Sensing-Throughput Tradeoff for Cognitive Radio Networks

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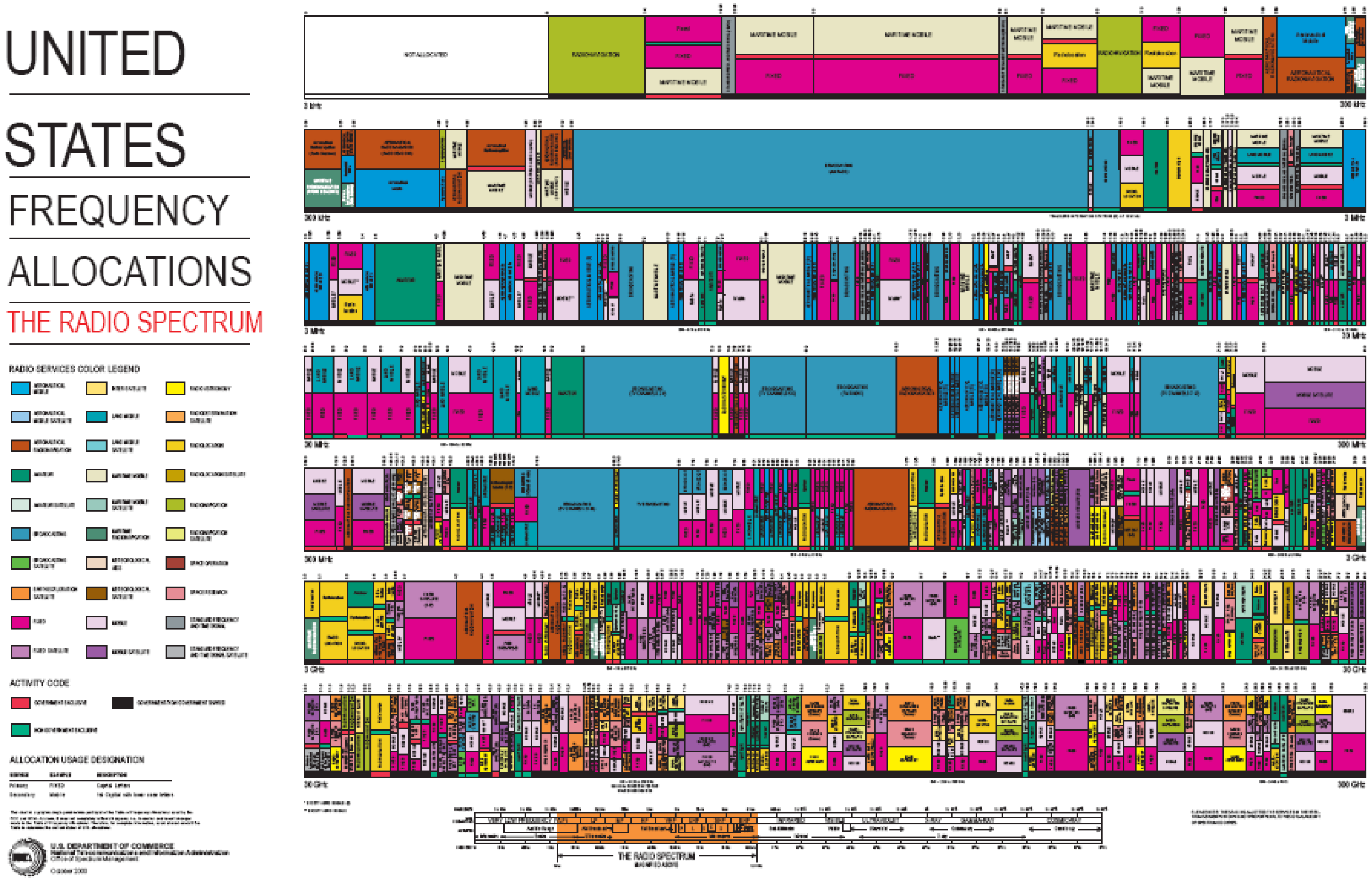
Outlines

- Motivations for Cognitive Radio
- Spectrum sensing
- Problem statement
- Single User Scenario
  - AWGN channel scenario
  - Rayleigh fading channel scenario
- Multi-slots Sensing
- Decision fusion cooperative sensing scheme
- Conclusion

