IEE2650: Cellular Communication Technologies

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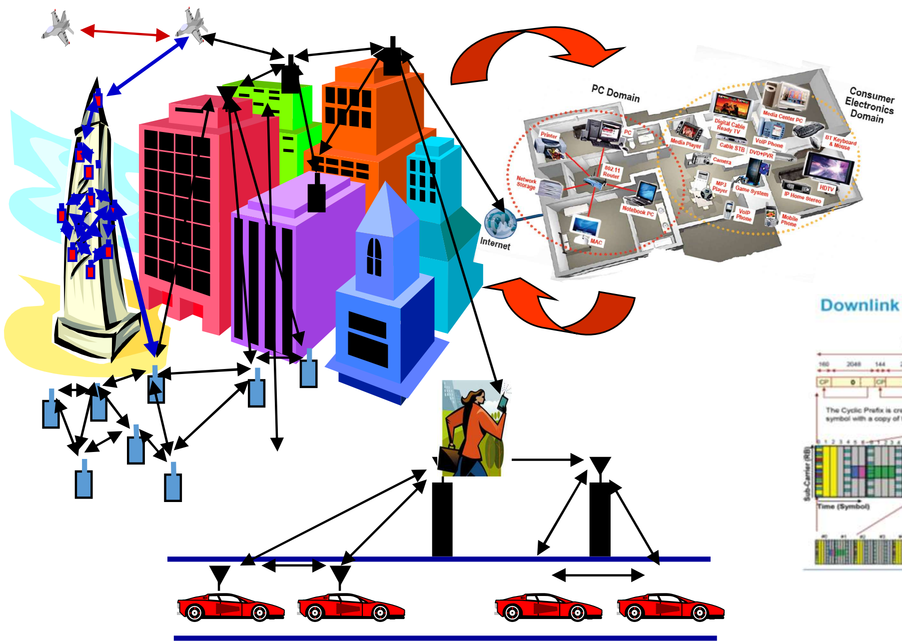
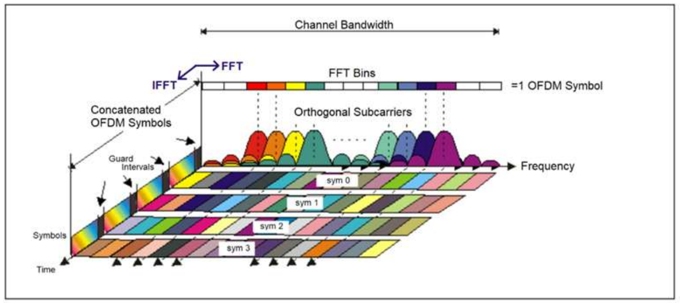
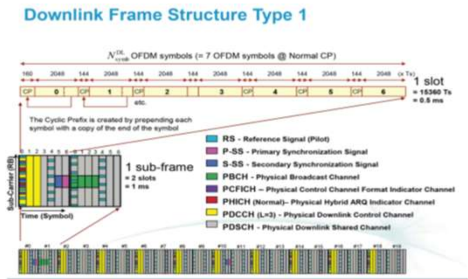
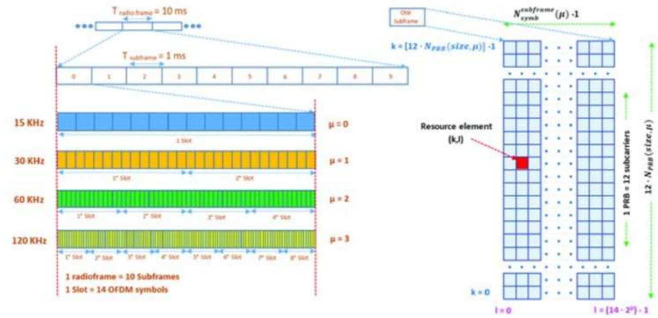




Frequency-Time Representative of an OFDM signal





CDMA Vs OFDM

Attribute	CDMA	OFDM
Transmission bandwidth	Full system bandwidth	Variable up to full system bandwidth
Frequency-selective scheduling	Not possible	A key advantage of OFDM although it requires accurate real-time feedback of channel conditions from receiver to transmitter
Symbol period	Very short—inverse of the system bandwidth	Very long—defined by subcarrier spacing and independent of system bandwidth
Equalization	Difficult above 5 MHz	Easy for any bandwidth due to signal representation in the frequency domain
Resistance to multipath	Difficult above 5 MHz	Completely free of multipath distortion up to the CP length
Suitability for MIMO	Requires significant computing power due to signal being defined in the time domain	Ideal for MIMO due to signal representation in the frequency domain and possibility of narrowband allocation to follow real-time variations in the channel
Sensitivity to frequency domain distortion and interference	Averaged across the channel by the spreading process	Vulnerable to narrow-band distortion and interference
Separation of users	Scrambling and orthogonal spreading codes	Frequency and time although scrambling and spreading can be added as well

