Distributed Spectrum Allocation for Autonomous Cognitive Radio Networks

A. Zubow, M. Döring, A. Wolisz

Telecommunication Networks Group
Technische Universität Berlin

Outline

- Motivation
- System model / Problem description
- Proposed solution for spectrum allocation
- Performance evaluation & Results
- Conclusions

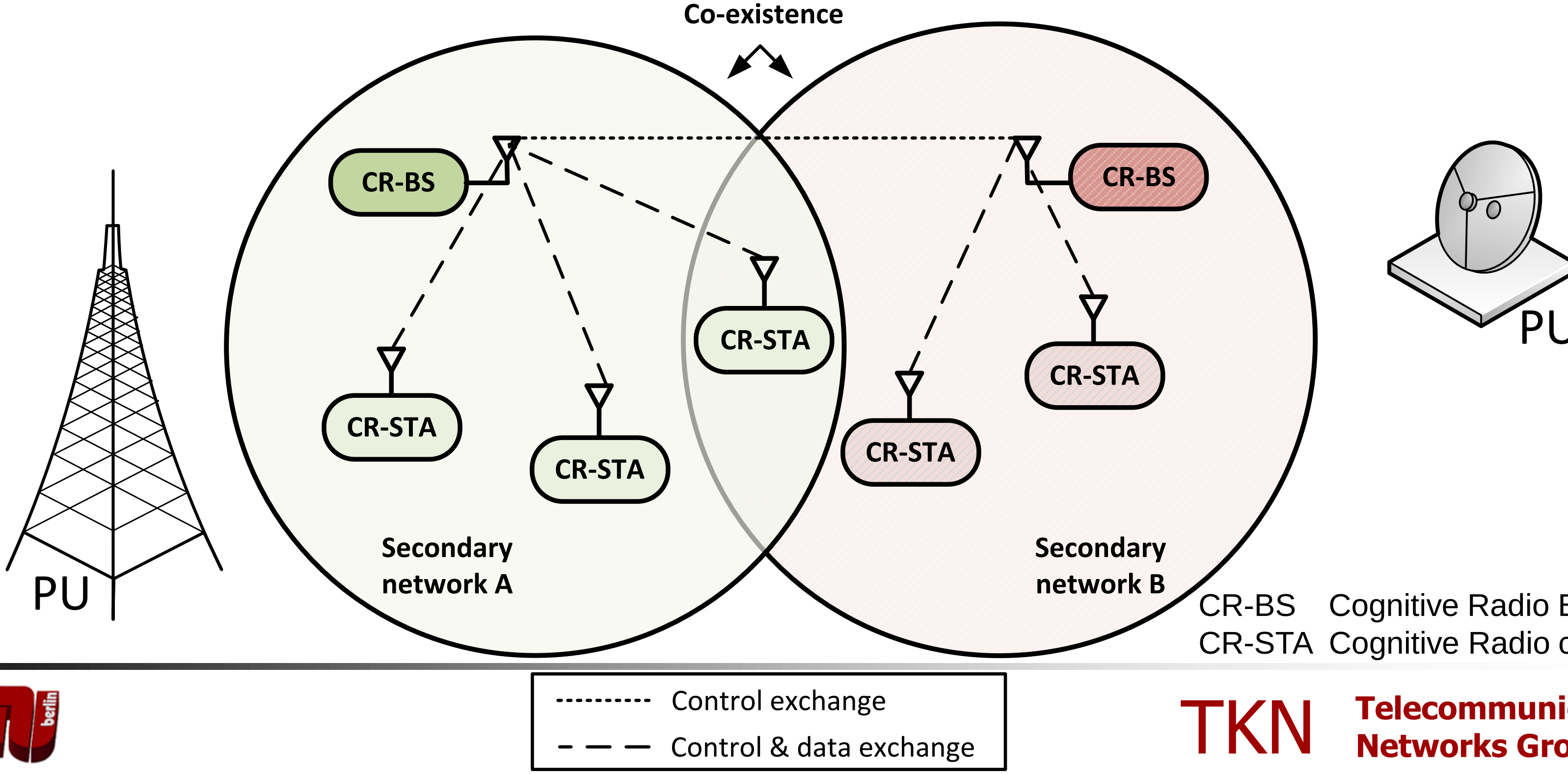
Motivation

- Given a **Cognitive Radio Network** (CRN) consisting of Primary Users (PU) and Secondary Users (SU)
- In the future we expect that **numerous groups of SUs** will access the secondary spectrum simultaneously
- This requires an intelligent and efficient **link layer** mechanism
  - Collision free access between SU groups,
  - No interference towards PUs

