Distributed Power Detection in Shadowing Environment and with Communication Constraint

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MOTIVATION

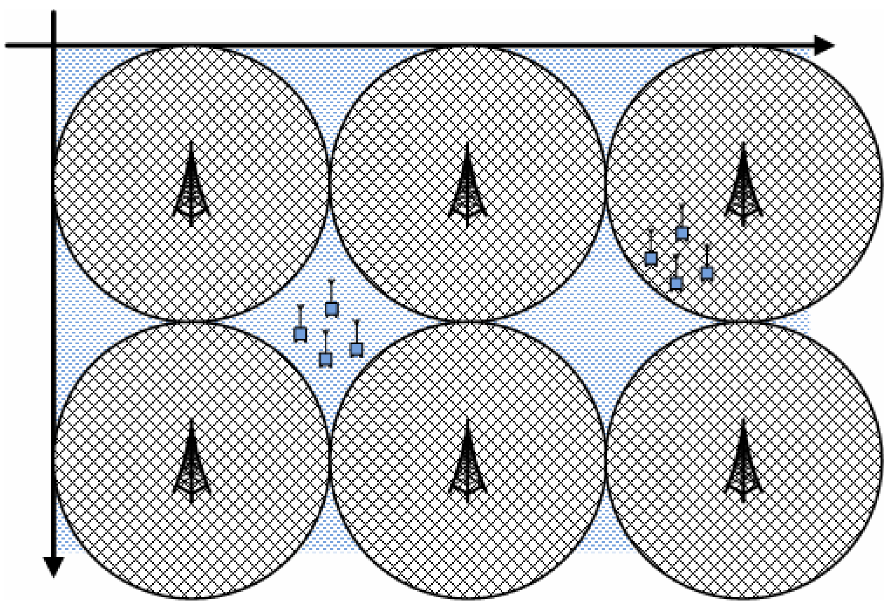
- Measurements show that the spectrum is underutilised
- Rightful owners leave it partially unused
- Sporadically used spectrum could be accessed by others
- This access is called Dynamic Spectrum Allocation (DSA)
- DSA access : Efficient and Adaptive
- Well performing detection scheme improves adaptivity

BACKGROUND WORK

- The simplest scheme uses the available channel power measurements
- Power detection of deterministic signal in noise has straightforward solution
- In the presence of fading the signal level becomes non deterministic
- Power detection under fast fading could be found in the literature
- Power detection under slow fading could be found in the literature but ignores the thermal noise effects

