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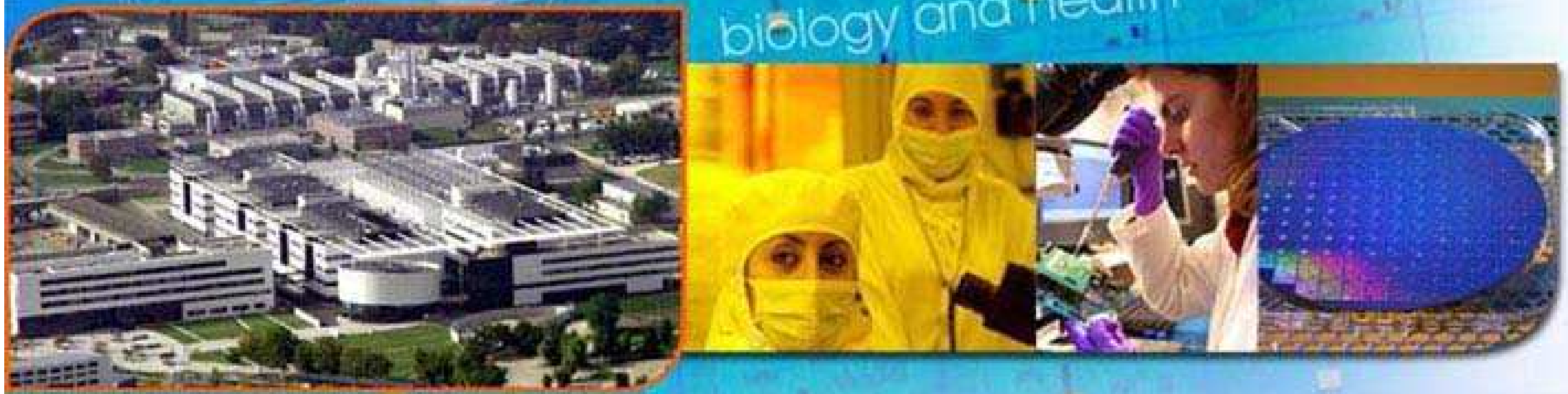

TECHNISCHE UNIVERSITÄT DARMSTADT

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Darmstadt

Multi-Cell Interference Aware Resource Allocation for Half-Duplex Relay Based Cooperation

WORKSHOP
“Interference Management and Cooperation Strategies in Communication Networks”

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Overview of the presentation

1. Context, Problems & Motivations
2. State of the Art
3. Model & Assumptions
4. Novel Approach
5. Simulation Results
6. Conclusions

1. Context, Problems & Motivations

Context

- Wireless OFDMA cooperative networks
- Downlink transmissions
- Backhaul between base stations (BS)

Motivations

- *WiMAX*, *LTE-Advanced* target higher rates, wider cell coverage
- Standards coexistence, increasing number of active terminal devices
- Demanding services, mobility of devices

Problems

- **Scarce** resources, regulated access to bandwidth
  ➔ **Frequency Sharing** causes **intra-** and **inter-cell interference**
- **Interference increases** with the reuse ratio of resources

Interference drawbacks:

- Link quality can drastically drop down for long periods
- Reduction of overall system capacity and decoding reliability
- Especially prejudicial for **border cell users**

➔ **Deal with inter-cell interference** is a MUST!

2. SOTA – Orthogonalization (1)

Frequency Sharing & Time Sharing

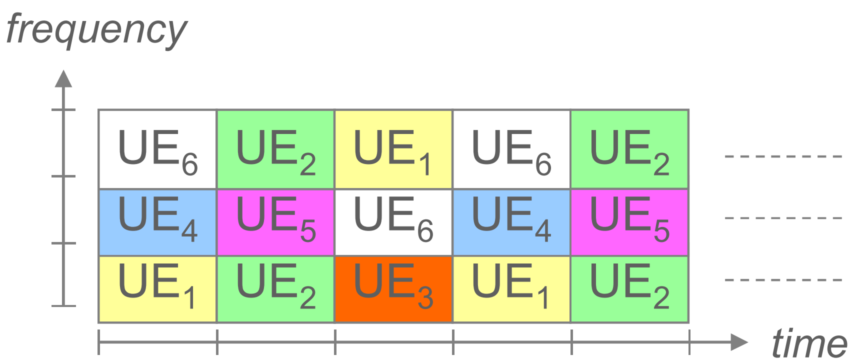
- Resource orthogonalized in time and/or in frequency domains
- **No interference** because resources aren't locally shared