Comparison

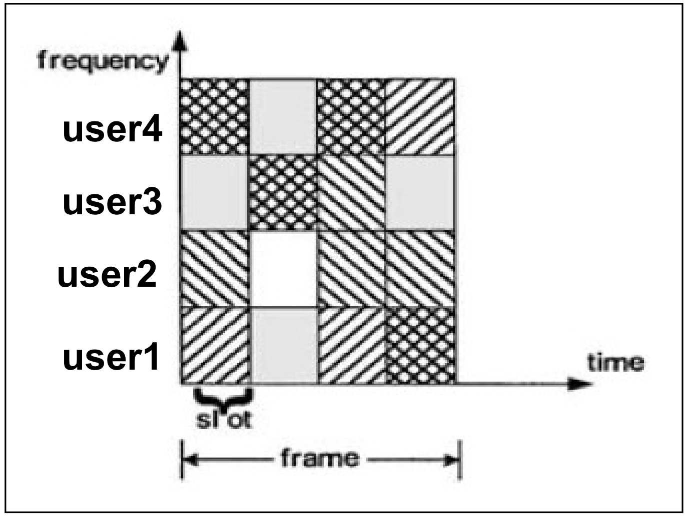
- **Frequency division multiple access** or **FDMA** is a channel access method used in multiple-access protocols as a channelization protocol.
- **FDMA** gives users an individual allocation of one or several frequency bands, or channels. ... **FDMA** requires high-performing filters in the radio hardware, in contrast to **TDMA and CDMA**

Multiple access technology – Downlink/Uplink

- Downlink and uplink transmission in 4G and 5G are based on the use of multiple access technologies, specifically:
  - orthogonal frequency division multiple access (OFDMA) for the downlink
  - single-carrier frequency division multiple access (SC-FDMA) for the uplink

OFDM-FDMA (OFDMA)

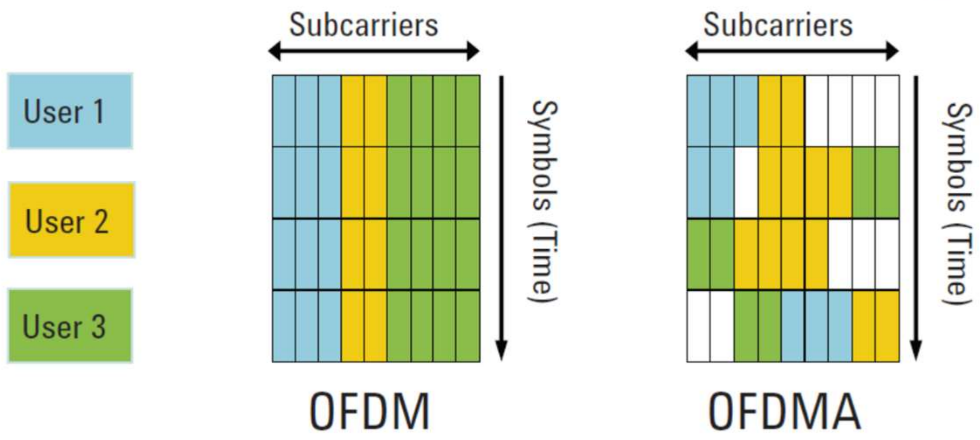
- Each terminal occupies a subset of sub-carriers
- Subset is called an OFDMA traffic channel
- Each traffic channel is assigned exclusively to one user at any time



- *The IEEE 802.16e/ WiMax use OFDMA as Multiple access technique*
  - *Bandwidth options 1.25, 5, 10, or 20 MHz*
  - *Entire bandwidth divided into 128, 512, 1024 or 2048 sub carriers*
  - *20 MHz bandwidth with 2048 sub carriers has 9.8 KHz spacing between sub carriers*

OFDM Vs OFDMA

- With standard OFDM, very narrow UE-specific transmissions can suffer from narrowband fading and interference.
- That is why for the downlink 3GPP chose OFDMA, which incorporates elements of time division multiple access (TDMA).
- OFDMA allows subsets of the subcarriers to be allocated dynamically among the different users on the channel, as shown below.
  - The result is a more robust system with increased capacity.
  - This is due to the trunking efficiency of multiplexing low rate users and the ability to schedule users by frequency, which provides resistance to frequency-selective fading.

