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.*

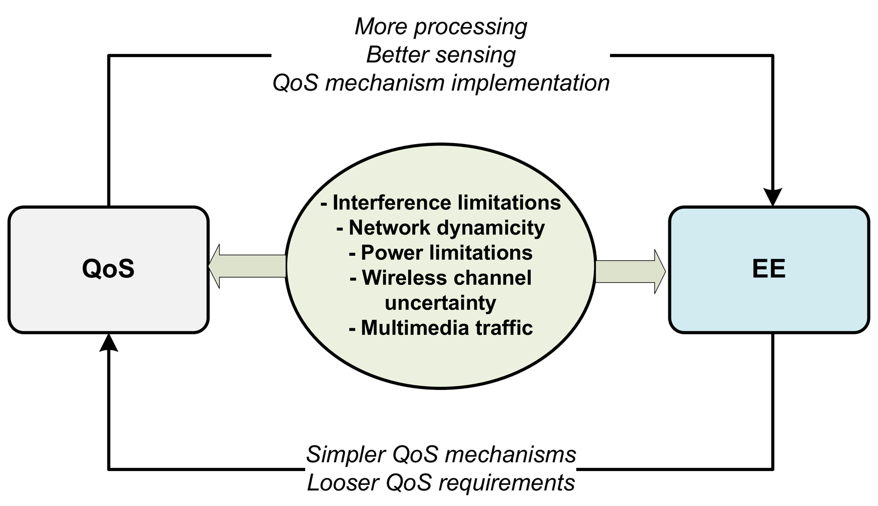


Fig. 2: EE and QoS interaction.

Fairness vs. EE

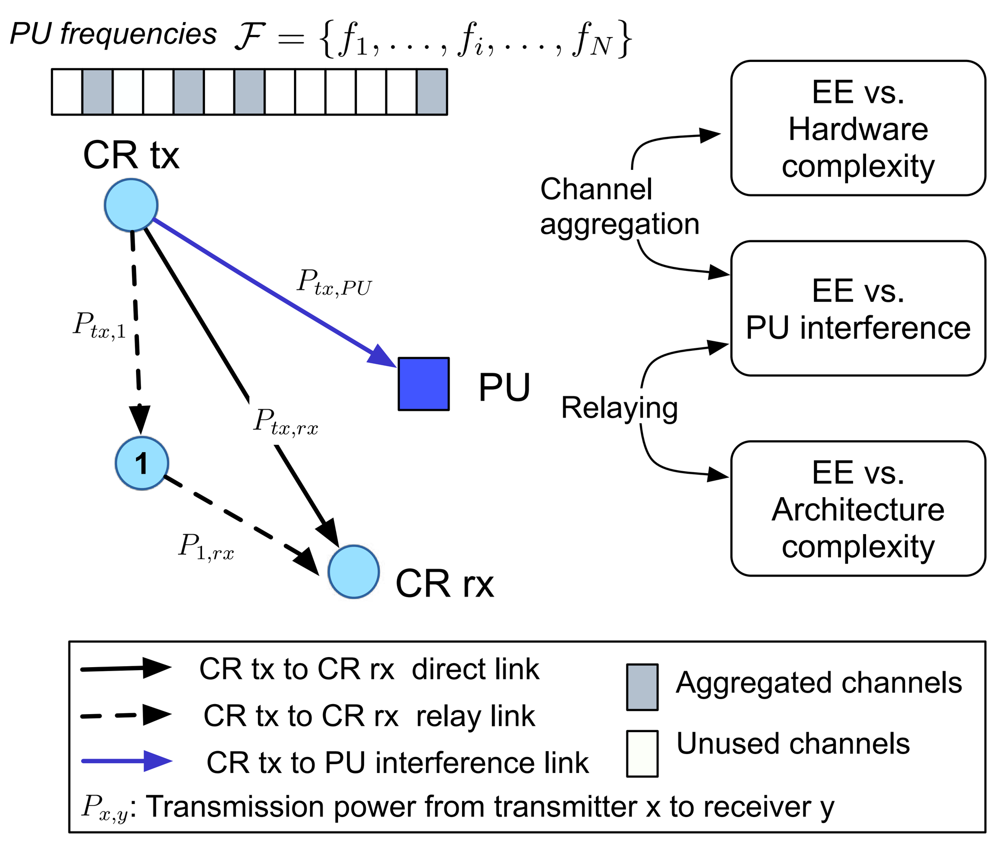
Fairness is largely considered as a secondary performance metric hence mostly is tried to be ensured along with the principal QoS objective. Providing high fairness may lead to sub-optimal operation regions resulting in lower EE. Hence, which degree of fairness (measured for example with *Gini index*)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