- **PHY Layer**: Non-Contiguous OFDM (NC-OFDM) allows use of fragmented spectrum in an efficient way

System Model

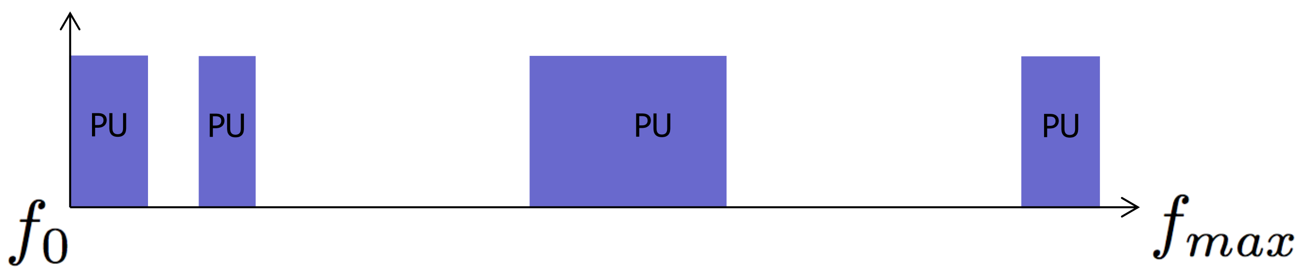
- **Focus**: co-existence of multiple **overlapping SU cells**
- Each cell consists of a base station (CR-BS) and associated client stations (CR-STA)
- Spectrum access within the cell is coordinated by CR-BS
- CR-BS has up-to-date PU spectrum information



CR-BS Cognitive Radio Base Station
CR-STA Cognitive Radio client

System Model – cont'ed

- All nodes are equipped with half-duplex **wideband NC-OFDM** transceivers
- **Total spectrum** $f_0 \ldots f_{max}$ is divided into NSC subcarriers (**including** spectrum used by **PUs**)
- CR-BSs exchange beacons in-band, used for neighbor discovery
- All nodes are time synchronized, e.g. by GPS, needed for beacon exchange
- **PUs** are completely **unaware** of SUs



Problem Formulation

- **Problem description**:
  - Find **optimal allocation of secondary spectrum** among SUs, which is not claimed by PUs
  - Ensure **interference avoidance** between co-located **CR-BSs** and strictly towards **PUs**
  - **Problem**: high computational complexity (NP-complete) requires heuristic

- **Instance**:
  - Set of CR-BSs
  - Interference represented by two **interference matrices**
    1. between CR-BSs,
    2. from CR-BSs towards PUs

Problem Description - Objective

- Goal is to find a **valid assignment** of subcarriers to CR-BSs:

$$A_{v,s} = \begin{cases} 1, & \text{if subcarrier } s \text{ is assigned to node } v \\ 0, & \text{otherwise} \end{cases}$$

- under constraint of achieving **max-min fairness**:

$$A = \arg\max_{A} \min_{v \in \mathrm{V}} \left(\sum_{s \in S} A_{v,s} \right)$$

Subject to

- **Interference avoidance between CR-BSs**

If $A_{v,s} = 1$ then $\forall u : (v,u) \in E_{\mathrm{SU}} \rightarrow A_{u,s} = 0$