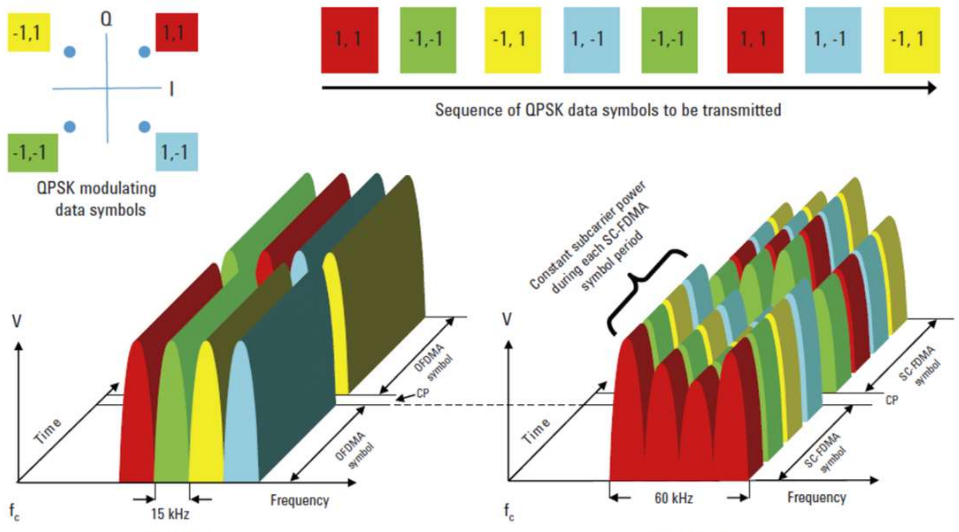


Multi Access Technology In Uplink

- The high peak-to-average ratio (PAR) associated with OFDM led 3GPP to look for a different transmission scheme for the LTE uplink.
- SC-FDMA was chosen because it combines the low PAR techniques of single-carrier transmission systems, such as GSM and CDMA, with the multi-path resistance and flexible frequency allocation of OFDMA.
- A brief description is as follows:
  - data symbols in the time domain are converted to the frequency domain using a discrete Fourier transform (DFT);
  - then in the frequency domain they are mapped to the desired location in the overall channel bandwidth
  - before being converted back to the time domain using an inverse FFT (IFFT). Finally, the CP is inserted. Because SC-FDMA uses this technique, it is sometimes called discrete Fourier transform spread OFDM or (DFT-SOFDM)

OFDMA (Multi-Carrier vs Single Carrier)

- For clarity this example uses only four (M) subcarriers over two symbol periods with the payload data represented by quadrature phase shift keying (QPSK) modulation.
- On the left side of Figure, M adjacent 15 kHz subcarriers—already positioned at the desired place in the channel bandwidth—each modulated for the OFDMA symbol period of 66.7 µs by one QPSK data symbol. In this four subcarrier example, four symbols are taken in parallel.
- After one OFDMA symbol period has elapsed, the CP is inserted and the next four symbols are transmitted in parallel.
    - For visual clarity, the CP is shown as a gap; however, it is actually filled with a copy of the end of the next symbol.
    - To create the transmitted signal, an IFFT is performed on each subcarrier to create M time-domain signals.
    - These in turn are vector-summed to create the final time-domain waveform used for transmission



