Fundamental Trade-offs for Energy Efficiency in Cognitive Radio Networks

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Abstract: We discuss the implications of facilitating higher energy efficiency (EE) in Cognitive Radio Networks (CRNs) from the perspective of fundamental trade-offs, i.e. what needs to be sacrificed to be energy-efficient. These trade-offs are identified as QoS, fairness, PU interference, network architecture, and security, which are also essential network design dimensions. We analyze these dimensions and their interactions focusing on EE.

QoS vs. EE

Three approaches for QoS in CRNs: (i) PU-centric (QoS vs. EE), (ii) SU-centric (PU interference vs. EE), (iii) hybrid schemes.

Various diversity techniques can be exploited for higher QoS and EE: link diversity, spatial diversity, channel diversity, and CR diversity.

Fairness vs. EE

Fairness is largely considered as a secondary performance metric hence mostly is tried to be ensured along with the principal QoS objective. Providing high fairness may lead to sub-optimal operation regions resulting in lower EE. Hence, which degree of fairness (measured for example with Gini index) must be decided along with EE and QoS.

PU Interference vs. EE

Metrics related to PU interference: 1- Probability of detection (Pd) 2- Perceived Interference on PUs

Interference occurs under under two cases: 1- Mis-detection of the PU: ensure high Pd 2- A re-appearing PU: Ensure low minimal interference intensity and level via optimizing the sensing (e.g., optimal sensing period) and transmission (e.g., optimal transmission time or power).

Lower PU interference at the two steps: 1) Sensing step: Satisfy Pd requirements 2) Transmission step: Decrease transmission power — Lower Shannon capacity (Logarithmic decrease) — Possible solutions: relaying (Nw. architecture vs. EE) and channel aggregation (hardware complexity).

Network Architecture vs. EE

Shorter distance bw. transmitter and receiver is known to be more energy-efficient. However, they may increase the network complexity or operational costs.

1- Small cells: Cognitive small cells are EE if interference is kept under control. Are they really green? 2- Relays: What kind of relay (dedicated or every node acts as a relay)?

Sensing depends on the architecture: Internal or external sensing, in other words sensing by CRs or sensing data from Radio Environment Maps (REMs)?

Security vs. EE

- Additional processing both at the transmitter and the receiver.
- In secure environments, alleviates EE as each entity spends processing power/time and some of the channel capacity for transmitting authentication and integrity messages.
- In environments with malicious or misbehaving nodes, improves EE by avoiding interactions with malicious users and detecting the misbehaving nodes.

Attacks mostly at the sensing step: PU emulation (PUE) attack, Spectrum Sensing Data falsification (SSDF) attack -> Optimal number of security bits for EE

Can we decrease the burden of security by applying social-aware CR protocols in which CRs evaluate the sensing performance of others and only interact with highly trusted CRs?

Future Research Directions

1. Social Network Analysis
   - Uncover the hidden structure or evolution of the CRN
   - Improved self-awareness as well as environment-awareness
   - Social connections among nodes can also improve CRN performance leading to higher EE (more secure operation)
   - Social-aware cooperative sensing, social-aware relaying, social-aware routing

But revealing of social connections: privacy concerns

2. Energy Harvesting
   - The process of extracting energy from external ambient sources such as RF environment, thermal variations, or kinetic energy
   - Improving EE or enabling energy-source free operation
   - It requires two main functionalities for being practical in wireless systems: energy generation and storage
   - Harvesting-aware traffic scheduling

3. User Behavior
   - The most important actor of any communication network is the user
   - Model the behavior, predict and operate accordingly -> higher EE

Reference