Frequency Hopping, Frequency Sharing

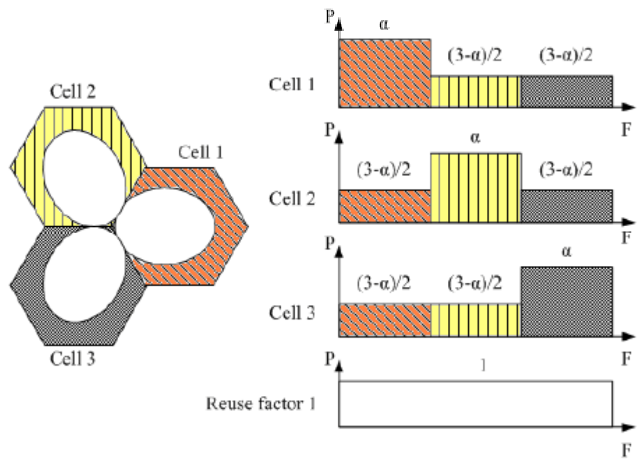
- Share of resource according to a resource reuse factor
- Some **interference** is generated but **kept under control**

Drawbacks / Limitations

- Unusable with huge number of users (very bad spectral efficiency)
- $\frac{nb_{users}}{nb_{resource\ units}}$ must not be too large



[Xiang07] *Soft Frequency Reuse*

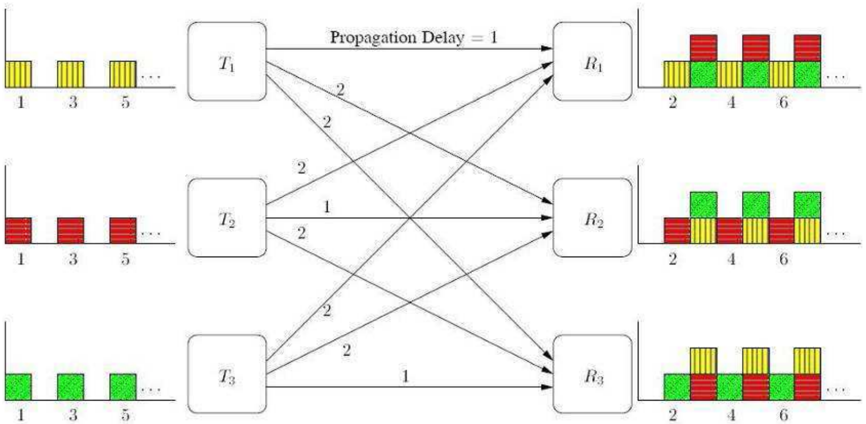


2. SOTA – Deal with Interference (2)

Interference Cancellation / Avoidance [Tse05], [Jafar08], [Perlaza08]

- Advanced signal processing techniques (SIC, DPC, Interference Alignment, Zero Forcing)
- Filter out interference at Transmitter and/or Receiver

Drawbacks / Limitations: CSIR/CSIT, complex processing, hardly implementable in practice



Noisy Interference

Interference treated as additional noise

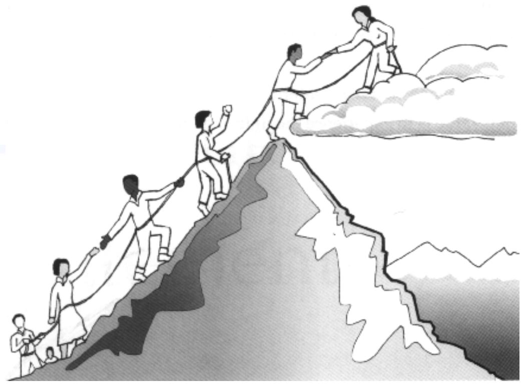
Drawbacks / Limitations: weak or limited perceived INR

Channel Aware Mechanisms [Boyd04], [Cover06], [Gesbert07]

- Adaptive MCS, Power Control (Water Filling)
- Graph Coloring, (Convex) Optimization

Drawbacks / Limitations: CSIR/CSIT, complex processing

2. SOTA – Cooperation (3)



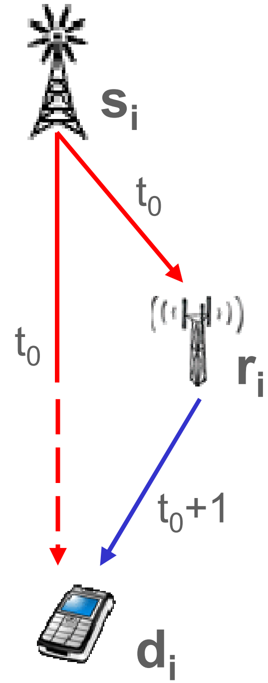
Cooperative Transmissions [Calvanese07], [Mohajer08]

