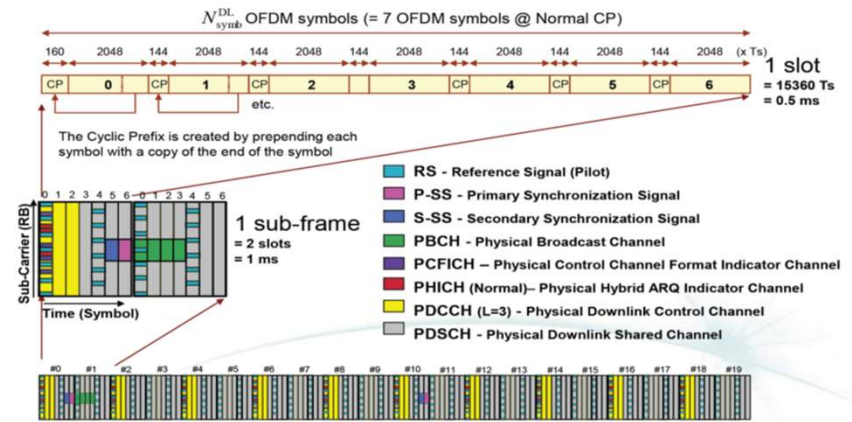
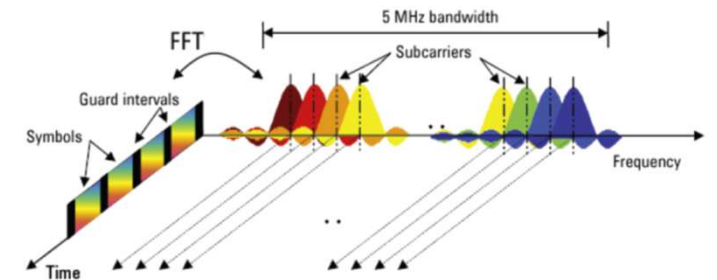
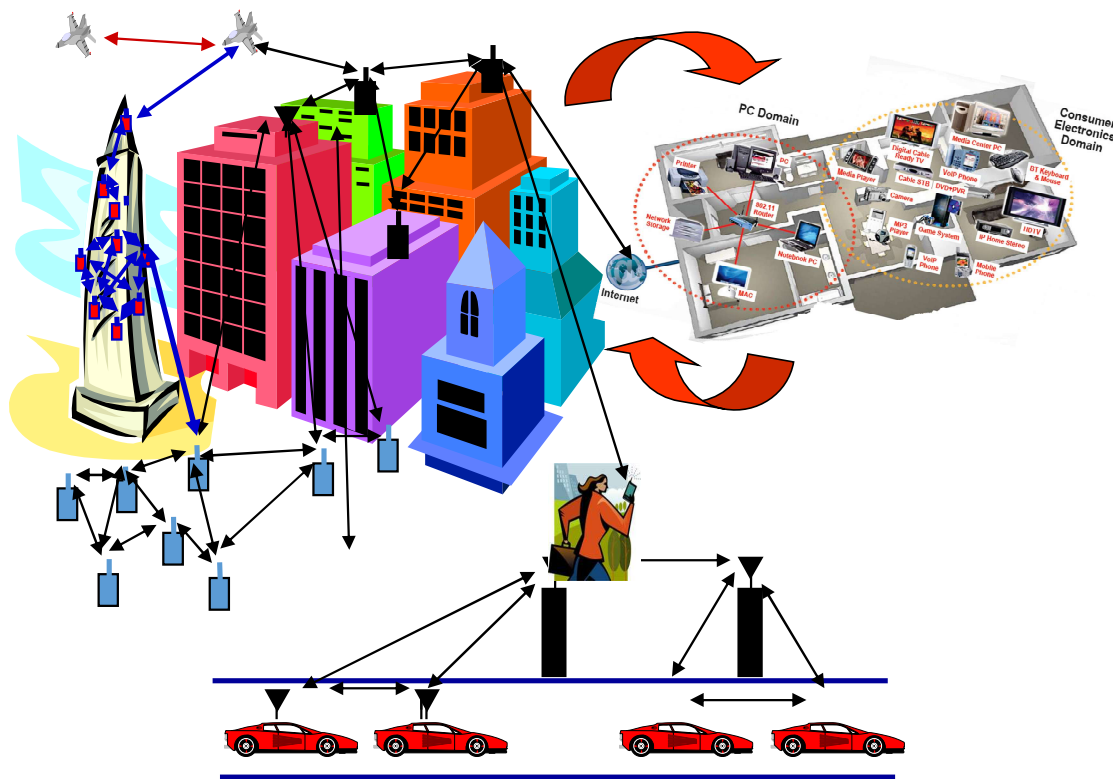


