

Cooperative Communication

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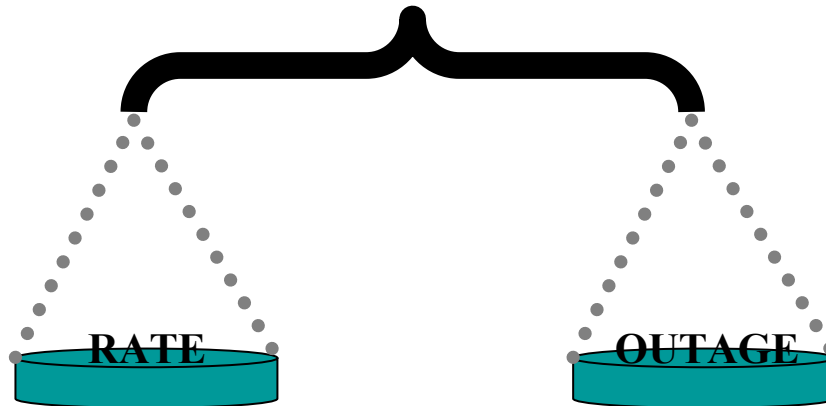


Outline

- Motivation
- A new paradigm
 - Relay channel
 - User cooperation
- A few recent results
- Future directions

Motivation

- Wireless communication
 - “Better” reliability
 - “Higher” data rates



“Better” Reliability

- Probability of error
 - Bit
 - Symbol
 - Frame
- Simple white Gaussian channels

$$BER \propto \exp^{-SNR}$$

- Fading channels

$$BER \propto \frac{1}{SNR}$$

“Higher” Data Rates

- Spectral efficiency (bits/seconds/Hertz)
- Achievable rates in AWGN

$$R \propto \log\left(1 + \frac{SNR^{Trans}}{D^2}\right)$$

- Fast fading channels (ergodic)

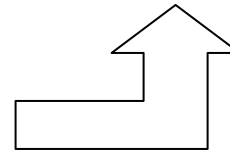
$$R \propto E_h \left[\log\left(1 + \frac{|h|^2 SNR^{Trans}}{D^\alpha}\right) \right]$$

Data Rates

- Ergodic capacity $R \propto E_h[\log(1 + \frac{|h|^2 SNR^{Trans}}{D^\alpha})]$
- Slow varying channels
- A bad realization may last as long as a frame
- Probability of outage

$$P_{out} = \Pr[\log(1 + \frac{|h|^2 SNR^{Trans}}{D^\alpha}) < r]$$

Target rate



Outage

- Probability of outage

$$P_{out} = \Pr[\log(1 + \frac{|h|^2 SNR^{Trans}}{D^\alpha}) < r]$$

- Lower bound on frame error rate

$$P_{out} \leq FER \propto \frac{1}{SNR}$$

Question

Can we improve *reliability* and *data rate* without increasing *power* or *bandwidth*?

Yes

Degrees of Freedom/Dimensions

[Telatar, Zhang & Tse]

- Free dimensions used for diversity

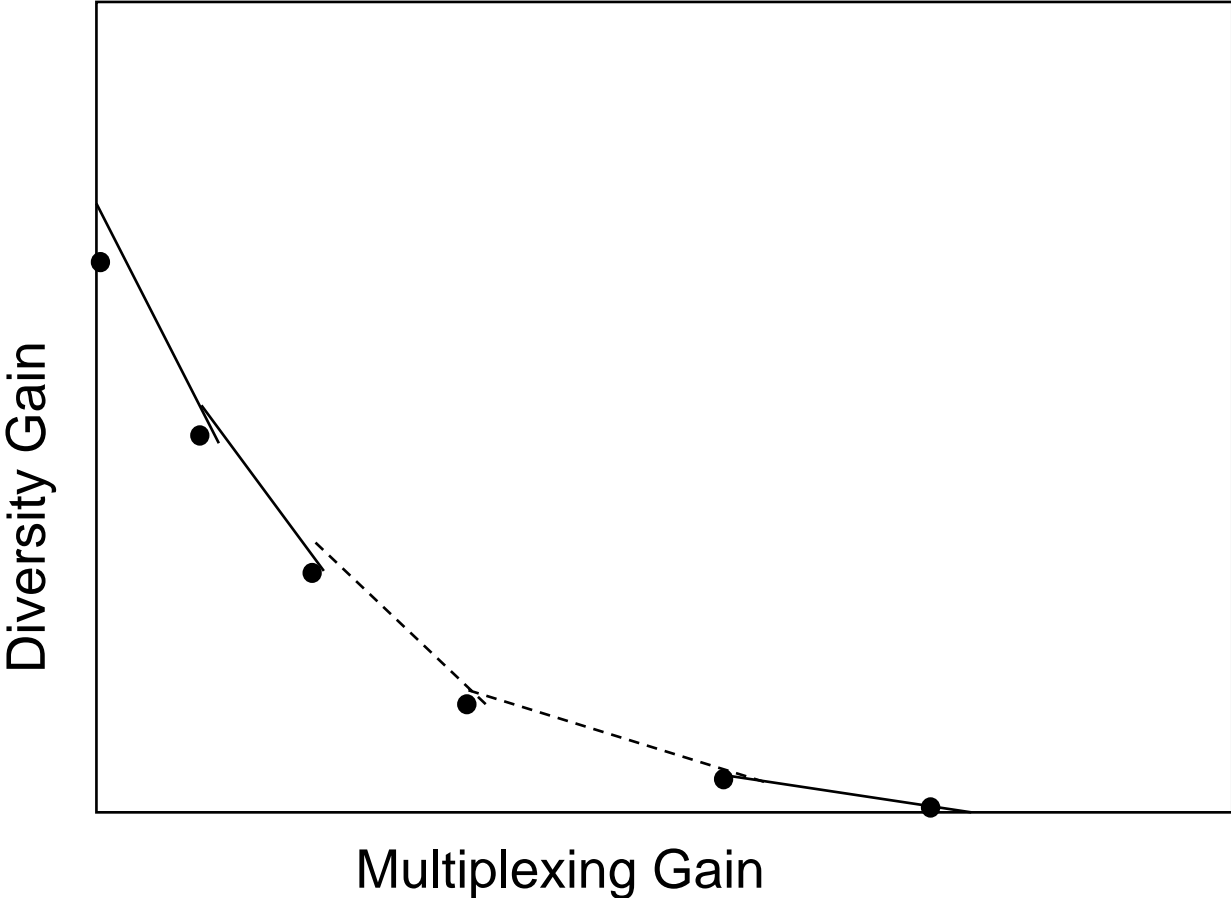
$$BER \propto \frac{1}{SNR^d}$$

- Free dimensions used for multiplexing (i.e., increasing rates)

$$R \propto mE\left[\log\left(1 + \frac{|h|^2 SNR^{Trans}}{D^\alpha}\right)\right]$$

- Tradeoff between diversity and multiplexing

Diversity versus Multiplexing

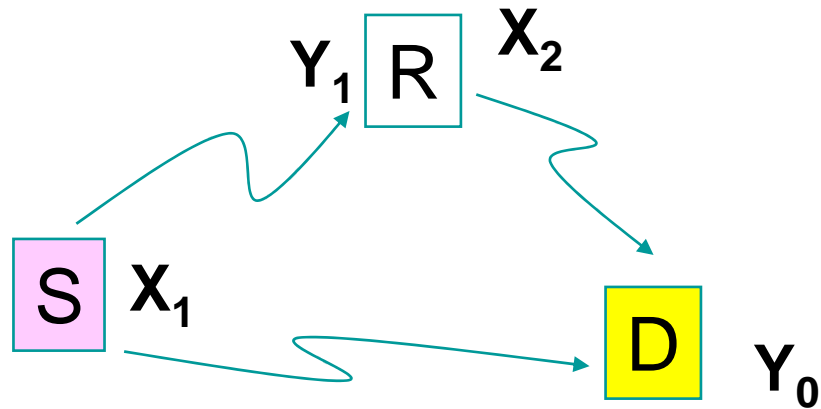


Additional Dimensions

- Spectral
- Temporal
- Spatial
 - Multiple antennas
 - *Cooperation*
- Feedback?
- Cross layer optimization?

