Decentralized Detection Schemes Applied to Cognitive Radio Networks

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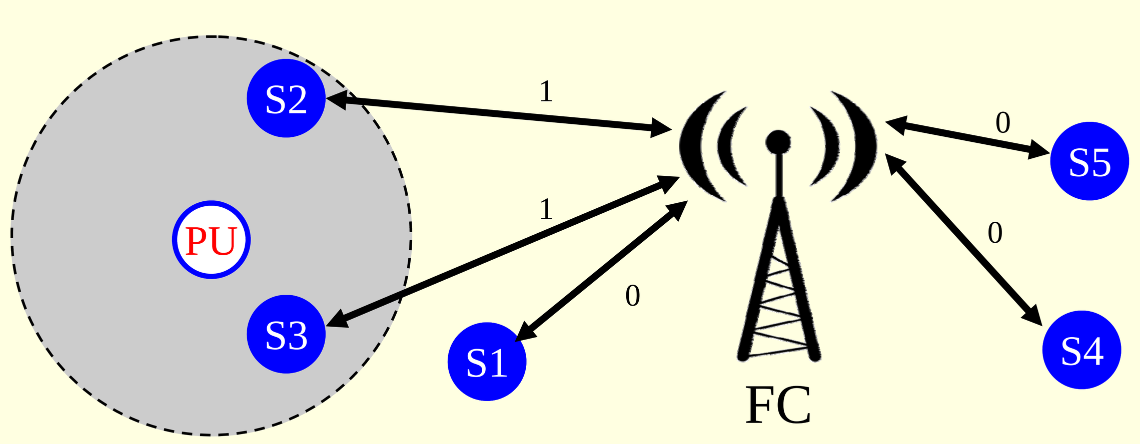
Introduction:

A cognitive radio network is related to an ultraband communications system, where many frequencies are used to communicate. However, it differs from this idea in that the cognitive radio only uses power from frequencies that are not currently being used. And so, the cognitive radio needs to be able to adapt to the environment in real time, and constantly change its communication traits.

A cognitive radio network is one in which if a primary user who has purchased bandwidth is not present, secondary users (who have not purchased bandwidth) can utilize that unused spectra to communicate. The detection problem occurs when the primary user re-enters the network's span and the secondary users can no longer communicate on the primary bandwidth.

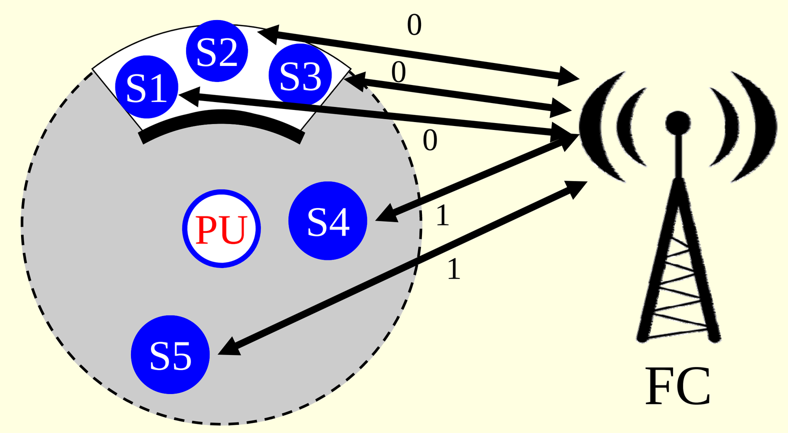
Decentralized Detection Overview:

1. **Sensor Decision** - Secondary Users (S#) decide independently whether they detect the Primary User (PU)
2. **Send to Fusion Center** - One bit decisions sent from the Secondary User to the Fusion Center (FC)
3. **Decision Scheme** - Fusion Center weights sensors depending on correlation to optimize the correct decision



Noise Considerations:

1. **Sensor Decision** - Noise from fading and obstacles can occur at each individual sensor when detecting for the presence of the primary user



2. **Channel Noise** - Noise from the channel occurs when secondary users send data to the fusion center

Different channel noise models needed!

$H_0 \equiv$ hypothesis that no PU exists

$H_1 \equiv$ hypothesis that PU is present

$$\omega\big|_{H_0} \sim \log\mathcal{N}\left(0,\sigma^2\mathbf{I}\right) \qquad y\big|_{H_0} \sim \log\mathcal{N}\left(0,\sigma^2\mathbf{I}\right)$$

$$\omega\big|_{H_1} \sim \mathcal{N}\left(0,\Sigma\right) \qquad y\big|_{H_1} \sim \mathcal{N}\left(\mu,\Sigma\right)$$

Solutions to Problem:

- Optimal solution desired, but nearly impossible to find mathematically
- Suboptimal solutions need to be tested

Suboptimal Solution 1:
Counting Rule

Suboptimal Solution 2:
HMM & ML Approximation

Suboptimal Solution 3:
Optimal Linear-Quadratic System

Counting Rule:

1. Ignore correlation between users
2. Final decision is just the majority of the decisions from the sensors

HMM & ML Approximation:

1. Treat the received bit as a Markov Process

Approximation:

$$p\left(u_1,u_2,\ldots,u_n\right) \cong$$
$$p\left(u_1\right)p\left(u_2|u_1\right)p\left(u_3|u_2\right)\ldots p\left(u_n|u_{n-1}\right)$$

1. Find the likelihoods of each decision and choose the maximum likelihood

$$L\left(\underline{u}\right)=\frac{P_1\left(0,0\right)^{n_{00}(1,n)}P_1\left(0,1\right)^{n_{01}(1,n)}P_1\left(1,0\right)^{n_{10}(1,n)}P_1\left(1,1\right)^{n_{11}(1,n)}}{P_0\left(0\right)^{n_0(1,n)}P_0\left(1\right)^{n_1(1,n)}P_0\left(0\right)^{n_0(2,n-1)}P_0\left(1\right)^{n_1(2,n-1)}}$$