IEE 2620: System Aspects in Communications

Professor Muhammad Mahtab Alam

Lecture 14

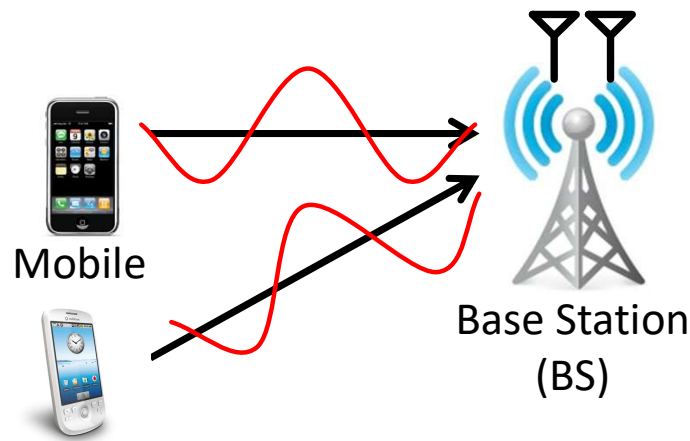


Outline

- Brief follow-up from last lecture
- MIMO systems
- Motivation for Cooperative Communication
- Cooperative Communication (CC)
 - CC Methods
 - Performance Evaluation
- Summary

Past Challenges in Wireless

Example: cellular network



1. Fading ✓
2. Multiplexing (Multiple Access) ✓

Past 15 years:

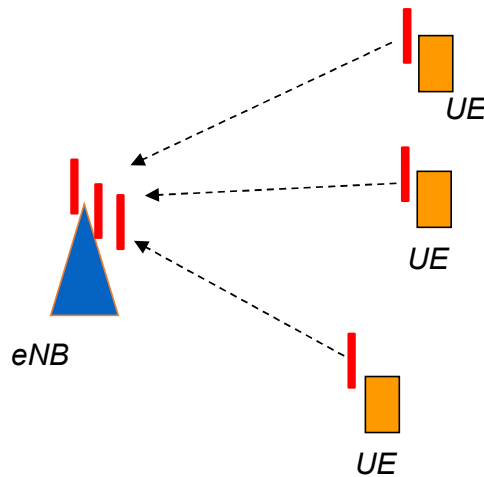
- MIMO
- Opportunistic communication
- Wideband Systems
 - ✓ CDMA, OFDMA

*System Gain:
pertains to point-to-point/single-cell performance*

Cooperation in MIMO system

- In general, cooperation in MIMO system aims to realize a single multiple-input multiple-output scheme by involving more than one transmitter and a receiver.
In other words, M terminals with N_T antennas each (for example with $N_T = 1$) cooperate for forming a unique «virtual» multiple antennas terminal with $M \times N_T$ antennas.
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Example 1



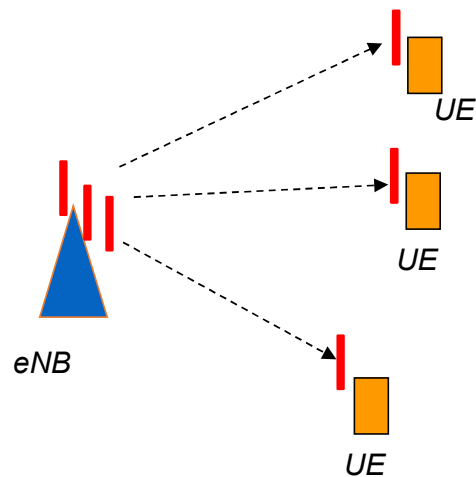
Uplink virtual MIMO: M terminals with a single antenna transmit simultaneously and in the same band to a base station with multiple antennas. The M terminals can be seen as a «virtual multiple antenna» with M elements and the entire system can be seen as a MIMO system (3×3 in this picture).