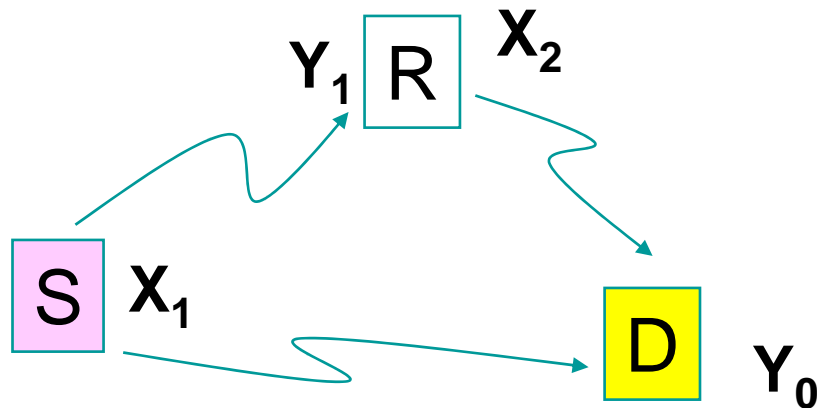
Fading Relay Channels

- A paradigm shift



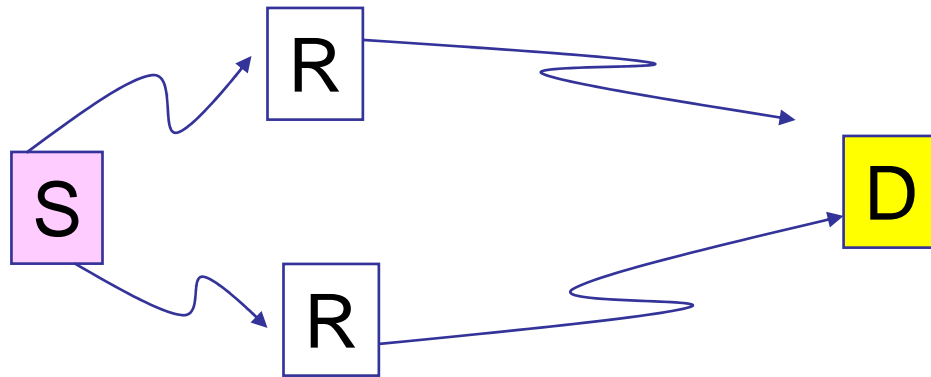
Historical Account

- Introduced in 1971 [Van der Meulen]
- Degraded relay channel in 1979 [Cover & El Gamal]
- Isolated work in the 80's and 90's
- Recent resurgence



Two Relays

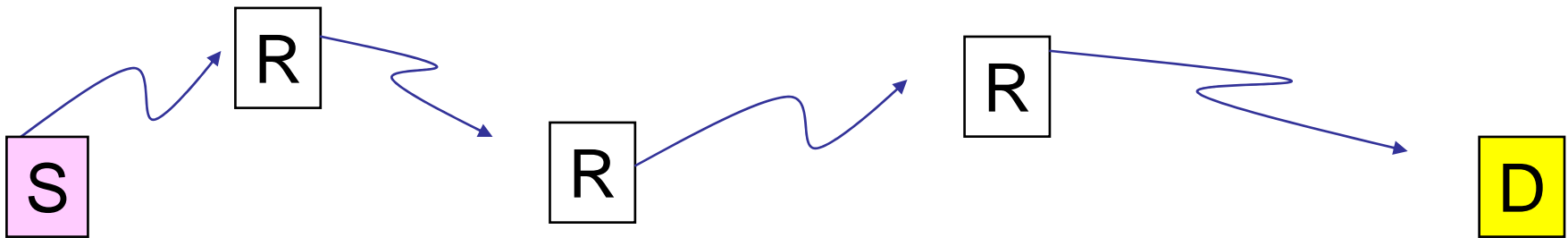
- A broader configuration [Shein & Gallegar]



Multi Hop Network

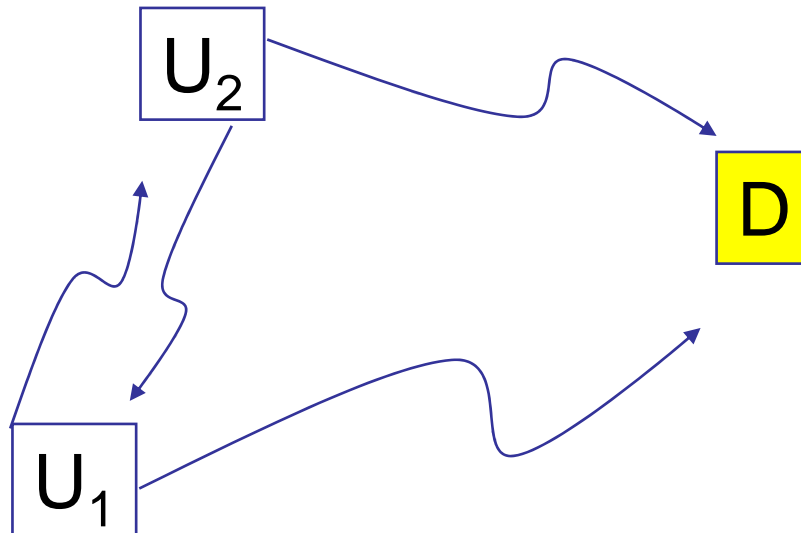
- Large body of recent work

[Gupta & Kumar, Gastpar & Vetterli, Reznik & Verdu & Kulkarni]