OFDMA
Data symbols occupy 15 kHz for one OFDMA symbol period

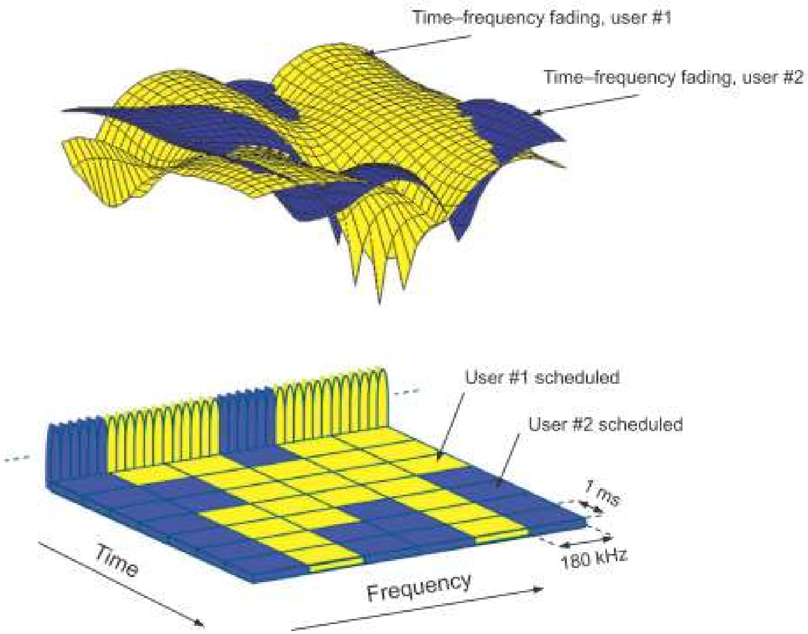
SC-FDMA
Data symbols occupy M*15 kHz for 1/M SC-FDMA symbol periods

OFDMA (Multi-Carrier vs Single Carrier)

- The most obvious difference between the two schemes is that OFDMA transmits the four QPSK data symbols in parallel, one per subcarrier, while SC-FDMA transmits the four QPSK data symbols in series at four times the rate, with each data symbol occupying M x 15 kHz
- Note that OFDMA and SC-FDMA symbol lengths are the same at 66.7 μs; however, the SC-FDMA symbol contains M "sub-symbols" that represent the modulating data.
- It is the parallel transmission of multiple symbols that creates the undesirable high PAR of OFDMA. By transmitting the M data symbols in series at M times the rate, the SC-FDMA occupied bandwidth is the same as multi-carrier OFDMA but, crucially, the PAR is the same as that used for the original data symbols.

Channel dependent Scheduling and Rate adaptation

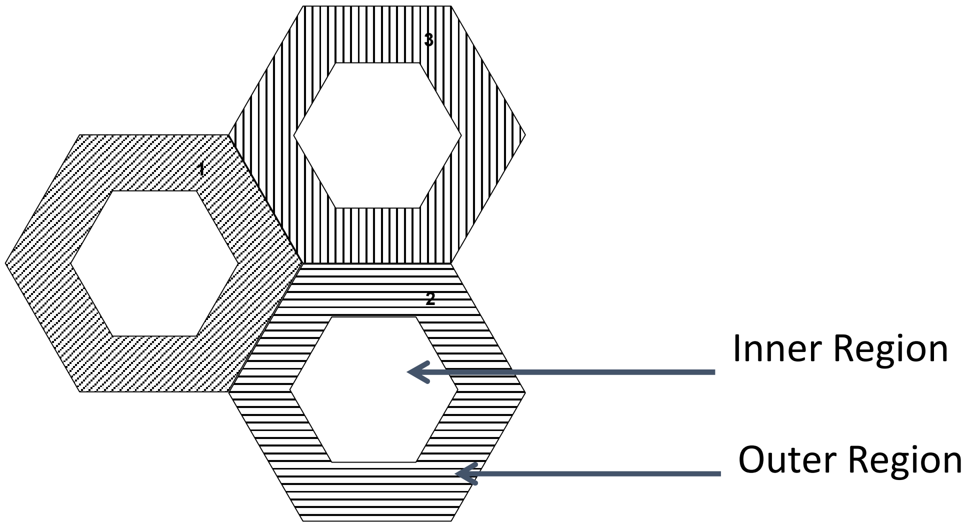
- Depending on the channel conditions, time – frequency resources are allocated to users by the scheduler
- Scheduling decisions taken once every **1ms** with frequency domain granularity of **180 kHz**.
- Scheduler allocates resources depending on the **Channel State Information**(CSI) provided by the UE



Inter Cell interference Coordination (ICIC)

- In 4G/5G, Frequency Reuse Factor equals to one (full spectrum availability at each Cell)
- This leads to high performance degradation specially the Users in cell edge.
- ICIC reduce ICI at cell edge applying certain restrictions on resource assignment.