SYSTEM MODEL I

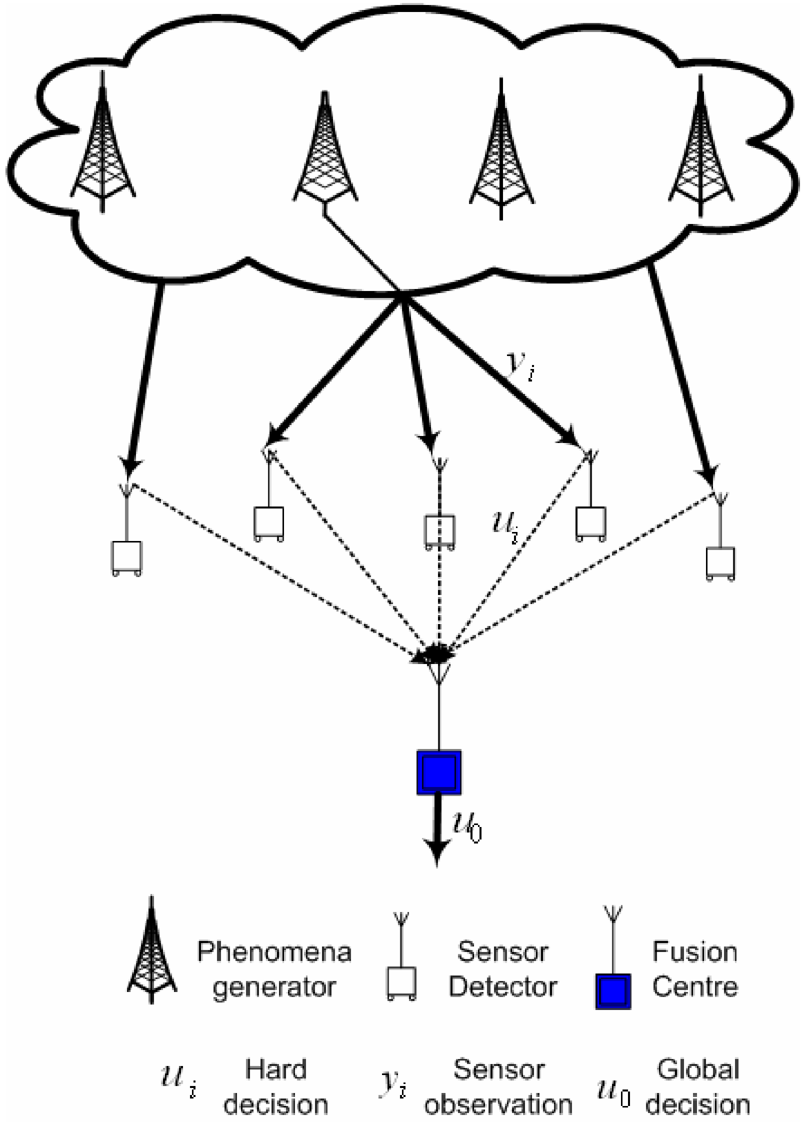
1. System components
2. Critical power level
3. Semi-mobile secondary users
4. The noise level is known
5. No deterministic components
6. Unknown coding and modulation
7. Power detection
8. Outage req. for primary users: P_{outage}



Primary signal is non-detectable : H_0

Primary signal is detectable : H_1

SYSTEM MODEL II



- ✓ Collaborative spectrum sensing
- ✓ Send measurements to the fusion
- ✓ The fusion decides and broadcasts
- ✓ Two schemes are studied
  - Centralized
  - Decentralized
- ✓ Decentralized is more challenging
  - less capacity and power requirement
  - cooperation between fusion and sensors for system wise optimization

POWER DETECTION

The primary signal is assumed to be absent if it is at most δ dB above the noise

$$H_0: \quad \sigma_n^2 = N_0/2 \cdot 10^{\sigma_{NF}/10}$$

$$H_1: \quad \sigma_1^2 = \sigma_n^2 \cdot \left(1 + 10^{\delta/10}\right)$$

The distribution of the measured samples is assumed to be Gaussian:

$$p\left(X_i \mid H_0\right) = \frac{1}{\sqrt{2\pi\sigma_n^2}} \exp\left(-\frac{X_i^2}{2\sigma_n^2}\right)$$

$$p\left(X_i \mid H_1\right) = \frac{1}{\sqrt{2\pi\sigma_1^2}} \exp\left(-\frac{X_i^2}{2\sigma_1^2}\right)$$

i.i.d

$$p\left(\mathbf{X} \mid H_0\right) = \frac{1}{\left(2\pi\sigma_n^2\right)^{N/2}} \exp\left(-\frac{1}{2\sigma_n^2} \sum_{i=1}^{N} X_i^2\right)$$

$$p\left(\mathbf{X} \mid H_1\right) = \frac{1}{\left(2\pi\sigma_1^2\right)^{N/2}} \exp\left(-\frac{1}{2\sigma_1^2} \sum_{i=1}^{N} X_i^2\right)$$

To decide optimally we use Bayes test and Neymann-Pearson approach

$$\ell'\left(X\right) \triangleq \frac{p\left(\mathbf{X} \mid H_1\right)}{p\left(\mathbf{X} \mid H_0\right)} \underset{H_1}{\overset{H_0}{\lessgtr}} \eta$$

$$\ell'\left(X\right) = \sum_{i=1}^{N} X_i^2 \underset{H_1}{\overset{H_0}{\lessgtr}} \frac{2\sigma_n^2\sigma_1^2}{\sigma_1^2 - \sigma_n^2}\left(\ln\eta - \frac{N}{2}\ln\left(\frac{\sigma_n^2}{\sigma_1^2}\right)\right) = \gamma$$

What is the distribution of ℓ' ?

