diversity order of two
- Inter-user channel coefficients are assumed to be known at the base station to do the optimal decoding

Amplify-And-Forward cont'd

$$\begin{bmatrix} Y_{0,BC} \\ Y_{0,MA} \end{bmatrix} = \begin{bmatrix} h_{10} \\ h_{12}\beta h_{20} \end{bmatrix} X_1 + \begin{bmatrix} 0 & 1 & 0 \\ h_{20}\beta & 0 & 1 \end{bmatrix} \begin{bmatrix} Z_1 \\ Z_0 \\ Z_0 \end{bmatrix}$$

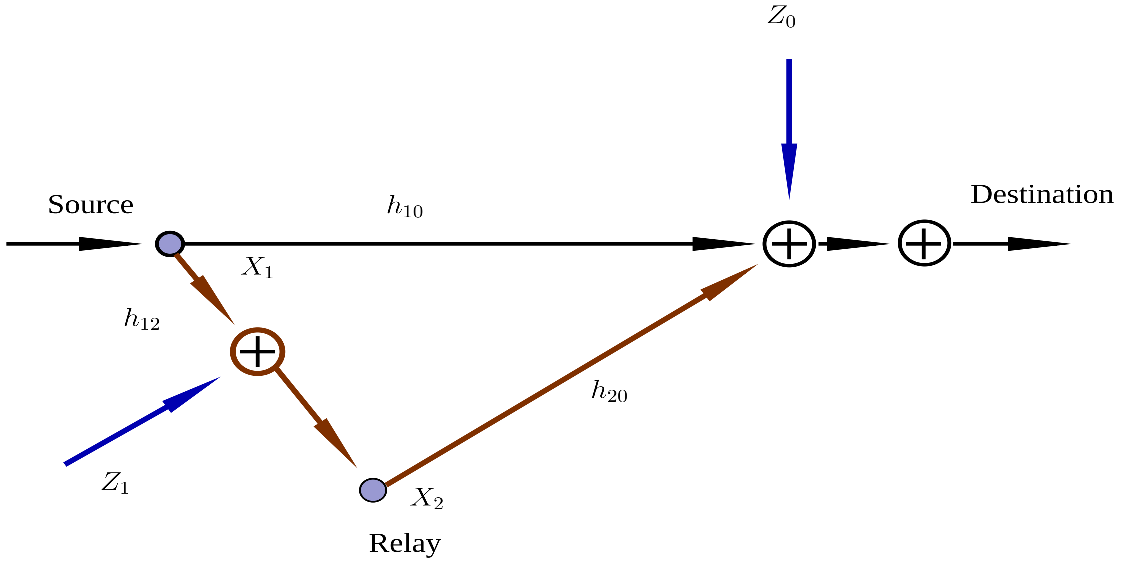

Figure 3: Amplify-and-Forward [Laneman et al.]

Amplify-And-Forward cont'd

- High SNR (Diversity-Multiplexing trade-off)
- Low SNR (Outage Capacity)