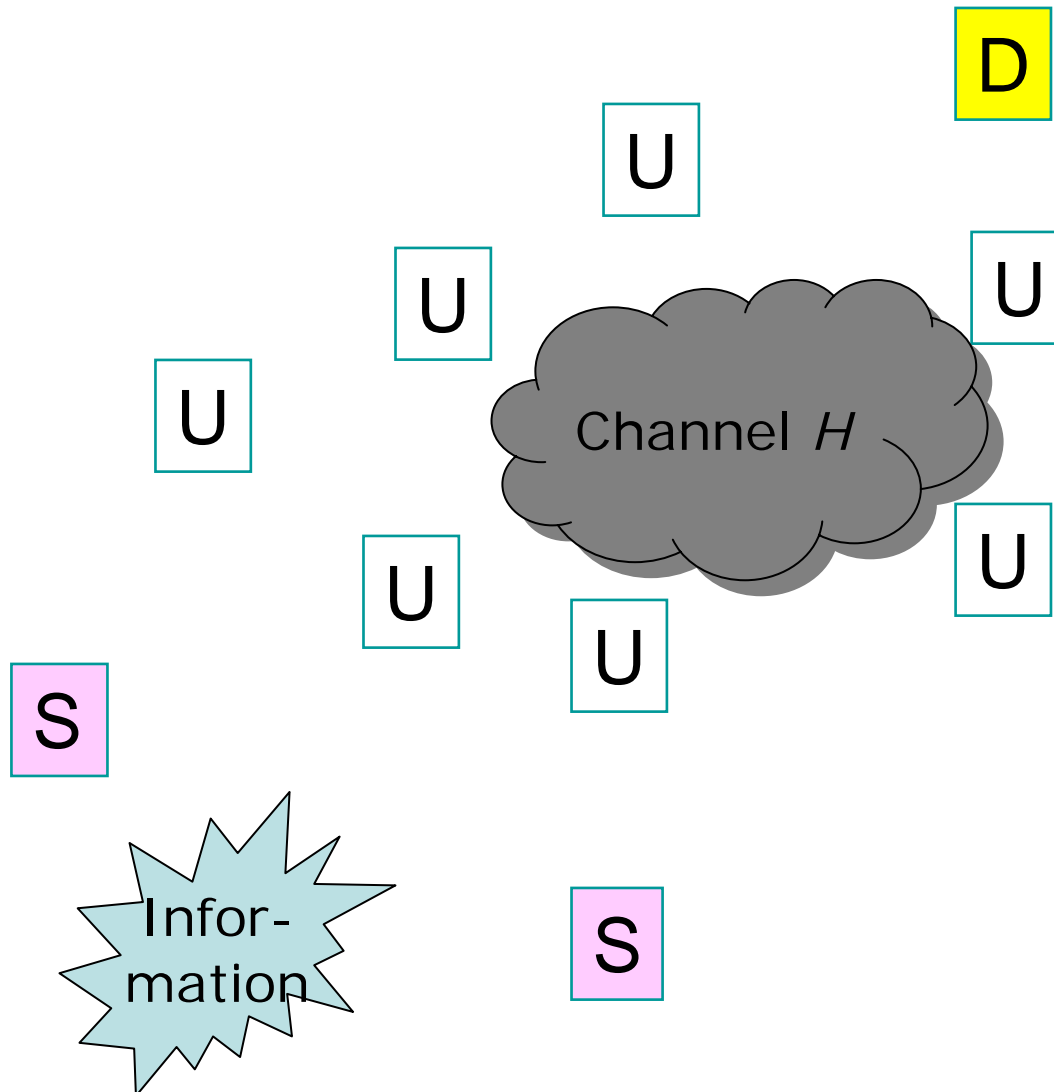


User Cooperation

- A multiuser perspective [Sendonaris & Erkip & Aazhang]



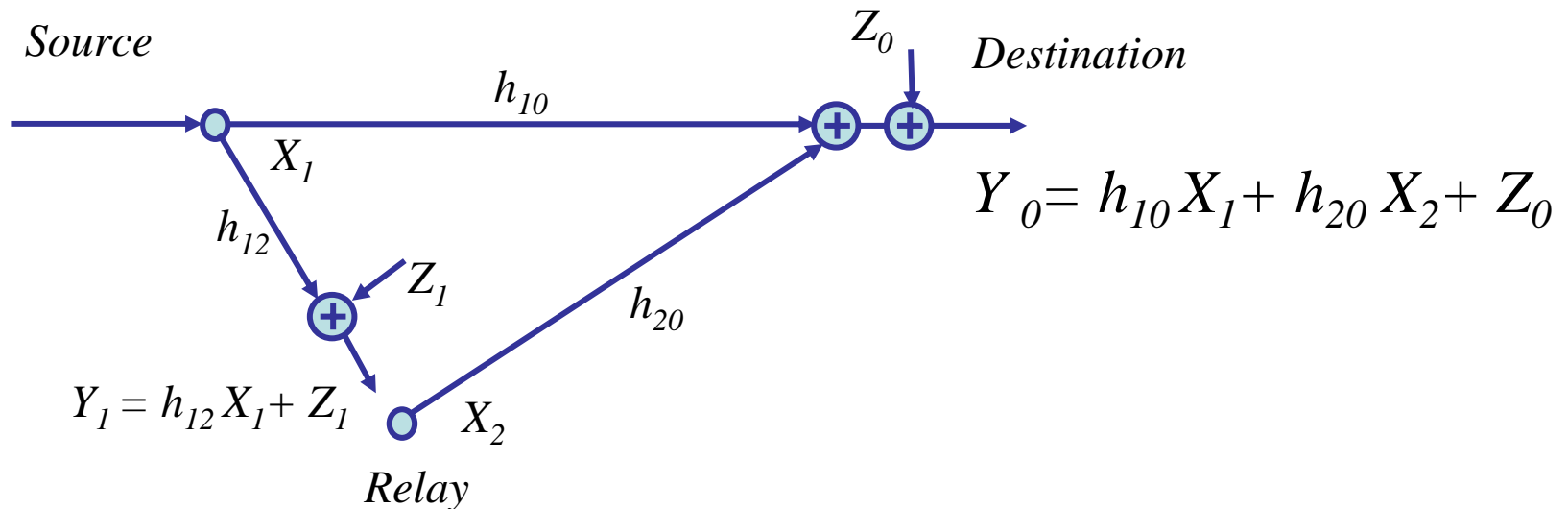
A Broader Picture: Network Coding



Gaussian Fading Model

- The channel qualities

$$\gamma_0 = \frac{|h_{12}|^2}{N_1}, \gamma_1 = \frac{|h_{10}|^2}{N_0}, \gamma_2 = \frac{|h_{20}|^2}{N_0}$$



Relay Operation

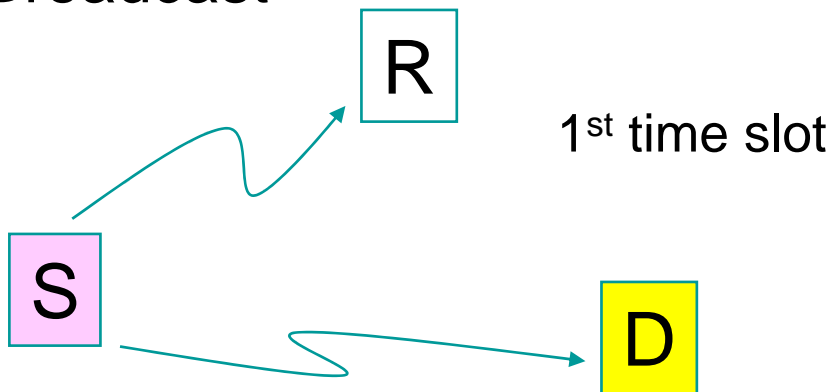
- Full Duplex
 - Relay can receive and transmit same time and same frequency band
 - RF isolation
 - Transmit signal may be 100-150 dB above received signal

