Design and Evaluation of Scheduling Algorithms for LTE Femtocells

(Entwurf und Bewertung von Resourcenzuweisungen für LTE Femtozellen)

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Diplomarbeit von Kay Henzel

13.03.2012

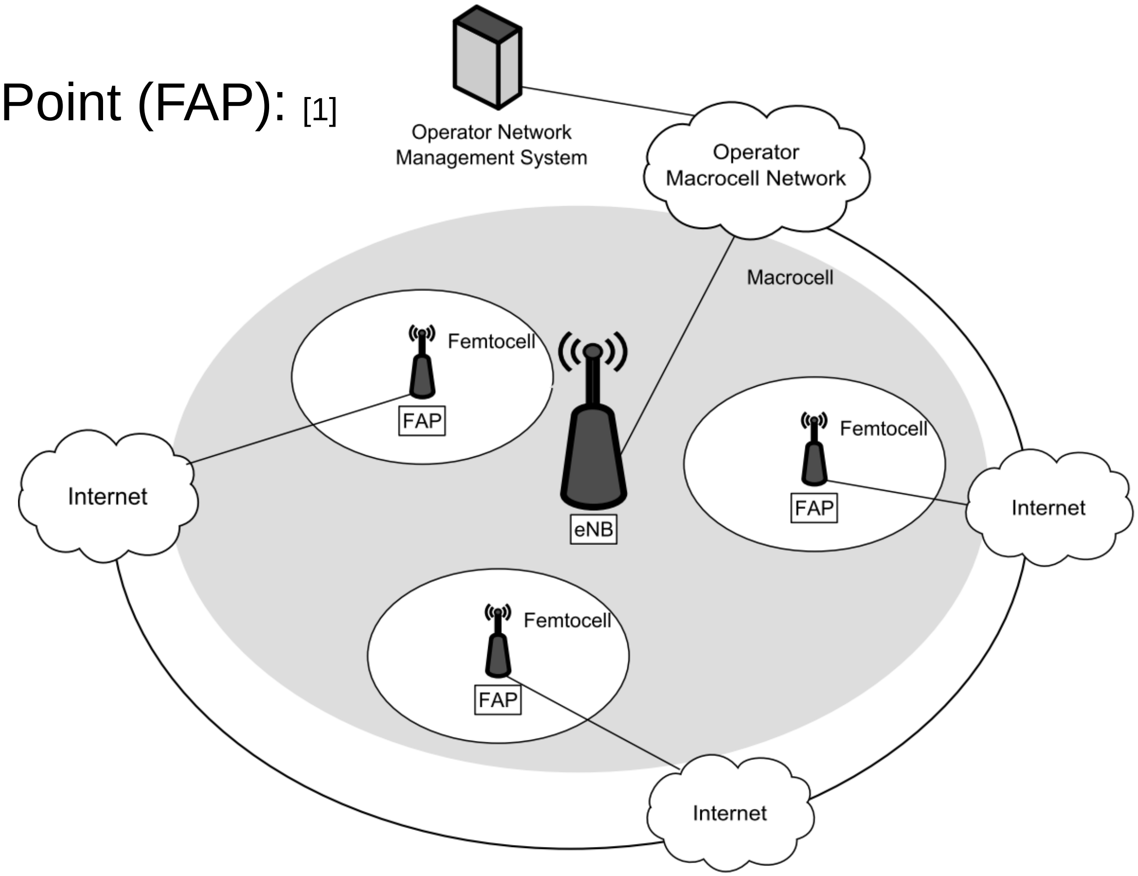
Overview

- Introduction and Motivation
- Radio Resource Management Problem
- Radio Resource Assignment Algorithms
- Simulation Scenario and Results
- Summary, Conclusion and Outlook

Introduction

Properties of a Femto Access Point (FAP): [1]

- Low power
- Serving small areas
- Operating in licensed spectrum
- Self-organising, self-managing
- IP-Backhaul (DSL)



Two-Tier Femtocell Network

Standardized by 3GPP:

- UMTS: Home Node B (HNB)
- LTE: Home eNode B (HeNB)

[1] ITU-R WP 5D/195

Motivation

70% of data traffic originates indoors

50% of voice calls are initiated from inside [2]

Advantages

- Improved indoor coverage

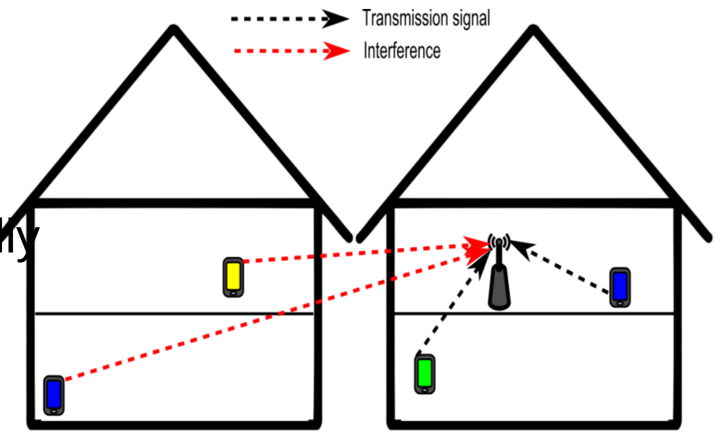
- Single radio access technology (RAT)
  → Reduced device complexity
  → Seamless handover

- Less power consumption

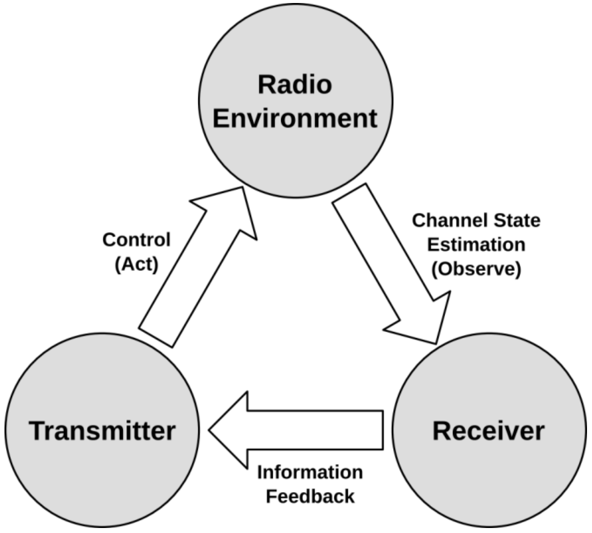
[2] G. Mansfield, "Femtocells in the US Market Business Drivers and Consumer Propositions," Femtocells Europe, ATT, London, U.K., June 2008.

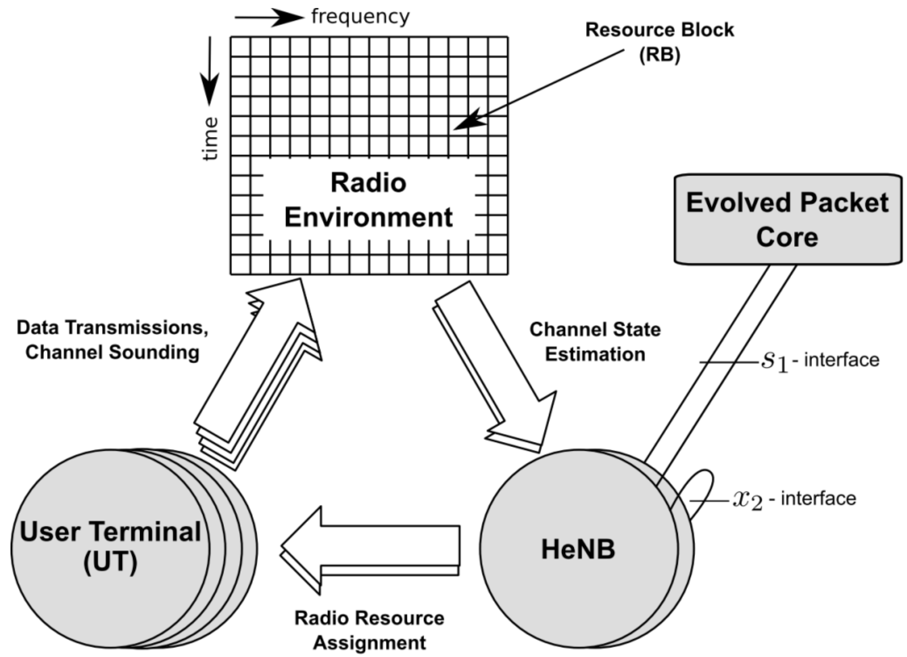
Self-Organizing Networks (SON)