1. **Broadcasting:** $\mathbf{s_i}$ broadcasts the packet; $\mathbf{r_i}$ and $\mathbf{d_i}$ listen
2. **Relaying:** $\mathbf{r_i}$ transmits a modified **(*)** version through $\mathbf{d_i}$
   (*) Amplify & Forward / Decode & Forward

Classical Strategy (1 band)

2n timeslots

s_i (chunk A)	m_1		m_2		m_3		…
r_i (chunk A)		n_1		n_2		n_3	
t	1	2	3	4	5	6	…



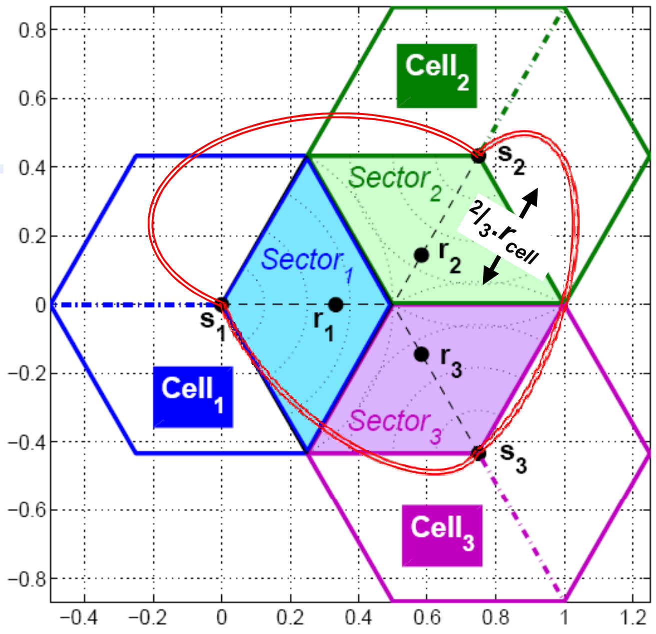
+
- + Spatial diversity, redundancy
- + Coverage extension
- + Decoding reliability at destination

-
- - AF protocol: noise and interference amplification
- - DF protocol: codebooks, error propagation **if** erroneous decoding

Cell viewpoint: Careful planning of cooperation
System viewpoint: Cooperative techniques add ‘network agents’
⇘ **Inter-cell Interference level increases**

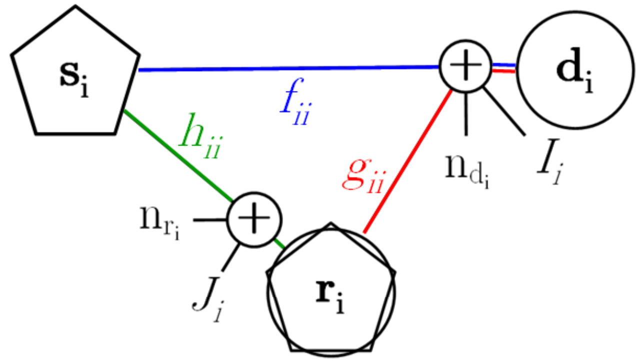
➔ ***Cooperative ‘Interference-Benefits’ Trade-off***

3. Model & Assumptions



System Model

- 3 adjacent sectors S_i with backhauling
- OFDMA techniques **cancel intra-cell interference**
- 1 active mobile user terminal $\mathbf{d_i}$ per sector
- 1 fixed relay $\mathbf{r_i}$ per sector
- 2 **shared** frequency bands (chunk)
- Synchronized DL transmissions



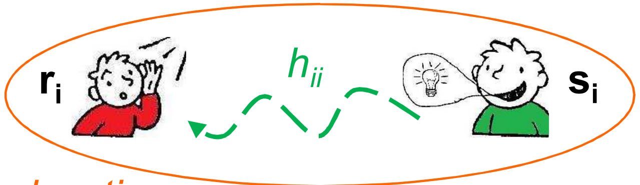
Communication Rate Limitations

- AWGN noise
- Inter-cell interference
- Fading, shadowing, path loss attenuation

Half-Duplex Relays Assumptions

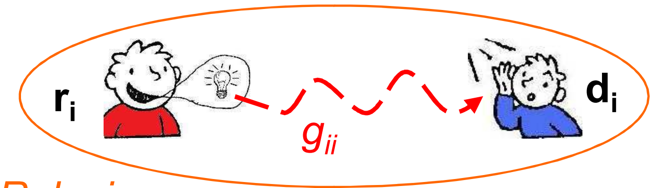
- **Full-duplex** devices require 2 distinct RF circuitries
- Constrained applications, devices (cost, size, power)

➔ No duplication of RF section



Broadcasting

XOR



Relaying

4. Novel Approach: Our proposal (1)

Half-Duplex…

- '**Deaf**' to Interference when relay is transmitting
- '**Vulnerable**' to Interference when relay is listening