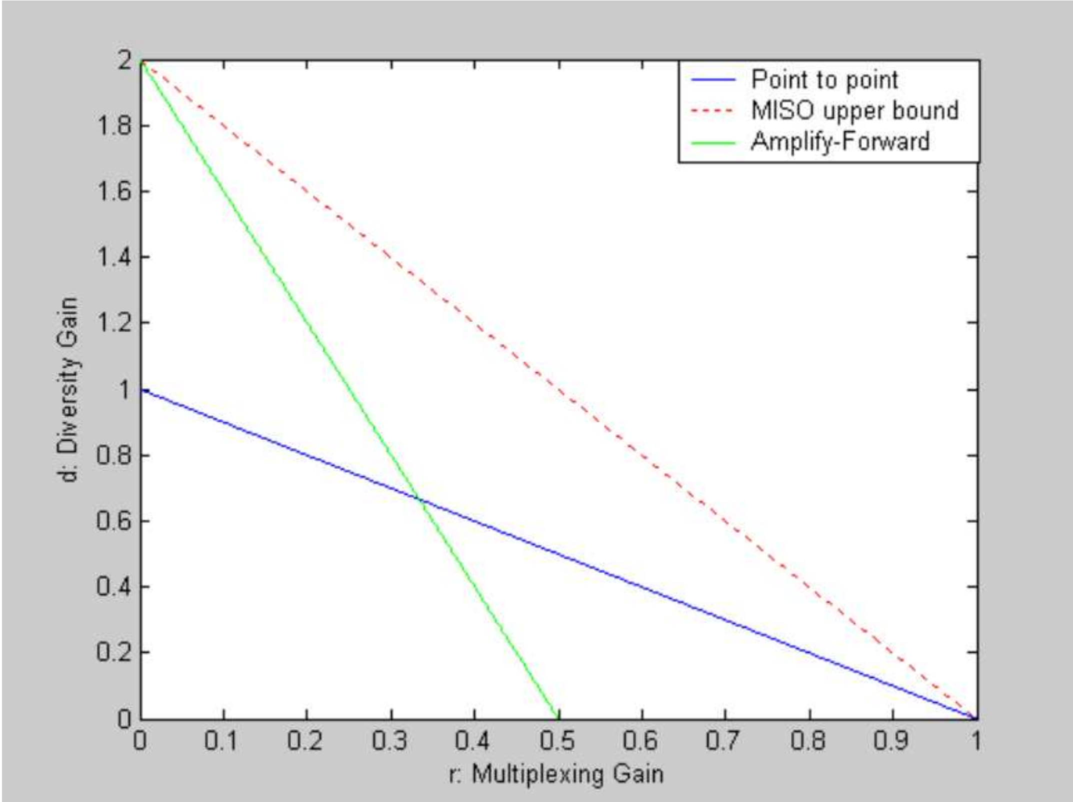

Figure 4: Diversity vs. Multiplexing (Laneman et al.)

Detect-And-Forward

- User detects partner's bits and then retransmits the detected bits
  - Partners assignment (via pairs)
  - CDMA implementation (two users), users' codes are orthogonal and channel coherence time is L (L=3)

$$
\begin{aligned}
X_1(t) &= a_1 b_1^{(1)} c_1(t), a_1 b_1^{(2)} c_1(t), a_1 b_1^{(3)} c_1(t) \\
X_2(t) &= \underbrace{a_2 b_2^{(1)} c_2(t)}_{\text{Period 1}}, \underbrace{a_2 b_2^{(2)} c_2(t)}_{\text{Period 2}}, \underbrace{a_2 b_2^{(3)} c_2(t)}_{\text{Period 3}}
\end{aligned} \tag{1}
$$

where $a_j = \sqrt{P_j/T_s}$, P_j is user j's power and T_S is symbol period

Detect-And-Forward contd.

- $\widehat{b}_j^{(i)}$ is estimate of j's i^{th} bit
- Power allocation (a_{ij})
  - Average power constraint is maintained
  - Cooperation in favorable interuser channel

$$X_1(t) = [a_{11} b_1^{(1)} c_1(t), a_{12} b_1^{(2)} c_1(t), a_{13} b_1^{(2)} c_1(t) + a_{14} \widehat{b}_2^{(2)} c_2(t)]$$

$$X_2(t) = [\underbrace{a_{21} b_2^{(1)} c_2(t)}_{\text{Period 1}}, \underbrace{a_{22} b_2^{(2)} c_2(t)}_{\text{Period 2}}, \underbrace{a_{23} b_2^{(2)} c_2(t) + a_{24} \widehat{b}_1^{(2)} c_1(t)]}_{\text{Period 3}}$$

Detect-And-Forward cont'd.

- Simplicity and adaptability to channel conditions
- The method fails in case of unsuccessful partner detection
- Hybrid decode-and-forward (to avoid error propagation)
  - Cooperative mode for low inst. SNR
  - Non cooperative mode for high inst. SNR

Detect-And-Forward cont'd.