Motivations for Cognitive Radio

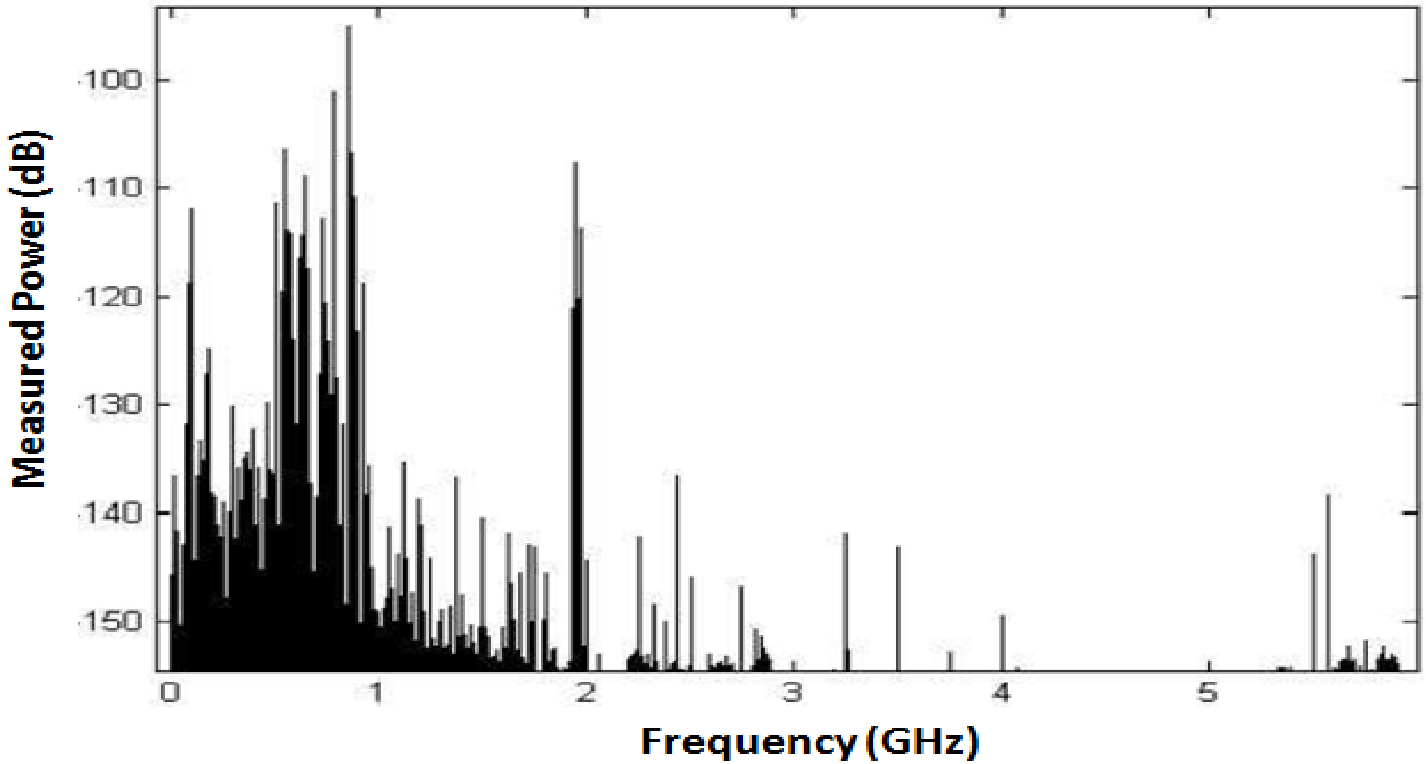
- Spectrum Scarcity



Frequency Spectrum Chart

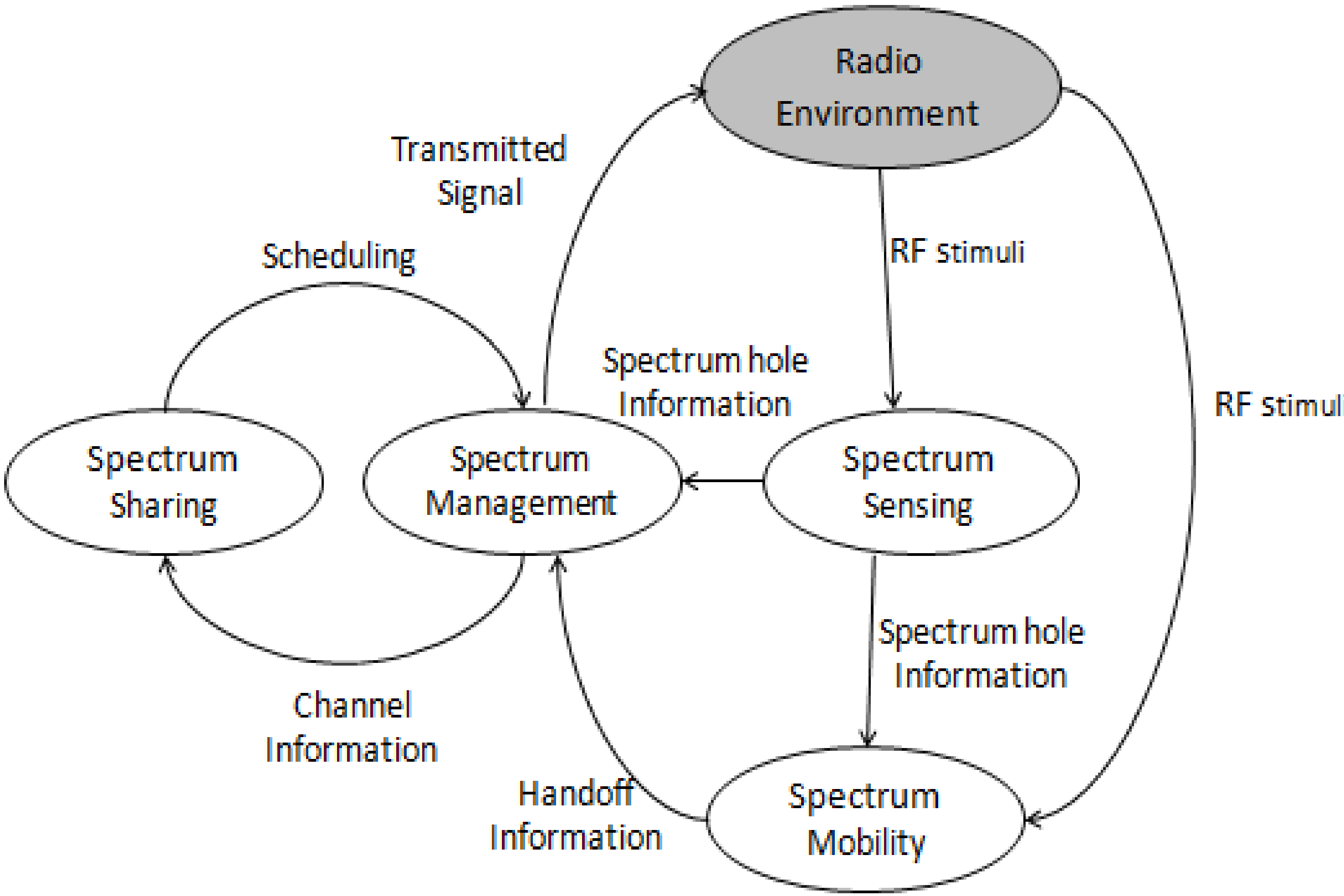
Motivations for Cognitive Radio

- Spectrum Underutilization

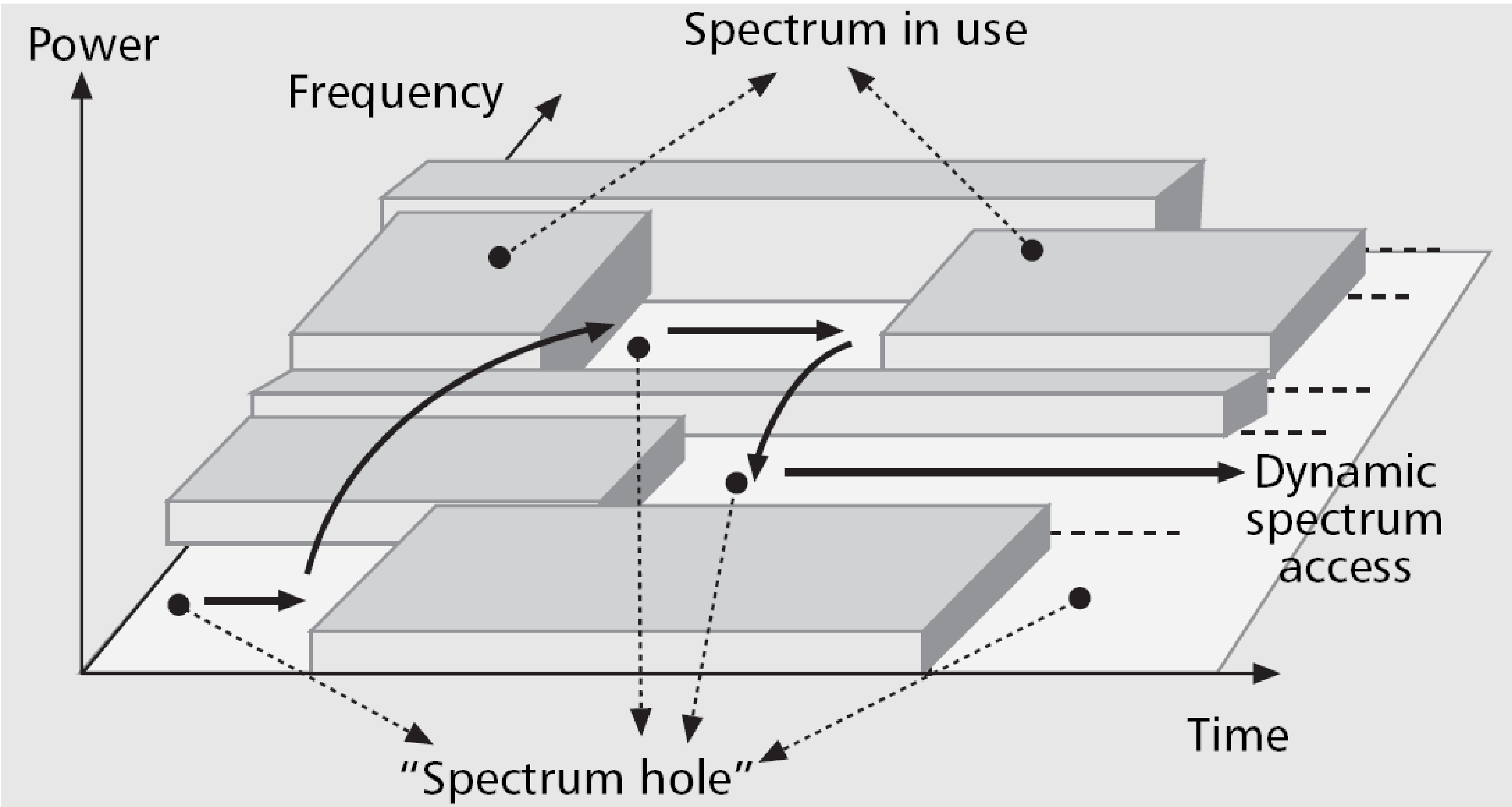


FCC spectrum measurements

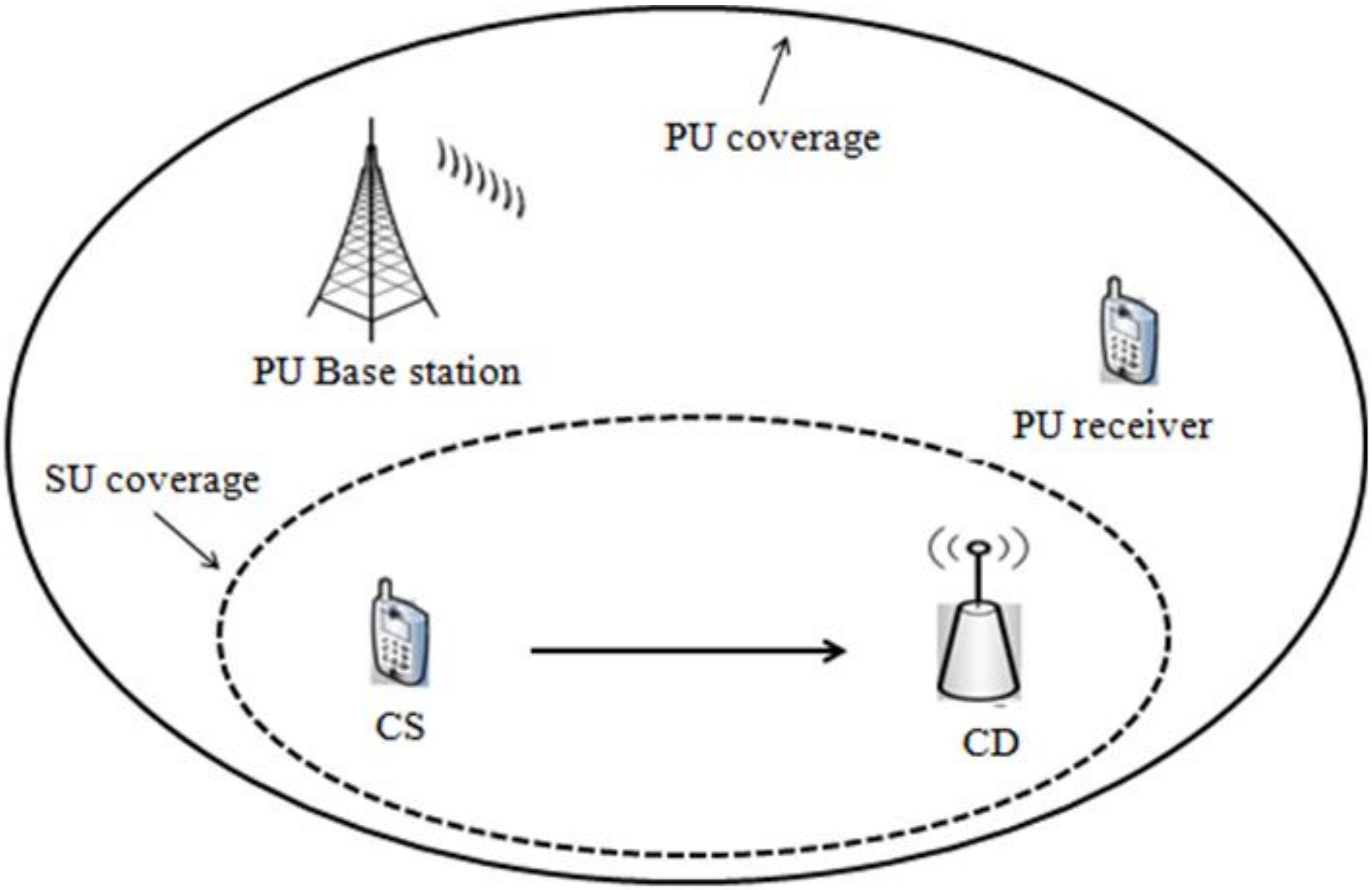
Cognitive Radio Cycle



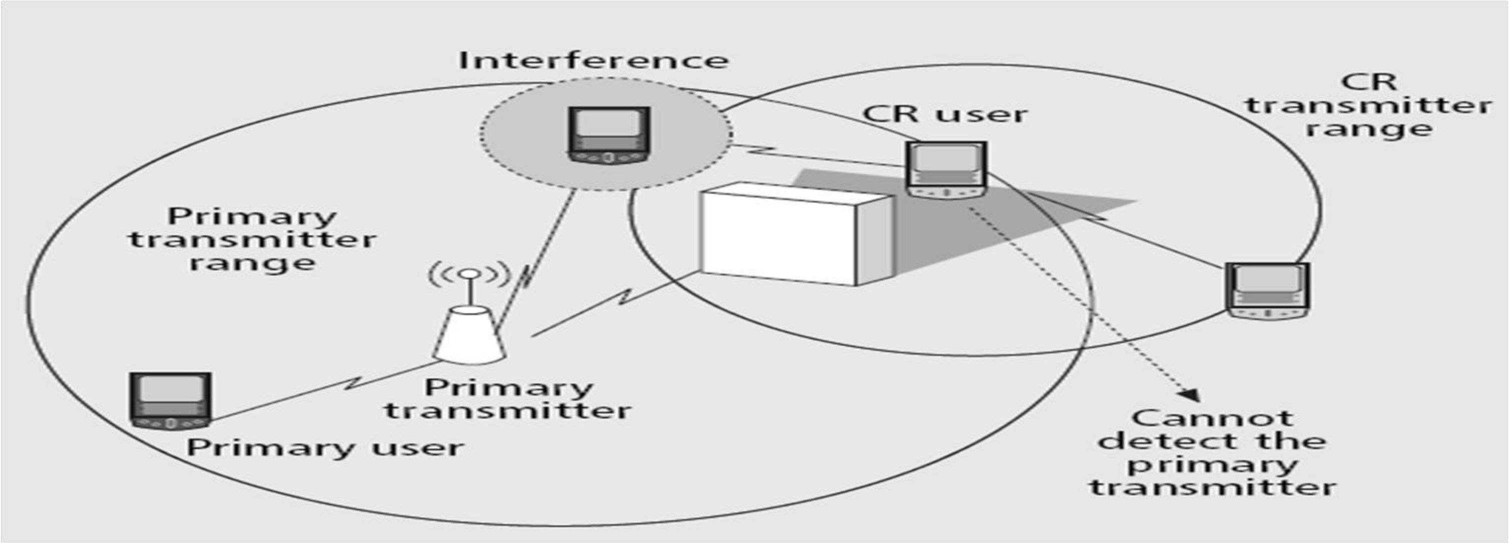
Spectrum Sensing

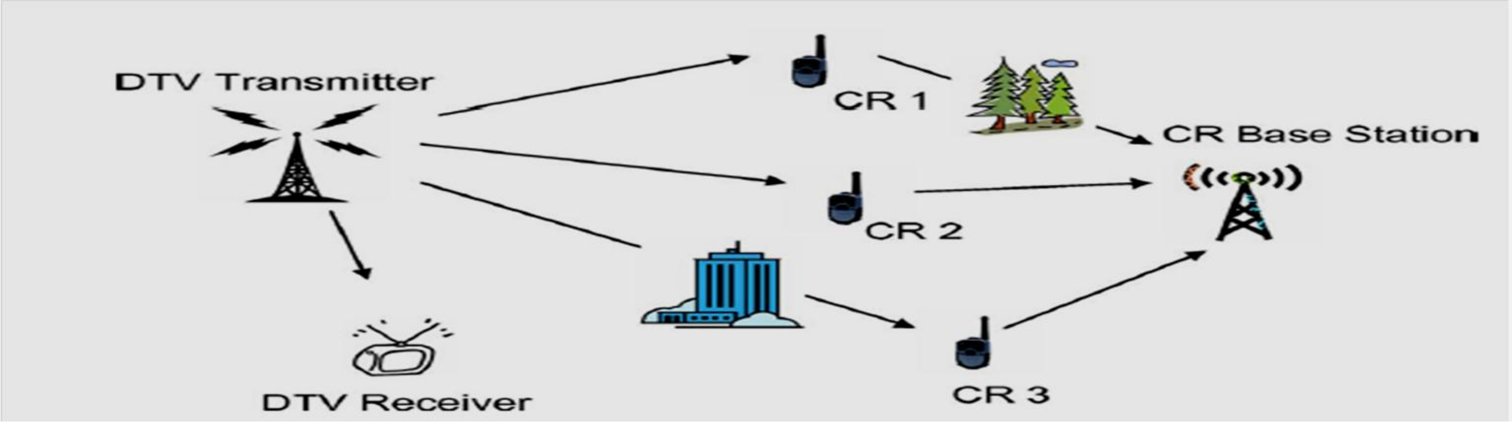


Single User Sensing Mode

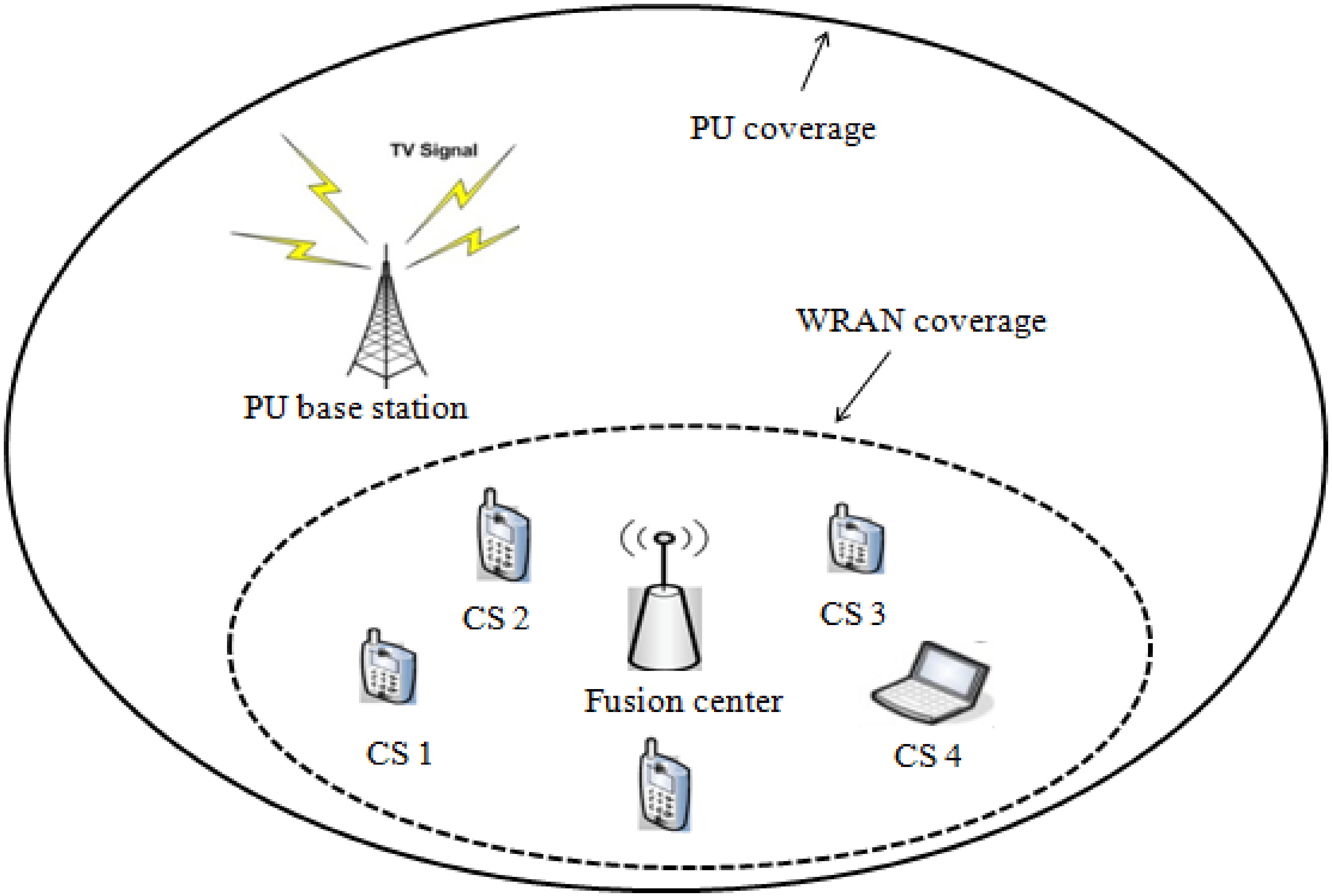