Relay Operation

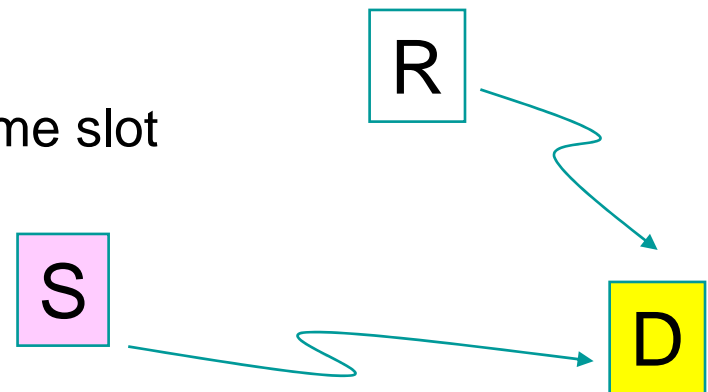
- Half duplex
 - Relay will not receive and transmit same time and same frequency band
 - Time division duplex
 - Frequency division duplex
 - Code division duplex

Multiple access

Broadcast



2nd time slot



Relay Function

- Fixed relaying
 - Decode and forward
 - Estimate and forward
 - Amplify and forward
- Adaptive relaying
 - Selection
 - Incremental

Amplify and Forward

[Laneman & Tse & Wornell]

- The codeword at the source $X_{1,1}, X_{1,2}, \dots, X_{1,n}$
- The received signal at relay $Y_{1,1}, Y_{1,2}, \dots, Y_{1,n}$
- The relay transmits $X_{2,i} = \beta Y_{1,i}$

Gaussian Vector Channel

- Mutual information

$$I(X_1; Y_{0,BC}, Y_{0,MA}) \leq \log \det \left[I + \left(P_S \begin{bmatrix} |h_{10}|^2 & h_{10} (h_{20} \beta h_{12})^* \\ h_{10}^* h_{20} \beta h_{12} & |h_{20} \beta h_{12}|^2 \end{bmatrix} \right) \begin{pmatrix} N_0 & 0 \\ 0 & |h_{20} \beta|^2 N_1 + N_0 \end{pmatrix}^{-1} \right]$$

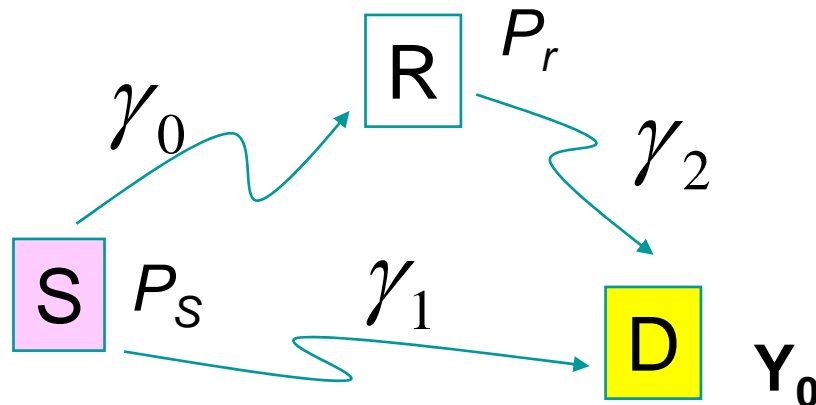
Achievable Rates for AF

- For Gaussian fading

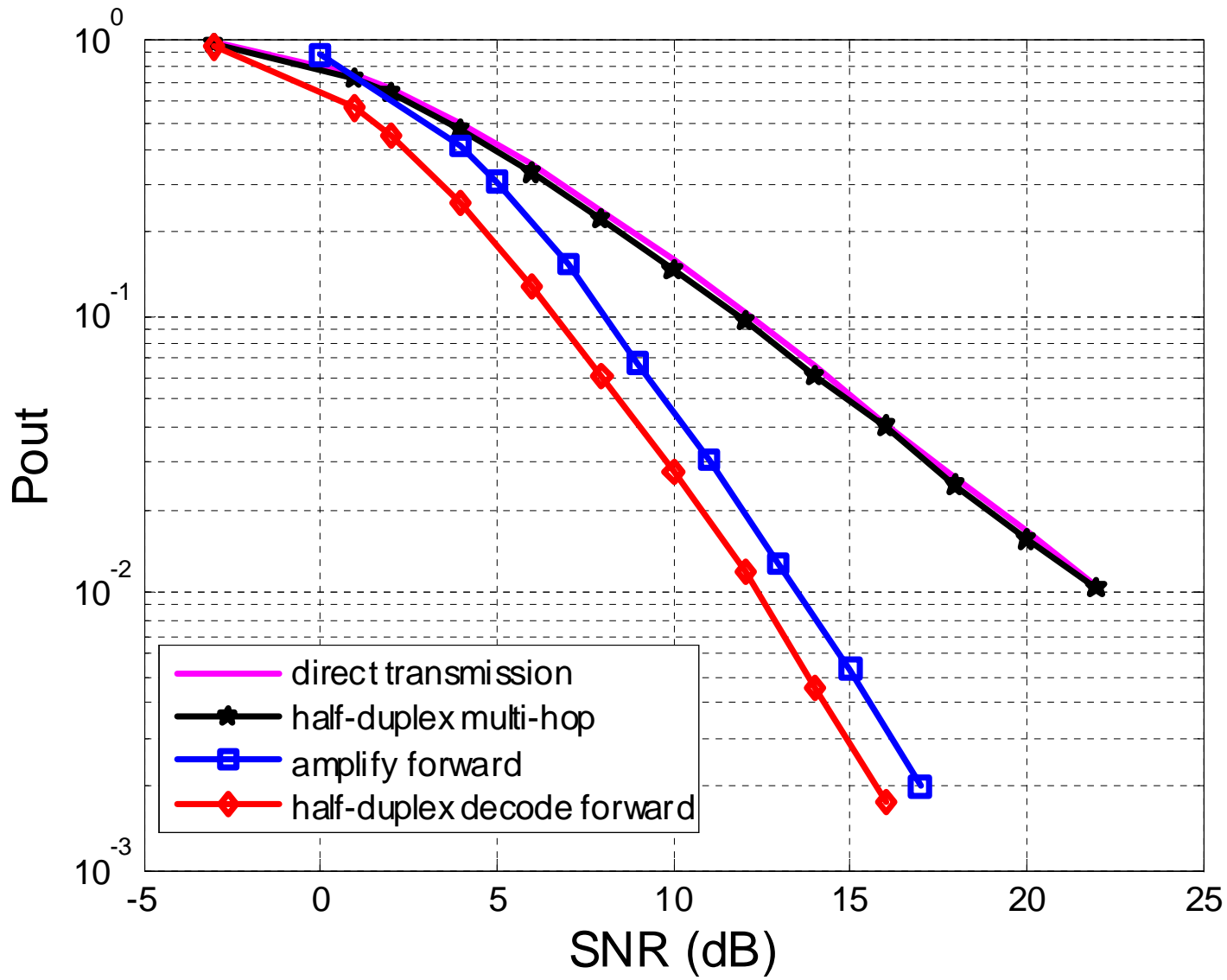
$$R_{AF}(\gamma, P_S, P_r) = \frac{1}{2} E\left[\log\left(1 + 2\gamma_1 P_S + \frac{4\gamma_2 P_S \gamma_0 P_r}{1 + 2P_S \gamma_0 + 2P_r \gamma_2}\right)\right]$$