- Users send two new bits per three symbols, isn't this counter productive?

$$\eta = (1-\upsilon) C_{\text{BSC}}(Q(\sqrt{\frac{\text{SNR}_0}{1-\upsilon}}))$$

  - Negligible loss of throughput at low SNR_0
  - Design tradeoff, L_{non-c}vs. L_c
  - L_c doesn't have to be constant all the time

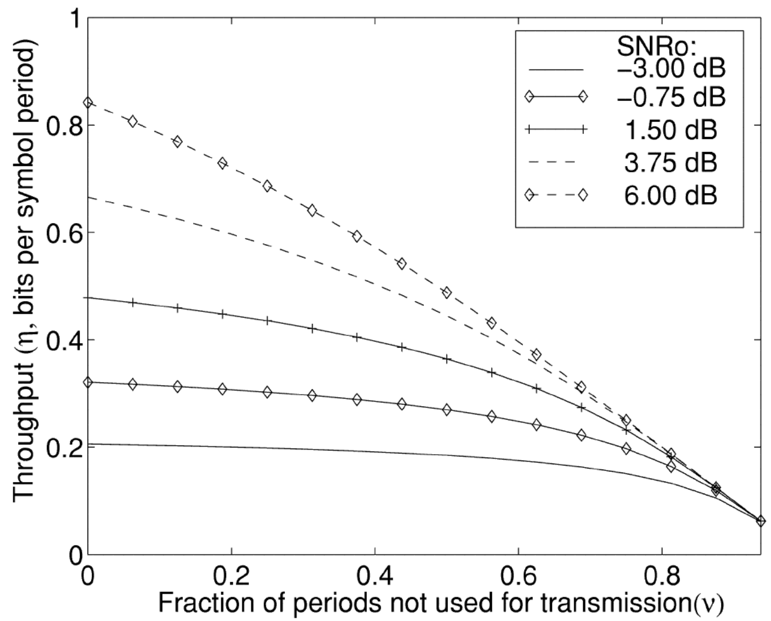

Figure 5: Throughput vs. unused symbol periods

Coded Cooperation

- Cooperation $\Longrightarrow$ Channel coding
  - Different portions of each user's code word are sent via independent fading path
  - The divided source data blocks are augmented by **CRC**
  - eg. original codeword has $N_1 + N_2$ bits (**puncturing**) the original codeword
    - First partition, valid codeword with N_1 bits Remaining N_2 bits are the puncture bits
    - In the first frame each user sends N_1 bits and in the second frame partner's 2^{nd} code partition

Coded Cooperation cont'd.