The advantage is clearly given by the increase of the throughput or capacity of a factor M (spatial multiplexing gain).

The disadvantage is given by the complexity of the system and by the need of **additional signaling for the coordination**. Of course the coordination is typically managed by the base station.

Cooperation in MIMO system

Example 2



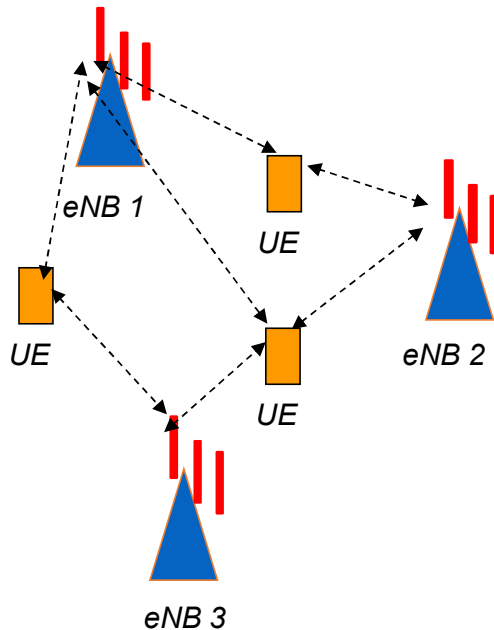
Downlink multi-user MIMO: the same concept of uplink virtual MIMO can be used in the downlink for exploiting the **spatial multiplexing gain** (a factor 3 also in this example).

Since here the decoding will be done at the terminals, which have less **computational capability**, *it is very important that the base station send signals properly encoded for helping the terminals in the detection of their interfered signal with reasonable complexity.*

Also, the terminals involved in virtual MIMO have to be selected carefully according to their channel conditions (CSI).

Cooperation in MIMO system

Example 3



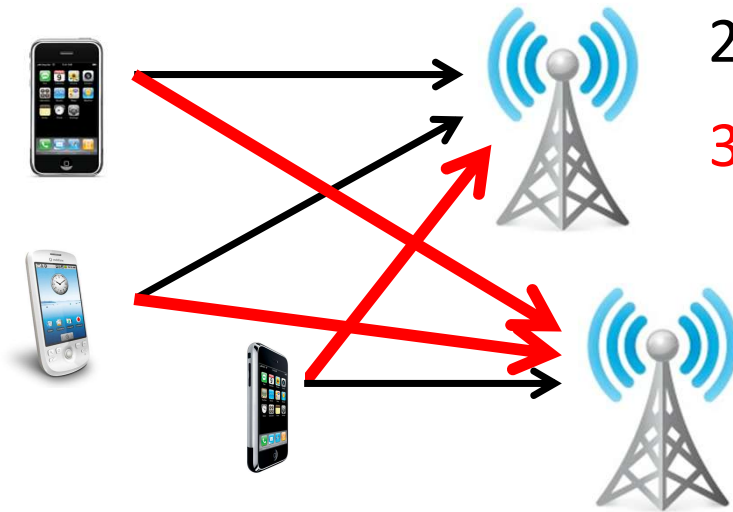
Network MIMO: the cooperation can be extended, in principle, to multiple base stations and multiple terminals, all creating an extended virtual MIMO system. We often denote this scheme, involving more BS, as Network or Distributed MIMO.

Of course complexity and challenges, due to the necessity of a strong coordination among many nodes, increase remarkably.

These configurations are also referred as examples of **Coordinated Multipoint (CoMP)** schemes.