How do we fix γ ?

DISTRIBUTED DETECTION

Procedure

Independent users sense the spectrum, calculate LLR and send it to the fusion

Centralized scheme

- The complete LLR is communicated
- The fusion adds the received LLRs and compares the result with a threshold
- Centralized scheme is equivalent to a single sensor system with more degrees of freedom when there is no shadowing.

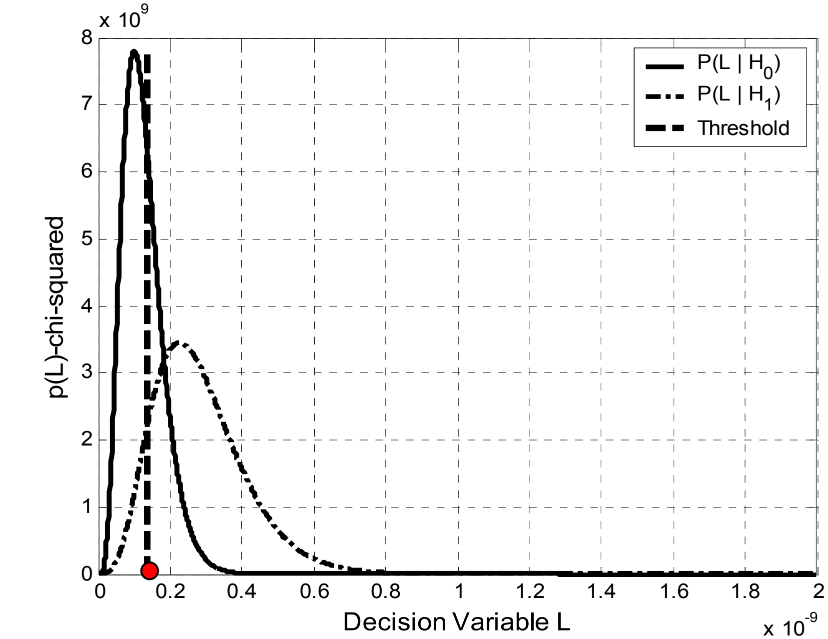
Decentralized scheme

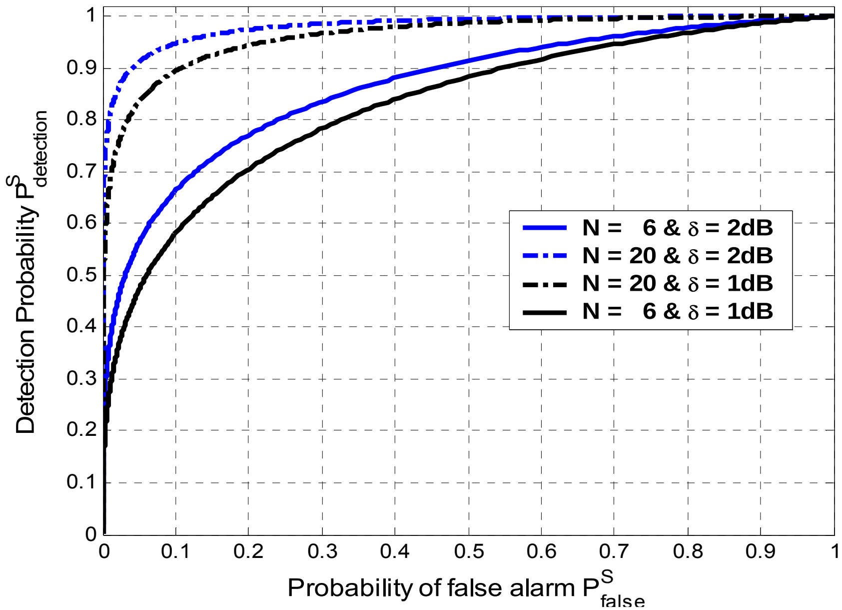
- A single bit decision is transmitted to the fusion
- Unlike centralized scheme two decision thresholds have to be set :