… per Chunk Relays

'**Half-Duplex**' property is made **independent on each chunk** (with OFDMA systems)

Half-Duplex per Chunk Strategy (2 bands)

(n+1) timeslots → n

s_i (chunk A)	m_1	m_2	m_3	m_4	m_5	…	
r_i (chunk B)		n_1	n_2	n_3	n_4	n_5	…
t	1	2	3	4	5	6	…

Idea

- Deal with the **Cooperative Interference-Benefits Trade-Off**
- Exploit '**half-duplex per chunk**' nature of relays

Proposals

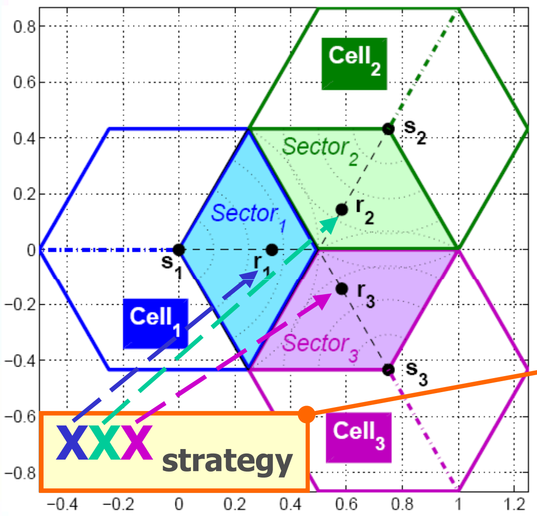
- Limit inter-cell interference on relays to improve effectiveness of cooperation
- Coordinate neighbor BS and RS transmissions (via backhaul)

➔ **Efficient Resource Allocation for Interference Mitigation**

A half-duplex relay cannot be interfered on "chunk B" by neighbor transmissions if:

- It transmits on "chunk B"
- It listens on "chunk A"

4. Novel Approach: Allocation Patterns (2)



Cooperation Planning

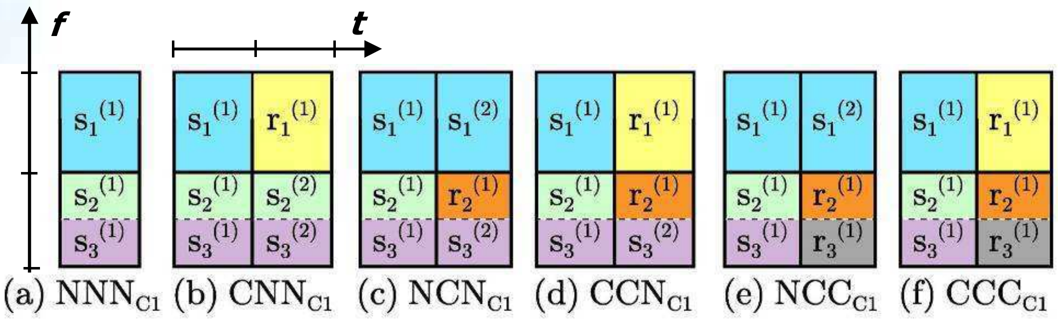
- '**On/Off**' Power Allocation / Cooperation Planning
  - Either relay r_i transmits at full power *('ON')*
  - Or r_i remains silent during 1 frame TX *('OFF')*

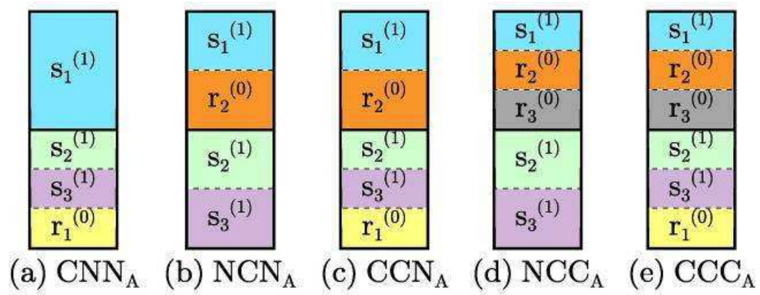
- 3-tuple of letters: 1 letter per sector
  - '**C**': Cooperation is planned in this sector
  - '**N**': No cooperative TX in this sector, just direct path

- Adopted cooperative strategy in index

Two Cooperative Strategies for Resource Allocation

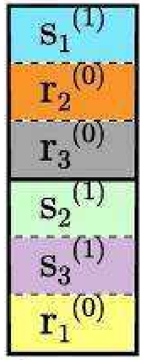
- *Classic patterns (C1)*: standard cooperative protocol (*reference*)
  Unbalanced allocation of chunks → one sector is advantaged (here S_1)
- *Advanced patterns (A)* exploit half-duplex per chunk nature of relays (*proposals*)





Advanced patterns cause **additional** interference **BUT** this is the issue of the **Cooperative Trade-Off**.

