



**WIRELESS WORLD**

R E S E A R C H F O R U M

## **WG4 White Paper**

# **Duplexing, Resource Allocation and Inter-cell Coordination: Design Recommendations for Next Generation Systems**

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# Outline

- ❑ Motivation
- ❑ Scope of the white paper
- ❑ Critical issues for the design of next generation systems:
  - ⇒ Duplexing
  - ⇒ Resource allocation
  - ⇒ Interference management and inter-cell coordination
- ❑ Challenges and further research topics



# Motivation

- ❑ Coexistence of different access technologies
- ❑ Hierarchical cellular deployment
- ❑ Wide variety of data services
- ❑ Requirements for
  - ⇒ transparent operation across different technologies
  - ⇒ adaptivity to varying network conditions and
  - ⇒ mobility
- ❑ Quality of Service (QoS) constraints

*introduce a number of challenges  
in the design of future generation systems and  
the specification of new air interfaces*



# Scope of the White Paper

- ❑ Identify the critical issues associated with the design of NG systems
- ❑ Investigate existing and propose new approaches
- ❑ Evaluate the relative merits of different approaches
- ❑ Recommend possible solutions, and
- ❑ Identify new challenges and further research topics

# Critical Issues for Next Generation Systems Design

Challenges in the design of future generation systems and the specification of a new air interface:

- ⇒ **efficiency and flexibility in the utilization of spectrum**
- ⇒ **dynamic resource allocation and exploitation of the multi-user diversity and**
- ⇒ **reconfigurable interference management and inter-cell coordination**



# Duplexing

Either *time or frequency separation* has been traditionally considered with

- ❑ **Time Division Duplex** intended for low mobility micro-cellular scenarios, while
- ❑ **Frequency Division Duplex** was preferred in high mobility wide-area deployments.

# Paired vs. Unpaired Spectrum and Link Asymmetry



- ❑ If unpaired spectrum is allocated, FDD cannot be used, whereas FDD and TDD options are possible when paired spectrum is allocated.
- ❑ **TDD enables asymmetric allocation** of degrees of freedom between uplink and downlink although not dynamically on a cell-by-cell basis, but rather on a system-wide basis, in order to avoid catastrophic interference scenarios.
- ❑ In order to address the **interference problem in TDD**, the following issues need further investigation:
  - ⇒ System synchronization (use the same switching point between UL and DL)
  - ⇒ Devising efficient and complex radio resource allocation algorithms



# Synchronicity and Guards

- ❑ In **FDD** uplink and downlink are **orthogonal in frequency**.
- ❑ In **TDD**, **temporal orthogonality** is only possible if cells have synchronized uplink and downlink plus guard times to account for propagation delays.
- ❑ The **overhead** represented by the **guard times** depends on the duplex time. However, duplex time needs to be kept short, in order to minimize physical-layer contribution to latency and ensure channel reciprocity.

# Link Reciprocity and Link Continuity

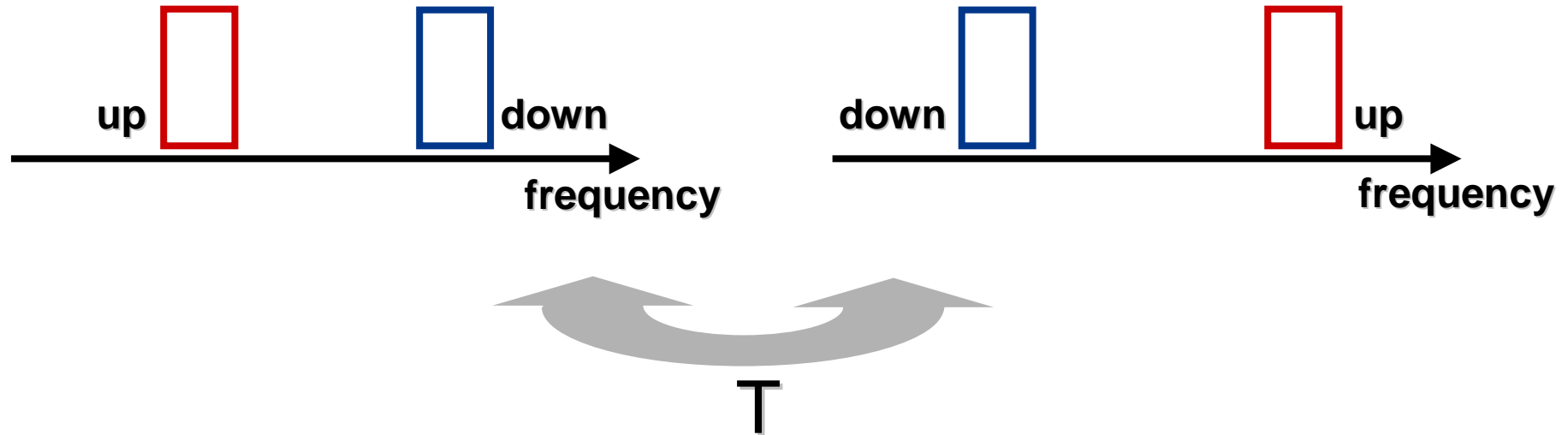
- ❑ **Link reciprocity** is regarded as the most attractive feature of **TDD**, while
- ❑ The **lack of reciprocity in FDD** makes these schemes dependant on the relay of Channel State Information through feedback.
- ❑ **Lack of link continuity in TDD** introduces latency, which propagates to the upper layers causing bottlenecks.