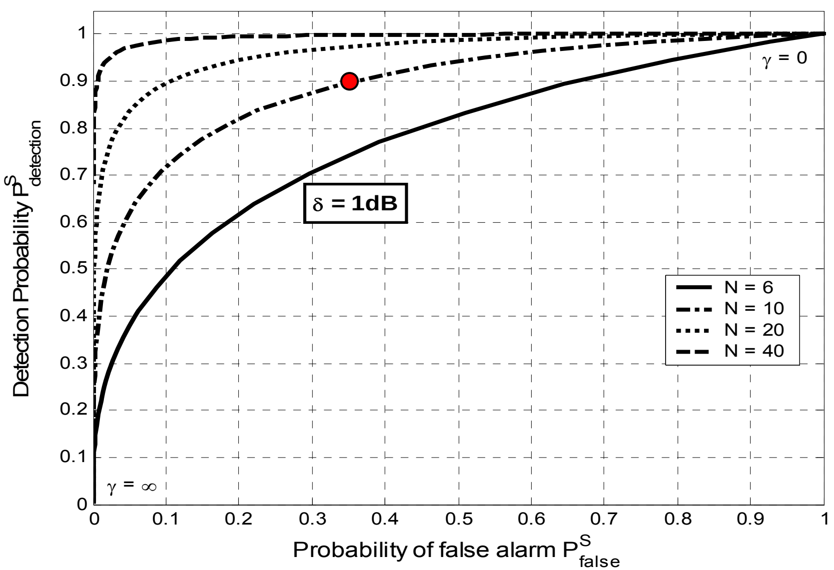
$$\text{minimize:} \quad P^{F}_{\text{miss}}\left(K,\gamma\right)+P^{F}_{\text{false}}\left(K,\gamma\right)$$

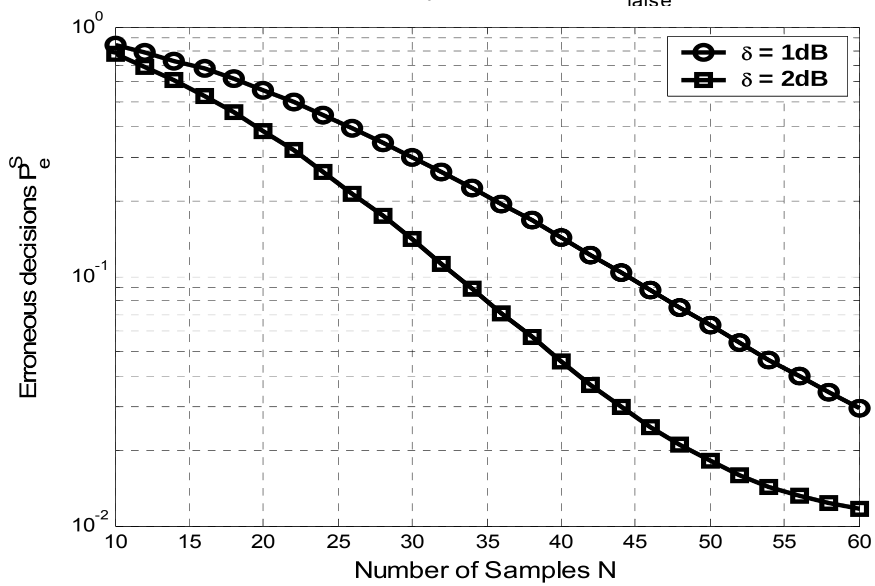
$$\text{subject to:} \quad P^{F}_{\text{miss}}\left(K,\gamma\right)\leq P_{\text{outage}}$$