- Number of femtocells can be very large
- Subscriber may switch them on and off frequently
- Operator may not be able to access them physically
- Uplink: Interference depends on UT positioning



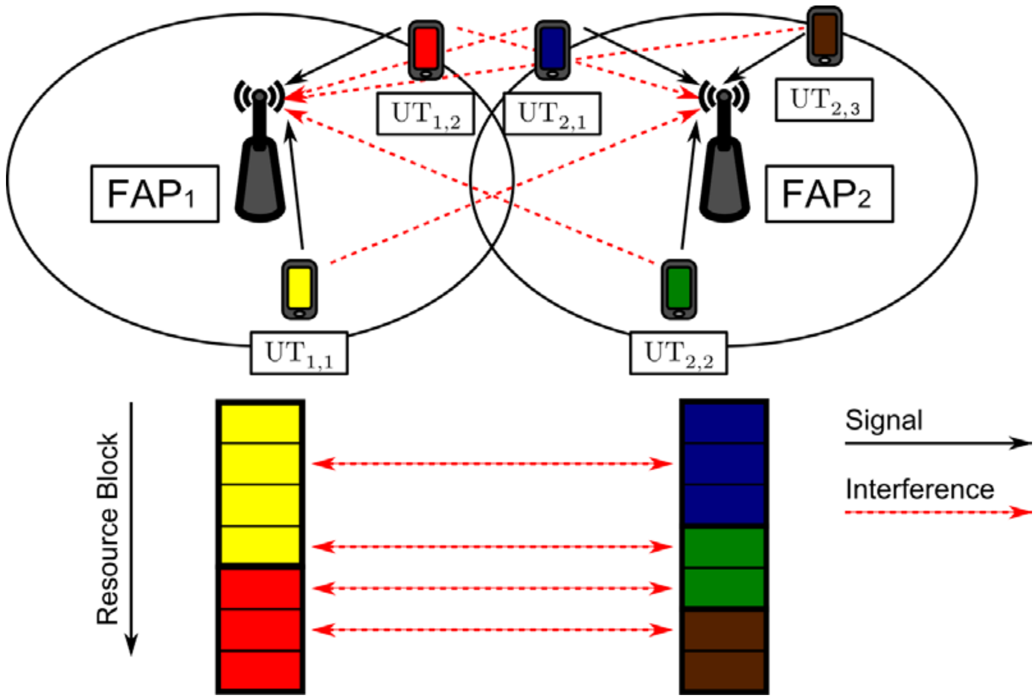
Approach based on Basic Cognitive Cycle [3]





[3] S. Haykin, Cognitive Radio: Brain-Empowered Wireless Communications. IEEE Journal on Selected Areas in Communications, 23(2): 201-220, 2005

Uplink Femtocell Interference Scenario



$$\mathrm{UT}_{k,j} \quad \begin{array}{l} k: \text{ Cell index} \\ j: \text{ UT index} \end{array}$$

Degrees of Freedom:

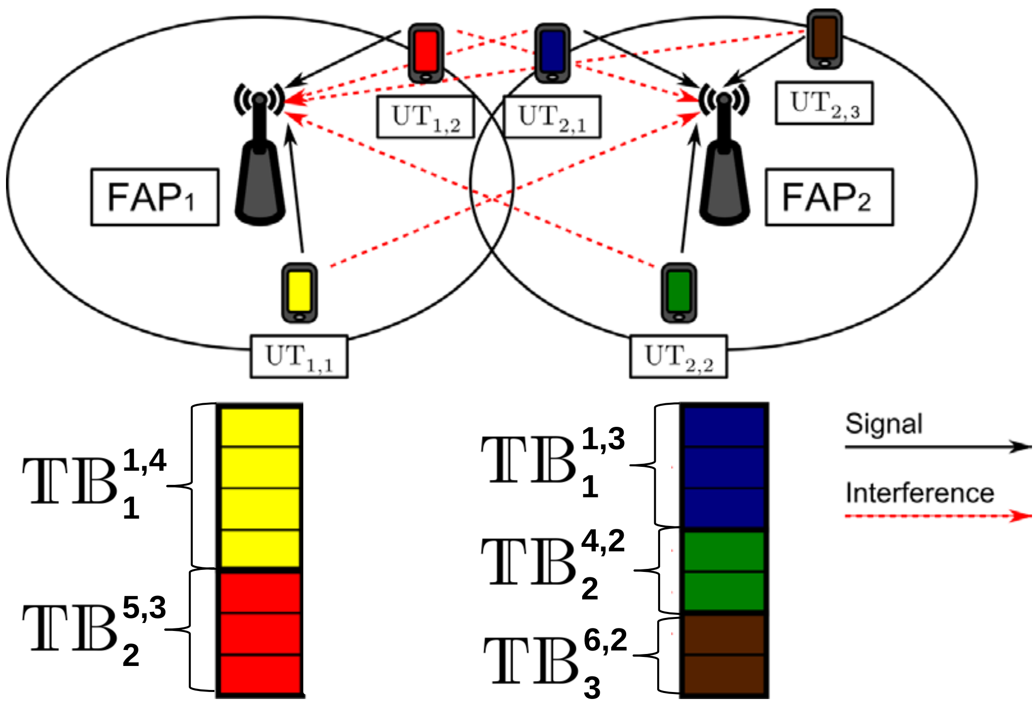
- How many RBs per UT
- Which Transmission Power
- Which Modulation and Coding Scheme (MCS)
- **Which RBs to which UTs**

LTE Constraint:

$$\mathbb{TB}_t^{s,l} = \{\mathrm{RB}_s, \ldots, \mathrm{RB}_{s+l}\}$$

$$\begin{array}{l} s: \text{ Start index of first RB} \\ l: \text{ Length of TB} \end{array}$$

Uplink Femtocell Interference Scenario



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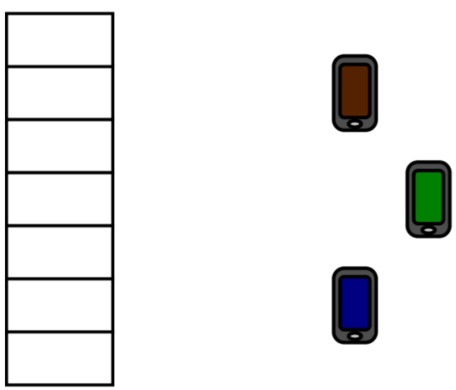
Radio Resource Management Problem

- ➢Selecting RBs forming TBs
- ➢Link Adaption
- ➢Assignment of UTs to TBs

Resource Fairness:

Equal amount of RBs in every TB [4]



Number of RBs Number of UTs

[4] 3GPP. Evolved Universal Terrestrial Radio Access (E-UTRA); Further advancements for E-UTRA physical layer aspects TR 36.814, 2010. V9.0

Radio Resource Management Problem

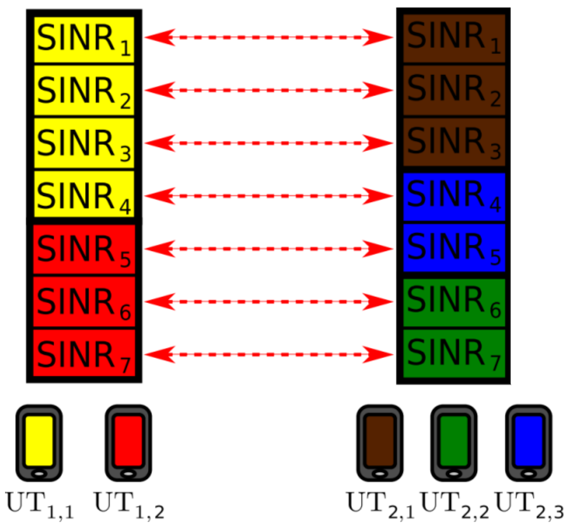
- Selecting RBs forming TBs
- **Link Adaption**
- Assignment of UTs to TBs