# Terminal Complexity

- ❑ In terms of **baseband processing complexity**, differences between FDD and TDD are small.
- ❑ The **SoC architecture and implementation** is simpler in TDD, as the burst characteristic allows for simplifications in the memory management and the scheduling of different building blocks.
- ❑ In terms of **RF complexity**, FDD requires a duplexer, whereas TDD has more relaxed constraints on the signal isolation between TX and RX chain.

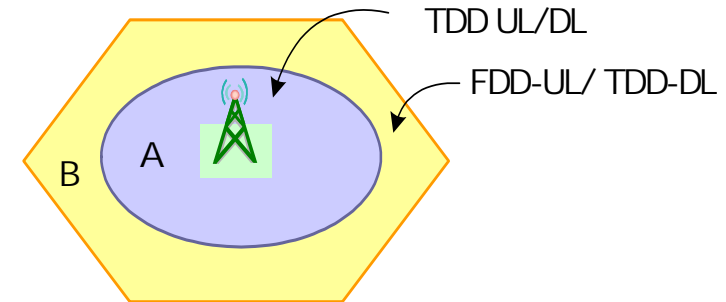
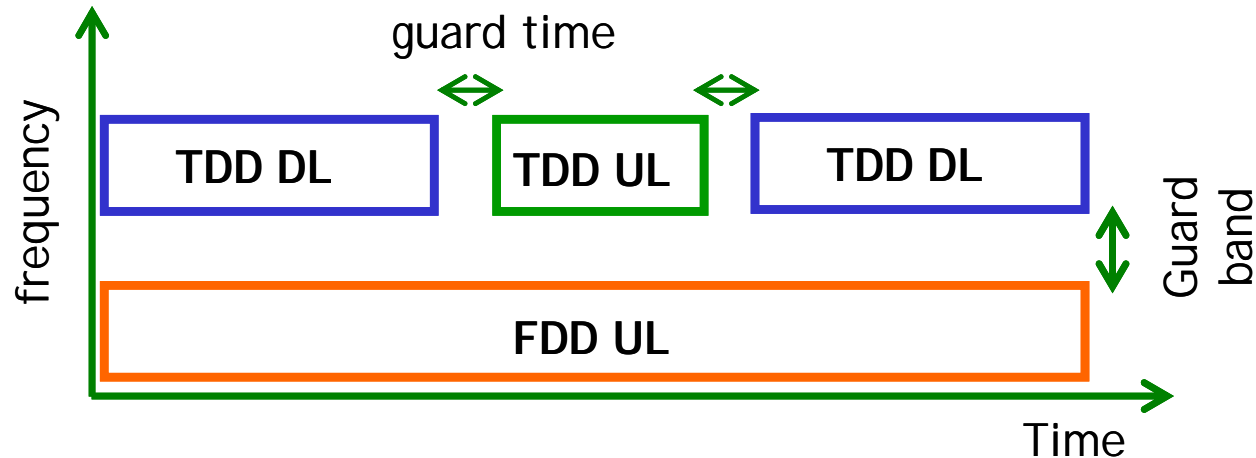
# Band Switching Duplexing



**Given paired spectrum blocks, instead of reserving a block for uplink and the other for downlink, alternate their use every  $T$  sec.**

- ❑ Reciprocity is achieved and synchronicity and guard times are as in TDD.
- ❑ Band Switching is both TDD and FDD: every unit of bandwidth is used, half of the time for uplink and half of the time for downlink and at every point in time, half the spectrum is used for uplink and half for downlink.