A Current Key Challenge

As # of mobile & BS ↗⑤

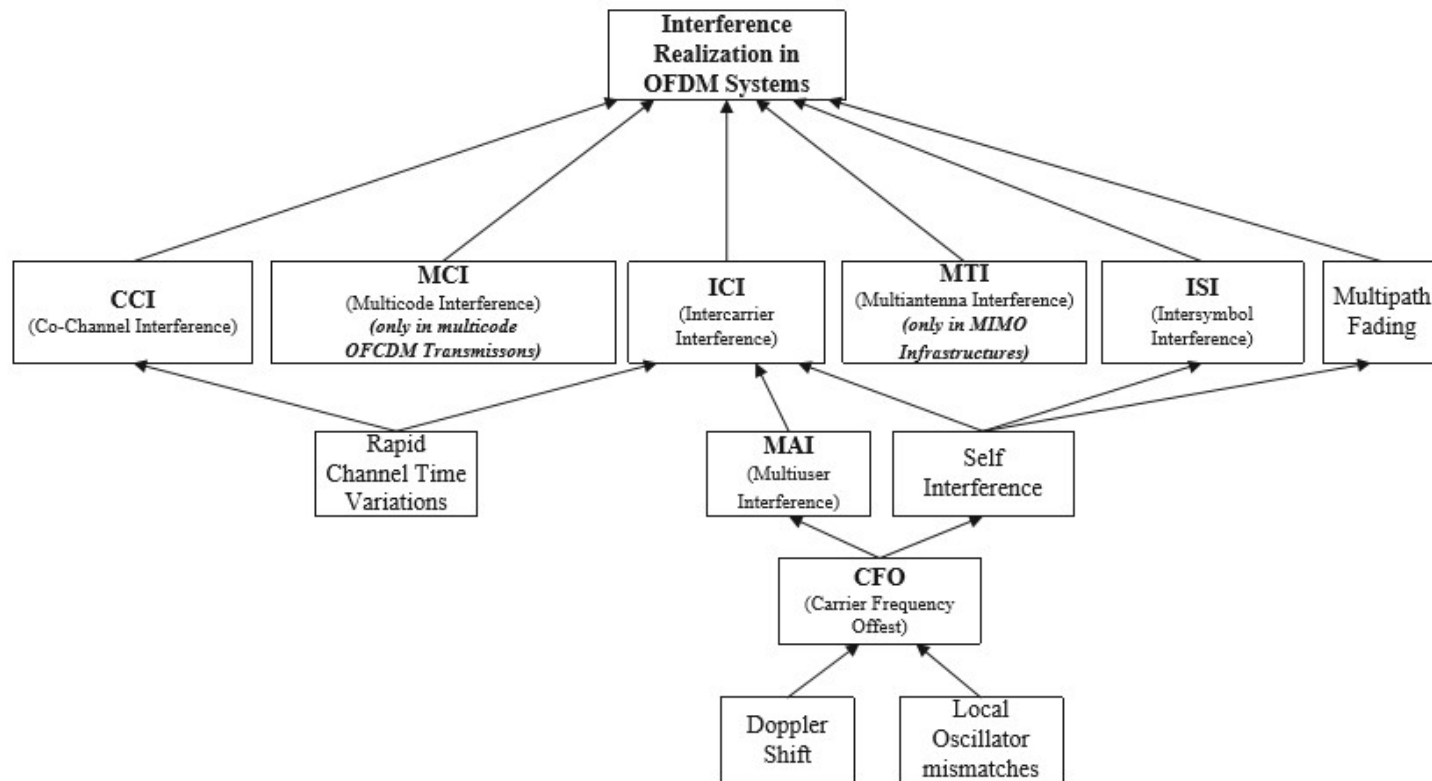


1. Fading ✓
2. Multiplexing ✓
3. **Interference**
Signal not intended to the receiving terminal (intercell)

Bad news: capacity of two-user **interference channel** remains open for 35+ years

*Performance of today's wireless system is majorly limited by **interference**!*

Representation of the major interference influences in OFDM systems



Interference: Major Bottleneck

- Narrowband system (GSM):
 - Orthogonalize it
 - Poor frequency reuse; shortage of resource
- Wideband system (CDMA, OFDMA):
 - Treat it as noise
 - Degrades if interferences get strong (cell-boundary users)
- Opportunities neglected in traditional paradigm...