$n_{ij}\left(k,l\right)=$ number of occurences of (ij)
in received string from indices [k,l]

Optimal Linear-Quadratic System:

1. Set up a linear system of equations and invert the matrix to solve the inverse problem.

$$C(i,j) \triangleq E_0\left(x_i,x_j\right)$$
$$B(i,j,k) \triangleq E_0\left(x_i,x_j,x_k\right)$$
$$A(i,j,k,l) \triangleq E_0\left(x_i,x_j,x_k,x_l\right)-C(i,j)C(k,l)$$
$$\begin{cases}\sum_k C(i,k)h(k)+\sum_{k,l}B(i,k,l)M(k,l)=v(i)\\ \sum_k B'(i,j,k)h(k)+\sum_{k,l}A(i,j,k,l)M(k,l)=Q(i,j)\end{cases}$$

$$y=\mathbf{C}x$$
$$x=\mathbf{C}^{-1}y$$
$$\sum_i x_i \underset{<}{\overset{>}{}} \tau$$

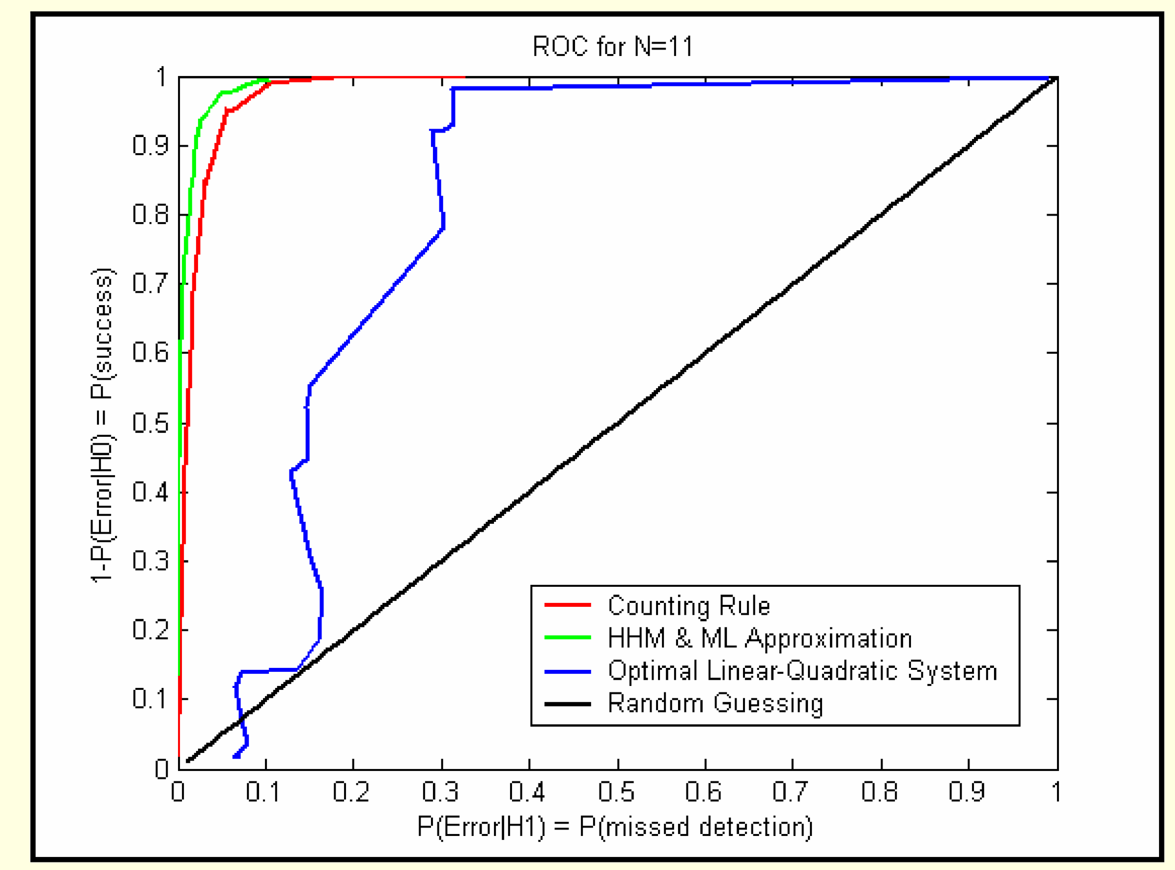
Picinbono, Bernard and Patrick Duvaut. "Optimal Linear-Quadratic Systems for Detection and Estimation." IEEE Transactions on Information Theory. Vol. 34, No. 2. March 1988. 304-311.

Problems Encountered:

The Optimal Linear-Quadratic System solution created a matrix with a condition number in the order of 10^{15}. Though the matrix was non-singular and invertible, the rows were still highly dependent on each other. Therefore, the simulated noise caused many problems in making this solution work properly.

Results and Comments:

In the following Receiver Operating Characteristics (ROC), we compare the three schemes discussed with the lower bound of just randomly guessing a bit.



As you can see, the HMM & ML Approximation performed much better than the Counting Rule. Taking advantage of the correlation can drastically improve error rates.

Conclusion:

As suggested by intuition, the correlation between sensors can be used to improve statistics in a decentralized detection scheme based on binary sensors. The Linear-Quadratic System may not have worked because of the implementation method, and should be reworked to produce even better results. Though an optimal solution was not found, a suboptimal solution that made improvements on the most general scheme was shown.

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