# Hybrid Division Duplexing



- ❑ Downlink communication is available in TDD DL, while uplink traffic can be sent in either TDD UL or FDD UL bands.
- ❑ The cell area is divided into two zones: terminals in the inner zone send uplink signals in TDD UL while those in the outer zone send signals in FDD UL.
- ❑ The BS can direct the terminal to send uplink data in either TDD UL or FDD UL based on location.
- ❑ HDD combines the advantages of TDD and FDD by providing high data rates and asymmetric service with nomadic users in TDD and reliable service to high-speed mobile users in FDD.

# Resource allocation within the context of OFDM



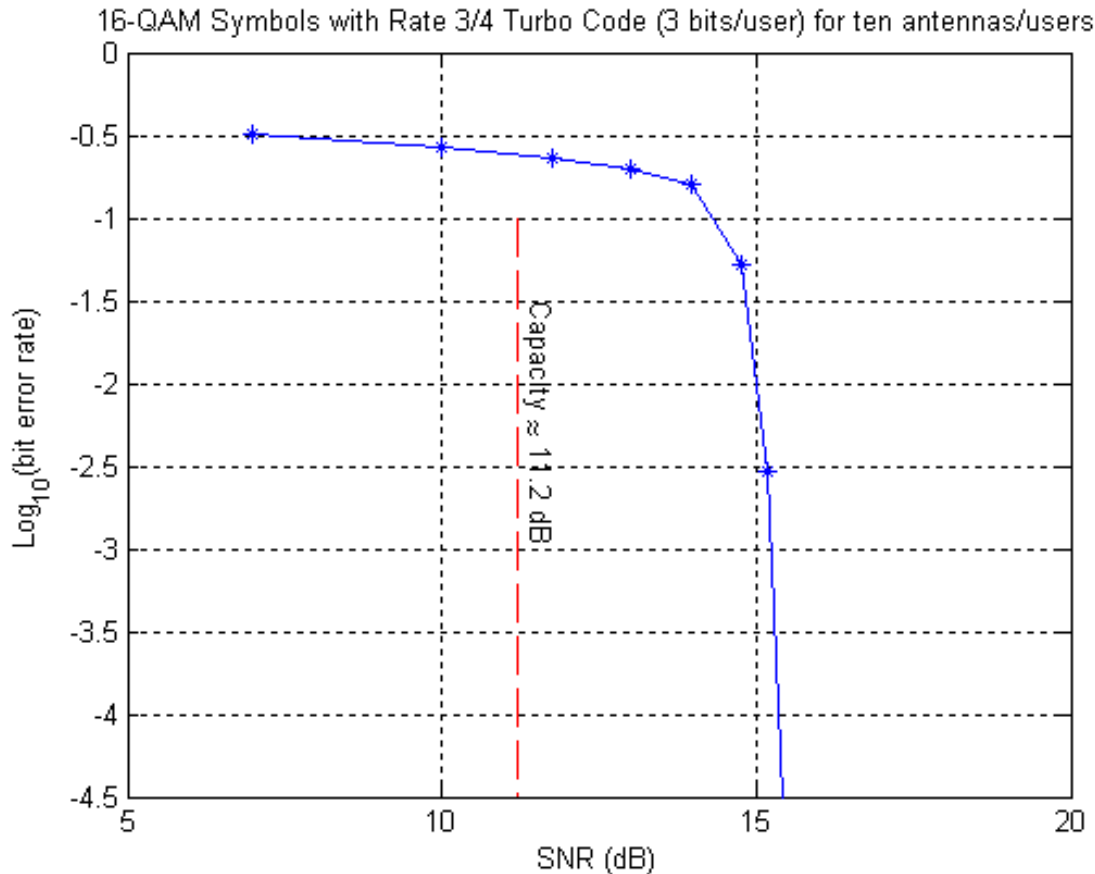
- ❑ Scheduling multiple users in a single OFDM symbol by assigning different tones to different users with optimal power allocation across the tones has been shown to offer performance enhancements.
- ❑ Overhead signaling associated with the link quality on different sub-carriers can be addressed by
  - ⇒ dividing the broadband channel into appropriate sub-bands based on the observed frequency selective fading;
  - ⇒ measuring at the terminal the SIR conditions for each sub-band;
  - ⇒ determining at the terminal and signaling to the transmitter the appropriate sub-bands to use and their optimum link modes,