Effective SINR [5] **for TB with index t:**

$$\mathrm{SINR}_{eff}(k,j,t) = I^{-1}\left(\frac{1}{|\mathbb{TB}_t^{s_t,l_t}|}\sum_{n=s_t}^{s_t+l_t-1} I(\mathrm{SINR}_n(k,j))\right)$$

SINR Mapping with the invertible “information measure” function $I(\cdot)$

Cell UT TB



[5] 3GPP-WG3. Effective-SNR Mapping for Modeling Frame Error Rates in Multiple-state Channels. C30-20030429-010

Radio Resource Management Problem

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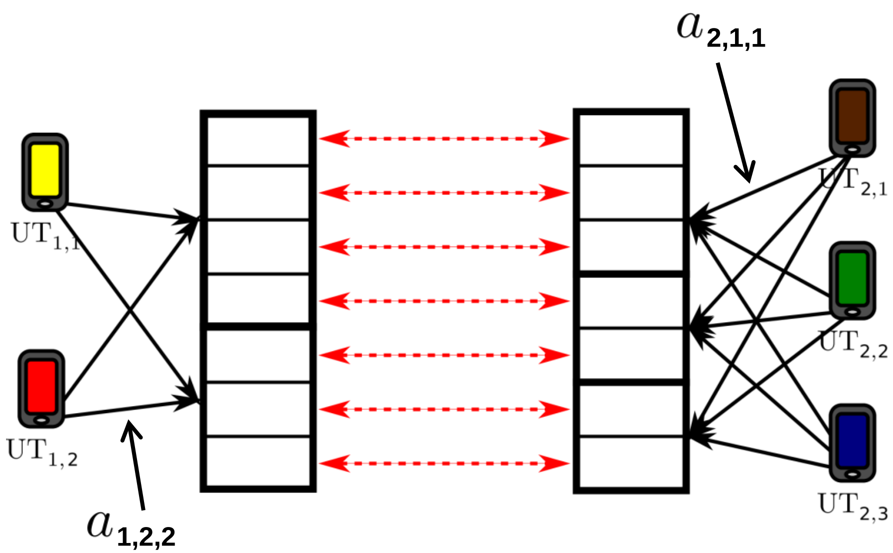
- Link Adaption
- Assignment of UTs to TBs



Cell Spectral Efficiency:

$$CSE = \frac{1}{KB}\sum_{k=1}^{K}\sum_{\forall \mathrm{UT}_{k,j}\in\mathbb{S}_k} n_{RB}\cdot r(\mathrm{SINR}_{eff},\mathrm{UT}_{k,j})$$

Optimization:

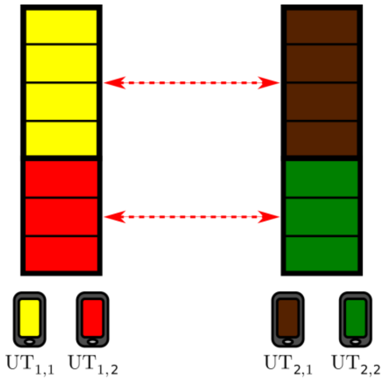
$$\max \sum_{k\in\mathbb{K}}\sum_{j\in\mathbb{S}_k}\sum_{t\in\mathbb{T}_k} a_{k,j,t}\cdot \underbrace{r(\mathrm{SINR}_{eff}(k,j,t))}_{\textbf{dependent on } a_{k,j,t}}$$

$a_{k,j,t}$ = 1 : UT_j in cell k transmits on $\mathbb{TB}_t$

Radio Resource Management Problem

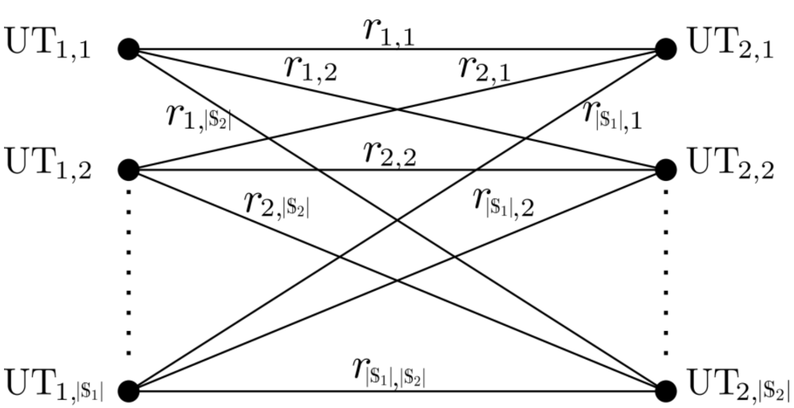
Additional Constraint:

Equal amount of UTs per cell/frame.



Single Interferer from each cell on each $\mathbb{TB}_t$

Reduction to Linear Assignment Problem:

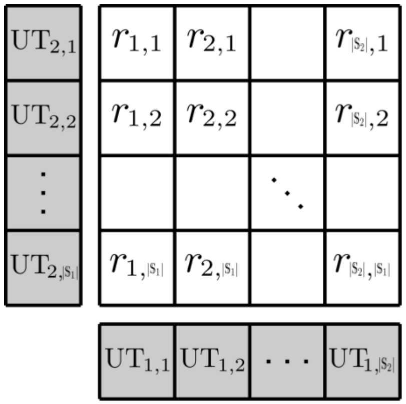


$$\max \sum_{i \in \mathbb{S}_1} \sum_{j \in \mathbb{S}_2} a_{i,j} \cdot r_{i,j}$$

$r_{i,j}$: utility e.g. throughput, SINR

Radio Resource Assignment Algorithms

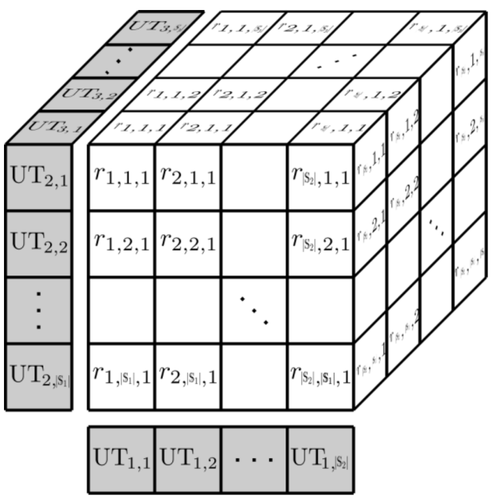
Two-dimensional algorithms:



Optimal Algorithm:

Hungarian/Munkres Algorithm
- Polynomial time $O(n^3)$
  (Operation Research)

Multi-dimensional algorithms:



No Optimal Algorithm (NP-hard [6])**:**

Brute Force $O((n!)^{|\mathbb{K}|})$

Number of UTs equals steps   Number of Cells equals dimensions

Heuristics:

Greedy Algorithm $O(n^{|\mathbb{K}|+1})$

Maximum-Regret Algorithm $O(|\mathbb{K}| \cdot n^{|\mathbb{K}|+1})$

[6] M. Garey and D. Johnson, Computers and Intractability, A Guide to NP-completeness, W.H. Freeman and Company: San Francisco, CA, 1979

Greedy Algorithm

Description:

- Locally optimized choices

Example for 2 dimensions:

	$UT_{1,1}$	$UT_{1,2}$	$UT_{1,3}$
$UT_{2,1}$	7	8	1
$UT_{2,2}$	9	11	8
$UT_{2,3}$	7	15	10

<u>Step1</u>: Localize maximum uncovered value

<u>Step2</u>: Cover row and column of maximum value

Solution: **{15}9}1}** **Sum:** **25**

Optimal solution: **{15,8,7}** **Sum:** **30**

Maximum-Regret

Description:

- Maximizes the regret [7]

Row regret : $\Delta_i^r = c_{d_i,i}^r - c_{e_i,i}^r \qquad c_{d_i,i}^r \geq c_{e_i,i}^r$

Column regret: $\Delta_i^c = c_{i,a_i}^c - c_{i,b_i}^c \qquad c_{i,a_i}^c \geq c_{i,b_i}^c$

Example for 2 dimensions:

	$\mathrm{UT}_{1,1}$	$\mathrm{UT}_{1,2}$	$\mathrm{UT}_{1,3}$	Δ^r
$\mathrm{UT}_{2,1}$	7	8	1	
$\mathrm{UT}_{2,2}$	9	11	8	
$\mathrm{UT}_{2,3}$	7	15	10	
Δ^c			$\boxed{7}$	

<u>Step1</u>: Compute row and column regret Δ^r Δ^c

<u>Step2</u>: Localize maximum uncovered regret value and take the higher one

<u>Step3</u>: Cover row and column of maximum value

Solution: **{15,8,7}** **Sum: 30**

Optimal solution: **{15,8,7}** **Sum: 30**

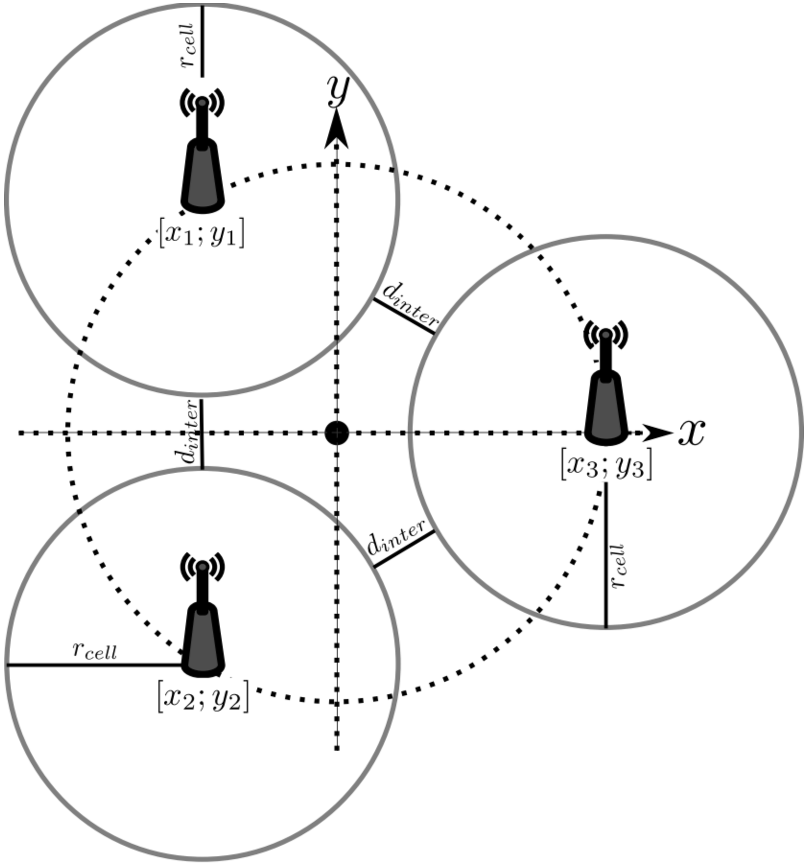
[7] Loomes, G. and Sugden, R. (1982), 'Regret theory: An alternative theory of rational choice under uncertainty', Economic Journal, 92(4), 805–24.

Simulation Szenario

Access to Femtocells: [8]

- **Closed Subscriber Group (CSG) cells:** Only accessable by members of the CSG
- **Hybrid cells:** Accessible as a CSG cell by members of the CSG and as a normal cell by all other UTs.

Parameter	Value
Number of active UTs per cell	2 - 8
Number of cells	2, 3, 4
Inter-cell Edge distance	-100m, -50m, 0m, 50m, 100m



[8] 3GPP TS 32.571 Home Node B (HNB) and Home eNode B (HeNB) management; Type 2 interface concepts and requirements; Release 10

Simulation Parameter

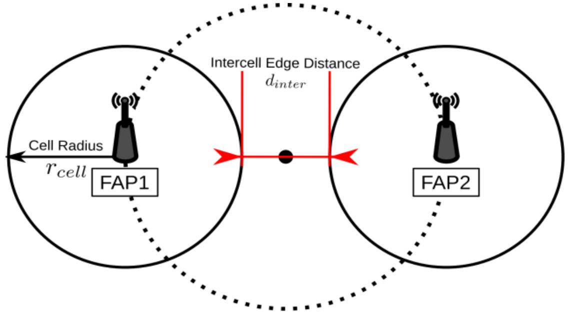
Parameter	Value	Comment
Duplex Scheme	FDD	---
Frequency Band	2500 MHz	---
System Bandwidth	20 MHz (100 RBs)	---
Frame Length	1 ms	---
Pathloss Model	InH NLoS	Guidelines for evaluation [9]
Traffic Model	Full Buffer	---
Adaptive MCS	13 MCSs	---
Transmit Power P_{Tx} UT	4.0 dBm (constant per subchannel)	---
Evaluated Sim. Runtime	1s	---
Cell Radius	100m	---

[9] ITU-R. Guidelines for evaluation of radio interface technologies for IMT-advanced m.2135, 2009.

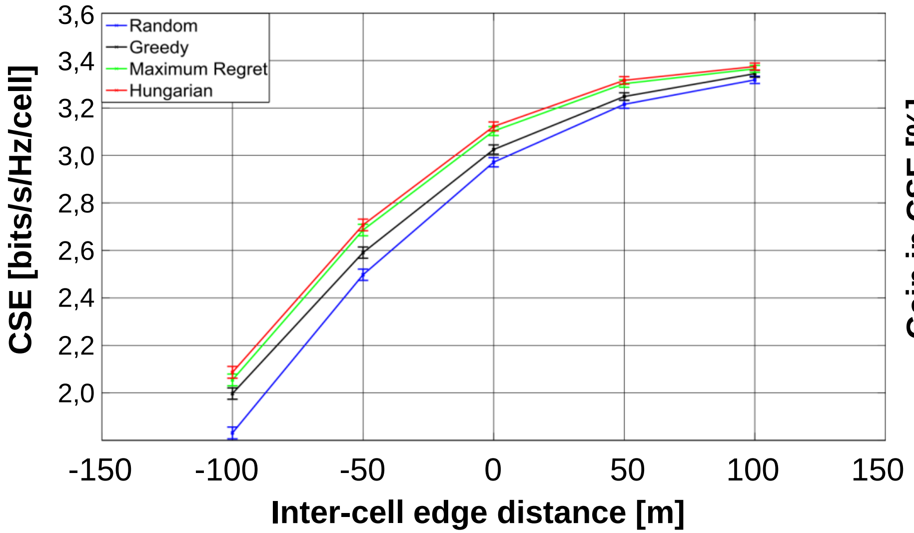
Results: Two Cell Scenario

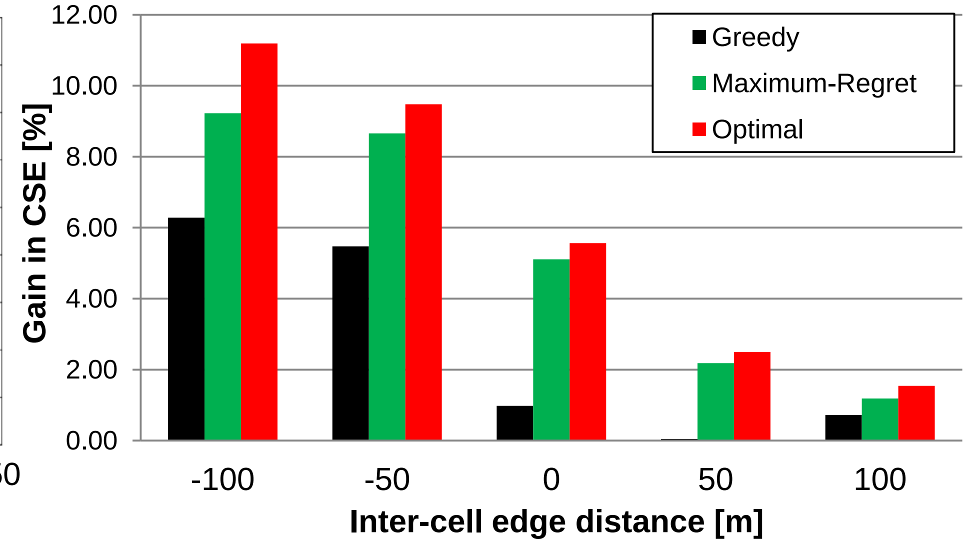
Comparison of the Strategies to:

- Random (Round Robin in Frequency Domain)



- **2 cells**
- **5 UTs per cell**





- CSE increases with inter-cell distance
- Strategies merge for increasing inter-cell distance

- Maximum-Regret produces close to optimal results

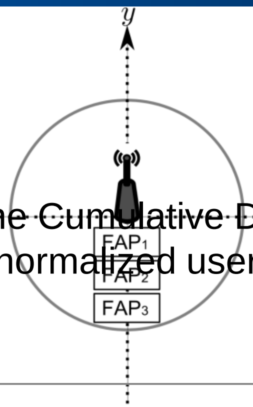
Results: Multicell

Comparison of the Strategies to:

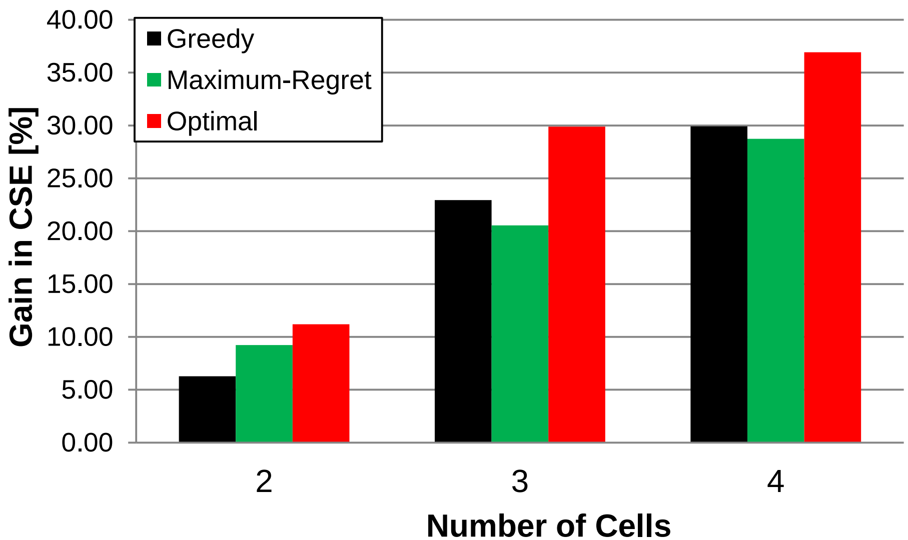
- Random (Round Robin in Frequency Domain)

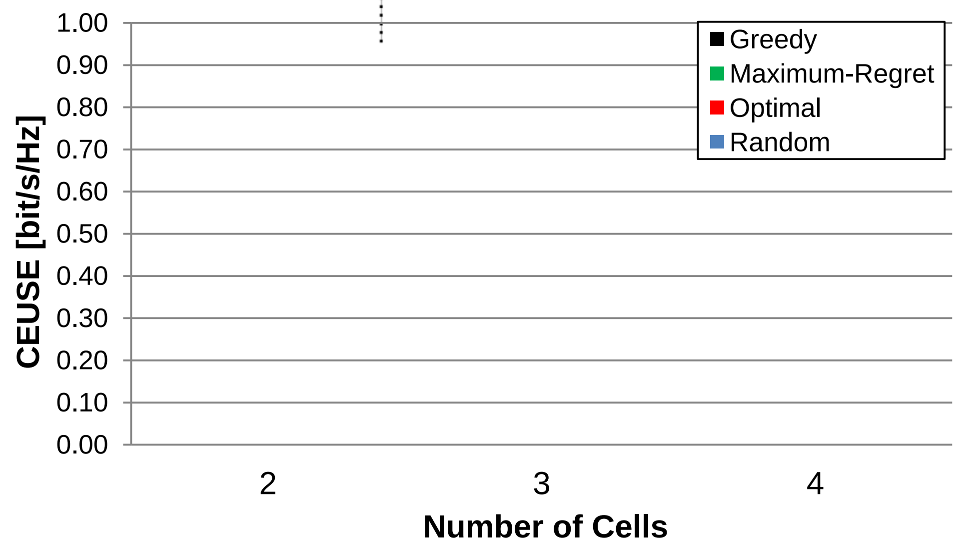
Fairness   **r Spectral Efficiency**
(CEUSE)

5% point of the Cumulative Distribution Function (CDF) of the normalized user througput.



- **2, 3, 4 cells**
- **5 UTs per cell**
- d_{inter} **= -100m**



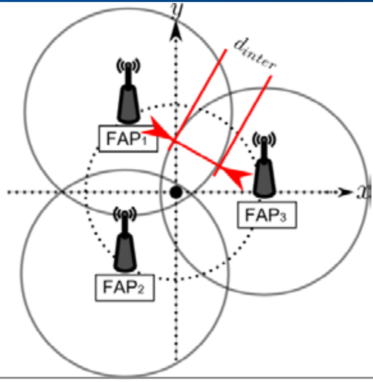


- CSE gain increases with the number of Cells
- the worst 5% of users are not served

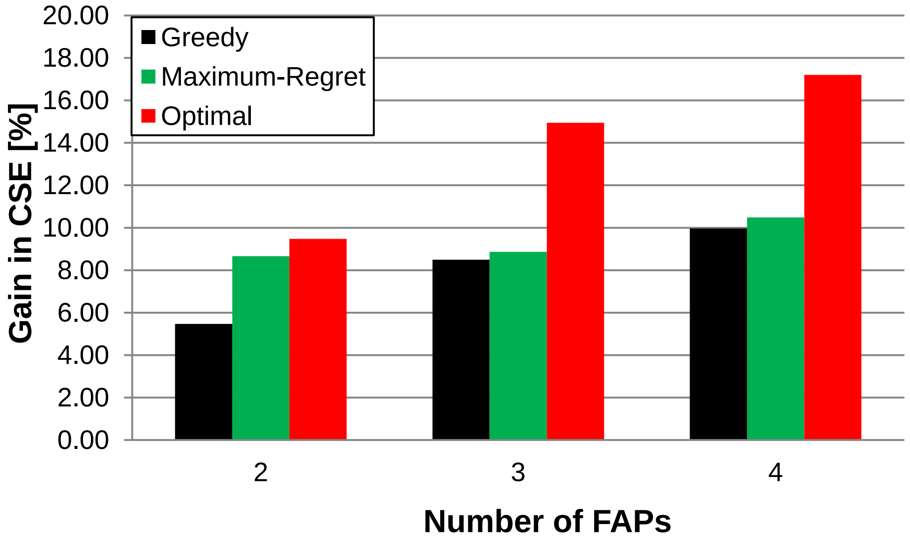
Results

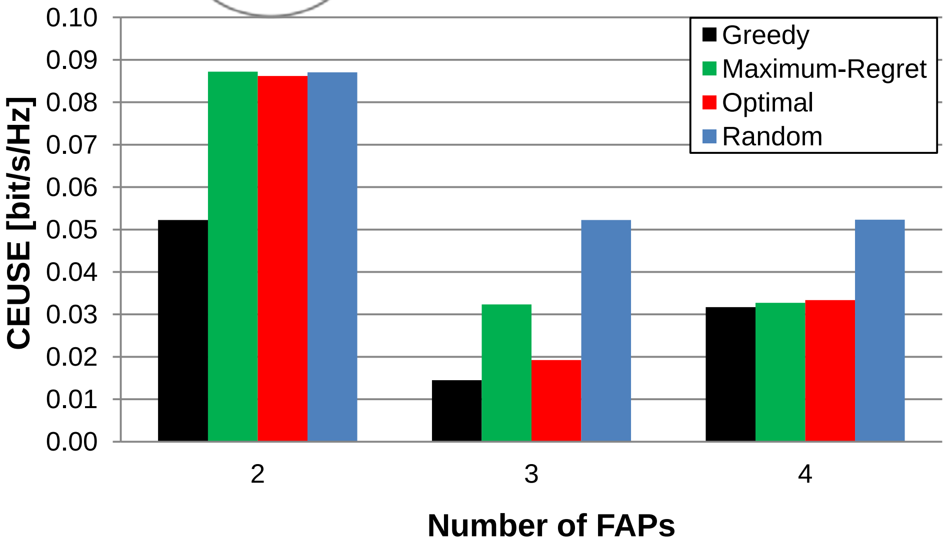
Comparison of the Strategies to:

- Random (Round Robin in Frequency Domain)



- **2, 3, 4 cells**
- **5 UTs per cell**
- d_{inter} **= -50m**





- CSE gain increases with the number of FAPs

- Cell Edge User suffer from CSE optimization
- Maximum-Regret improves fairness for two and three cells.