- **Outage avoidance**

$$\exists s : A_{v,s} = 1, \forall v$$

- **PU protection**

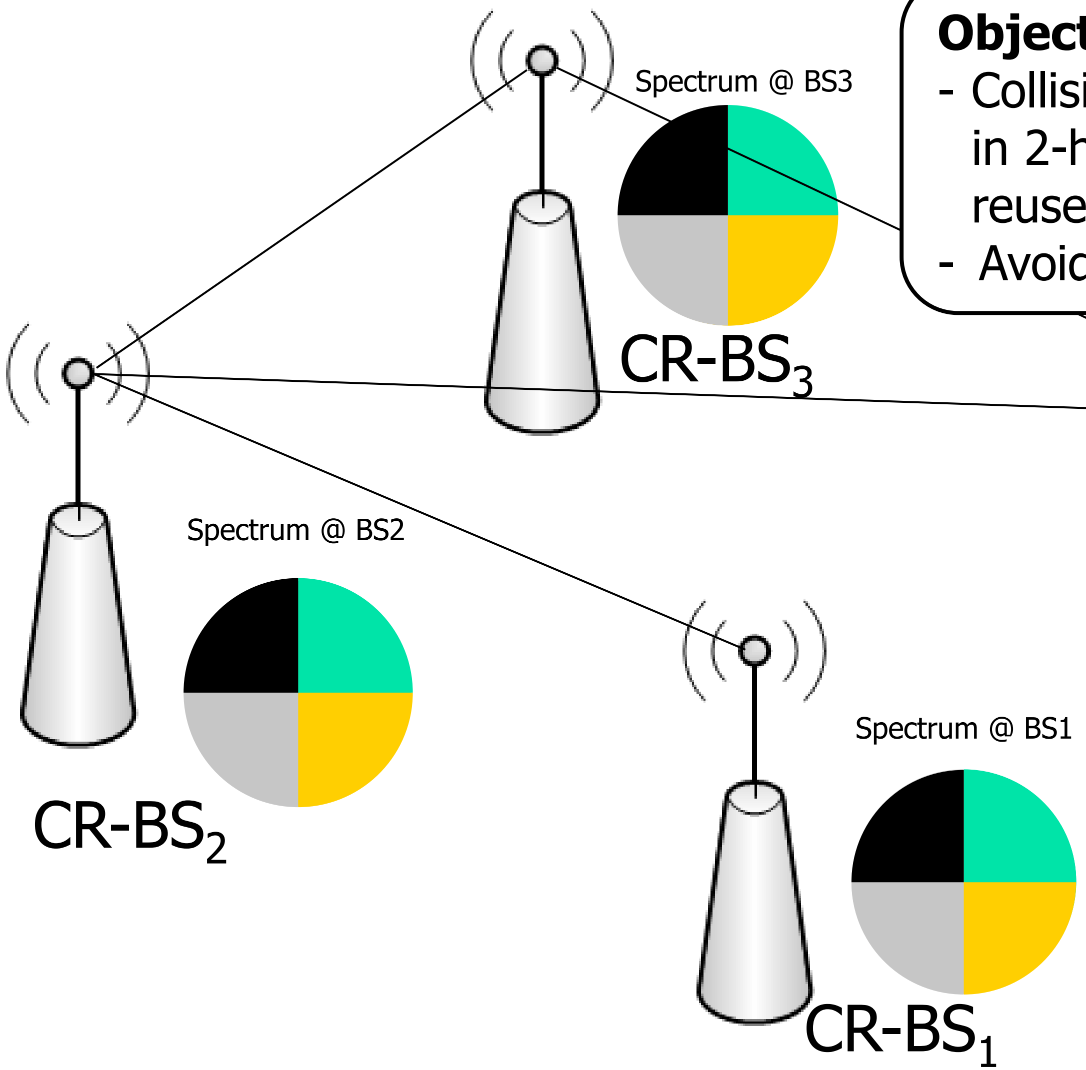
If $A_{v,s} = 1$ then $\forall u \in \mathcal{P} : (v,u) \notin E_{\mathrm{PU}}$

Proposed Spectrum Allocation Solution

Collision-free Assignment w/ respect to CR-BS

- Estimating the **interference graph**
  - Assumption: interference range is twice the wireless communication range
  - Re-use of spectrum beyond two-hop neighborhood
- Calculating the spectrum share
  - Every CR-BS calculates a **ranking number** (r_v)which is unique in its two-hop neighborhood,
  - CR-BSs **exchange** their ranking number and the highest so far known ranking number (r_v^{max}) with neighboring CR-BS using beacons,
  - From both numbers each CR-BS can calculate its **specific spectrum share in the total spectrum (including primary spectrum)** $\left(\left\lceil \frac{\Delta f \times (r_v - 1)}{r_v^{\max}} \right\rceil + 1, \left\lceil \frac{\Delta f \times r_v}{r_v^{\max}} \right\rceil\right)_{\Delta f\,=\,f_{max} - f_0}$