Cooperation; **cooperative interference management**

Cooperative Interference Management

- For scenarios in which space limitations prevent the use of multiple antennas, IC can still be realized using cooperative methods.
- A recently studied concept is **interference forwarding**, where a user forwards the interference signal to the desired receiver.
- **By effectively increasing the interference level**, the weak interference regime is transformed into the strong interference regime at the desired receiver, thereby facilitating IC.
- Alternatively, the forwarded interference signal can be used to spatially cancel out interference from the payload signal, as in the case of multi-antenna receivers.
- The **interference correlation across the cooperating users is essential for interference forwarding to provide gains.**

Interference Cancellation in Cellular Networks (1/2)

- Today's cellular networks are **designed to operate at higher spectral efficiencies** and thus they must face the problem of interference.
- Although the capacity of cellular networks is not yet fully understood, **Shannon's formula $C = W \log_2(1 + \text{SINR})$** tells us that the rate of a single link can be increased by either choosing a **higher transmission bandwidth W or by lowering the SINR**.
- In view of spectrum scarcity, it is clear that any improvement on the interference control and management side is more than just favorable; and eventually shall bring us closer to the yet unknown capacity of cellular networks.

Interference Cancellation in Cellular Networks (2/2)

- Interference Cancellation (IC) techniques are expected to become a core component in downlink handheld receivers.
- Qualcomm, for example, in recent past has underlined the importance of IC receivers for addressing the thousand-times spectral efficiency challenge.
- Such advanced receivers are usually equipped with multiple-antennas, which use the **additional spatial degrees-of-freedom to subtract interference without decoding it, a concept known as spatial IC.**

- Cooperative Communication (CC)
 - CC Methods
 - Performance Evaluation

Introduction (1/2)

- **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.

Introduction (2/2)

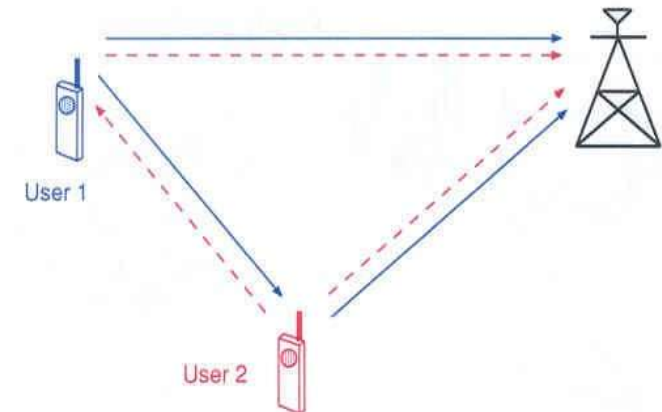
- **Motivation** for ad-hoc/cellular networks with cooperative transmission
 - Wireless **links are unreliable** due to multi-path propagation
 - **Spatial diversity is bandwidth efficient** to combat fading
 - Spatial diversity is difficult to achieve due to processing complexity, power consumption, ...
- **Solution:** Cooperative Transmission
 - Allow users to share their antennas cooperatively to assist each other for successful reception
- **Advantages** of cooperative transmission: Virtual antenna array
 - Boosted reception **reliability**
 - Achieved higher **data rates**
 - **Bandwidth** efficient and increased **coverage**

“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.

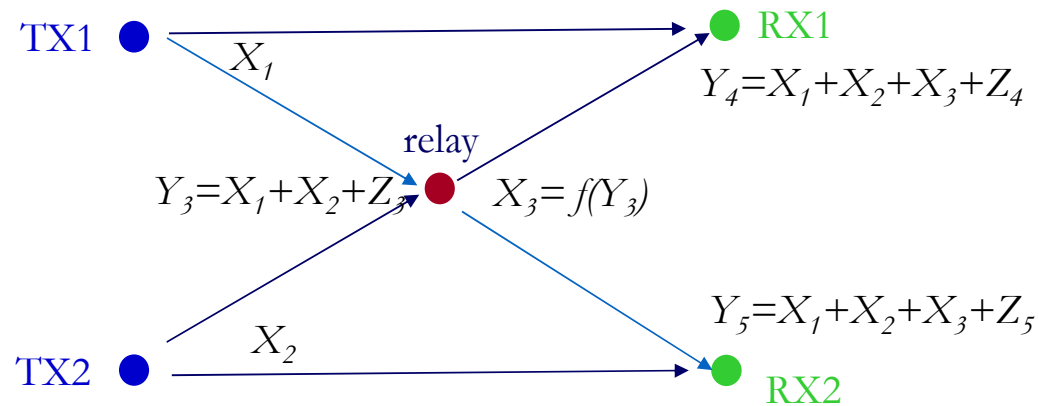
Cellular Cooperative Communication Systems