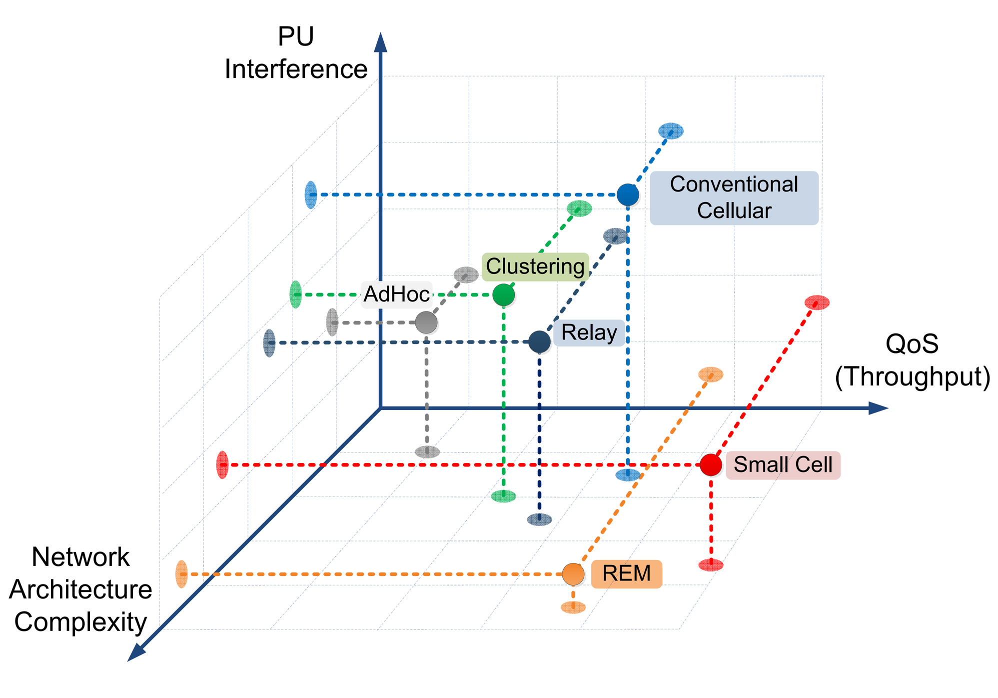
PU Interference vs. EE

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 *time* 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?