- Outage

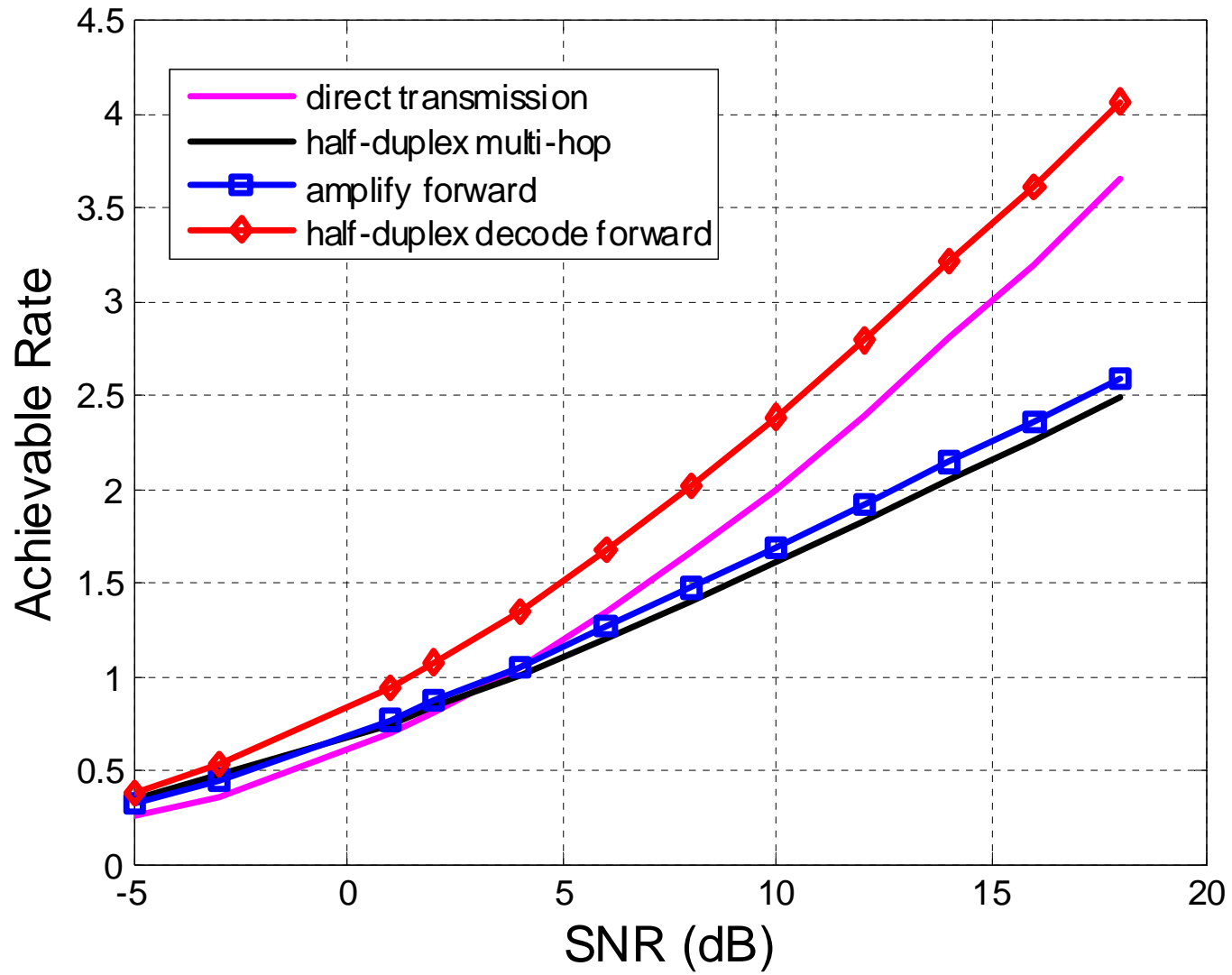
$$P_{out} = \Pr[R_{AF} \leq r] \leq FER$$