4. Novel Approach: Adaptive RRM (3)



(e) CCC_A

Unbalanced assignments

A sector may be more '**protected**' from inter-cell interference *(here S_1)*

➔ System requirements (QoS, priority order, etc.) define '**advantaged**' sector

Adaptive Allocation of Resources

Perceived power of signal and interference **depends on communication context**:

- Location of destinations (path loss attenuation)
- Shadowing, Fading (specific to each link and each chunk)

Each pattern experiences a different SINR

➔ A pattern **can perform well** in a scenario and **be worse** in another!

Selection of the pattern optimizing an utility function

- Power consumption
- Overall amount of mutual information

Optimal pattern is selected among **subsets of patterns:**

- All classical patterns
- All advanced patterns
- All patterns

5. Simulation Results: Methodology

Metric, Utility Function

Results are computed on the viewpoint of destination $\mathbf{d_1}$

- Location of $\mathbf{d_1}$ in its sector is under control
- $\mathbf{d_2}$ and $\mathbf{d_3}$ move randomly in their sector (N_{pos})
- Random channel states for all links (fading, shadowing) (N_{chan})
- Sector S_1 is advantaged in comparison to S_2 and S_3

} Average over $N_{pos}.N_{chan}$ communication contexts

Sum of mutual information amount (**GMI_{d1}**), given location of $\mathbf{d_1}$

➔ Specific expressions derived for each pattern

Power Consumption

- Each pattern involves specific transmitters (cooperation planning)
- Patterns spread over 1 or 2 timeslots

➔ Power budget for transmission is specific to each pattern

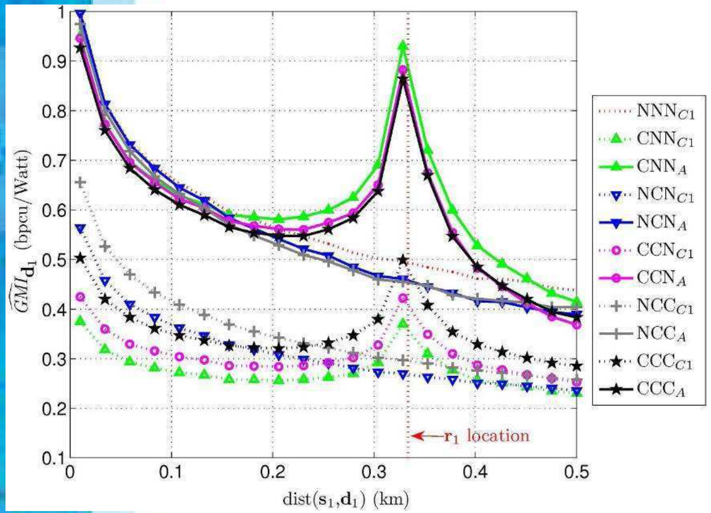
Novel standards are willing to **reduce TX power**

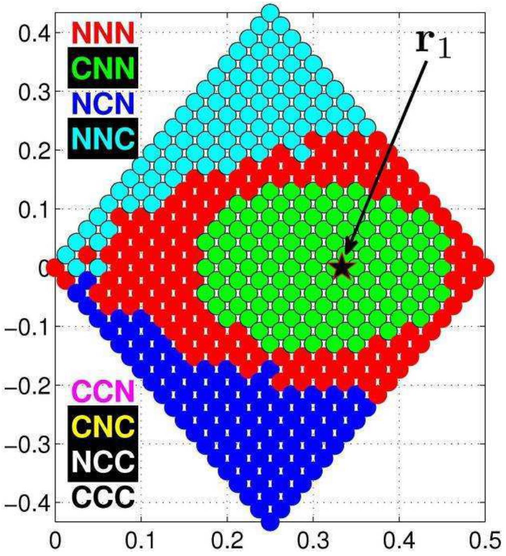
- Penalize patterns with high power budget
- Grant patterns with low power budget

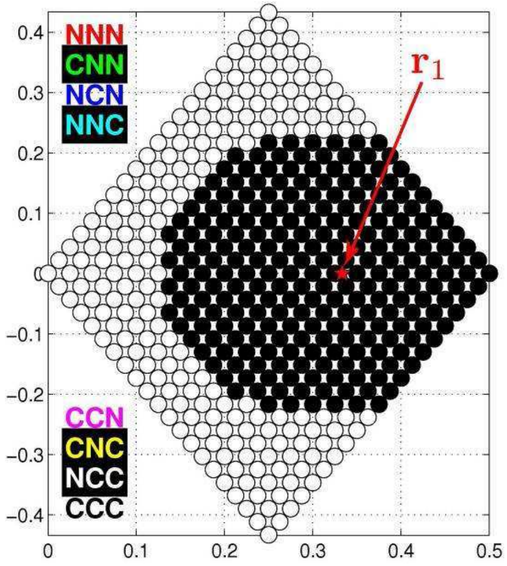
➔ **GMI_{d1}** is weighted by overall transmission power

