COGNITIVE RADIO

Technology Survey & Future Research Directions

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Outline

- Introduction
- Issues
- Standardization efforts
- Conclusions and future research directions

Introduction

Current static spectrum allocation policies

The radio spectrum is growing in **scarcity**
Unlicensed frequencies are getting **crowded**

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Licensed frequency bands are often **underutilized**
Federal Communication Community (FCC), 2002

=

"**Artificial scarcity**" / "**Inefficient usage**" of the radio spectrum

Introduction

Current static spectrum allocation policies

The radio spectrum is growing in **scarcity**
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Licensed frequency
Federal Com
ized

New York City: ± **87% of the spectrum remains unused**
Jan. 2004-Aug. 2005 / Shared Spectrum Company (SSC)

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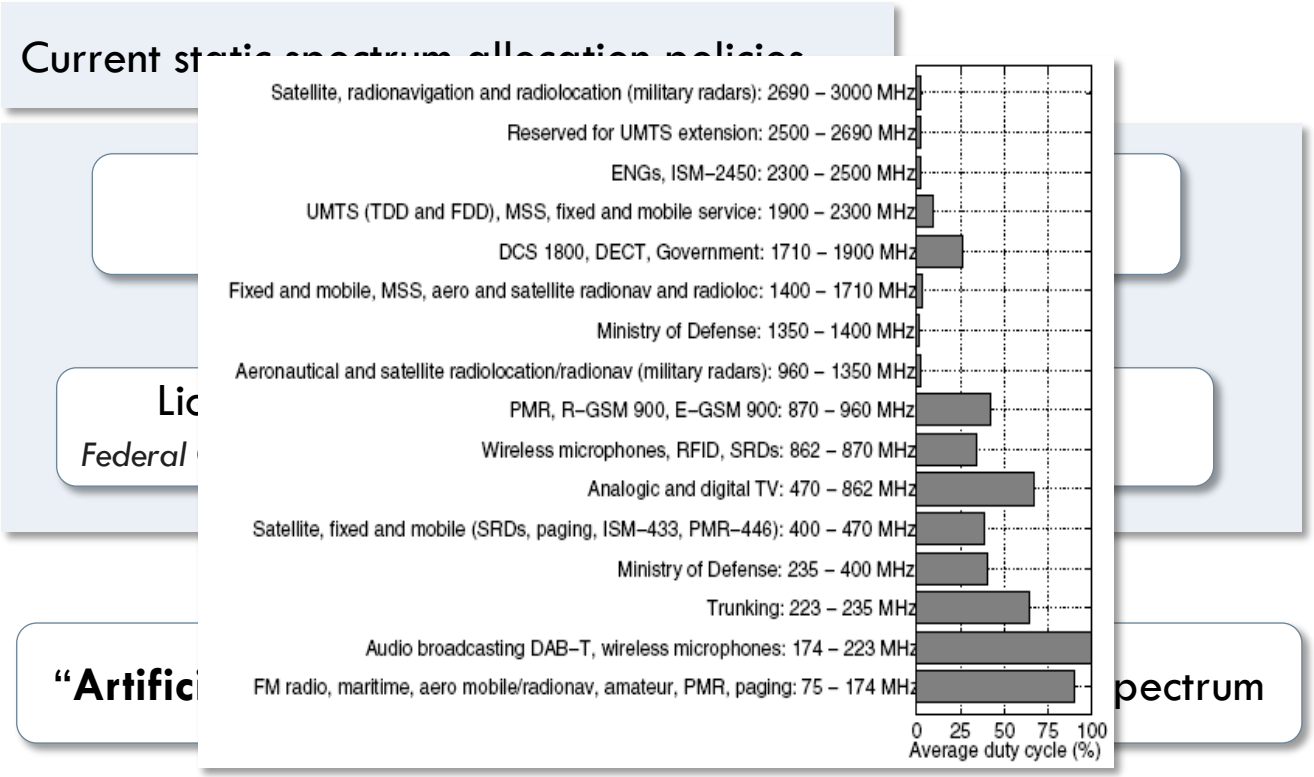
"**Artificial scarcity**" / "**Inefficient usage**" of the radio spectrum

Introduction



Occupancy statistics (Barcelona, Spain)

M. Lopez-Benitez, A. Umbert and F. Casadevall, "Evaluation of Spectrum Occupancy in Spain for Cognitive Radio Applications," Vehicular Technology, 2009. VTC Spring 2009. IEEE 69th conference on, 2009, pp. 1-5.