Summary and Conclusion

Summary:

- Described the challenges of uplink radio resource management
- Researched and implemented suitable RRM algorithms
- Implemented a central scheduling unit in openWNS Simulator
- Evaluated algorithms in openWNS Simulator

Conclusion:

- Centralized RRM strategies can significantly increase the CSE (up to 37%).
- Achieved CSE gain depends on inter-cell interference power.
- CEUSE suffers from maximizing CSE.

Outlook

Outlook:

- Additional RRM algorithms such as Decomposible Costs [10]
- Same number of UTs per frame.
- Compare against decentralized resource assignment strategies.
- Reduction of Interferer: The assignment of the radio resources can be computed partially with the focus on the strongest interferer.

[10] Approximation algorithms for multi-dimensional assignment problems with decomposable costs. H. Bandelt, Y. Cramab, F. C.R. Spieksma.

Thank you for your attention!

Maciej Mühleisen

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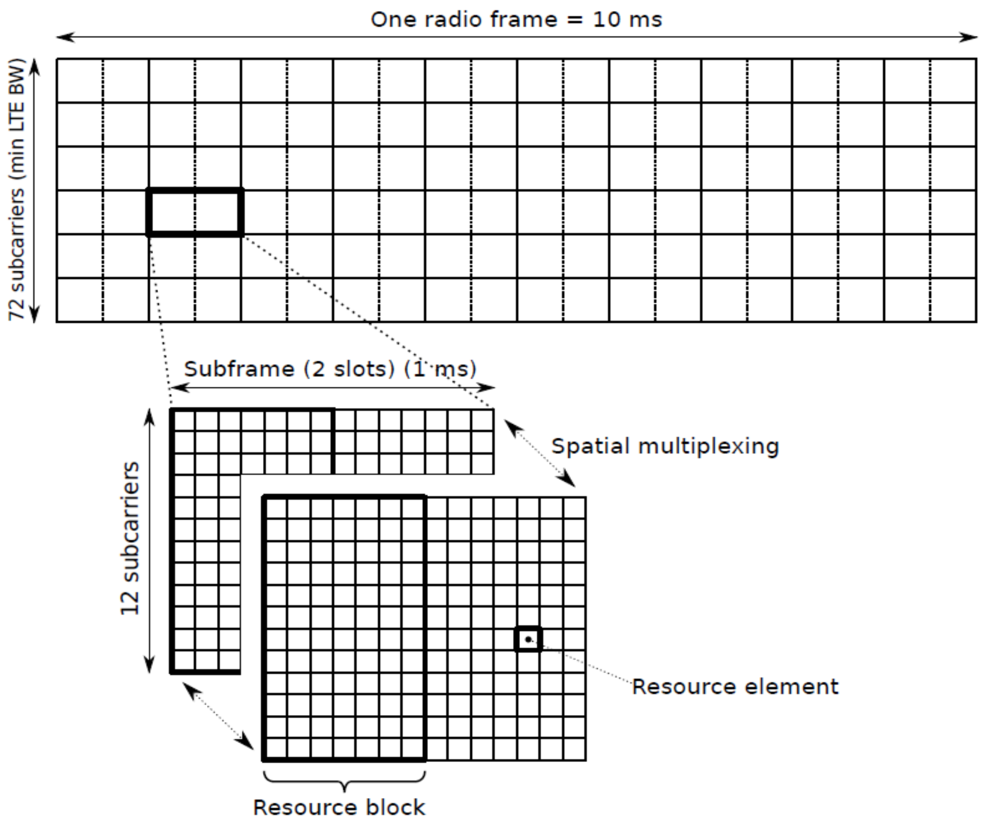
Fragen