- In CCCS each wireless user is assumed to transmit data as well as act 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.

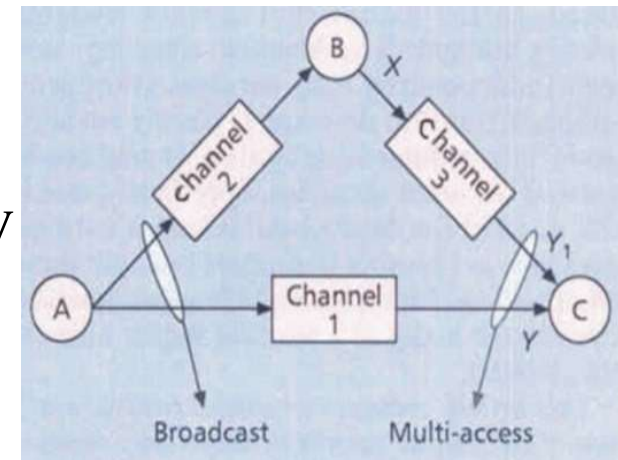
General Relay Strategies



- Can forward message and/or interference
 - **Relay can forward all or part of the messages**
 - Much room for innovation
 - **Relay can forward interference**
 - To help subtract it out

Relay Channels

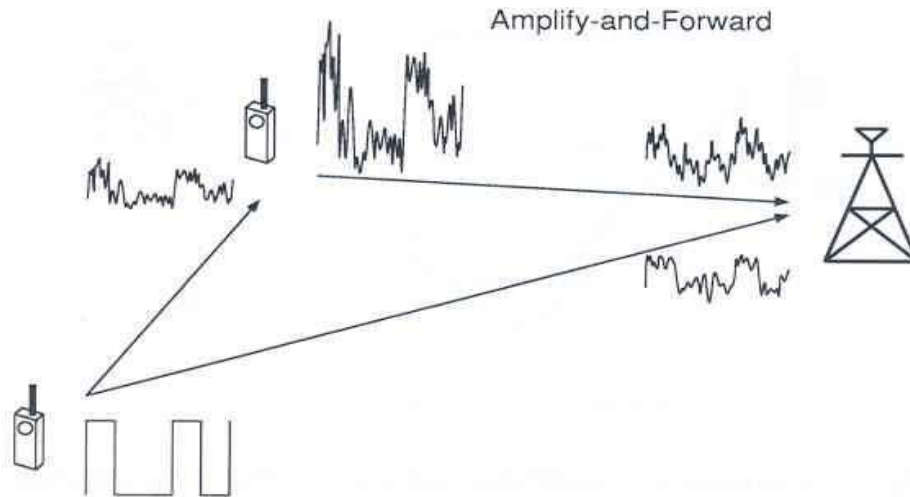
- A **relay channel** is a **three-terminal network** consisting of a **source**, **relay** and **destination**.
- The **source broadcast** to both relay and destination.
- Also, the **relay forward** the received message to the destination.
- Relay systems can achieve **distributed spatial diversity** in wireless networks of single-antenna devices transmitting over fading channels.
- Relaying can be used to form a **virtual antenna array**.
- The strategy of cooperative diversity can be exploited by source and relay.



