Optimal Power Allocation of a Single Transmitter-Multiple Receiver Channel in a Cognitive Radio Environment

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Introduction

- Wireless sensor networks (WSNs) consist of the placement of sensors over a broad area in order to acquire data.
- The sensor nodes are limited by battery power, computational resources and storage space.
- Very often, the battery of the nodes is not changed because they are inaccessible, and eventually the battery is exhausted.
- When sufficient number of nodes die, the network may not be able to perform its task.

Motivation

- WSNs have an increasing impact in a great variety of industrial, medical and environmental applications.
- Let us assume that we have some sensors located on a desert and each of them is very distant from the others. We would like to keep the sensors operational with as low maintenance as possible.
- Among other design criteria of sensor devices, the battery life-cycle is of great interest. Indeed, it is crucial to maximize the battery life-cycle of each sensor.
- We address the problem of minimizing the transmit power of a WSN while satisfying certain transmission rate constraints.

Scenario

- We consider a spectrum sharing communication system where a secondary sensor node (SN) is communicating with multiple secondary receivers in presence of a primary SN.
- All fading channels are assumed to be ergodic and stationary.

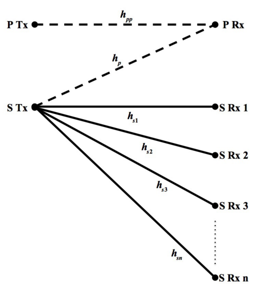

Figure 1
Wireless sensor link in a spectrum sharing environment with multiple secondary receivers.

Independent Peak Transmission Rate Constraint

- The problem can be formulated as:

$$\min \; P\left(|h_{s\,1}|,|h_{s\,2}|,\ldots,|h_{s\,n}|\right)$$

$$\text{s.t. } R\left(|h_{s\,i}|\right)=\log\left(1+P\left(|h_{s\,1}|,|h_{s\,2}|,\ldots,|h_{s\,n}|\right)\cdot|h_{s\,i}|^2\right)\geq R_{\min}\quad \forall i\in\{1,n\}$$

$$\text{and } P\left(|h_{s\,1}|,|h_{s\,2}|,\ldots,|h_{s\,n}|\right)\leq P_{h_p}(\varepsilon)$$

where:

$P\left(|h_{s\,1}|,|h_{s\,2}|,\ldots,|h_{s\,n}|\right)$ is the transmit power

$R\left(|h_{s\,i}|\right)$ is the transmission rate

$|h_{s\,i}|^2$ is the channel gain

$$P_{h_p}(\varepsilon)=\frac{Q_{\text{peak}}}{F^{-1}_{|h_p|^2}(1-\varepsilon)}$$

$R_{\min}$ is the minimum transmission rate required

Q_{peak} is the interference limit between the primary and secondary SN

ε is the threshold for the limit of interference allowed

- The power is given by:

$$P\left(|h_{s\,1}|,|h_{s\,2}|,\ldots,|h_{s\,n}|\right)=\begin{cases}\max\limits_{i\in\{1,n\}}\left\{\dfrac{e^{R_{\min}}-1}{|h_{s\,i}|^2}\right\} & \text{if } \max\limits_{i\in\{1,n\}}\left\{\dfrac{e^{R_{\min}}-1}{|h_{s\,i}|^2}\right\}\leq P_{h_p}(\varepsilon)\\ \text{no solution} & \text{if } \max\limits_{i\in\{1,n\}}\left\{\dfrac{e^{R_{\min}}-1}{|h_{s\,i}|^2}\right\}> P_{h_p}(\varepsilon)\end{cases}$$

Sum of Peak Tranmission Rate Constraint

- The problem can be formulated as:

$$\min \; P\left(|h_{s\,1}|,|h_{s\,2}|,\ldots,|h_{s\,n}|\right)$$

$$\text{s.t. } \sum_{i=1}^{n} R\left(|h_{s\,i}|\right)\geq R_{\min}$$

$$\text{and } P\left(|h_{s\,1}|,|h_{s\,2}|,\ldots,|h_{s\,n}|\right)\leq P_{h_p}(\varepsilon)$$