Adaptive Fractional Frequency Reuse Coordination:



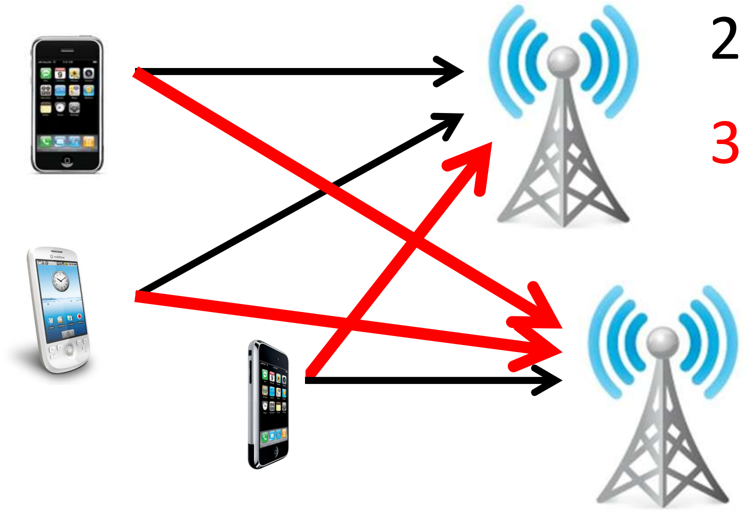
Outline

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

- Summary

A Current Key Challenge

As # of mobile & BS ↗⑤



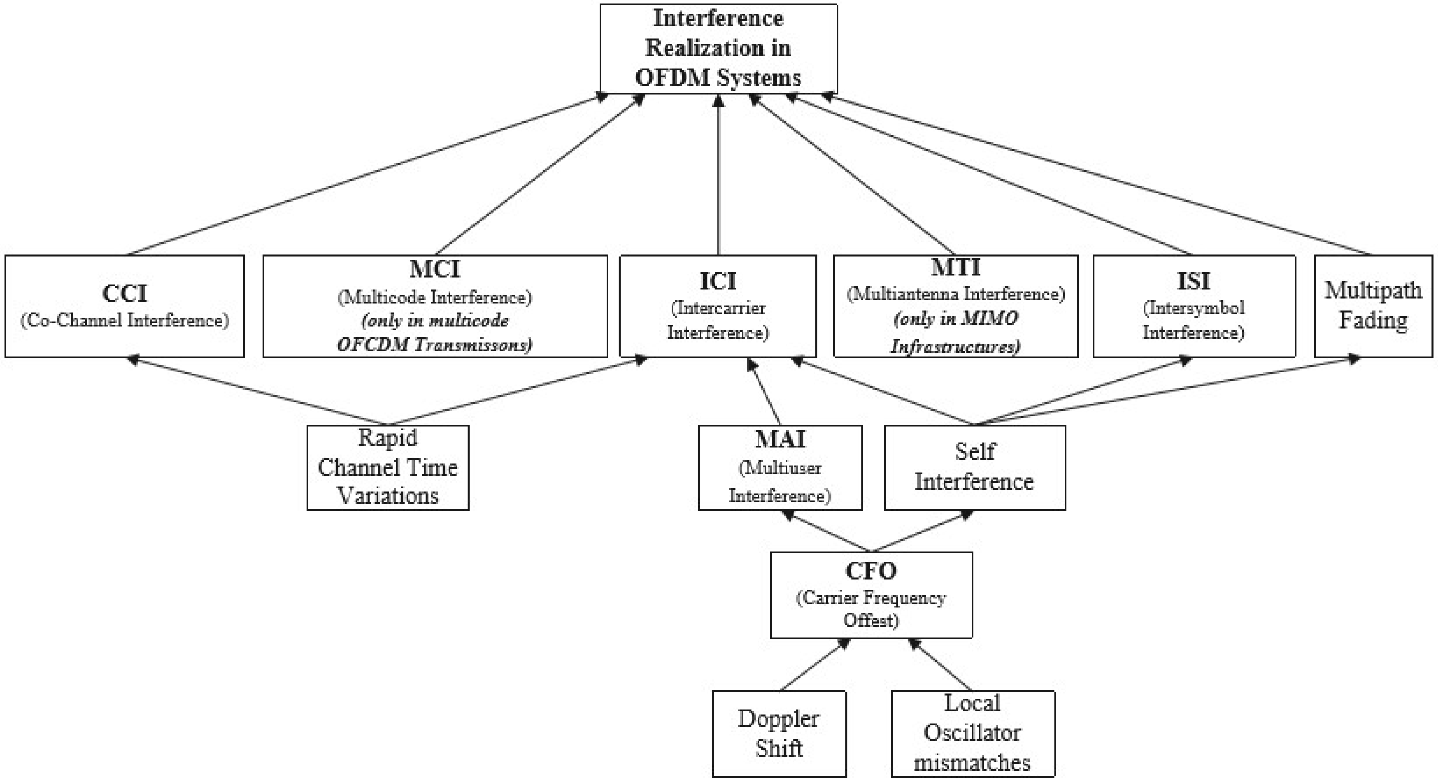
1. Fading ✓
2. Multiplexing ✓
3. **Interference**