und

Diskussion

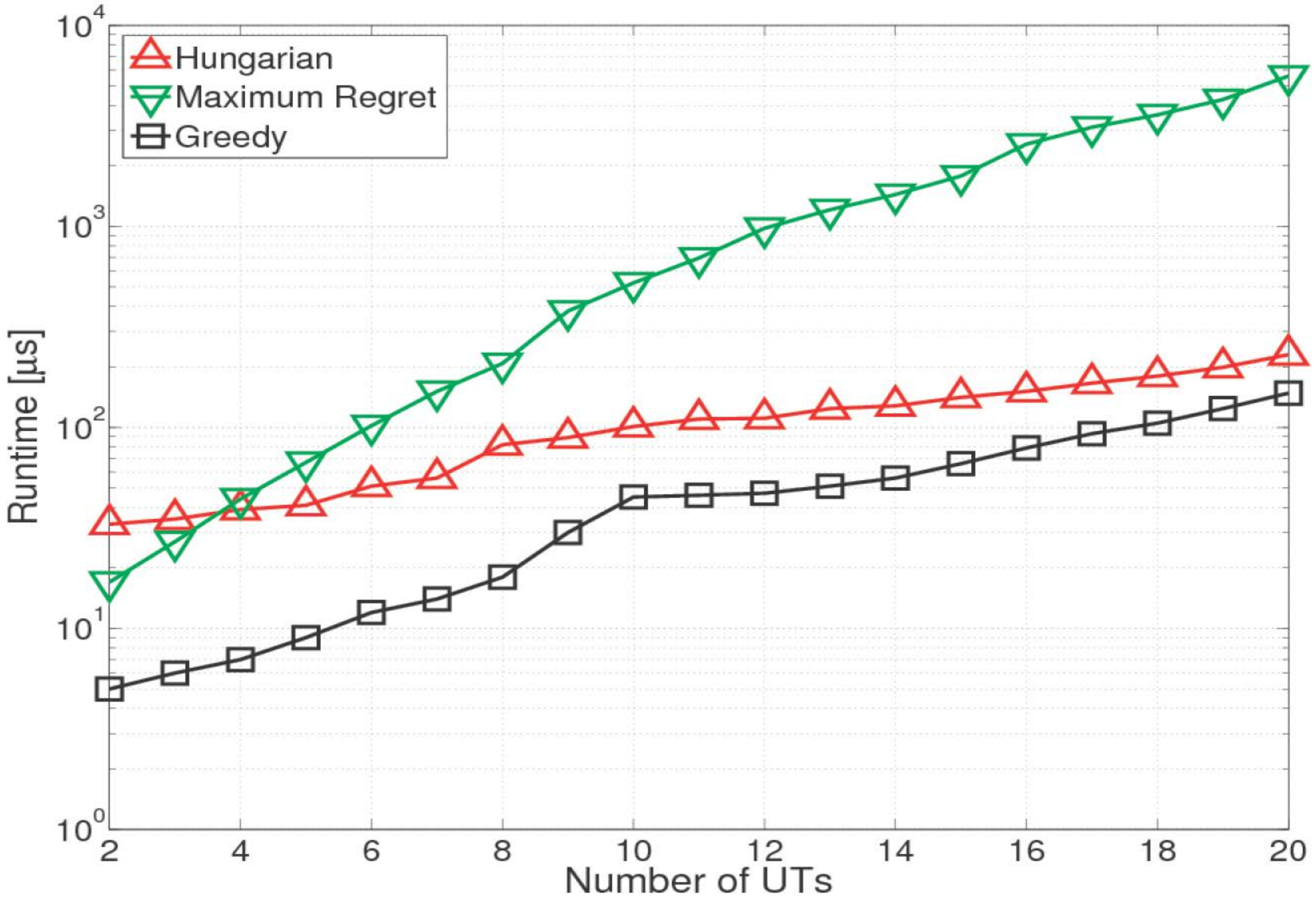
Radio Environment / Resource Structure



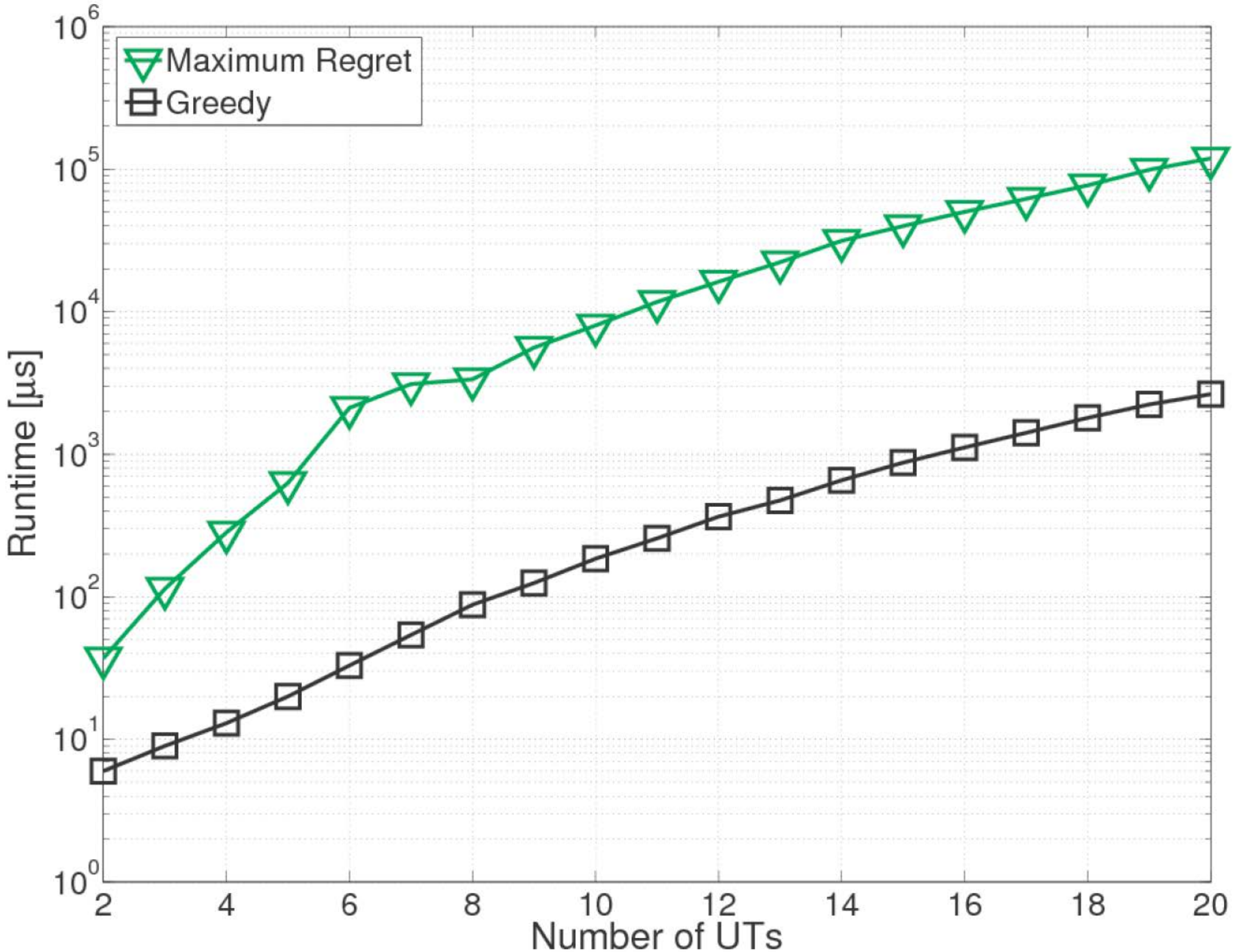
Resource Block (RB)

- In the following the smallest resource of a system is a resource block (RB)
- RBs for each UT are allocated continously in transport blocks (TBs) (*LTE requirement*)