- We apply Newton's method to obtain the unique positive real root P^* of the polynomial:

$$f\left[P\left(|h_{s\,1}|,|h_{s\,2}|,\ldots,|h_{s\,n}|\right)\right]=\prod_{i=1}^{n}\left(1+P\left(|h_{s\,1}|,|h_{s\,2}|,\ldots,|h_{s\,n}|\right)\cdot|h_{s\,i}|^2\right)-e^{R_{\min}}=0$$

- The power is given by:

$$P\left(|h_{s\,1}|,|h_{s\,2}|,\ldots,|h_{s\,n}|\right)=\begin{cases}P^* & \text{if } P^*\leq P_{h_p}(\varepsilon)\\ \text{no solution} & \text{if } P^*> P_{h_p}(\varepsilon)\end{cases}$$

Product of Peak Tranmission Rate Constraint

- The problem can be formulated as:

$$\min \; P\left(|h_{s\,1}|,|h_{s\,2}|,\ldots,|h_{s\,n}|\right)$$

$$\text{s.t. } \prod_{i=1}^{n} R\left(|h_{s\,i}|\right)\geq R_{\min}$$

$$\text{and } P\left(|h_{s\,1}|,|h_{s\,2}|,\ldots,|h_{s\,n}|\right)\leq P_{h_p}(\varepsilon)$$

- We apply the bisection method to obtain the unique positive real root P^* of the function:

$$f\left[P\left(|h_{s\,1}|,|h_{s\,2}|,\ldots,|h_{s\,n}|\right)\right]=\prod_{i=1}^{n}\log\left(1+P\left(|h_{s\,1}|,|h_{s\,2}|,\ldots,|h_{s\,n}|\right)\cdot|h_{s\,i}|^2\right)-R_{\min}=0$$

- The power is given by:

$$P\left(|h_{s\,1}|,|h_{s\,2}|,\ldots,|h_{s\,n}|\right)=\begin{cases}P^* & \text{if } P^*\leq P_{h_p}(\varepsilon)\\ \text{no solution} & \text{if } P^*> P_{h_p}(\varepsilon)\end{cases}$$

Simulations

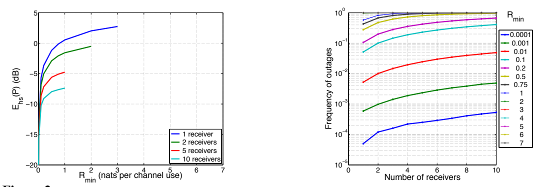

Figure 2
Performance comparison between different number of receivers under an independent peak transmission rate constraint.

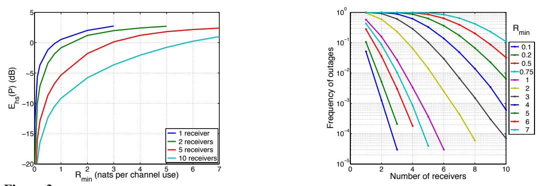

Figure 3
Performance comparison between different number of receivers under a sum of peak transmission rate constraint.

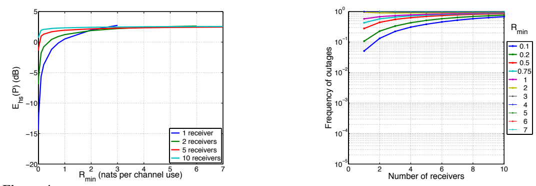

Figure 4
Performance comparison between different number of receivers under a product of peak transmission rate constraint.

Contribution and Impact

- The solution of the power minimization problem of a WSN in a cognitive radio environment under different rate constraints has been analyzed.
- The novelty of our results can be interpreted as a cheaper and easier implementation choice that yields energy efficient sensor devices and increases their battery life-cycle.