<u>Signal not intended to the receiving terminal (intercell)</u>

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 = Wlog2(1 + 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)

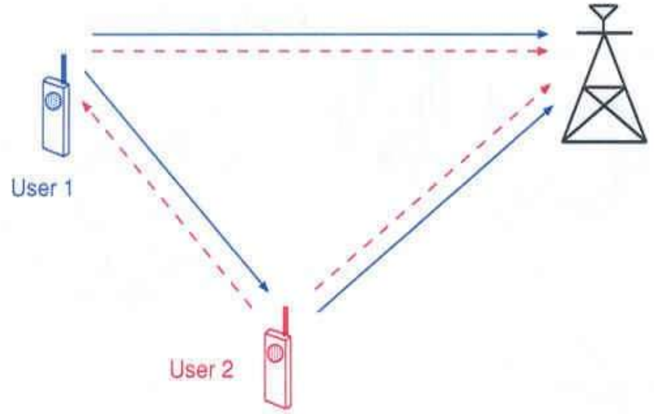
- **Motivation** for ad-hoc/cellular networks with cooperative transmission
  - Wireless links are unreliable due to multi-path propagation
  - Spatial diversity is bandwidth efficient to combat fading
  - Spatial diversity is difficult to achieve due to processing complexity, power consumption, ...
- **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.

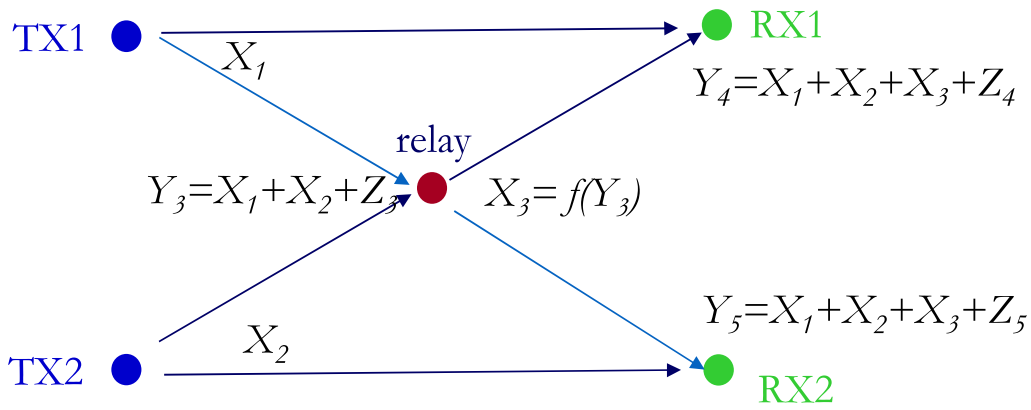
Cellular Cooperative Communication Systems

- 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.