5. Simulation Results: Curves

N_{pos} = 1 000
N_{chan} = 500





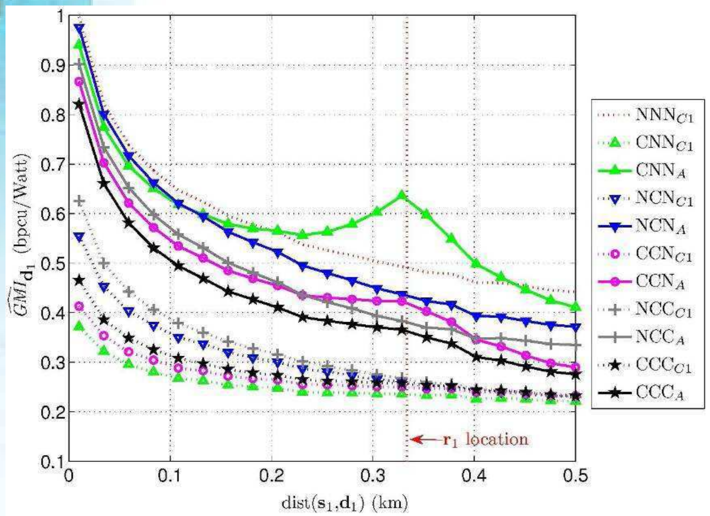


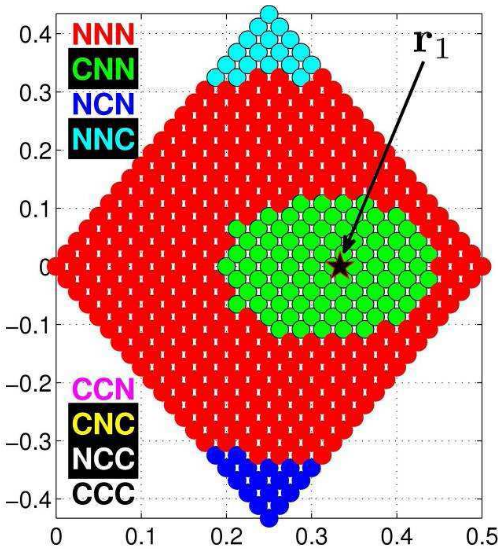
ODF protocol

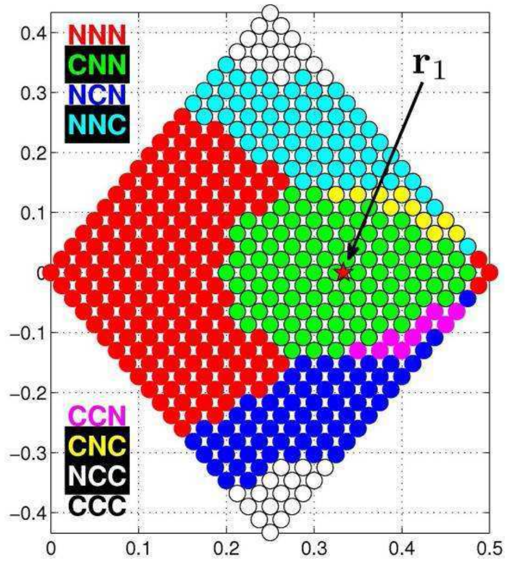
OAF protocol

High TX Power (10W – 1W)

Low TX Power (10mW – 1mW)







6. Conclusions

Conclusion

- Cooperative transmissions
- **Coordinated** frequency allocation between sectors
- Minimization of power budget
- **Channel aware** resource allocation

Future work

Generalization to **more than 2 chunks** (for instance, 50 chunks – *LTE-A.*, *WiMAX*)

Idea

- Available bandwidth can be divided into **pairs of chunks**
- On each pair of chunks, use the optimal **allocation pattern** we just introduced

Each cell has a **RRM scheduler** (several UE_i to serve):

- Priority Scheduling (sort UE_i according to priority)
- AMC, Frequency Scheduling (define MCS for UE_i and chunks where transmit)

A common **RRM controller**:

- Combine requirements of three schedulers
- **Double Optimization:**
  - How **optimally pair chunks** according to weighted coefficients?
  - **Which pattern is optimal** on the current pair of chunks?

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Thanks!