Hidden node Problem





Cooperative sensing Mode



Energy detection terminology

- Received signal at CR receiver

$$y(n) = h_{ps}\,\theta\,x_p(n) + w(n)$$

$$\theta = \begin{cases} 1 & H_P = H_1 \\ 0 & H_P = H_0 \end{cases}$$

- Statistic Metric

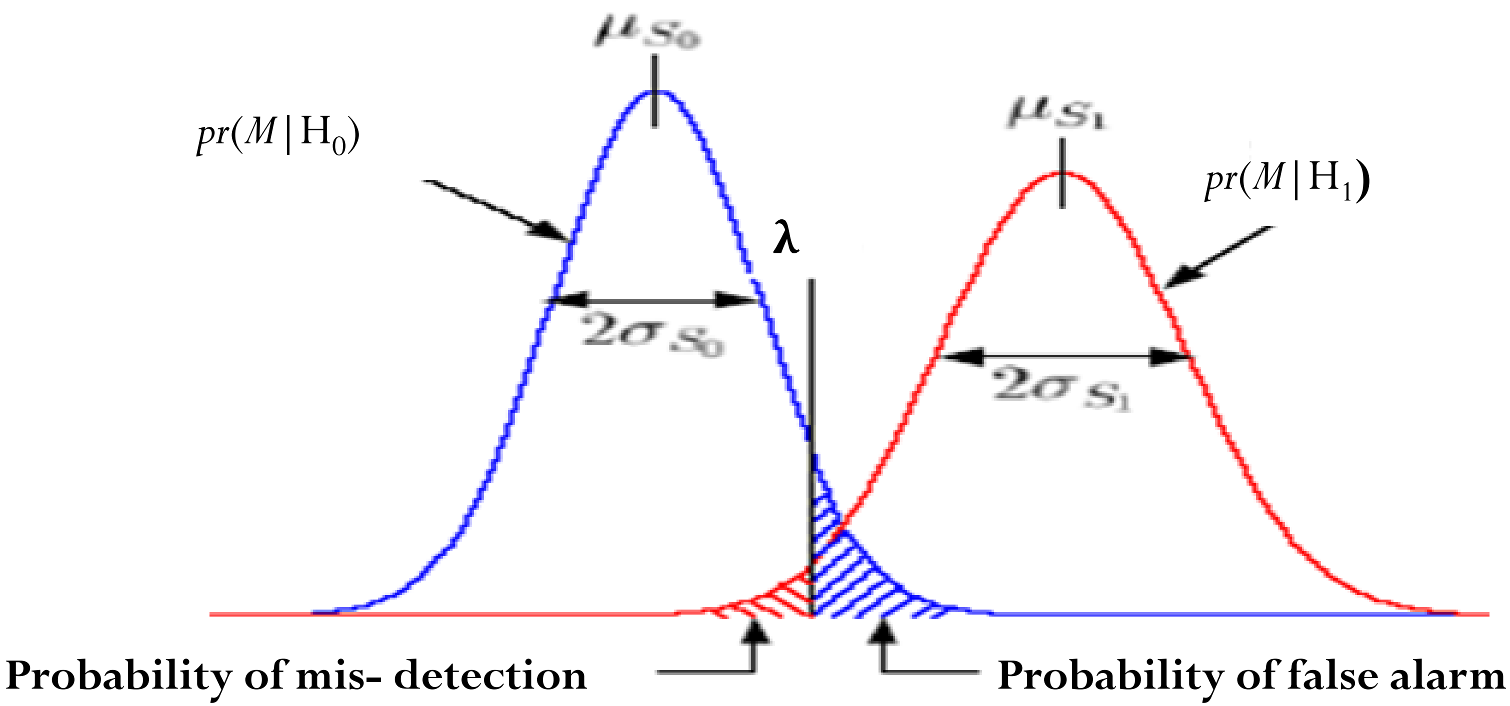
$$M = \frac{1}{N}\sum_{n=1}^{N} |y(n)|^2$$

- Decision

$$\begin{cases} M > \lambda & \text{then decide } H_1 \\ M < \lambda & \text{then decide } H_0 \end{cases}$$

Detection & false alarm probabilities

$$P_d = pr(M > \lambda | H_1) \quad \& \; P_f = pr(M > \lambda | H_0)$$