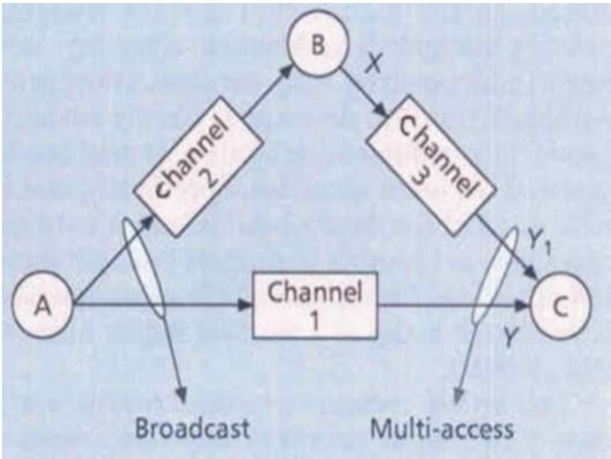
General Relay Strategies



- 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

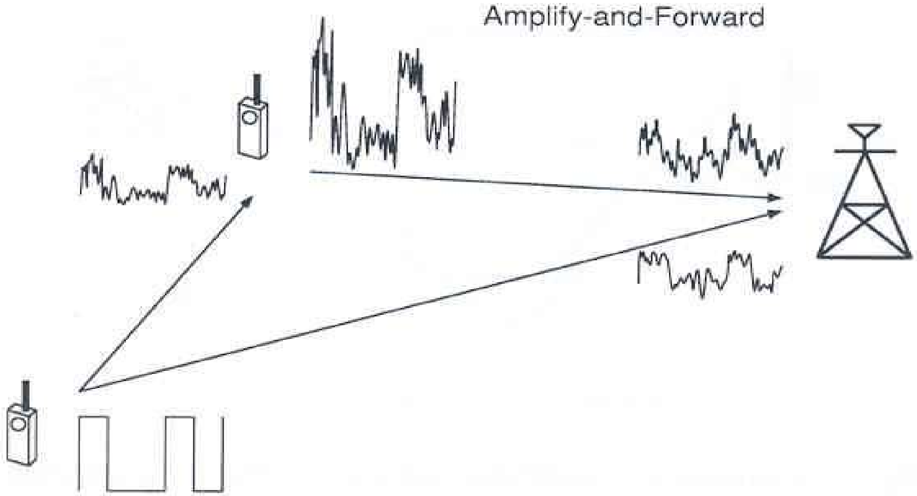
• A relay channel is a three-terminal network consisting of and a source, rely and destination.
• The source broadcast to both relay and destination.
• Also, the relay forward the received message to the destination.
• Relay systems can achieve distributed spatial diversity in wireless networks of single-antenna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