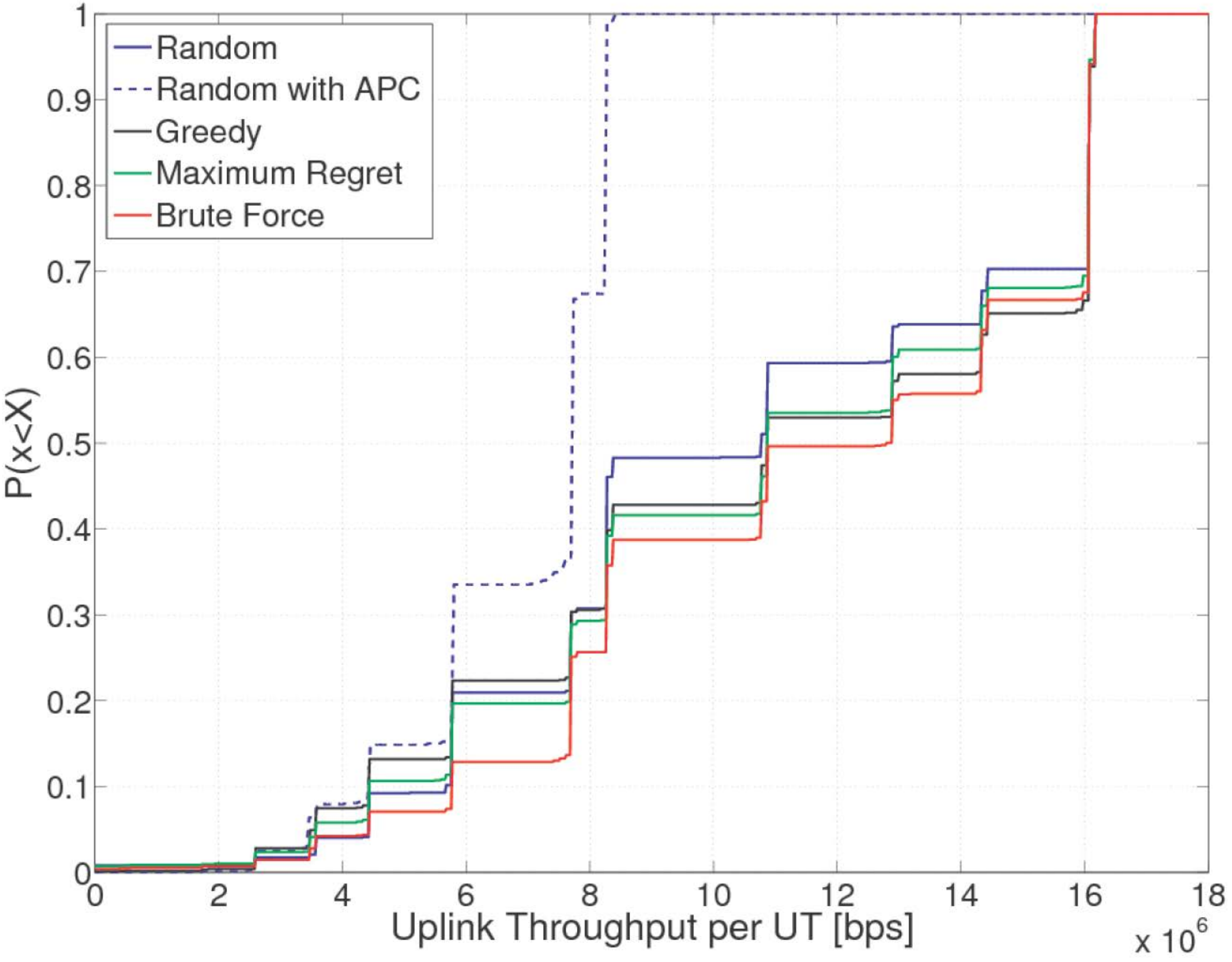
Runtime: 2FAPs



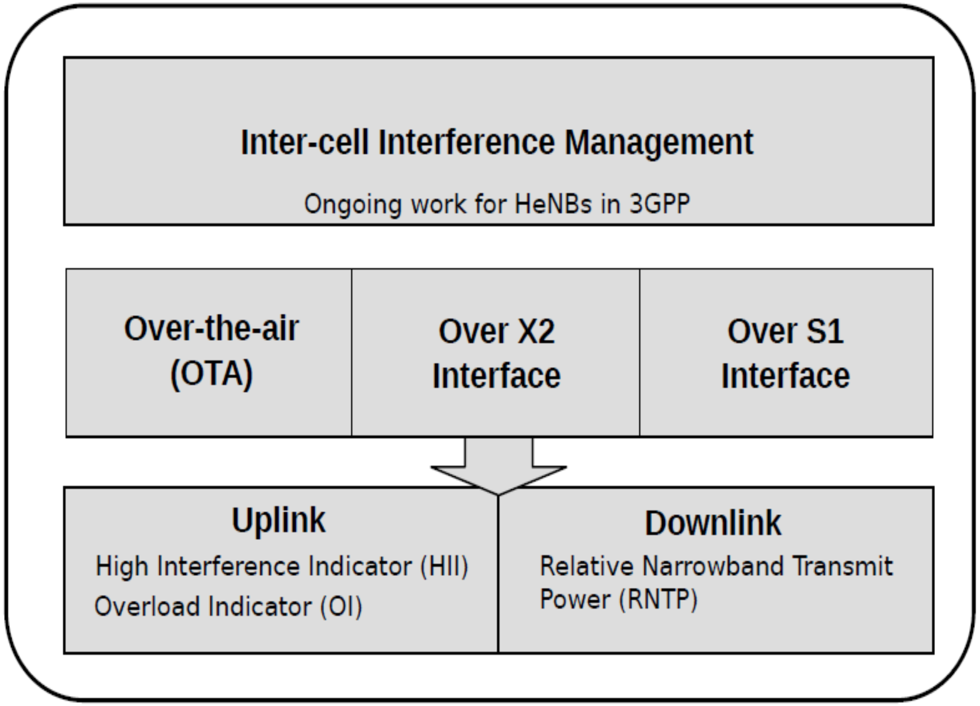
Runtime: 3FAPs



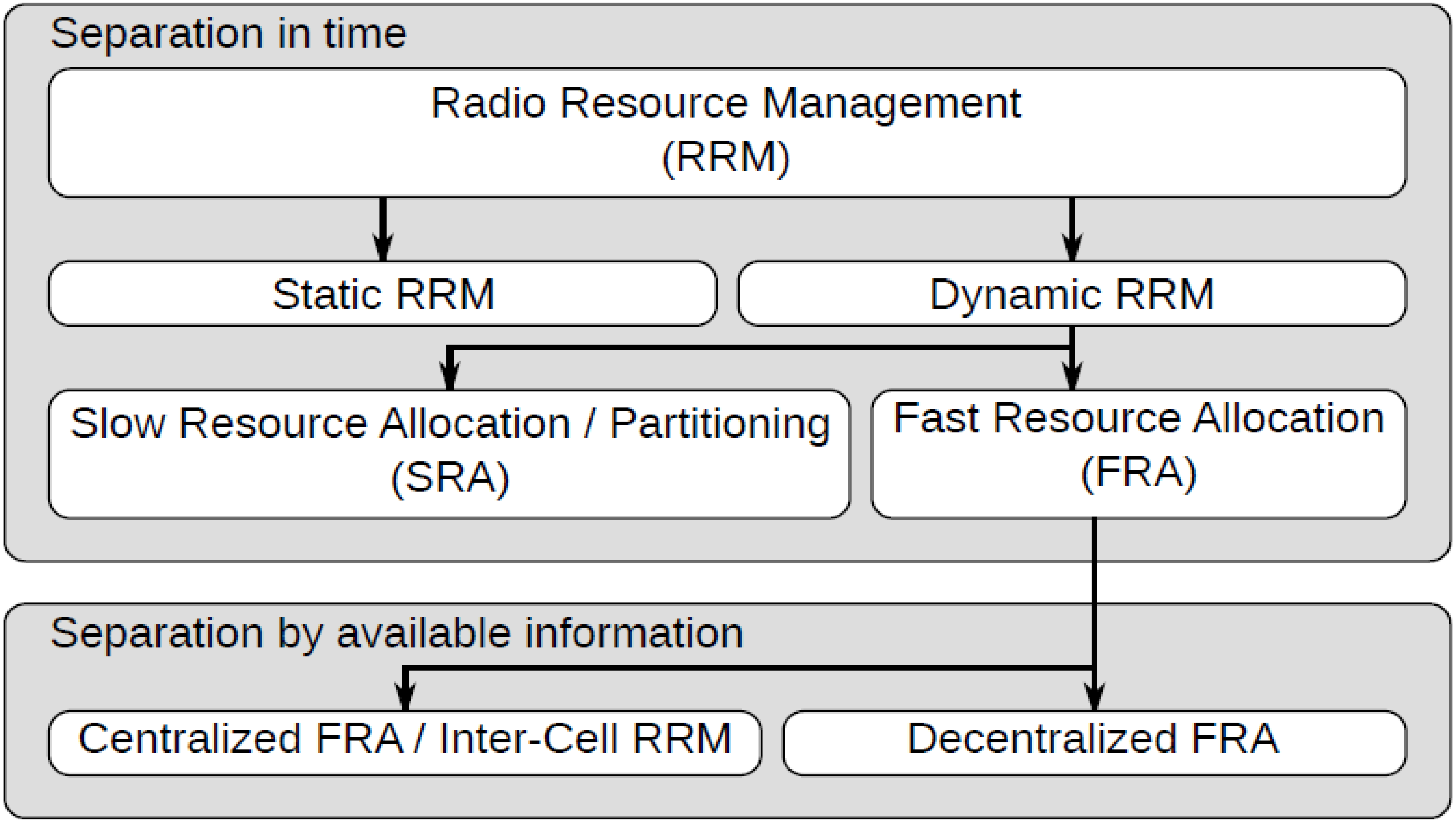
CDF: 3FAPs and 5UTs



Channel State Information

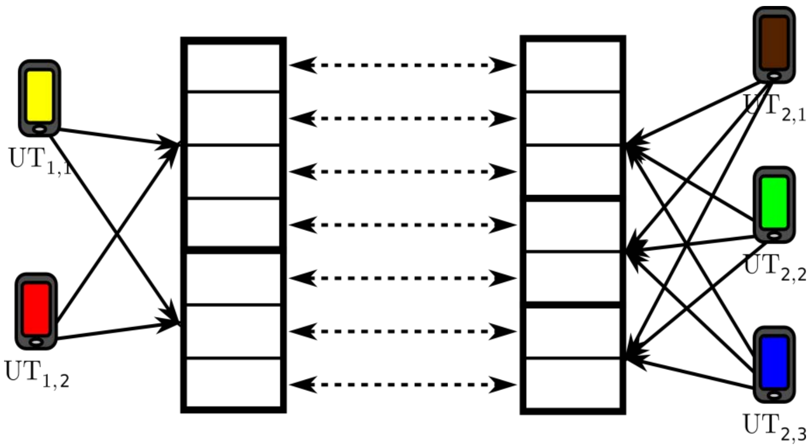


Radio Resource Management



Radio Resource Management Problem

- ➢Selecting RBs forming TBs
- ➢Link Adaption
- ➢Assignment of UTs to TBs



Cell Spectral Efficiency:

$$CSE = \frac{1}{KB} \sum_{k=1}^{K} \overbrace{\sum_{\forall \mathrm{UT}_{k,j} \in \mathbb{S}_k} n_{RB}(\mathrm{UT}_{k,j}) \cdot r(\mathrm{SINR}_{eff}, \mathrm{UT}_{k,j})}^{\text{Cell Throughput}}$$

Optimization:

$$\max \sum_{k \in \mathbb{K}} \sum_{j \in \mathbb{S}_k} \sum_{t \in \mathbb{T}_k} a_{k,j,t} \cdot r(\mathrm{SINR}_{eff}(k,j,t))$$

Constraints:

$$\sum_{t \in \mathbb{T}_k} a_{k,j,t} = 1 \qquad \text{for } j,k \mid j \in \mathbb{S}_k \wedge k \in \mathbb{K}$$

$$\sum_{k \in \mathbb{K}} a_{k,j,t} = 1 \qquad \text{for } j,t \mid j \in \mathbb{S}_k \wedge t \in \mathbb{T}_k$$

$$\sum_{j \in \mathbb{S}_k} a_{k,j,t} = 1 \qquad \text{for } t,k \mid t \in \mathbb{T}_k \wedge k \in \mathbb{K}$$

$$a_{k,j,t} \in \{0,1\}$$