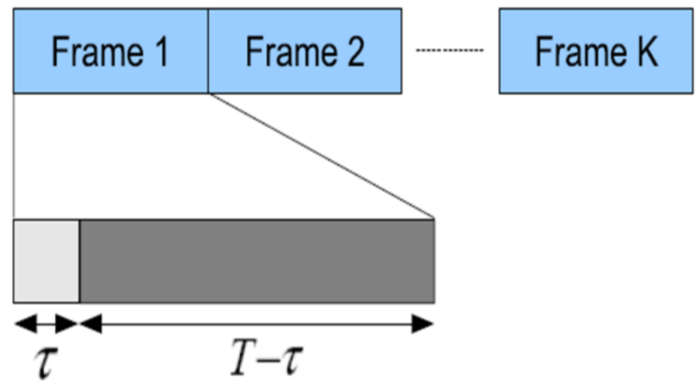


Problem Statement

$$max_{\tau}\ R(\tau) = R_0(\tau) + R_1(\tau)$$

$$\text{s.t.:}\qquad 0 < \tau < T,\ P_d(\tau) \geq \overline{P_d}$$

- Optimization Carried in Scenarios:
  - Single User Scenario
  - Multi-slot Spectrum Sensing



Single User Scenario

Generate random vector θ indicates PU status

↓

θ=1 ---> Generate PU data
θ=0 ---> No data

↓

Multiply with channel gain coefficients & AWGN added

↓

From N received samples, decision metric is evaluated

↓

Compared with λ, decision vector is obtained

↓

Compared decision and θ vectors to evaluate P_d & P_f

- Test Metric

$$M = \frac{1}{N}\sum_{n=1}^{N}|y(n)|^2|$$

$$M_{|H_0} = \frac{1}{N}\sum_{n=1}^{N}|w(n)|^2$$

$$M_{|H_1} = \frac{1}{N}\sum_{n=1}^{N}\left|\left(h_{ps}\ x_p(n) + w(n)\right)\right|^2$$

$$P_f = Q\left(\left(\frac{\lambda}{N_o} - 1\right)\sqrt{N}\right)$$

$$P_d = Q\left(\left(\frac{\lambda}{(\gamma+1)N_o} - 1\right)\sqrt{N}\right)$$

- Threshold

$$\lambda = (\gamma + 1)N_o(\frac{1}{\sqrt{\tau\, f_s}}Q^{-1}(\overline{P_d}) + 1)$$