Loyalty
Entrepreneurship
Team work
Innovation

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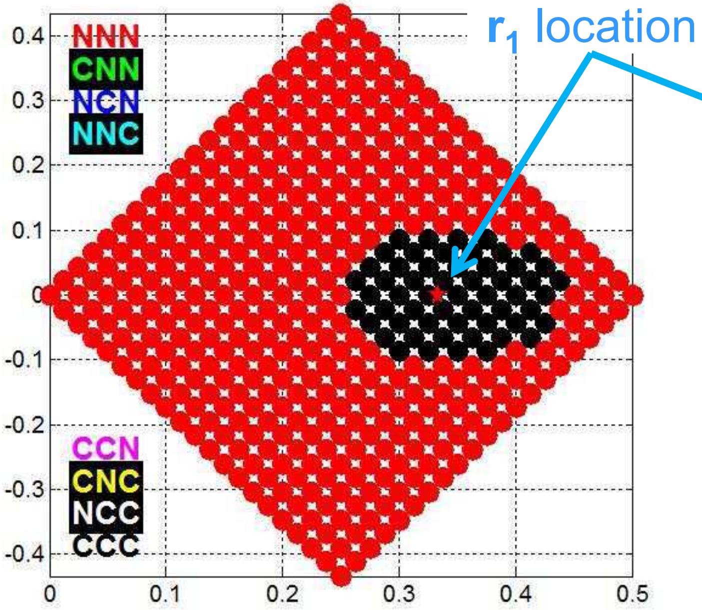
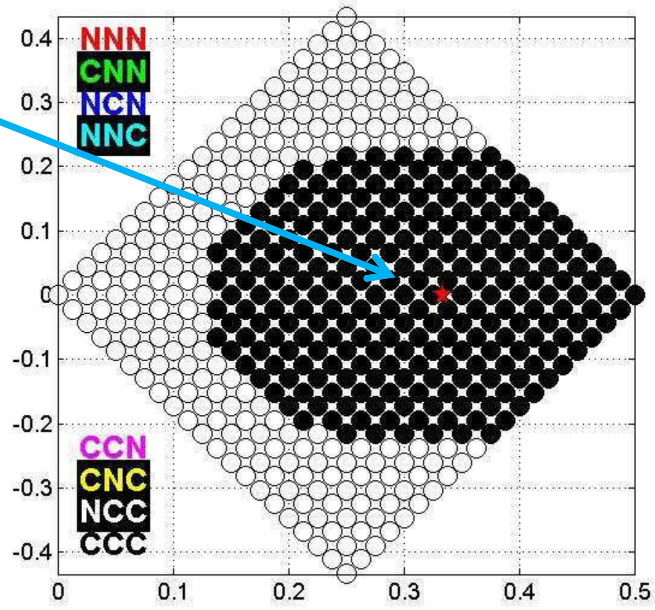
Classical vs. *Advanced* Patterns (DF protocol)

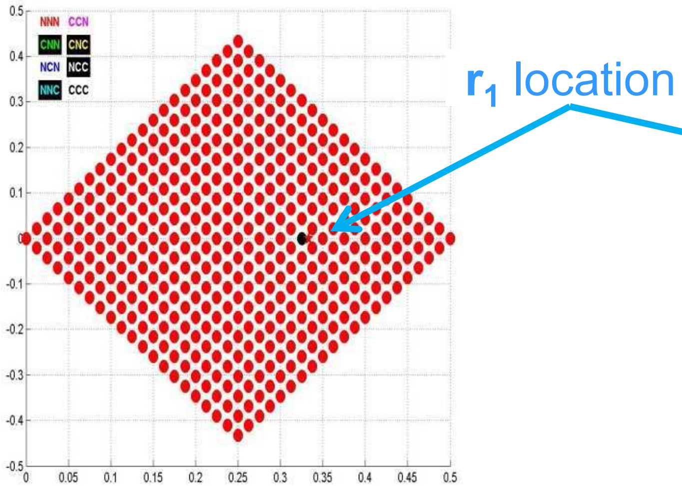


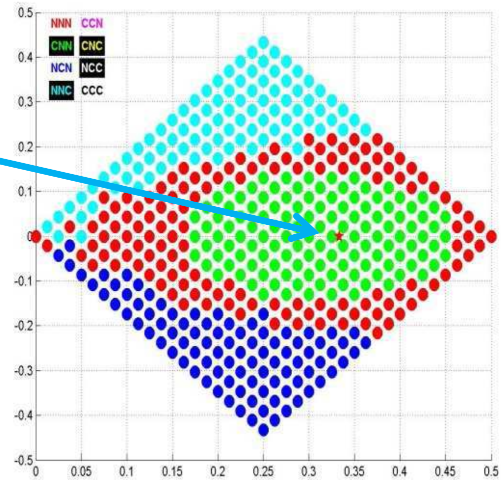
Selection among all classical allocation patterns