# Resource allocation within the cell and multi-user scheduling

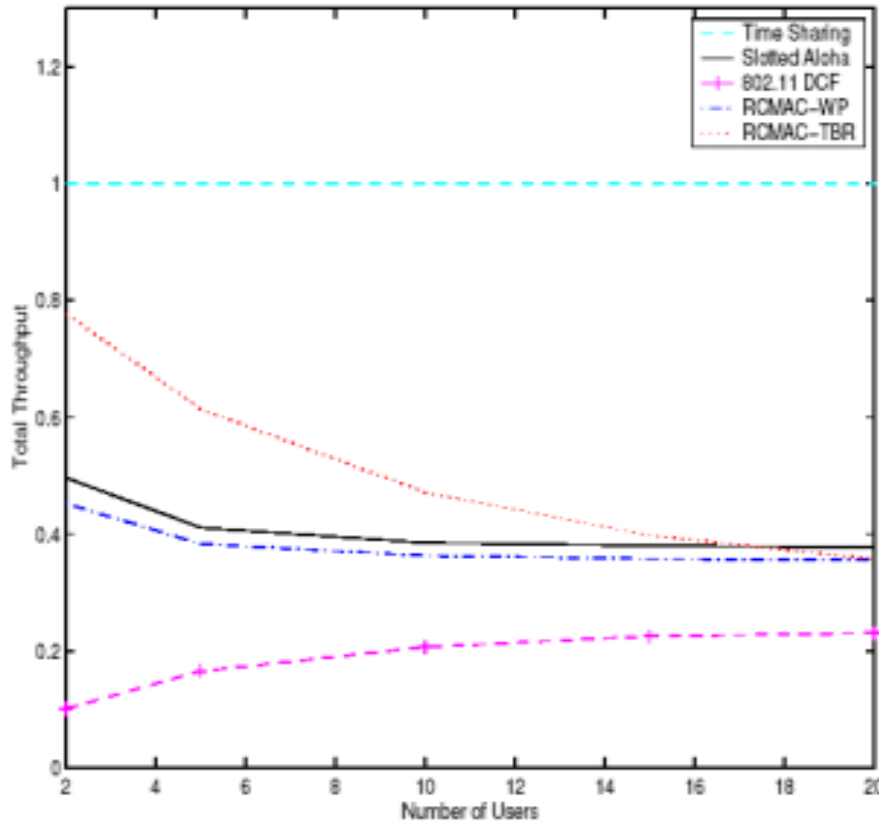
- ❑ Sphere encoded multiple messaging
- ❑ Distributed scheduling with service differentiation
- ❑ Jointly Opportunistic Beamforming and Scheduling
- ❑ Cross-Layer and QoS considerations

# Sphere-Encoded Multiple Messaging



- Transmission scheme achieving **near capacity** performance in multi-antenna multi-user scenario.
- Basic idea: to control the interference seen by all users based on the introduction of a **vector perturbation**.
- The vector perturbation places the largest signal components along the smallest singular values of the inverse channel, and vice versa.