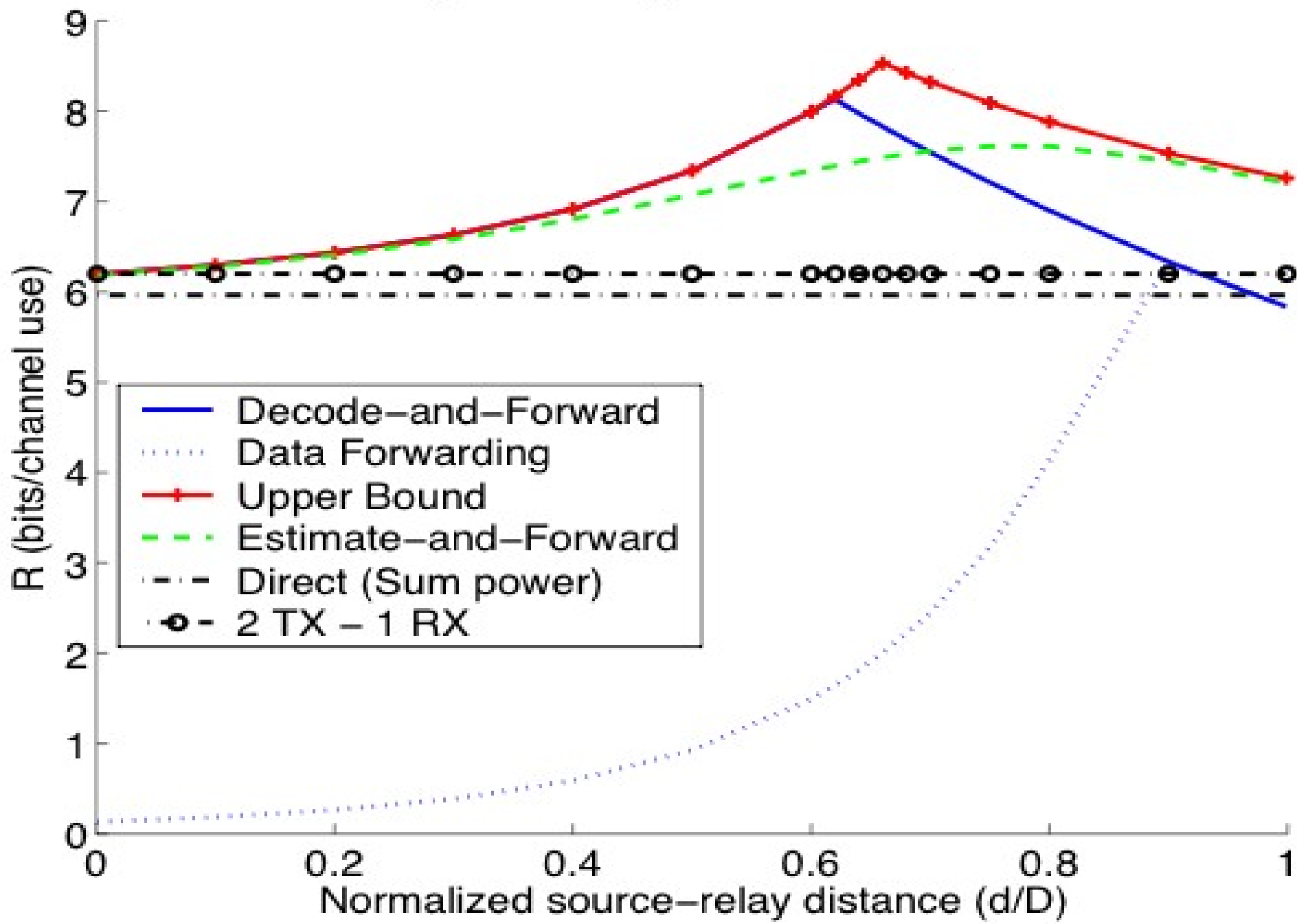
Diversity Gain in Outage



Achievable Rate



$$P_1 = 20\text{dB}, P_2 = 10\text{dB}, \alpha = 3.5$$

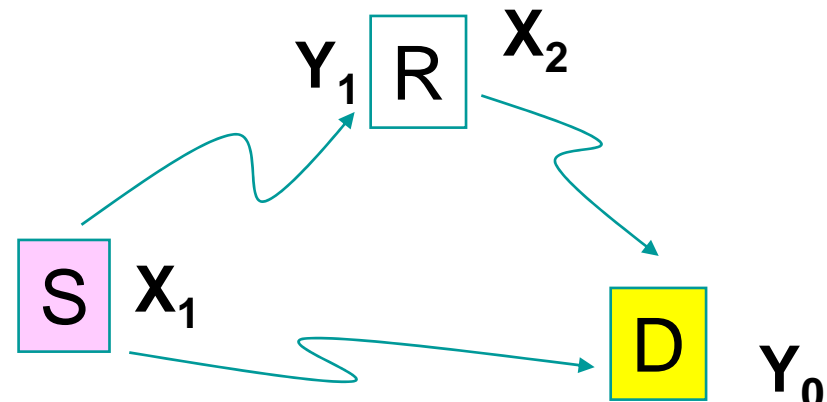
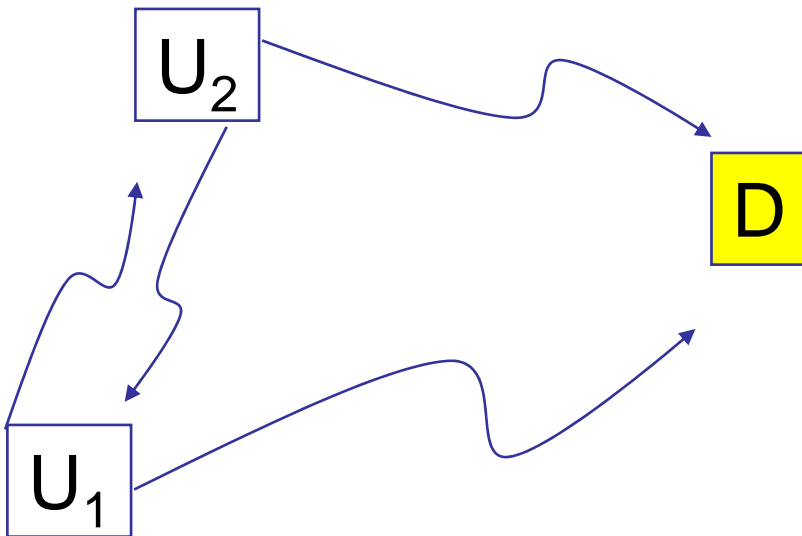


The Promise

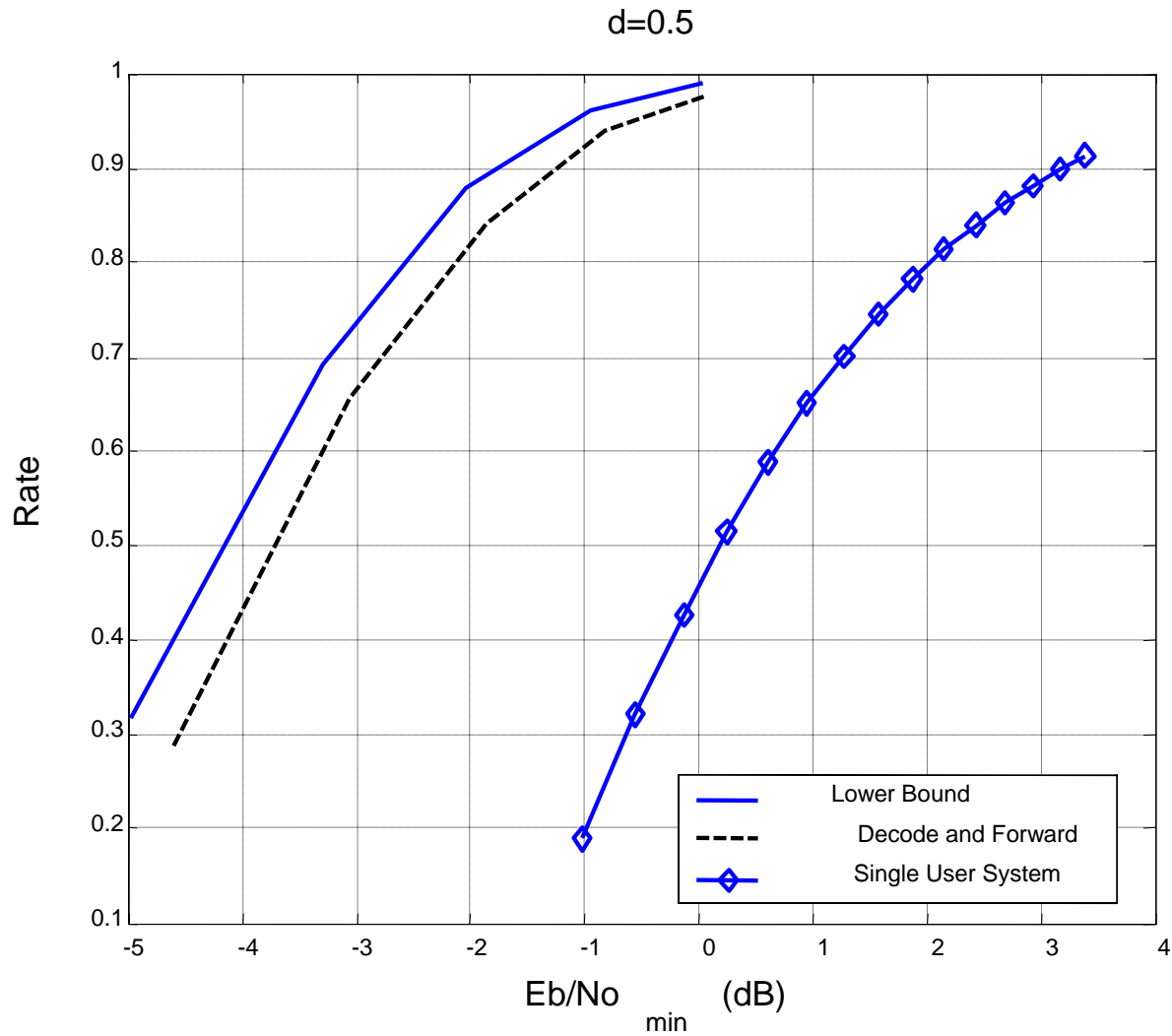
- Diversity gain
- Rate increase
 - Scale?