Cooperative Communication Methods

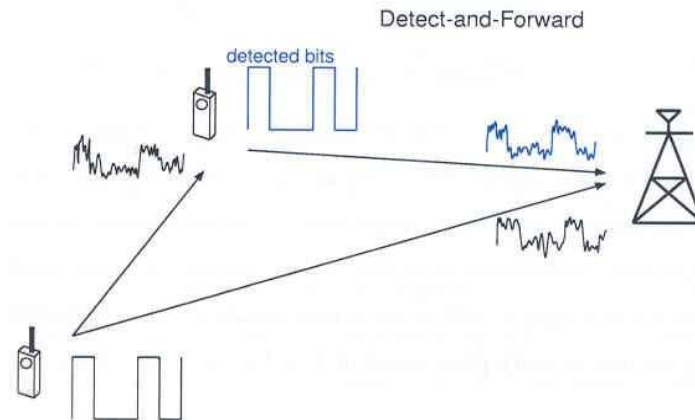
Amplify and Forward Method

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



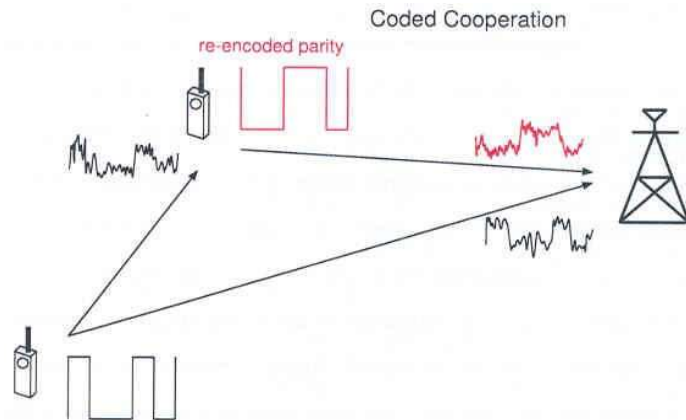
Detect/Decode and Forward Method

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



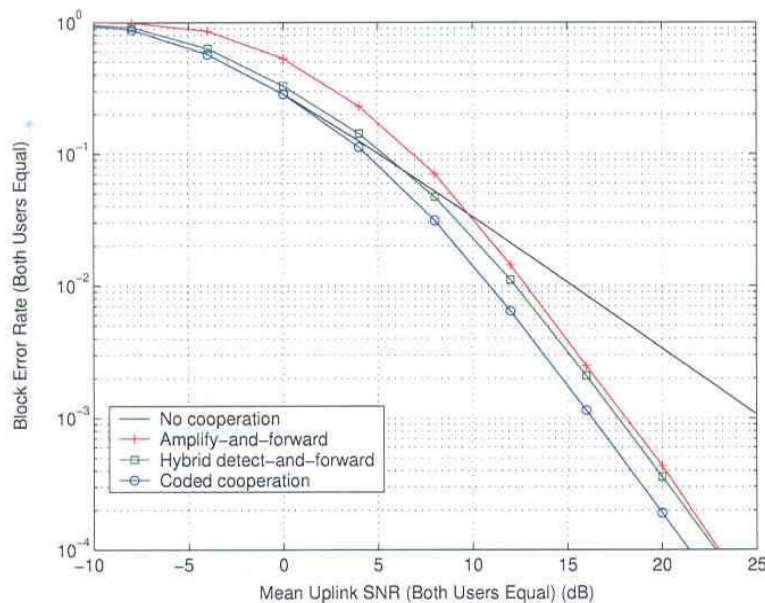
Coded Cooperation Method

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



Performance Evaluation: scenario #1

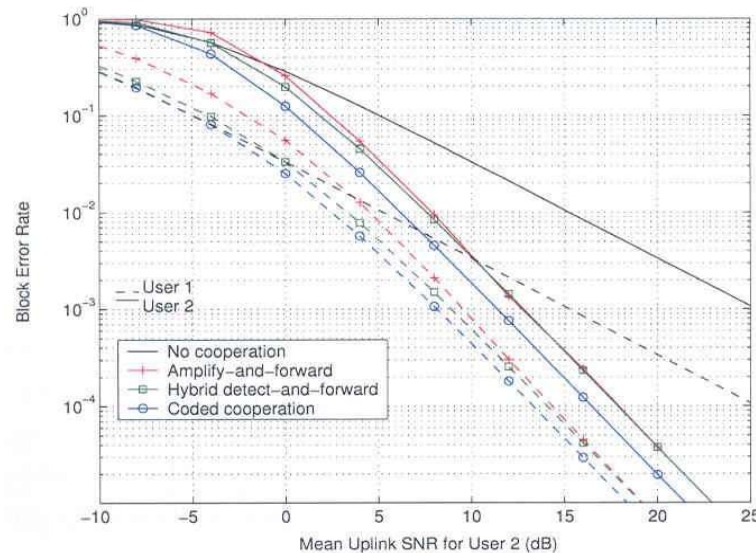