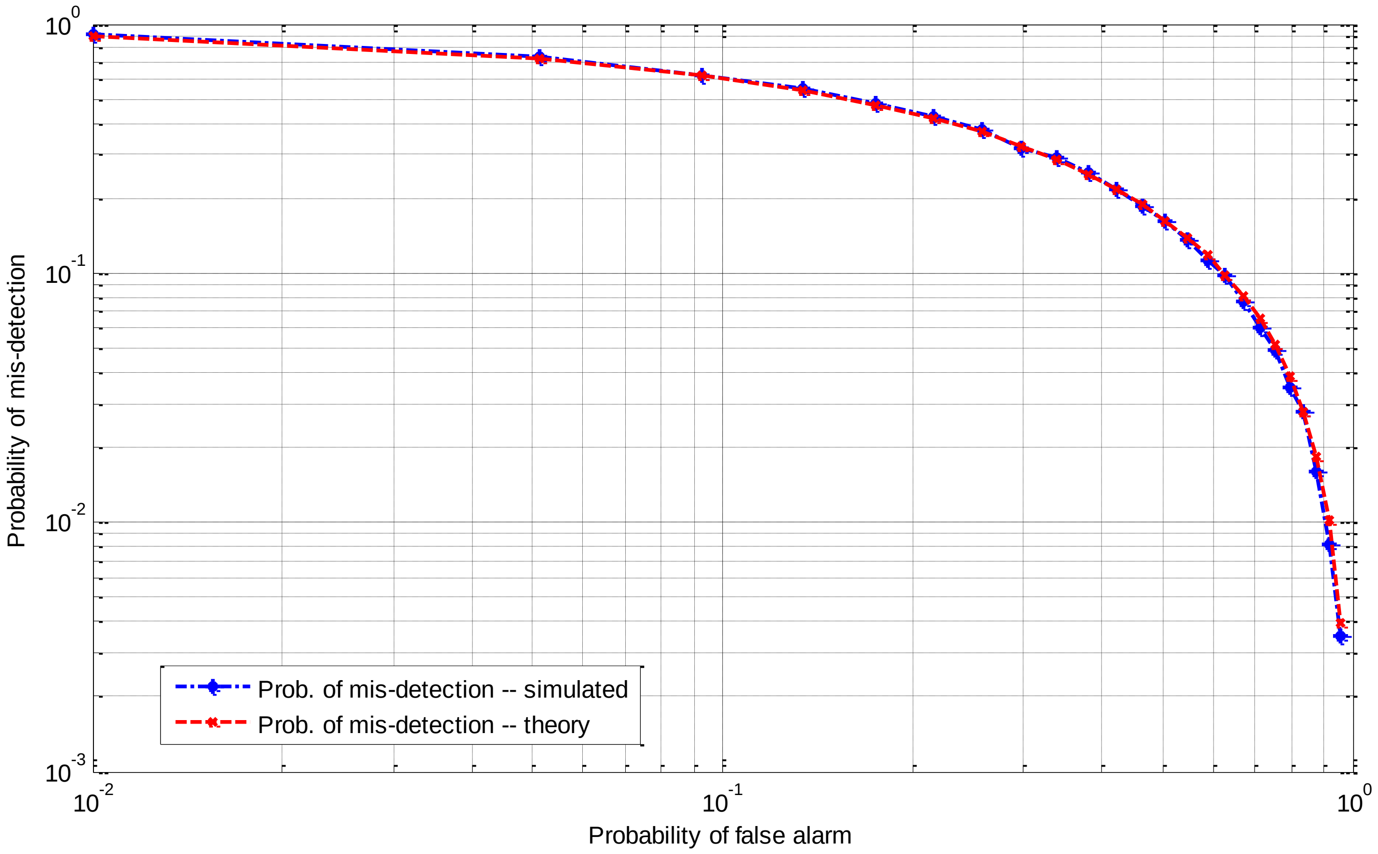
$$P_f = Q\left((\gamma + 1)Q^{-1}(\overline{P_d}) + \gamma\sqrt{N}\right)$$