Current Focus

- Information theoretic analysis
 - Multiple antennas
- Code construction
- Feedback

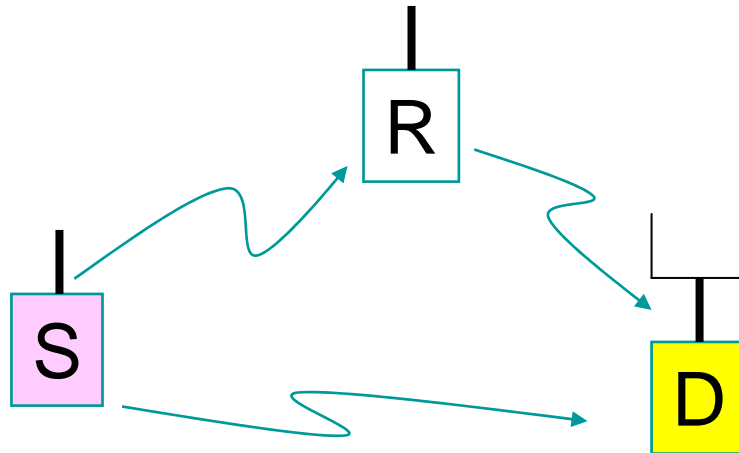


Performance Limit

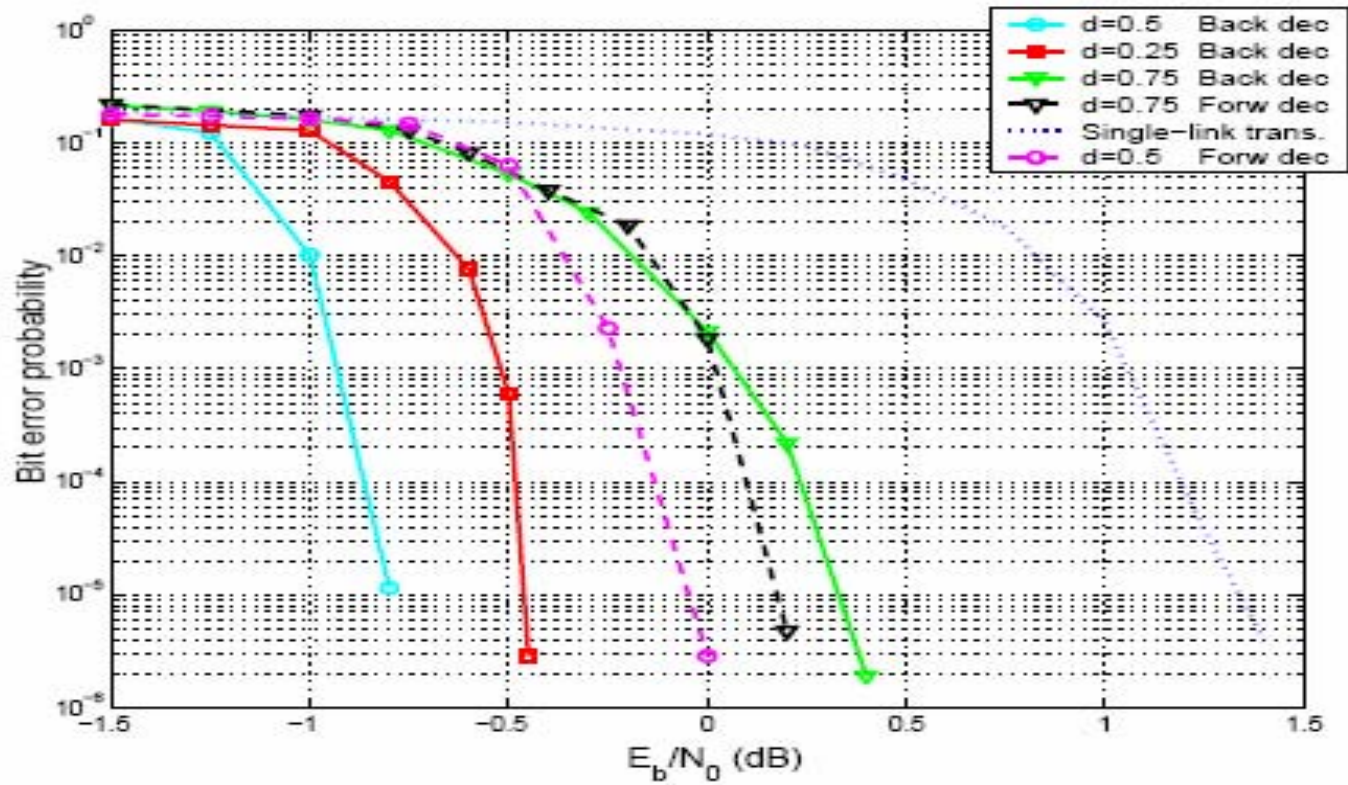


Multiple Antennas

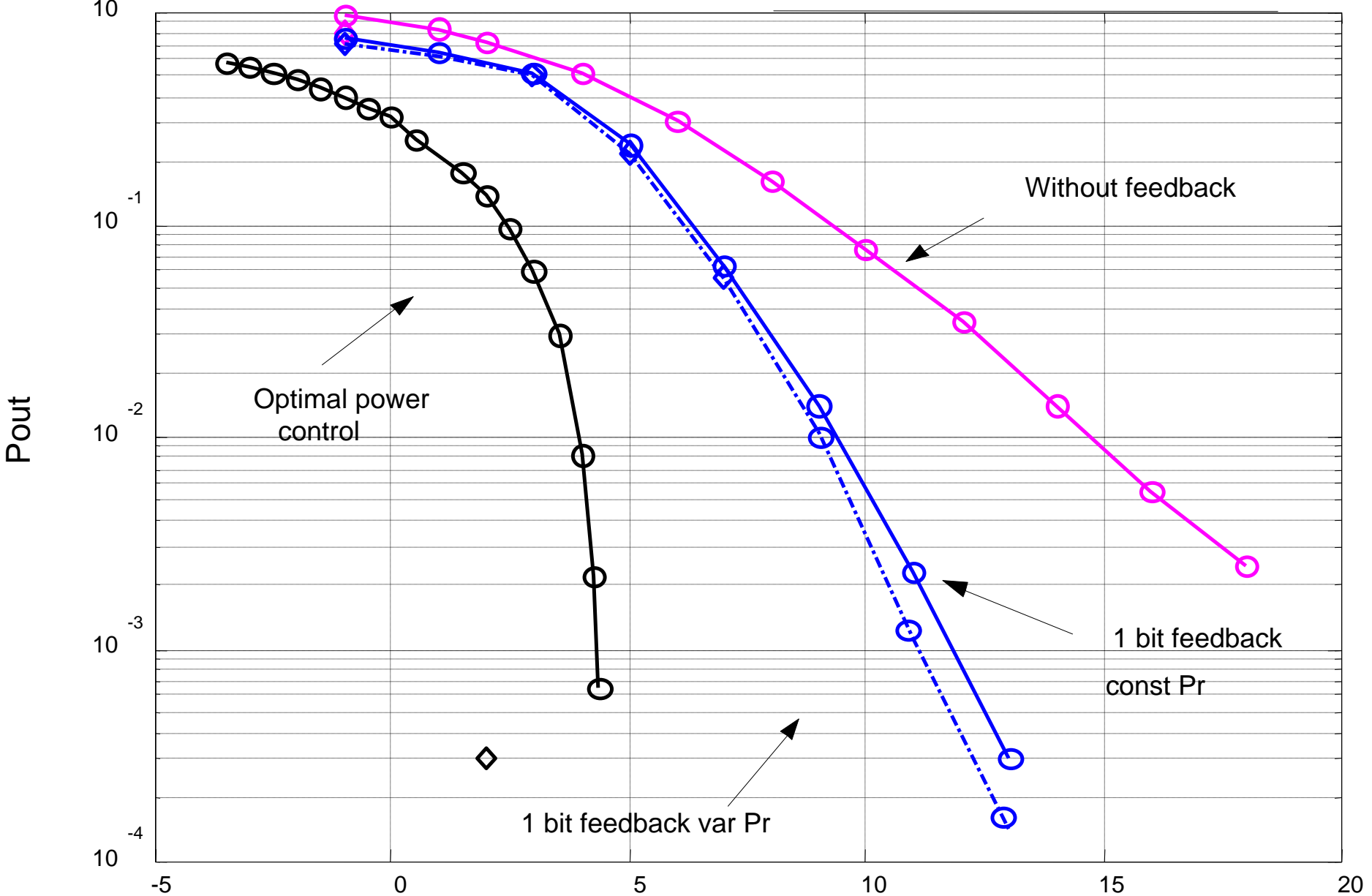
- Multiplexing gain?
- Diversity gain?



