Trade-offs of Energy Efficiency versus Performance in Cognitive Wireless Networks

Maice Costa and Anthony Ephremides
Department of Electrical and Computer Engineering
University of Maryland
College Park, MD 20742
Email: {mcosta, etony}@umd.edu

I. Abstract

Improving energy efficiency in wireless networks is important, not only to reduce the costs and the environmental impact of network operation, but also to support the computational burden of new multimedia applications under energy constraints. Therefore, energy efficiency concerns have been incorporated in many research and development efforts for future networks.

The adaptability of cognitive radios has been identified as a valuable tool to develop energy efficient communication systems, even though cognitive networks envisioned to primarily overcome the spectrum underutilization [1] and [2].

In this work, the traditional model for cognitive networks is considered, with one licensed user which has priority to use the network resources (Primary User, PU), and multiple unlicensed users that follow some etiquette to access the channel (Secondary Users, SU).

We discuss two important trade-offs involving the energy efficiency: the *Energy-Throughput* trade-off, pointed in [3] as one of the fundamental trade-offs for a green radio research framework, and the *Efficiency-Accuracy* trade-off, which arises from opposite trends in energy efficiency and sensing accuracy when increasing the transmission power. Results are presented for both the primary and secondary users, comparing the performance with different spectrum sharing schemes, namely the Underlay, Interweave, and Hybrid schemes [4], and show that different schemes benefit different types of users.

Regarding the spectrum sharing scheme, we emphasize the possibility that primary and secondary users access the channel simultaneously, causing interference to each other, with the Underlay scheme. A power constraint is imposed to the secondary users, and is shown to be effective in protecting the PU from interference. Under this scheme, we characterize the transmission power that maximizes the energy efficiency for the PU, since the PU has freedom to choose its transmission power.

Figure 1 presents the energy-throughput trade-off in the case of non-cooperative Underlay scheme. In particular, this Figure illustrates the effect of the power constraint imposed to the secondary users. For a single user, the maximum transmission power may be larger than that used by the PU, depending on the required SINR in the primary destination. As the number of interfering nodes increases, the transmission power of the SUs is reduced to protect the PU. Note that the PU remains oblivious to the number of SUs, and its performance remains virtually unaltered.

The Interweave and Hybrid spectrum sharing schemes rely on spectrum sensing to determine access constraints to the secondary users. When the sensing is imperfect, the secondary users may cause inadvertent interference to the primary user. Therefore, the use of spectrum sensing increases the complexity in the relationships between the system parameters. Our results for the *Efficiency-Accuracy* trade-off consider the effect of errors in sensing, and are not specific to any sensing technique.

Figure 2 illustrates the trade-off between energy efficiency and sensing accuracy in the case of an Energy Detector. For a fixed false alarm probability $Q_f = 0.1$, the detection probability is increased by increasing the SNR and the transmission power of the PU. We assume a single SU, transmitting with maximum power allowed by the spectrum sharing etiquette. As the power of the PU increases, the transmission power of the SU also increases. In this figure we observe that the SU may have more interest in sensing accuracy than the PU, once the value of Q_d that maximizes energy efficiency of SU is lager than the one that maximizes the energy efficiency of the PU. It is worth mentioning that the larger values of energy efficiency verified for the SU in comparison to the PU come at

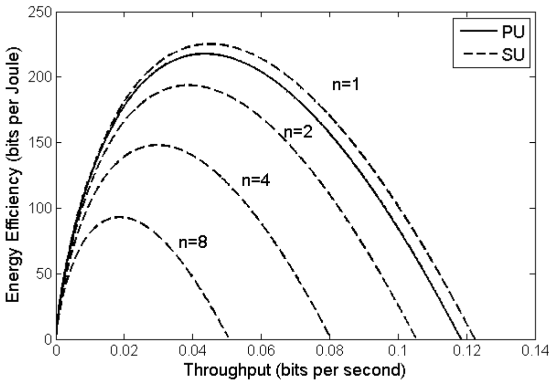

Figure 1. Energy-Throughput Trade-Off with Underlay Spectrum Sharing.

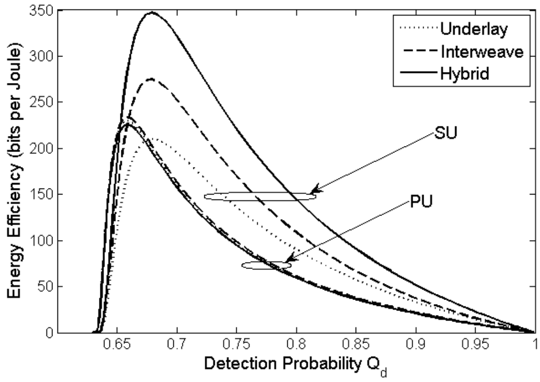

Figure 2. Energy Efficiency versus Detection Probability

the expense of a smaller throughput for the SU, accompanied by smaller values of transmission power.

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