An Ultra-Wide Overlay Cognitive Radio System for Wireless Back-hauling for Small Cells

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Outline

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- COUWBAT MAC Layer
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Motivation

- Wireless access technologies such as **WLAN** have recently gain **very high bitrates**, therefore **backhauling** has become the **bottleneck**
- **Cognitive Radio Networks (CRN)** in combination with **Software Defined Radios (SDR)** can be a solution for backhauling
- **PHY Layer**: Non-Contiguous OFDM (NC-OFDM) allows use of fragmented spectrum in an efficient way
- This requires an intelligent and efficient **link layer** mechanism
Contributions

- Designing a particular MAC which allows contention-free access, while providing fixed delay and high throughput.
- Integrating an in-band signaling scheme which can use different subchannels in distinct neighboring cells.
- Evaluating the performance of our MAC scheme both analytically and by means of network simulations with ns3.
- The source code of our ns3 simulation model is available via github.
System and Modeling
COUWBAT System Model

- **Scenario**: wireless wideband overlay cognitive radio backhauling for small cells (e.g. WLAN)

- Hierarchical structure:
  - CR Base Station (CR-BS)
  - CR Client Stations (CR-STA)

- Stationary network, medium-range communication links (max. 300m), target data rate of 1 Gbps
COUWBAT Physical Layer

AED Engineering GmbH, Munich
**General Parameters**

- 3 GHz analog bandwidth
- Three transmission bands of each 1.024 GHz digital bandwidth with Direct-RF
  - Divided into two logical bands of 512 MHz with 2048 subcarriers each
- Every subcarrier can be switched separately on and off
- Different constellation per subcarrier possible
- 8192 points FFT
FPGA architecture

Diagram showing the FPGA architecture with the following components:
- Linux Host
  - PCI Express
  - Mapper
  - IFFT
  - Polyphase Filter
  - Interpolation and DUC
    - DAC
  - Front End
  - Demapper
  - FFT
  - Polyphase Filter
  - DDC and Decimation
    - Preamble Detector
  - ADC
COUWBAT MAC Layer
Channelization and Framing

- **Control phase** - in-band control channel
  - Selected frequencies only...
- **Data phase**

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Design Considerations
Design Considerations

- Assumption: Whole spectrum is dedicated to licensed users, but via a database available spectrum fragments for secondary usage can be requested for a given time in a given area
- Spectrum can be revoked on short notice
- Every CR-BS has low latency access to the database
- Each CR-STA is controlled by its CR-BS only
Signaling Overhead as Function of Subchannel Width

- Number of subcarriers [FFT size]
  - 10
  - 20
  - 30
  - 40

- Required signaling data [Bytes]
  - 0
  - 500
  - 1000
  - 1500
  - 2000
  - 2500

64 subchannels with 8MHz channel bandwidth each [32 subcarriers per subchannel]
Radio Resource Map (RRM) size
Radio Resource Map Size

Number of available subchannels

RRM symbols [OFDM symbols]

RRM size [Bytes]

Slots

Number of allocatable DL/UL frames

QPSK + 1/2
QPSK + 3/4
16QAM + 1/2
16QAM + 3/4
64QAM + 1/2
64QAM + 2/3
64QAM + 3/4
Brutto PHY Rate

Number of available subchannels

Brutto PHY rate [Gbit/s]
MAC Rate

Number of available subchannels

Aggregated MAC throughput [Gbit/s]

- QPSK + 1/2
- QPSK + 3/4
- 16QAM + 1/2
- 16QAM + 3/4
- 64QAM + 1/2
- 64QAM + 2/3
- 64QAM + 3/4
Framing – Revisited

- Association

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Association Phase

Number of slots in contention phase
12345678

Average association time of last STA [s]
1 2 3 4 5 6 7

Number of STAs
- 32
- 16
- 8
- 4
- 2

Number of slots in contention phase
1 2 3 4 5 6 7 8
Scanning Phase

Number of slots in contention phase

Overhead [%]

1 2 3 4 5 6 7 8

0.2 0.4 0.6 0.8 1 1.2 1.4 1.6 1.8 2
Performance Evaluation
NS3 Simulation Model

- 1 CR-BS, n CR-STA
- Placement: random and fixed
  - Height: CR-BS 30m, CR-STA 6m
- Bandwidth 512MHz (2048 subcarrier)
  - 64 subchannel, 32 subcarrier each
- Okumura Propagation Model (small city, urban environment) and Nakagami Fading Model
  - Both per subchannel
- Transmit power 17dBm
- 7 MCS (QPSK 1/2,3/4; 16-QAM 1/2,3/4; 64-QAM 1/2,2/3,3/4)
- Trace-based PU, but not interfering (database)
NS3 Topology

ns3

upper layers

MAC
BS

interface

PHY

Channel

upper layers

MAC
STA

interface

PHY
UDP End-to-End Delay

![Graph showing CDF of transmission time vs. reception time for CR-STA RX (DL) and CR-BS RX (UL).]
MAC level throughput w/o PU

Distance [m]

50 100 150 200 250 300 350 400

Throughput [Gbps]

0 0.2 0.4 0.6 0.8 1.0 1.2

- No PU Downlink
- No PU Uplink
- Toggle PU Downlink
- Toggle PU Uplink
- Skopje Trace PU Downlink
- Skopje Trace PU Uplink
Skopje Trace/ Uplink/ Multiple Stations

Throughput [Gbps] vs Distance [m] for different numbers of STAs (2-8).

- 2 STAs
- 3 STAs
- 4 STAs
- 5 STAs
- 6 STAs
- 7 STAs
- 8 STAs
Conclusions
Conclusions

- Proposed the COgnitive Ultra-Wide BAckhaul Transmission system, which allows flexible usage of a very wide range of non-continuous, allocatable spectrum.

- Designed a flexible Cognitive MAC, which allows fast adaptation on spectrum changes, while protecting primary users.

- Evaluated the design analytically, as well as by a self-deployed ns3 model.

- Integration/Test on real hardware was due to certain difficulties not possible (no stable synchronization between boards) – nevertheless, a demonstrator was set up.
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Thank you.

Acknowledgement
This work has been supported by the COUWBAT project of the German Federal Ministry of Education and Research (BMBF 16KIS0029) and the European Union's Horizon 2020 research and innovation program under grant agreement No 645274 (WiSHFUL project)