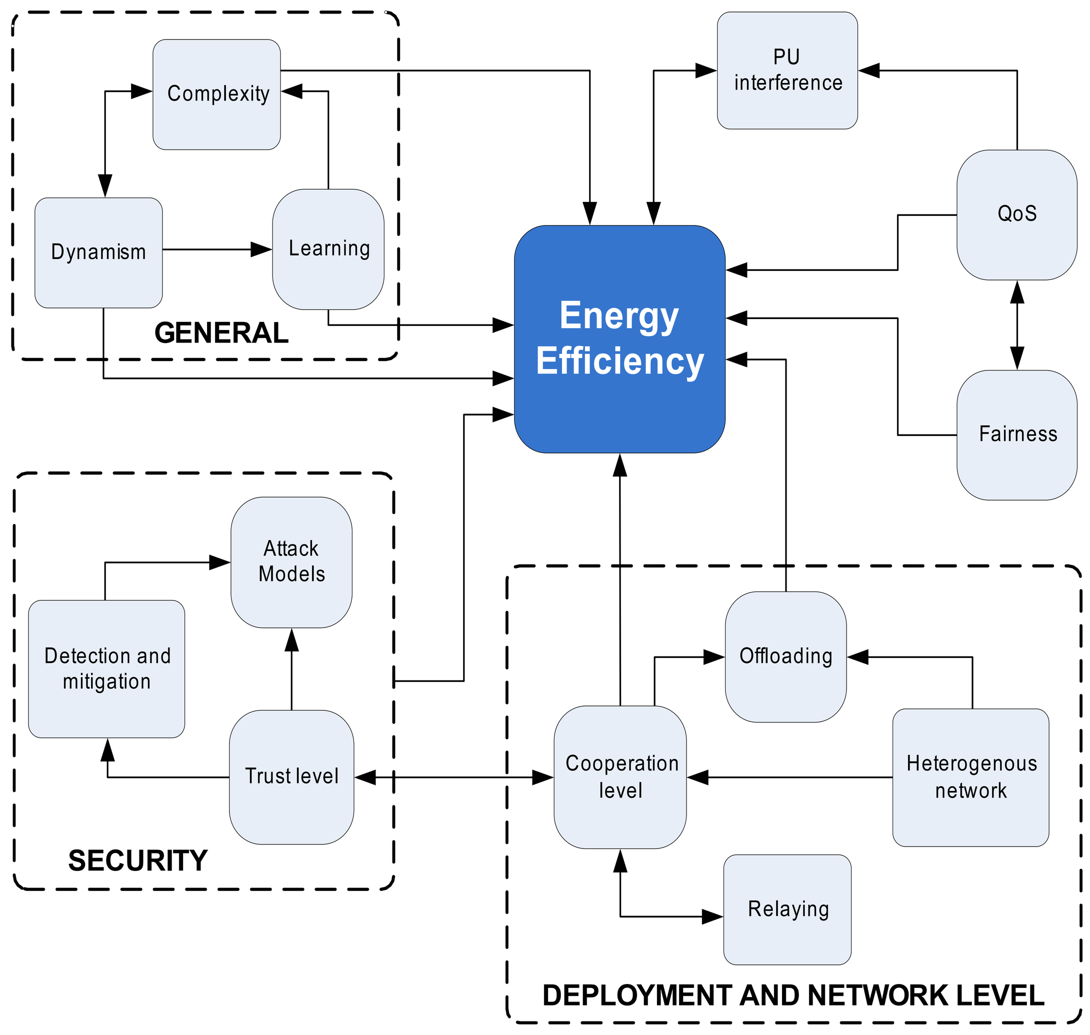


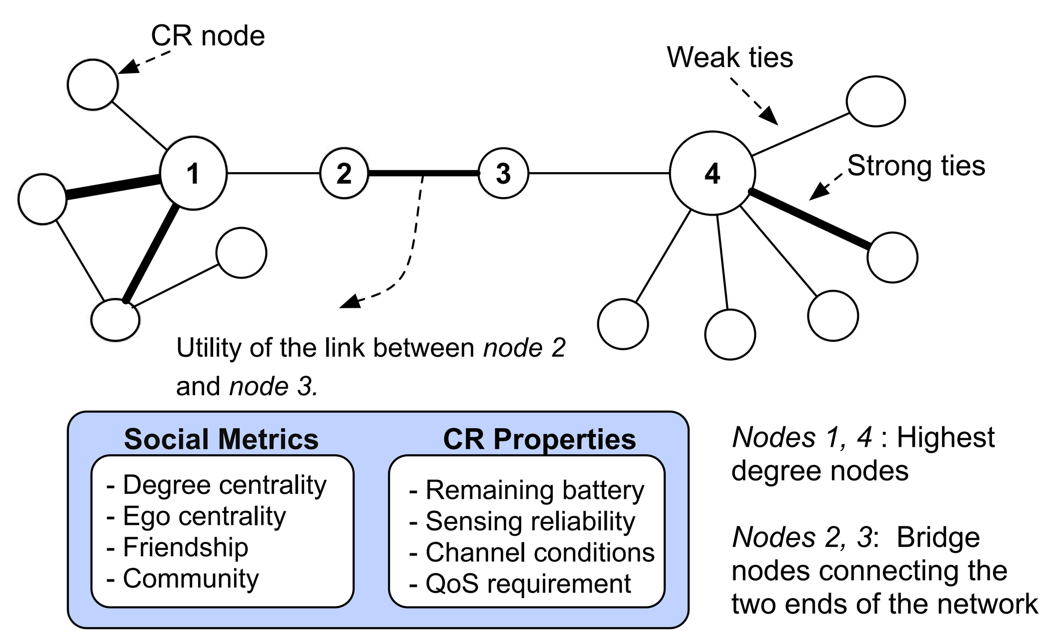
Fig. 1: Interaction between EE related concepts for CR.

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

S. Eryigit, G.Gur, S. Bayhan, and T. Tugcu, "Energy Efficiency is a Subtle Concept: Fundamental Trade-offs for Cognitive Radio Networks," *to appear*, IEEE Communications, SI on Energy-Efficient Cognitive Radio Networks, 2014.