# Distributed Scheduling in Wireless Data Networks with Service Differentiation



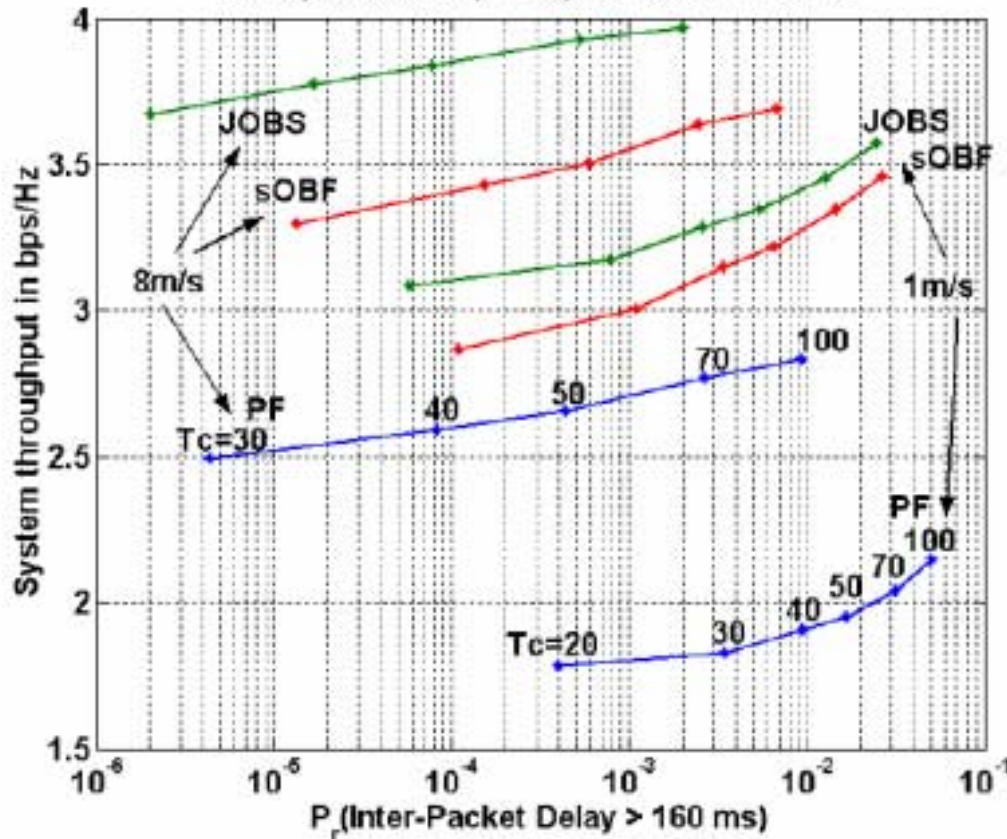
- ❑ Existing approaches, such as Slotted Aloha and IEEE 802.11 DCF (Distributed Coordination Function) fail to provide differentiated service to users.
- ❑ In Regulated Contention Medium Access Control (RCMAC), the user's access probability dynamically varies with a **differentiation function**.
- ❑ The user's **dynamic weight** is taken into account as function of the user's priority, queue length or delay of packets.

Weight Proportional (WP)  
Threshold Based Regulation (TBR).