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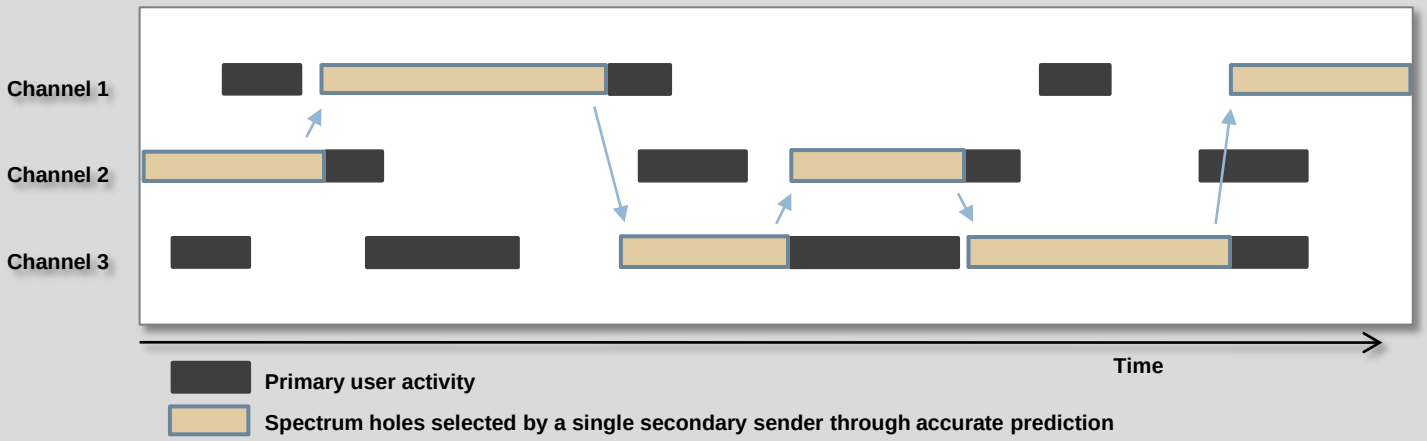
WHITE SPACES / SPECTRUM HOLES / OPPORTUNITIES
(variable in time and space)

Introduction

Current static spectrum allocation policies



WHITE SPACES / SPECTRUM HOLES / OPPORTUNITIES
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Introduction

Current static spectrum allocation policies

Cognitive Radio (CR)

⇓

Dynamic access

to the entire radio spectrum

without harmful interference to primary users

⇓

Efficient usage of the radio spectrum

(variable in time and space)

Introduction

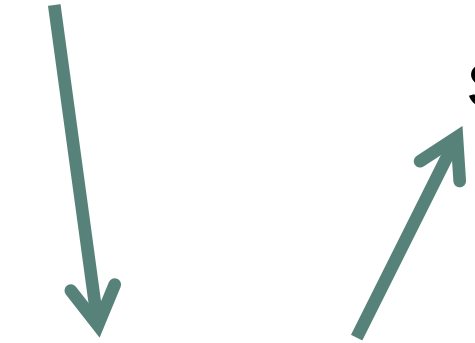
- A CR (secondary) user must be able to dynamically:
  - Analyze its radio environment (spectrum sensing)
  - Learn based on past experience (prediction)
  - Select the best transmission parameters (spectrum decision)
    - ⇨ Performance enhancement
    - ⇨ Protection of primary (licensed) systems
  - Coexist with other CR users (spectrum sharing)
- Distributed and Centralized architectural approaches

Issues

- CR issues are mostly related (but not limited) to the physical (PHY) and medium access control protocol (MAC) layers
- Spectrum sensing
  - Several approaches at the PHY layer
  - Energy detection is the simplest detection technique
    - ! Does not enable distinction between primary and secondary activity
    - ! Requires coordinated silent (sensing) periods (MAC)
  - Sensing accuracy is enhanced by cooperation (MAC)

Issues

Cooperation between CR users
(e.g., for accurate spectrum sensing and efficient spectrum sharing)



CR MAC PROTOCOLS

SIGNALING MECHANISMS

- Exchange of sensing and control information between CR users
- Usually based on a dedicated common control channel
  - ✓ Easy to deploy
  - ✓ Efficiently supports broadcasting
  - ! Requires an additional radio
  - × Prone to congestion and jamming attacks