$$N = \tau\ fs$$

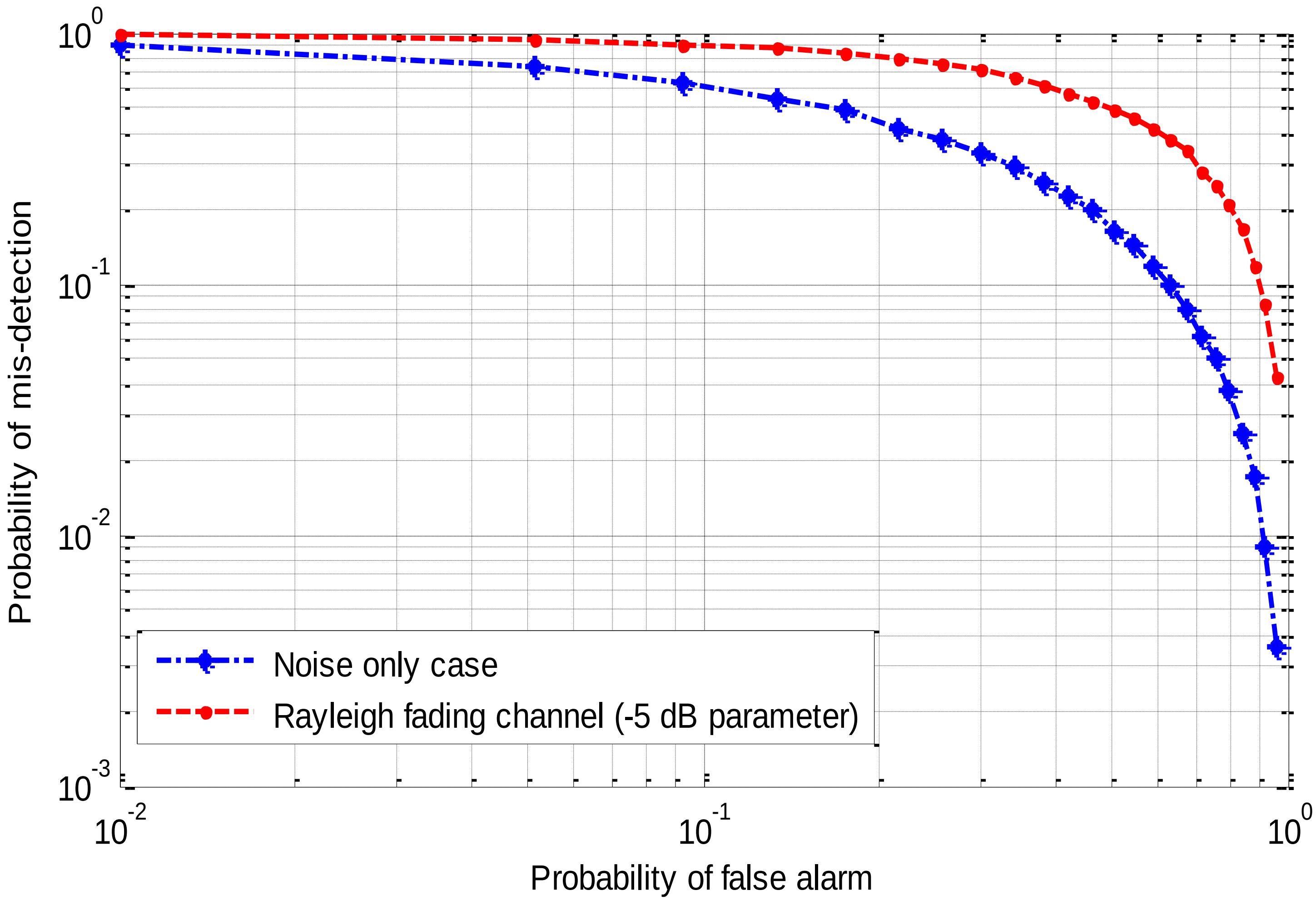
- So,

$$P_f(\tau) = Q\left((\gamma + 1)Q^{-1}(\overline{P_d}) + \gamma\sqrt{\tau\, f_s}\right)$$