Selection among all proposed allocation patterns

Low TX power





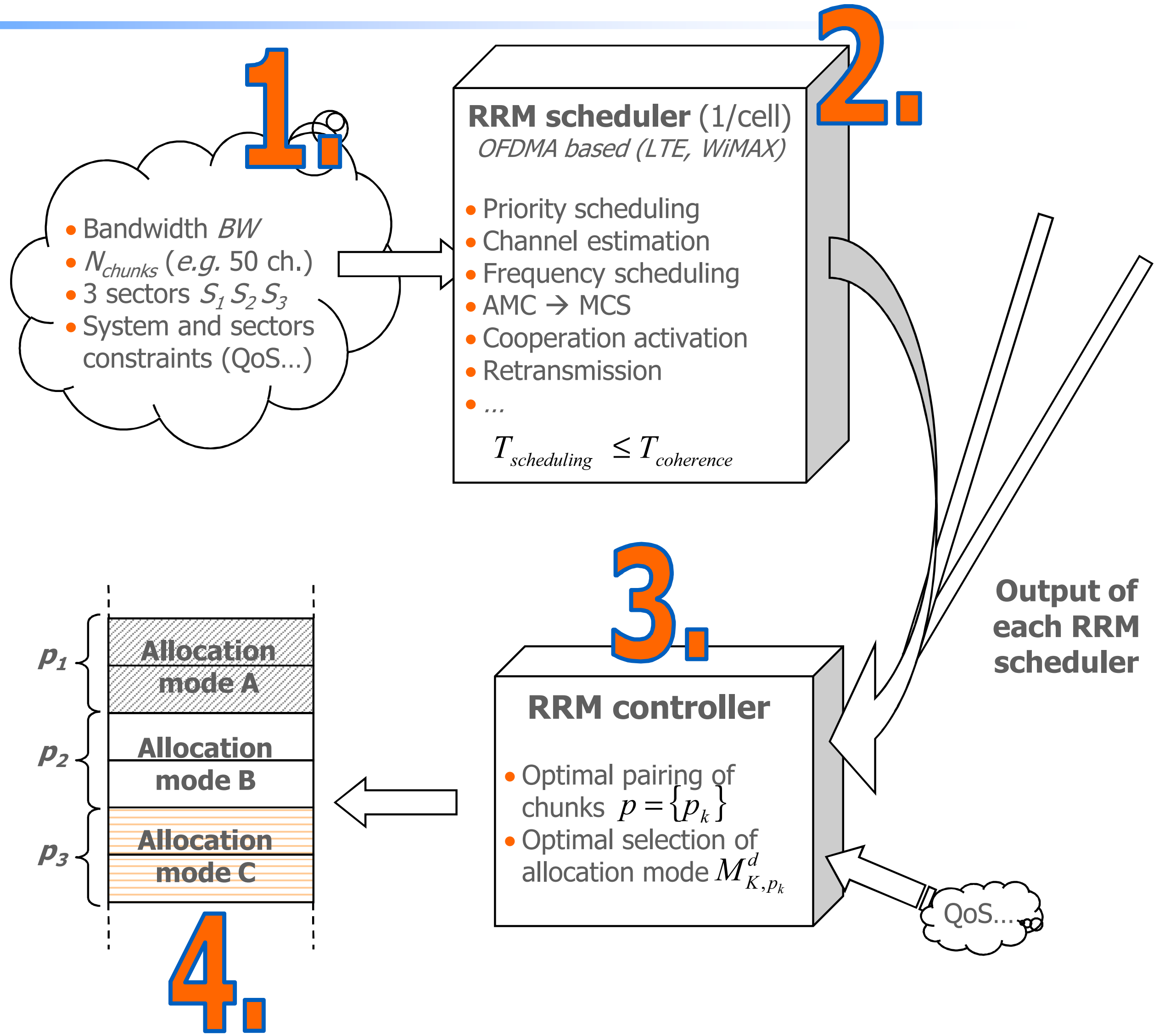
High TX power

Adaptive RRM Algorithm: Extension to more than 2 chunks

1. *{Resources, constraints}* pool
2. **Step 1:** Resource allocation
   - Assign chunks to sectors
   - Identify cooperative chunks

   … Compliant with requirements
3. **Step 2:** Resource allocation

   Double optimization:
   - Pairing of chunks
   - Allocation pattern
4. Previous work on each pair p_k



We assumed **one user per sector** but this algorithm applies to **several users per sector**

- **Centralized scheduler** assigns x_i chunks to sector S_i
- These x_i chunks can be **orthogonally** allocated (OFDMA) to at most x_i users in S_i

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