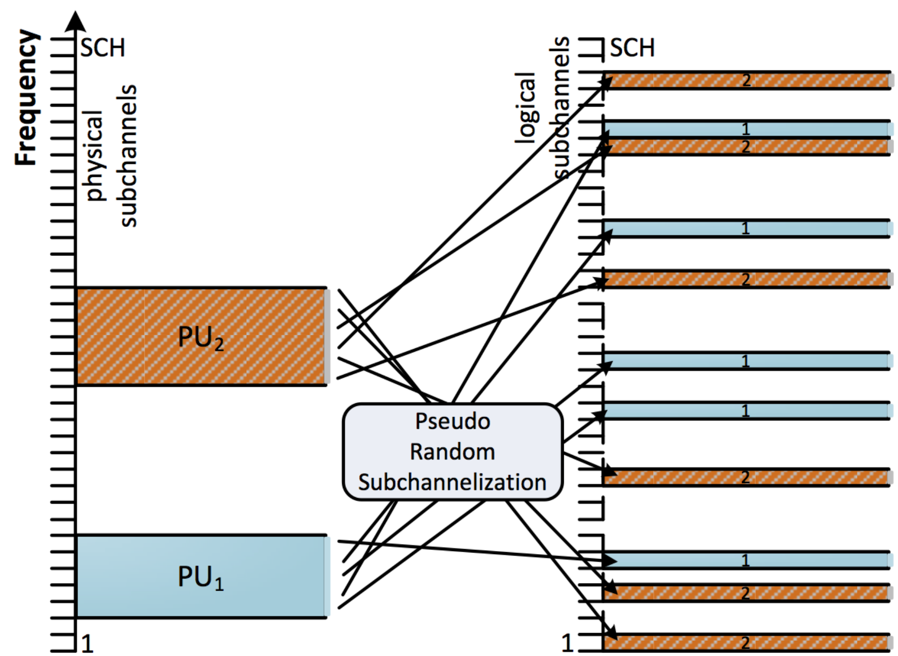
Illustrative Example



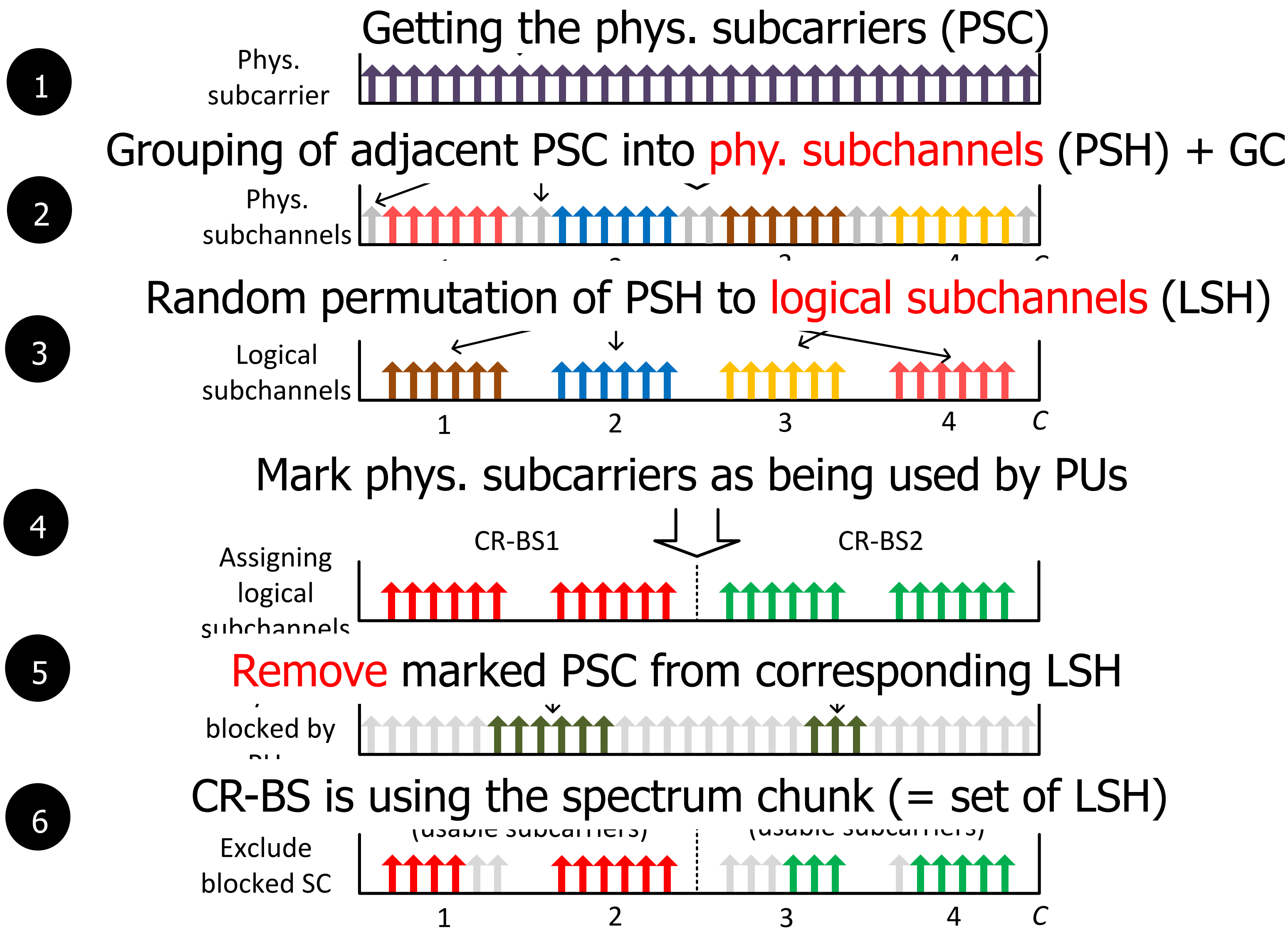
Objectives:
- Collision free spectrum assignment in 2-hop neighborhood (spatial reuse after 2-hops)
- Avoid unused spectrum

PU Protection by excluding Subcarriers

- Spectrum occupied by PUs is excluded from assigned secondary spectrum
- **Problem:**
  - It is likely that spectrum used by a PU is continuous
  - Hence, a SU can be fully blocked.
- **Solution:**
  - To avoid complete blocking of SUs by PUs a distributed subchannel permutation scheme is applied
  - Each PU is scattered over the spectrum of all CR-BSs