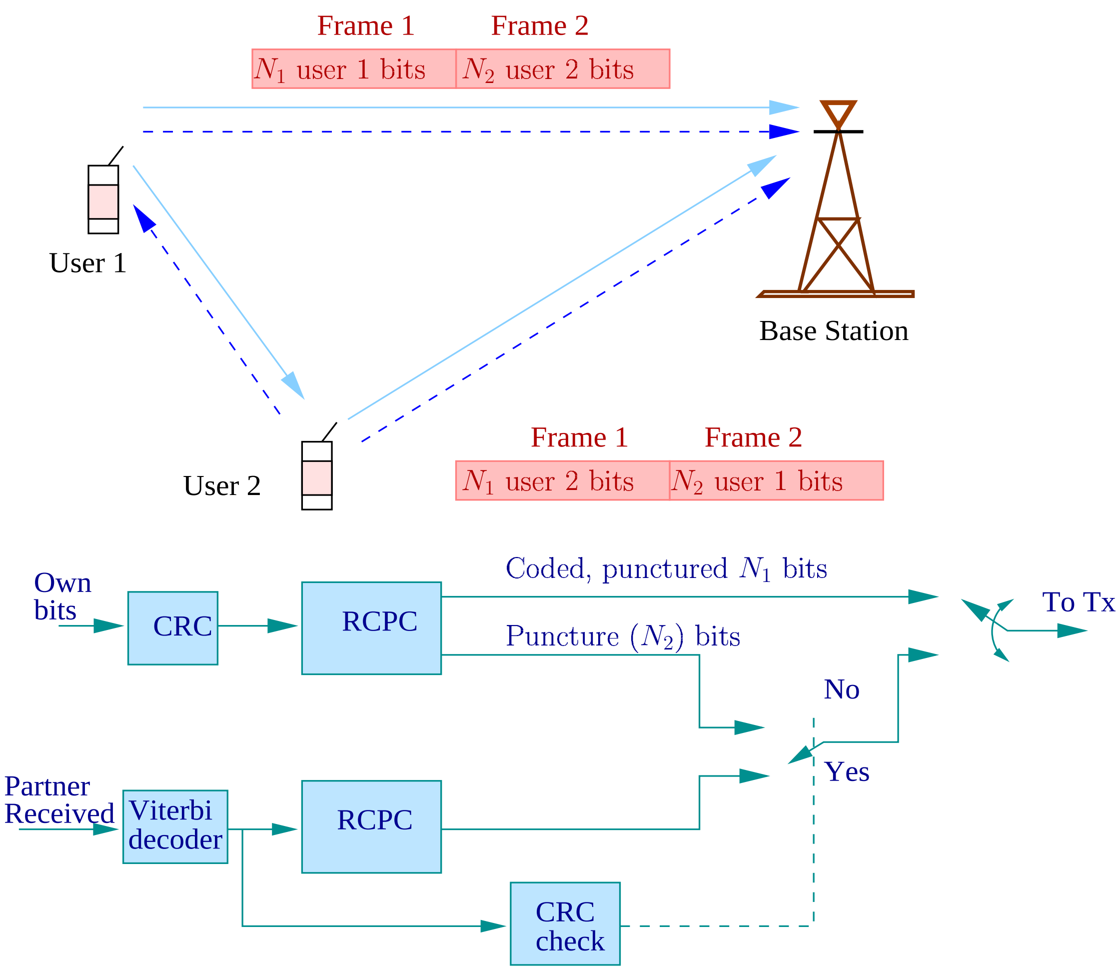

Figure 6: Coded Cooperation [Nosratinia et al.]

Coded Cooperation cont'd.

- Users act independently in the second frame
  - both users cooperate
  - user 1 cooperate and user 2 doesn't
  - user 2 cooperate and user 1 doesn't
  - both users don't cooperate
- Level of cooperation (in the eg. N_2/N)
- Other channel codes can be employed (block codes, convolutional codes, ...)

Performance

- Case studied by [Sendonaris et al.]
- For equitable comparison, coded base line system of overall rate 1/4 is used
  - RCPC rate 1/2 for Hybrid and decode-and-forward and amplify and forward
  - 25% level of cooperation for coded cooperation