LDPC Example



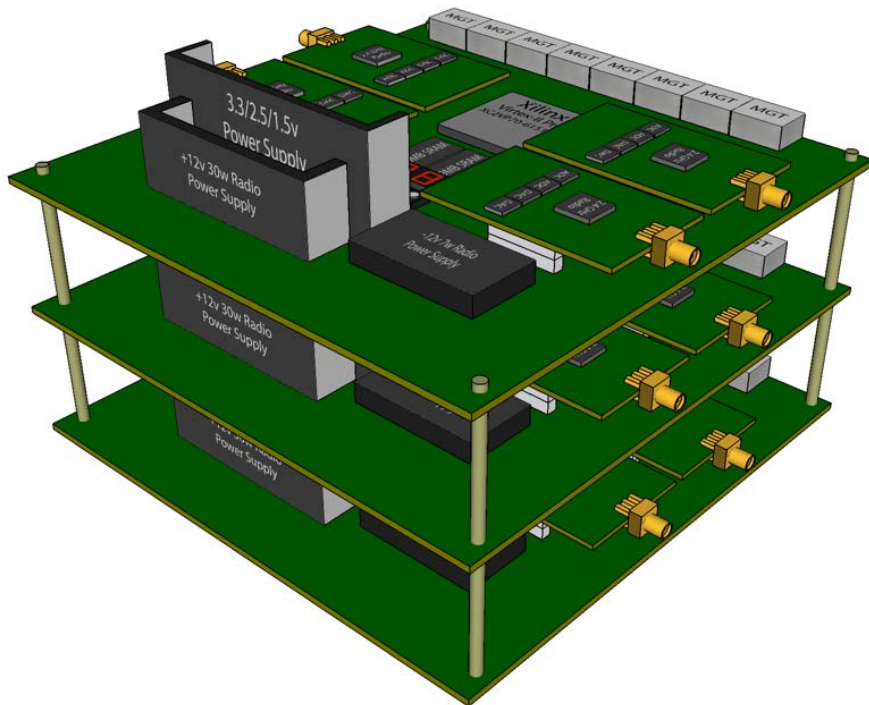
Amplify and Forward ($R=1, \alpha=3, d=0.5$)



Conclusions and Possible Directions

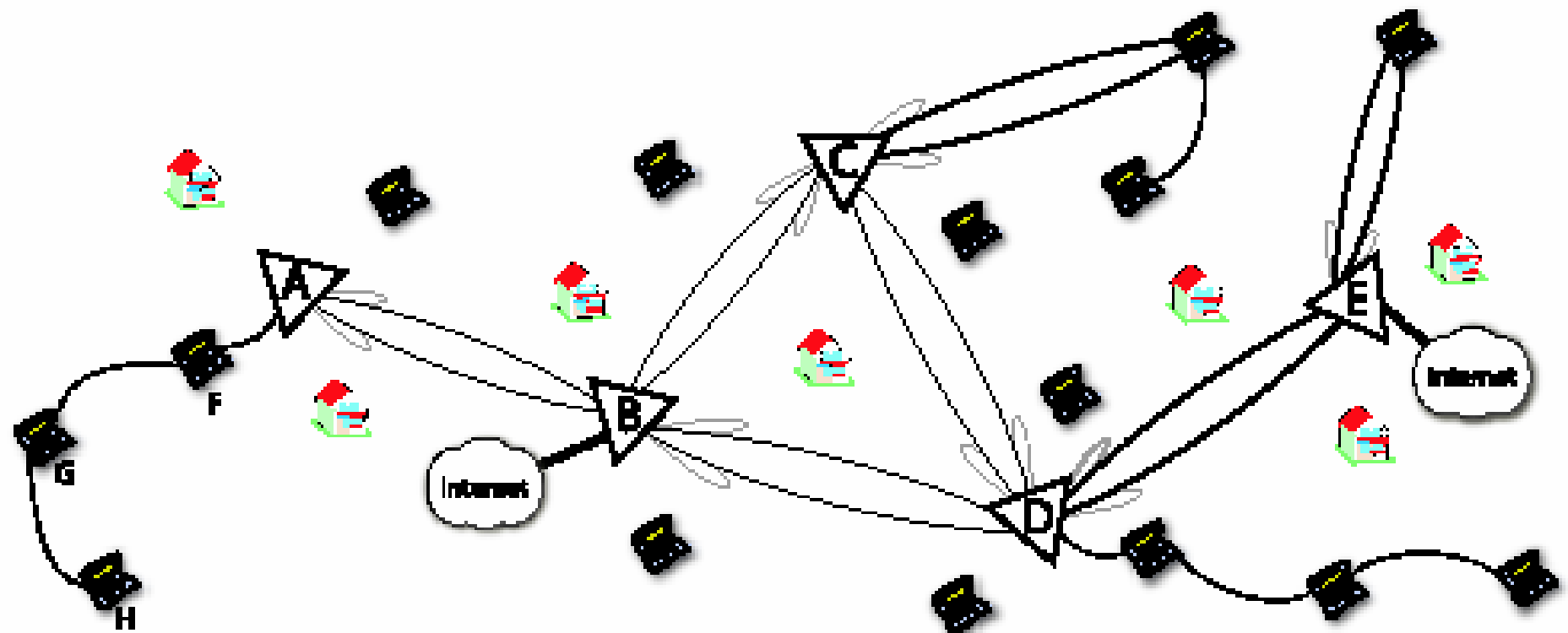
- A new paradigm
 - Low to mid SNR's
 - Application: handhelds with limited form factors
 - Implications on larger networks
- Code construction
- Feedback for power and rate control
- Implementation

Research Platform



TAP: A Mesh Network

- Transit Access Point



Channel?

- Network is the channel