RESULTS - SINGLE USER









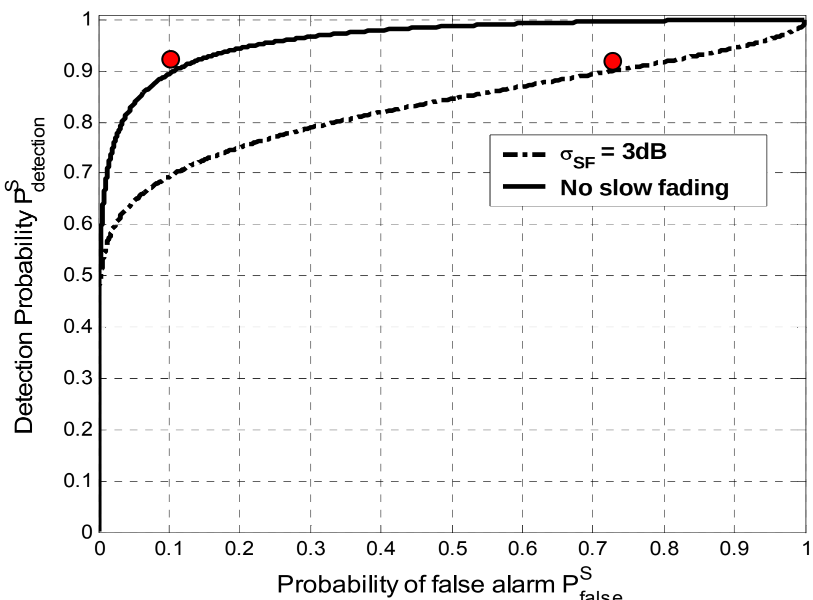
RESULTS - SHADOWING

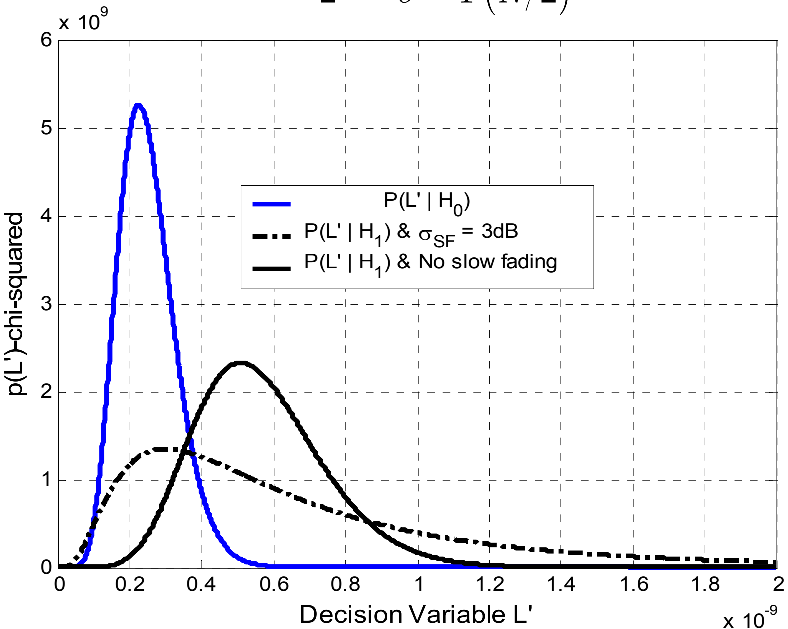
- The signal level is not deterministic at a particular distance separation
- We assume that the signal level is distributed log-normally

$$p(L'|H_1) = \int_0^\infty p(L'|\sigma^2) \cdot p(\sigma^2|H_1)\, d\sigma^2$$

$$p(\sigma^2|H_1) = \frac{1}{\sqrt{2\pi \cdot \sigma_{SF}^2 \cdot \sigma^2}} \cdot \exp\left(-\frac{\left(10\log_{10}\sigma^2 - 10\log_{10}\sigma_1^2\right)^2}{2\sigma_{SF}^2}\right)$$

$$p(L'|\sigma^2) = \frac{(L')^{N/2-1} \cdot \exp\left(-L'/2\sigma^2\right)}{2^{N/2} \cdot \sigma^N \cdot \Gamma(N/2)} \cdot u(L')$$