# Jointly Opportunistic BF and Scheduling

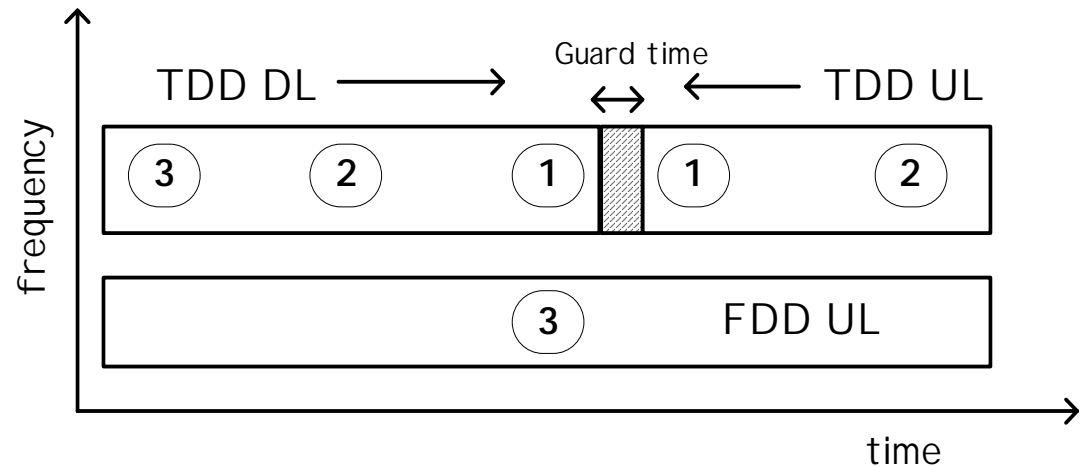
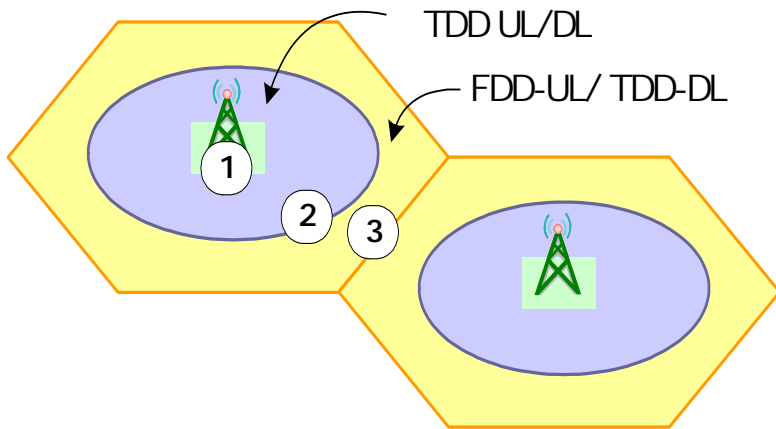
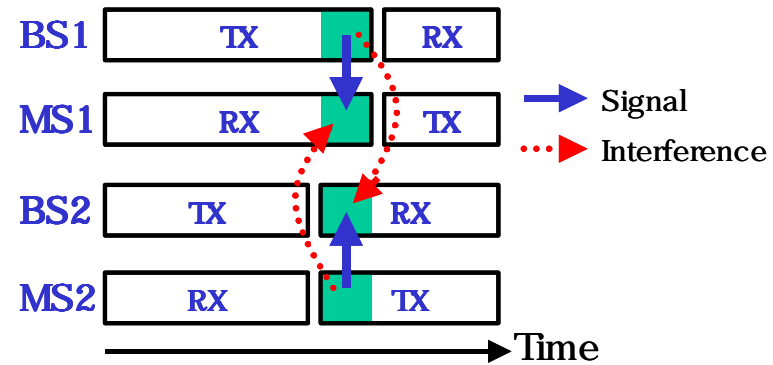
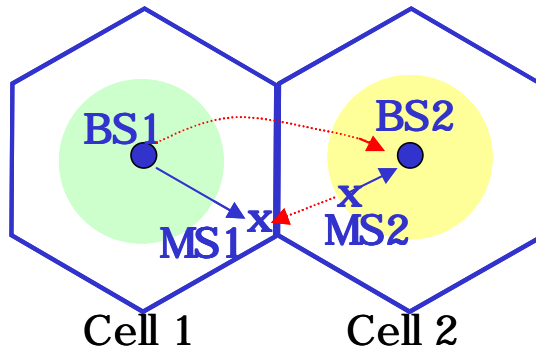


4 Ant., 20 Mobiles, L=15, Ts=2mS 11 Beams



- In standard Opportunistic BF, high throughput and good delay properties are conflicting objectives.
- JOBS aims to meet QoS requirements by providing sufficient average throughput, *while satisfying certain packet delay constraints*.
- JOBS makes use of information available at the BS, on past and present MS reports and waiting times of the mobile population.