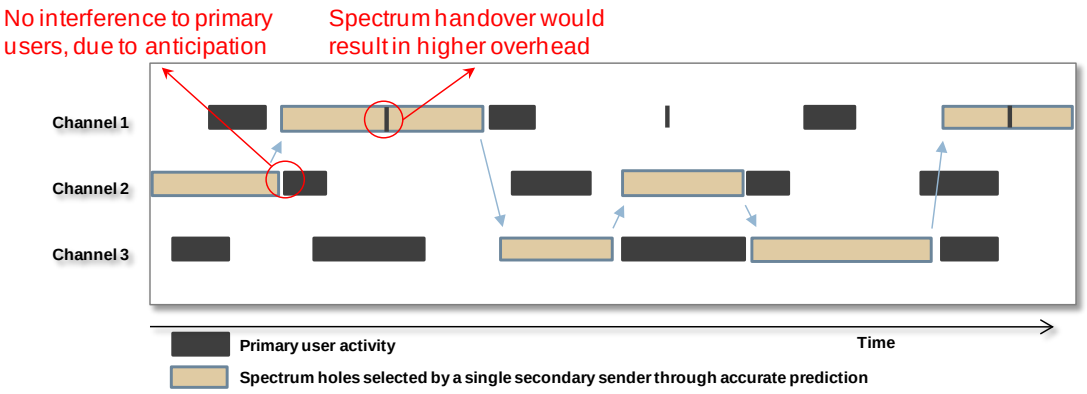
Issues

- CR MAC proposals

Proposal	Network Architecture	Spectrum Access	Number of Radios/ Transceivers	Control Channel
Ghaboosi, Latva-aho, and Xiao	Mesh	Random	2	Yes
Niyato and Hossain	Mesh	Random	1	-
Hamdaoui and Shin	Ad-hoc	Hybrid	1	Yes
Kondareddy and Agrawal	Ad-hoc	Hybrid	2	-
Jia and Zhang	Ad-hoc	Random	2	Yes
Pawelczak et al.	Ad-hoc	Random	1 or 2	Yes
Joe and Son	Ad-hoc	Random	Multiple	Yes
Nan, Hyon, and Yoo	Ad-hoc	Hybrid	2	Yes
Su and Zhang	Ad-hoc	Time-slotted	2	Yes
Le and Hossain	-	Time-slotted	1	Yes
Hsu, Weit, and Kuo	Ad-hoc	Random	2	Yes
Ma, Han, and Shen	Ad-hoc	Random	3	Yes
Choi, Patel, and Venkatesan	Ad-hoc	Random	2	Yes
Zhao et al.	Ad-hoc	Hybrid	1	-
Hsieh et al.	Infrastructure	TDMA	2	Yes
Zhang, Fitzek, and Iversen	Infrastructure	Random	1 (CR devices) Multiple (Access Points)	-
Ghaboosi et al.	Ad-hoc	Random	2	Yes
Timmers et al.	Ad-hoc	Random	2	Yes

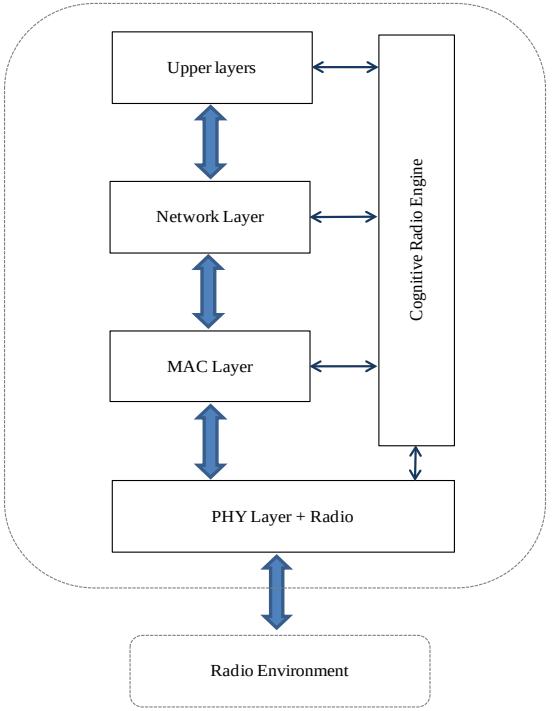
Issues

- Proactive decision making
  - Based on past experience/traffic modeling/machine learning
  - Benefits
    - Reduce energy and time which are needed to find an available channel
    - Prevent harmful interference to primary users
    - Reduce the number of spectrum handovers



Issues

- Seamless spectrum handovers
- Cross-layer design approaches
- Energy efficiency
- Upper layer protocols
  - Must be spectrum-aware
  - When a primary user appears on a link, the routing protocol must decide to either switch to another channel or compute an alternative path
  - …



Standardization Efforts

- IEEE 802.22
  - Wireless Regional Area Networks (WRAN)
  - VHF and UHF frequency bands
  - Centralized architectural approach
- IEEE SCC41
  - Dynamic Spectrum Access Networks (DySPAN)
  - Several working groups that address specific issues
  - IEEE 1900.4 is the first published IEEE SCC41 standard (27 February 2009)

Conclusions and Future Research Directions

- CR aims an efficient usage of the radio spectrum
- In the critical path to the future wireless networks
- Many issues still need further investigation
  - New business models
  - More flexible regulation policies
  - Distributed sensing solutions characterized by:
    - An effective protection of primary users
    - Low signaling overheads
    - An efficient usage of the radio spectrum

Conclusions and Future Research Directions

- Proactive decision making
  - Practical algorithms for primary user traffic modeling and prediction
  - Appropriate CR MAC-level mechanisms

LCT-CISUC

- Robust and efficient alternatives to the common control channel
- Energy efficient solutions
- Upper layer protocols which are spectrum-aware
- ...

Thank you …