Challenges of spectrum sensing in cognitive radios

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Public CWC & VTT GIGA Seminar ’08
4th December 2008
Outline

• Introduction
• Current spectrum use
• Challenges
• Performance metrics
  • Interference considerations
  • Time aspects
  • Example
• Conclusions
• References
Introduction

• Cognitive radio has the capability to sense and be aware of its operational environment and adjust its radio operating parameters accordingly.
• Cognitive radio adds *intelligence* on top of software defined radio (SDR) in which RF operating parameters, e.g. frequency range, modulation type, or output power, can be set or altered by software.
• Cognitive radio has the potential to improve the efficiency in resource use (spectrum) by opportunistically exploiting available resources.
• Cognitive radio is to be understood as a technique applicable to a variety of systems.
Current spectrum use

• Radio regulations of the ITU have internationally governed the use of radio spectrum since 1906
  • Static spectrum allocations for different services (e.g. mobile, fixed, broadcast)
  • Major goal: Protection from interference
• Two aspects of efficiency in spectrum use
  • Spectrum occupancy: What is the utilization rate of the spectrum over time (%)?
  • Spectral efficiency: How efficiently a system uses its spectrum (bit/s/Hz)?
• Measurements on current spectrum use indicate that some parts of spectrum have low occupancy in some areas
  • Average spectrum occupancy measured only 5.5% with maximum 13.1% in urban and minimum 1% in rural area in US [SSC05]
• Cellular mobile communication systems are very efficient in spectrum use (both spectrum occupancy and spectral efficiency)

ITU = International Telecommunication Union
Current spectrum use

• A paradigm shift from static spectrum allocations to more dynamic and liberal use is envisioned
• Spectrum requirement planning is usually made for worst case scenario but spectrum availability is a problem
  • E.g. IMT systems* at WRC-07
• Cognitive radio is a potential technique to improve spectrum occupancy

►WRC-11 Agenda item 1.19 “to consider regulatory measures and their relevance, in order to enable the introduction of software-defined radio and cognitive radio systems, based on the results of ITU-R studies, in accordance with Resolution 956 [COM6/18] (WRC-07)”

WRC = World Radiocommunication Conference
Challenges

• Cognitive radio is not allowed to cause harmful interference to the primary users of the spectrum
  ▶ Identification of primary users is critical
• Challenges for cognitive radio
  • High probability of detection of primary users
  • Uncertainty due to radio wave propagation
  • Own performance (no protection from interference guaranteed)
  • Time (e.g. sensing time, data transmission time)
  • Range (e.g. sensing range, interference range, communication range)
  • Transmission
  • Control data
Performance metrics

• Receiver operating characteristics (ROC)
  • Probability of detection – how well cognitive radio notices the presence of primary users?
  • Probability of false alarm – how well cognitive radio can exploit spectrum opportunities?
• Time
  • Time between failures in detection – how often primary user tolerates interruption?
  • Sensing time – how much time is used for monitoring the spectrum use vs. actual data transmission?
  • Sensing rate – how often spectrum must be sensed?
• Transmission
  • Traditional measures: throughput, delay, reliability and precedence [ETSI01] – performance of cognitive radio is not guaranteed!
  • Suitability of spectrum opportunities – how good are the spectrum opportunities?
Interference considerations

No talk zone, no SUs allowed when PU transmitting due to interference from SU

Requirement for sensing: Sensing range ≥ Interference range + Communication range of PU
Interference considerations

- Interference is caused at the primary user receivers while spectrum sensing can identify only primary user transmitters.
- Some systems use the spectrum passively without transmitting at all (e.g. radio astronomy service).
- Current systems (e.g. TV receivers) are not designed to tolerate opportunistic spectrum use on their band or adjacent bands.
- Some services (e.g. satellite) are critical and must be protected from interference at all times in all locations of the Earth.
- Cognitive radio has to obey the rules of the specific band.
Time aspects

1) Single radio sensing, separate control channel

- SU Data Transmission Time
- Maximum Tolerable Interference Time
- PU Data Transmission Time

2) Cooperative sensing, no separate control channel

- SU Data Transmission Time
- Maximum Tolerable Interference Time – Sensing Time
- PU Data Transmission Time
Example of performance metrics

Theoretical ROC for Welch’s periodogram, see [Sarvanko08].
Conclusions

• Cognitive radio offers potential to increase spectrum occupancy by identifying and exploiting spectrum opportunities
• Future systems will be intelligent in terms of spectrum use but existing systems cannot be changed
  • Introduction of cognitive radio capabilities in future wireless networks should have no impact on the existing networks if they are to be deployed on the same bands
  • Characteristics and restrictions of existing systems must be taken into account in the cognitive radio development
• Technical challenges vs. regulatory constraints
  ▶ Now is the time!
• Cooperation in all forms will become crucial
References

- [ETSI01] “Digital cellular telecommunications system (Phase 2+) (GSM); General Packet Radio Service (GPRS); Service description; Stage 2, 3GPP TS 03.60 version 7.5.0, Release 1998,” ETSI, January 2001.