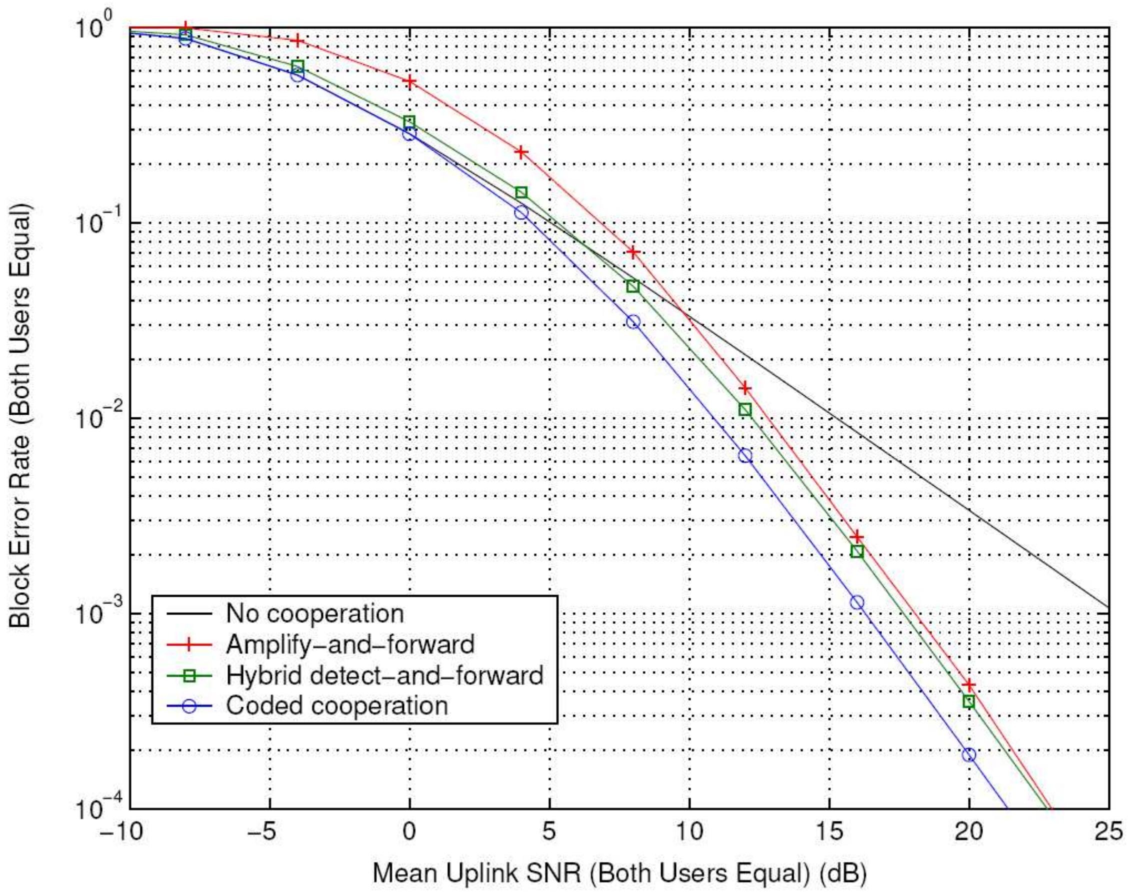

Figure 7: Performance of cooperative signaling methods (-10dB inter-user SNR)

Multiple Access

- Base station receives original and relayed transmissions separately (assumption)
- Separation in time (Different time slot)
  - Hardware implication
- Separation in frequency (Different spectrum)
- Use of spreading code [Sendonaris et al.]
  - Sufficient isolation is required

Challenges

- Loss of rate to the cooperating mobile
- Overall interference in the network
- Cooperation assignment and hand off
- Fairness of the system, "market force and QoS"
- Transmit and receive requirement on the mobiles
- User data has to be encrypted (security)

References

1 A. Nosratinia, T. E. Hunter and A. Hedayat, "Cooperative communication in wireless networks", *IEEE Communication Magazine*, Vol. 42, Issue 10, Oct. 2004, pp. 74-80.

2 T. M. Cover and A. A. E. Gamal, "Capacity Theorems for the Relay Channel", *IEEE Trans. Info. Theory*, Vol. 25, no 5, Sept. 1979, pp. 572-84.

3 A. Sendonaris, E. Erkip, and B. Aazhang, "User Cooperation Diversity Part I and Part II," *IEEE Trans. Commun.*, vol. 51, no. 11, Nov. 2003, pp. 1927-48.

4 J.N. Laneman, D.N.C. Tse, and G.W. Wornell , "Cooperative diversity in wireless networks: Efficient protocols and outage behavior" *IEEE Transactions on Information Theory*, vol. 50, Issue 12, Dec. 2004, pp. 3062-3080.

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