Illustrative Example

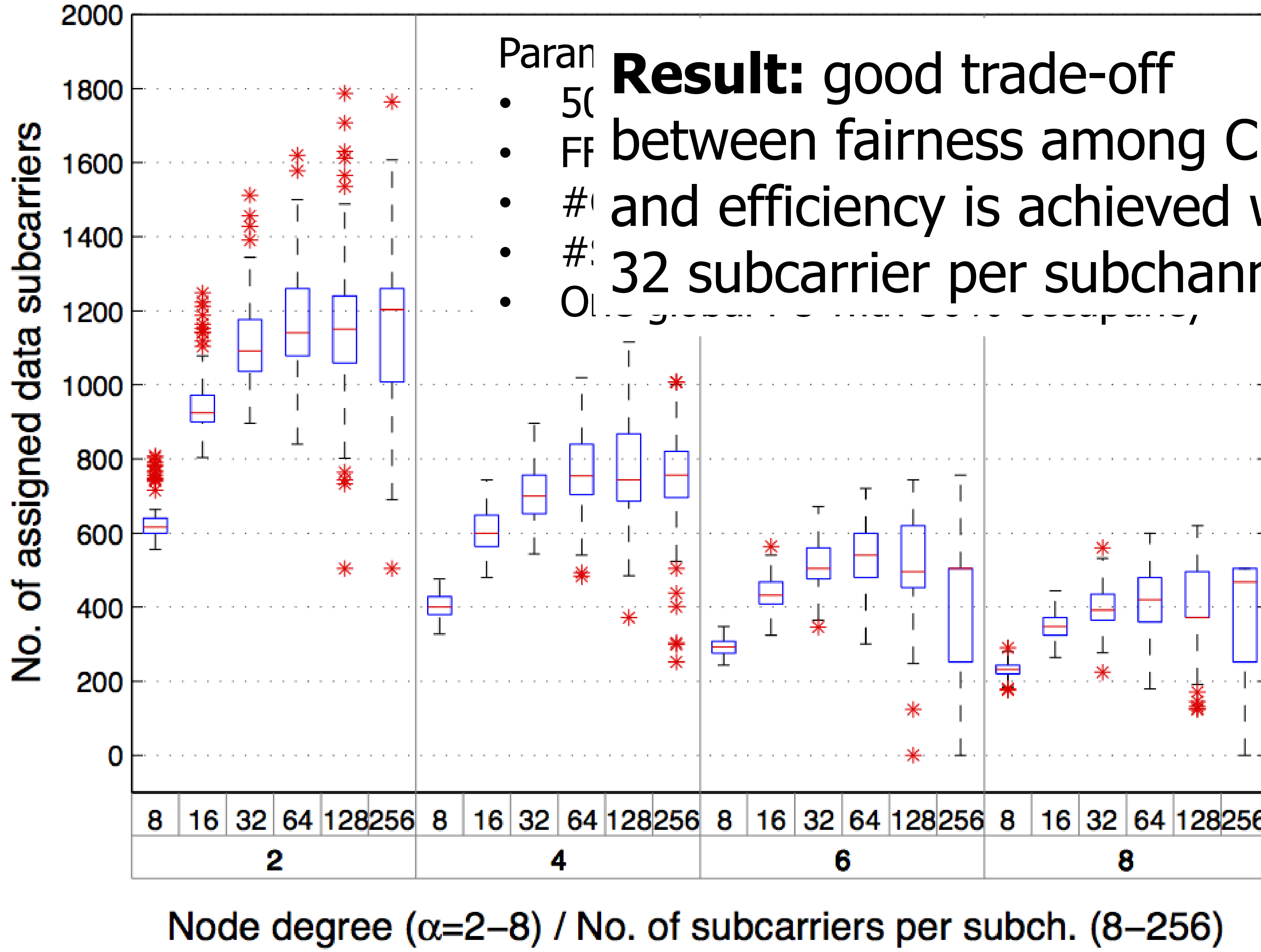


Performance Evaluation

Evaluation Methodology

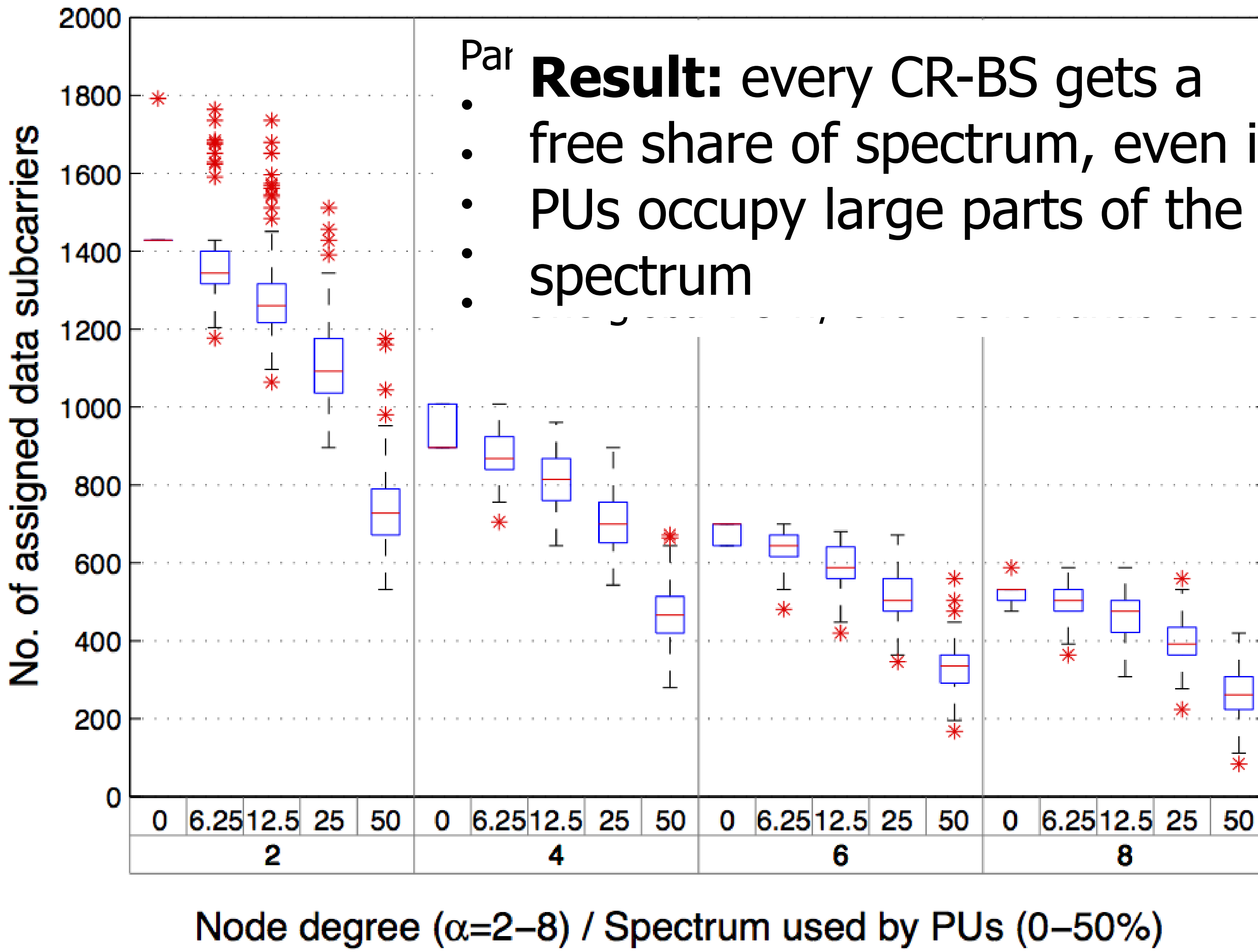
- Simulation in Matlab
- Comparison with optimal solution (Gurobi solver)
- Different scenarios concerning
  - Optimal number of subcarriers per subchannel,
  - Impact of PUs,
  - Comparison with global optimum.