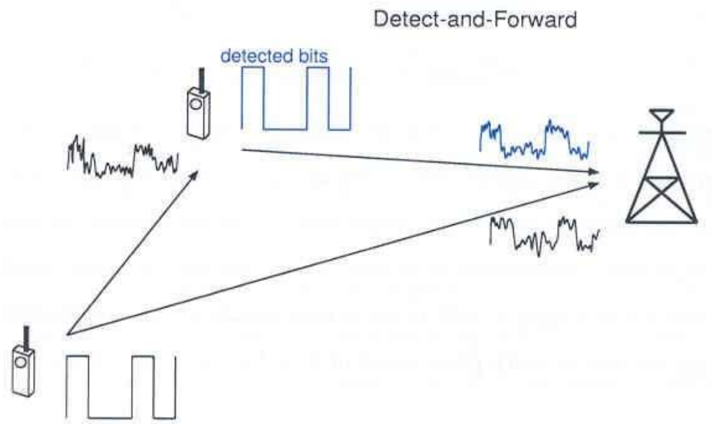
Amplify and Forward Method

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



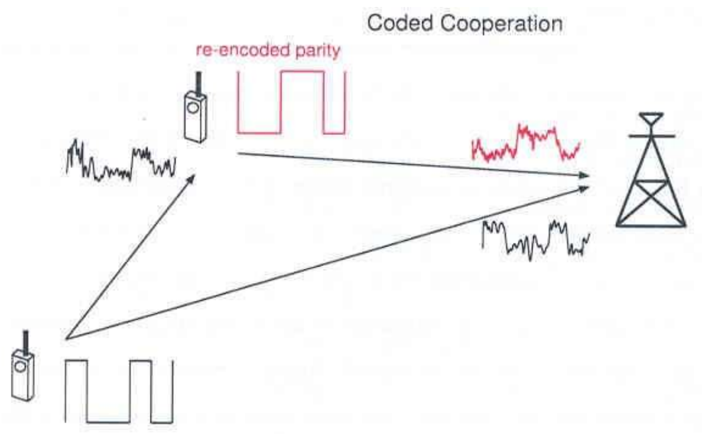
Detect/Decode and Forward Method

- 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



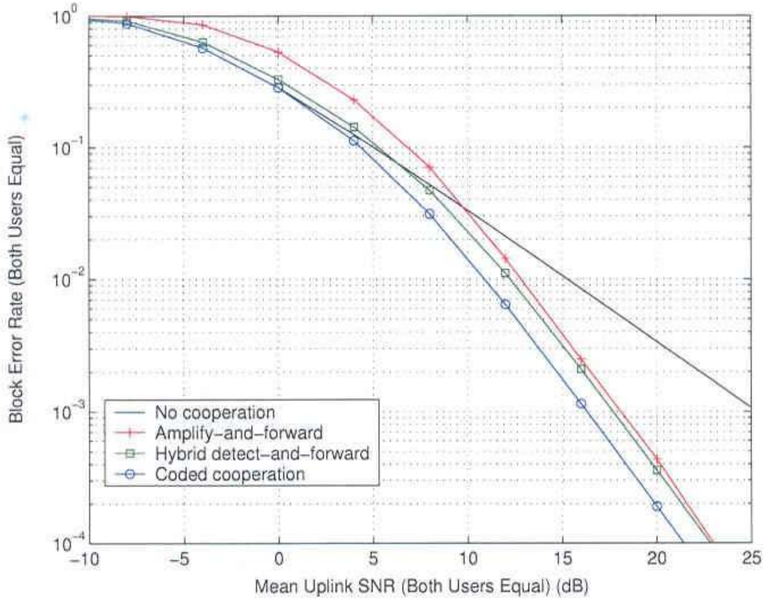
Coded Cooperation Method

- 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

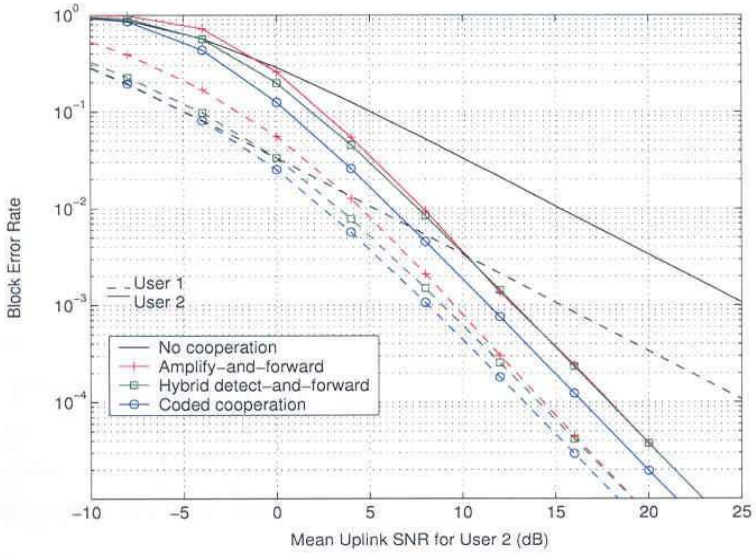
- The user channels is the same in uplink (to the base station).
- The inter-user channel is 10 dB below that of the uplink channel.



- 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.

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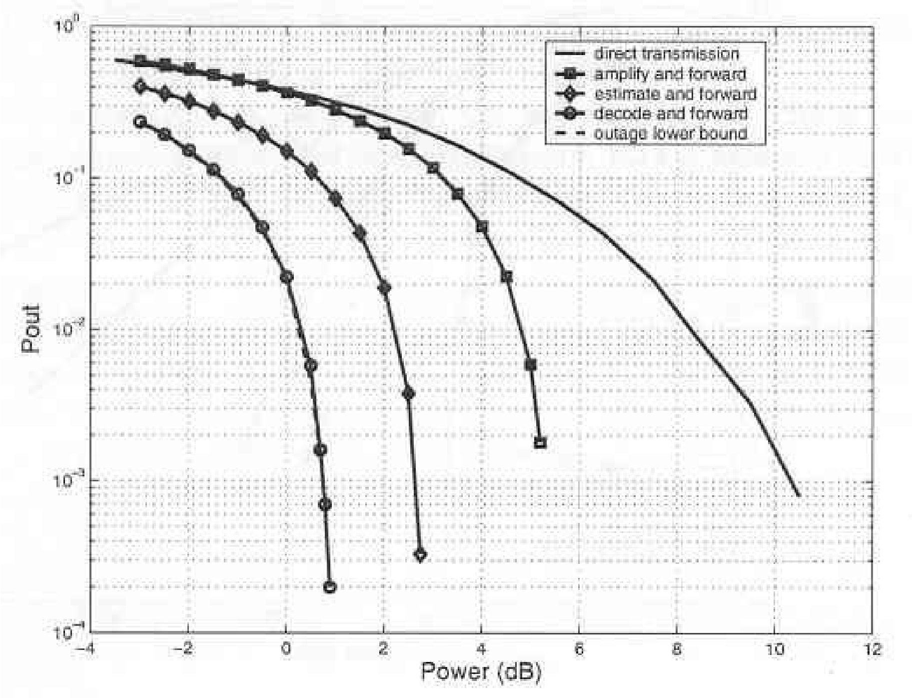
Power Control with Perfect Feedback



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.