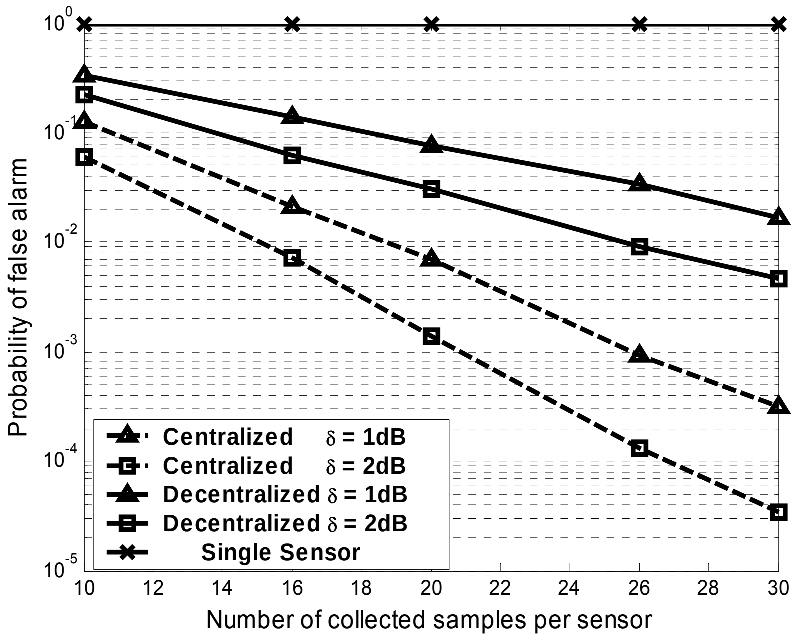


RESULTS – DISTR. SCHEME

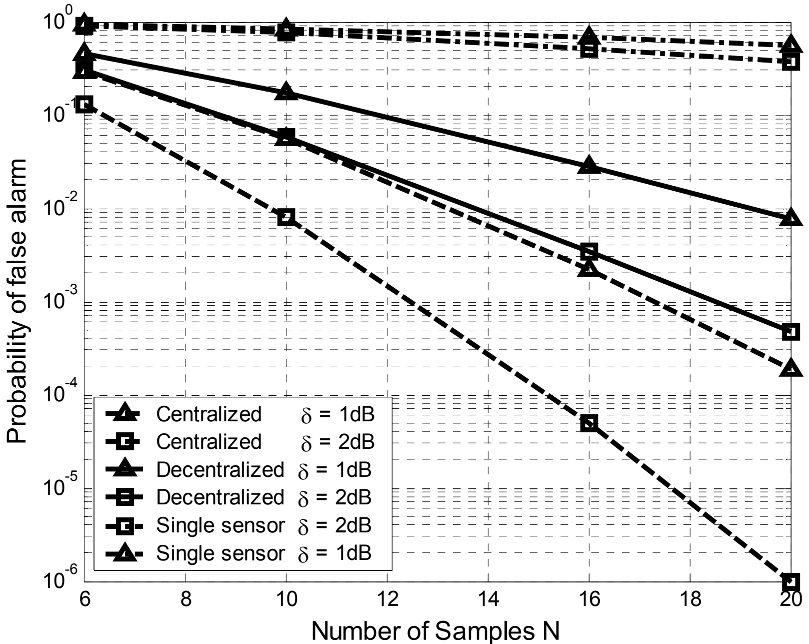
- For single user the shadowing samples are correlated
- The user should consider the probability of deep fading

- Assume independent shadow fading among the secondary users
- The mean and the variance of the shadowing distribution is common
- The effect of shadowing could be averaged out

with shadowing



without shadowing



CONCLUSIONS

1. The problem of power detection in slow fading environment was studied
2. The performance depends on the outage requirement, the SNR and on the number of power samples
3. For a single user in the presence of shadowing nearly no reuse
4. The performance was improved by cooperative spectrum sensing
5. The performance was affected by the amount of information conveyed to the fusion
6. Two extremes were studying providing useful performance bounds for any practical distributed detection scheme

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