Optimal number of subcarriers per subchannel



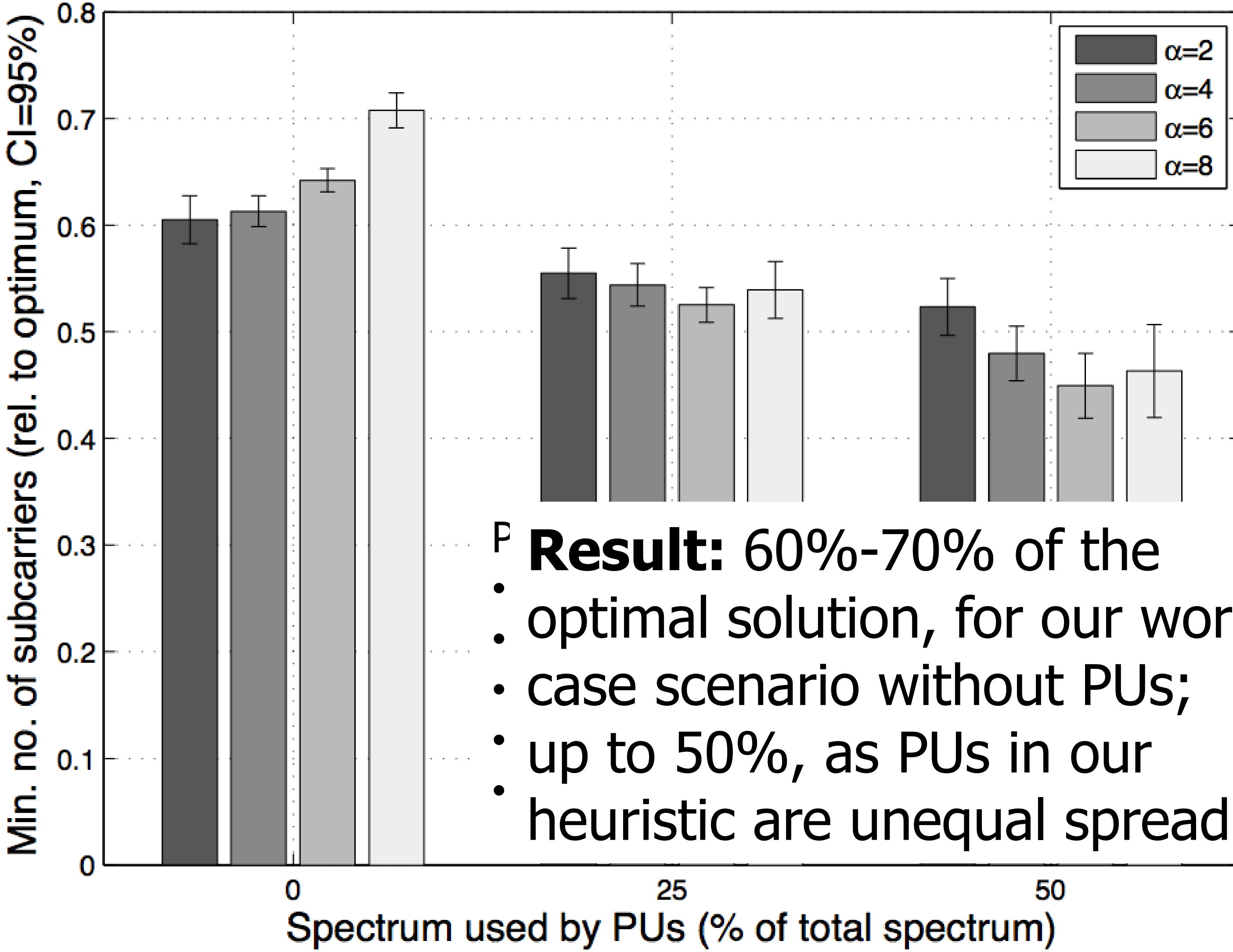
Result: good trade-off between fairness among CR-BS and efficiency is achieved with 32 subcarrier per subchannel

Impact of PUs on spectrum assignment



Result: every CR-BS gets a free share of spectrum, even if PUs occupy large parts of the spectrum

Relative Performance of Proposed Algorithm to the global optimum



Result: 60%-70% of the optimal solution, for our worst case scenario without PUs; up to 50%, as PUs in our heuristic are unequal spreading

Conclusions

- A **fully distributed algorithm** for spectrum allocation in autonomous CRNs was proposed:
  - Low computational complexity,
  - Low communication overhead,
  - Achieving fairness, i.e. available spectrum is split equally among spatially co-located SU groups,
  - No need of a Common Control Channel

Paper: Anatolij Zubow, Michael Döring and Adam Wolisz, "Distributed Spectrum Allocation for Autonomous Cognitive Radio Networks", *European Wireless*, Barcelona, Spain, 2014

Acknowledgment: This work has been supported by the COUWBAT project of the German Federal Ministry of Education and Research (BMBF 16KIS0029).

BACKUP

Algorithm extension

- Number of neighbors is not homogenous for the whole network, there exist sparse and dense parts
- Edge nodes have often lower number of neighbors

- Problem: usable spectrum is unused

- Optimization: Utilize unused spectrum
- In addition a second set of ranking numbers is needed and reported to all its two-hop neighbors

Gain from Algorithm Extension

Parameters:

- 50, 100, 200 nodes with variable # of neighbors
- FFT size = 8192
- #Guards per subchannel = 2 left + 2 right
- #Subcarriers per subchannel = 32
- 12, 25, 50 PUs uniformly distributed w/ occupancy of 2%, 1%, 0.5% respectively