# Scheduling to Reduce Interference in HDD



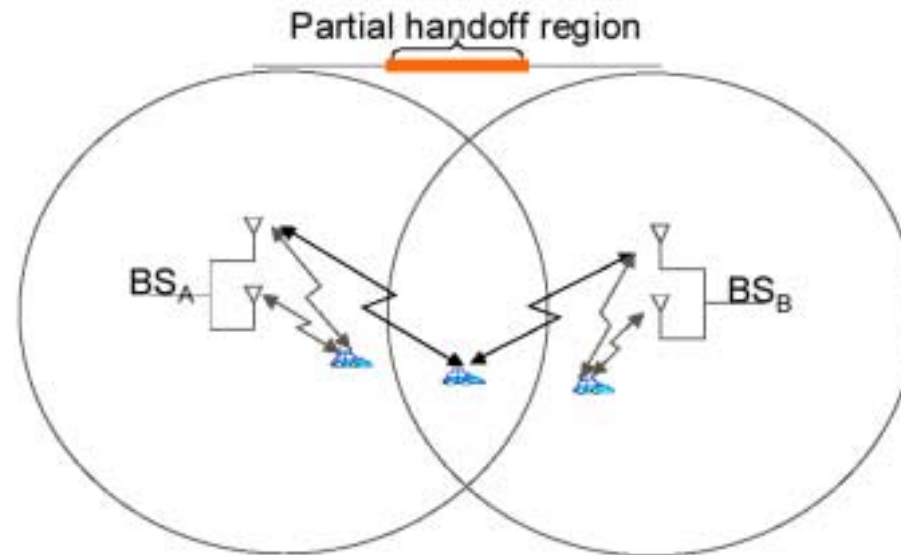
# Cross Layer and QoS considerations

- ❑ **QoS based adaptive MAC states for Resource Usage Efficiency**
- ❑ **Optimized scheduling for QoS support:** joint channel and QoS adaptation mechanism
- ❑ **QoS optimized access network technology:** a 'tool box' of air interface technologies would provide a flexible mapping to a Radio QoS Class and cater to a range of network QoS requirements
- ❑ **Cross layer optimization critical parameters:**
  - ⇒ Channel State Information
  - ⇒ QoS parameters
  - ⇒ PHY layer resources

# Handoff and Delay Sensitivity

- ❑ **Soft handoff** is beneficial from the point of view of system capacity but imposes timing and QoS limitations.
- ❑ If handoff delay could be minimized, transmission from the base station with the best link to the user would achieve significant fraction of the macro-diversity gain without utilizing additional resources.
- ❑ **Fast cell switching**, which exploits the selection diversity gain by appropriately choosing the base station for a particular user based on instantaneous channel conditions, is a promising alternative to soft handoff for delay sensitive packet service.
- ❑ Alternatively, the **coordination required for soft handoff or interference avoidance schemes to be performed by the mobile**, through some simple over-the-air signaling rather than centrally in the network.

# Partial Handoff



- ❑ In the partial handoff region the mobile terminal communicates simultaneously with multiple base stations.
- ❑ Partial handoff does not necessitate the handoff of all the transmit antennas from the serving base station to the target base station.
- ❑ The advantage of partial handoff over conventional handoff is that it reduces the effect of transmit antenna correlation.

# Inter-cell Interference considerations

Three interference scenarios:

- A. No in-cell interference, averaged out-of-cell interference (e.g. synchronous CDMA),
- B. No in-cell interference, bursty out-of-cell interference and (e.g. CDMA or OFDM)
- C. Averaged in-cell interference, averaged out-of-cell interference (e.g. asynchronous CDMA).

Performance comparisons in terms of system throughput indicate:

- B clearly outperforms the transmission option C with any number of users.
- In spite of the large variance in the interference power statistics, performance of option B is comparable to that of option A that requires in-cell orthogonality.

# Inter-cell Interference co-ordination

Techniques to address inter-cell interference co-ordination:

- ❑ interference avoidance
- ❑ interference averaging and
- ❑ interference smoothing

Basic approaches:

- ❑ No CSI/interference knowledge available at the transmitter
- ❑ Exploit CSI or any other network or contextual information

# Super-position coding for unknown interference

- ❑ Objective: make sure that at least some data are correctly received even when the interference is large.
- ❑ At the *transmitter* side: the sum of  $K$  codewords encoding the symbols intended for the  $K$  receivers.
- ❑ At the *receiver* side:
  - Step 1: The receiver with the worst channel decodes the codeword with the corresponding rate and all the other codewords appear as noise.
  - Step 2: The next-worst receiver is able to decode the rate corresponding to the worst and subtract it from the received signal.
  - Step  $n$ : The best receiver decodes all codewords.

# Self-organization of base stations

- ❑ **Self-organization of base stations:** probe the environment and adjust accordingly a number of parameters, such as their antenna configuration and transmit power
- ❑ The **information** to be exploited:
  - ⇒ Geographical Information (location-based and propagation characteristics)
  - ⇒ Spatial/temporal information (available coverage, capacity and interference patterns);
  - ⇒ Network information (services offered, traffic);
  - ⇒ Contextual information (user profile).



# Summary

- In the design of next generation systems and the specification of a new air interface
  - ⇒ Duplexing
  - ⇒ Radio resource management and
  - ⇒ Inter-cell co-ordinationwill play a major role.
  
- Critical parameters and a number of promising strategies need to be assessed.

# Challenges and further research topics

- ❑ Requirements and limitations of duplexing schemes
- ❑ Cross layer design for next generation systems
- ❑ QoS based optimization of RRM
- ❑ Inter-cell interference co-ordination techniques evaluation
- ❑ Self organization: techniques and performance assessment
- ❑ ...