- The user channels is the same in uplink (to the base station).
- The inter-user channel is 10 dB below that of the uplink channel.



- 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:

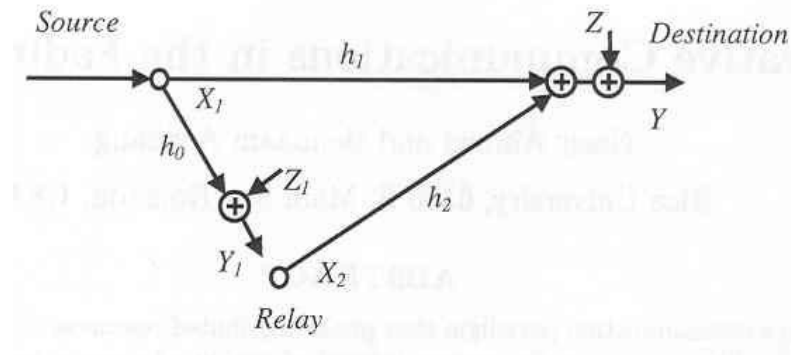
$$h_i \text{ where } i \in \{0, 1, 2\}$$

- 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:

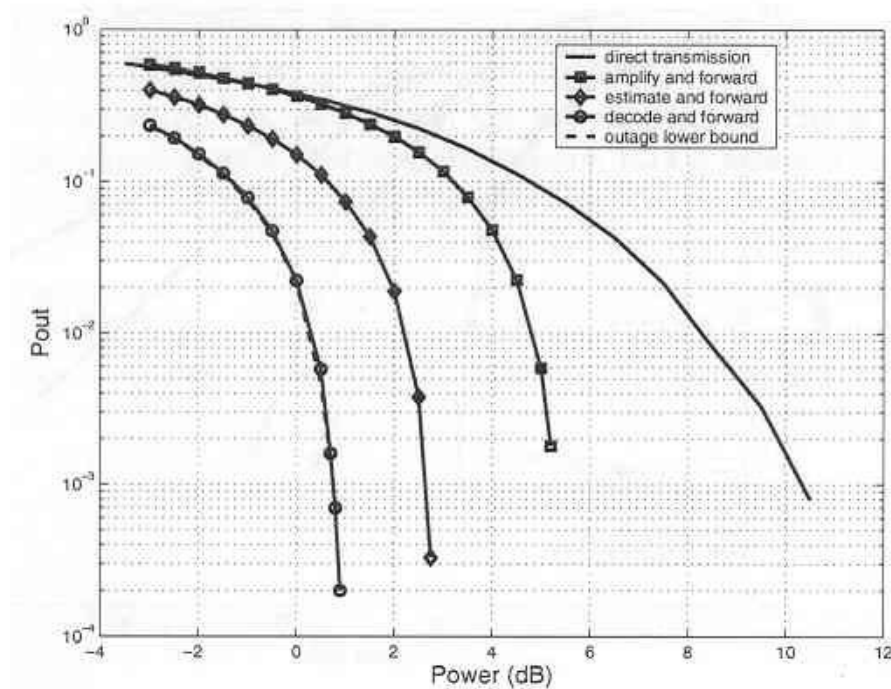
$$\gamma_0 = |h_0|^2$$

$$\gamma_1 = |h_1|^2$$

$$\gamma_2 = |h_2|^2$$



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.

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