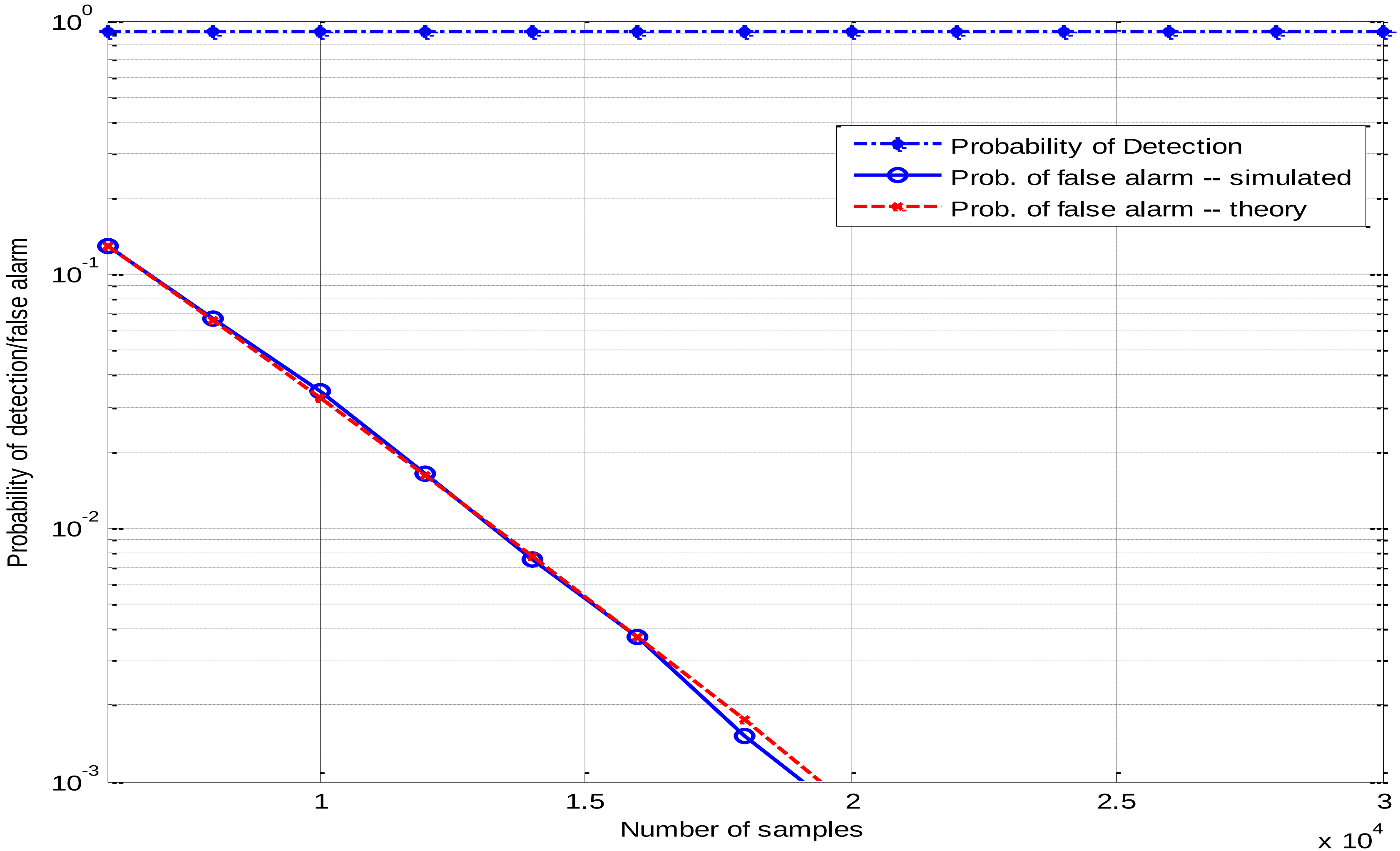
Simulation Results



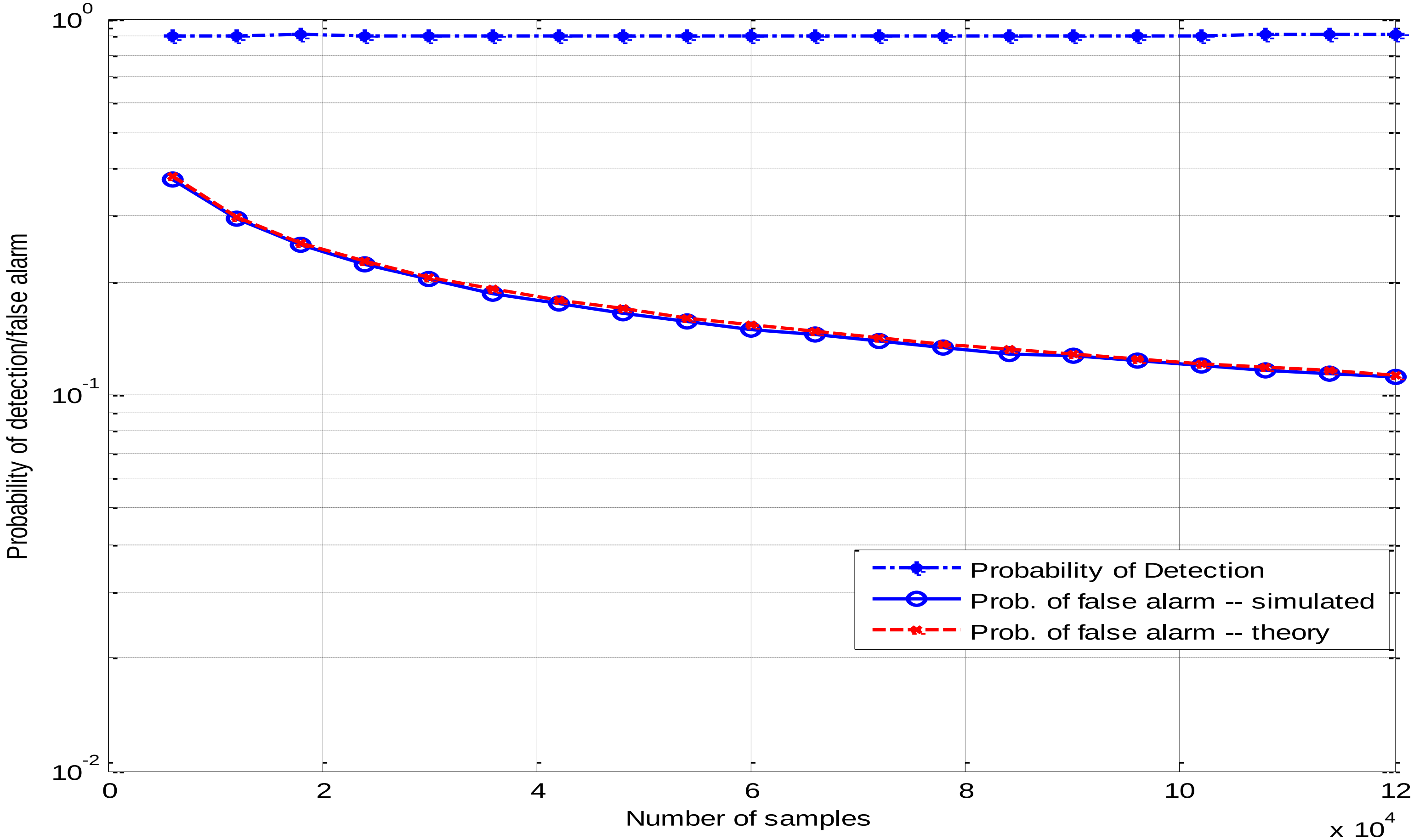
ROC curve in case of AWGN noise channel



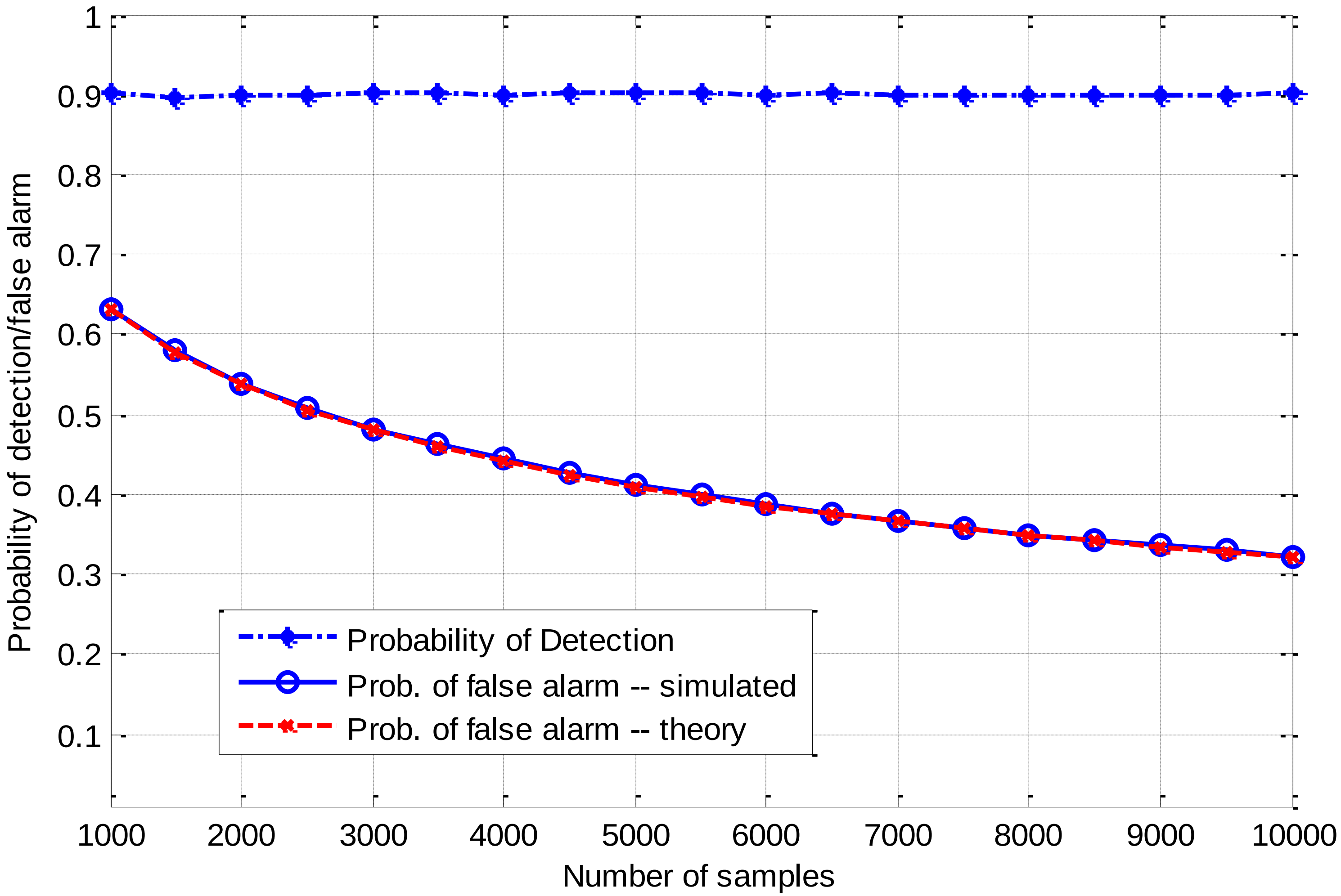
ROC curve of Rayleigh flat fading channel compared with AWGN noise channel



False alarm and detection probabilities vs. the number of samples (AWGN channel)



Prob. of detection & false alarm vs. N (AWGN noise only case)



Prob. of detection and false alarm vs. N (for flat Rayleigh faded channel case with parameter = 0.2)

Throughput Evaluation

- There are two scenarios in calculating secondary user throughput

Scenario I
PU absent & no. false alarm

- Channel Shannon capacity

$$C_0 = log_2(1 + SNR_S)$$

- Prob. of its occurrence

$$(1 - P_f)P(H_0)$$

- Then, SU throughput be

$$R_0(\tau) = \frac{T - \tau}{T}(1 - P_f(\tau))P(H_0)C_0$$

Scenario II
PU exist & no. mis- detection

- Channel Shannon capacity

$$C_1 = log_2\left(1 + \frac{P_s}{P_P + N_0}\right) = log_2\left(1 + \frac{SNR_s}{SNR_P + 1}\right)$$

- Prob. of its occurrence

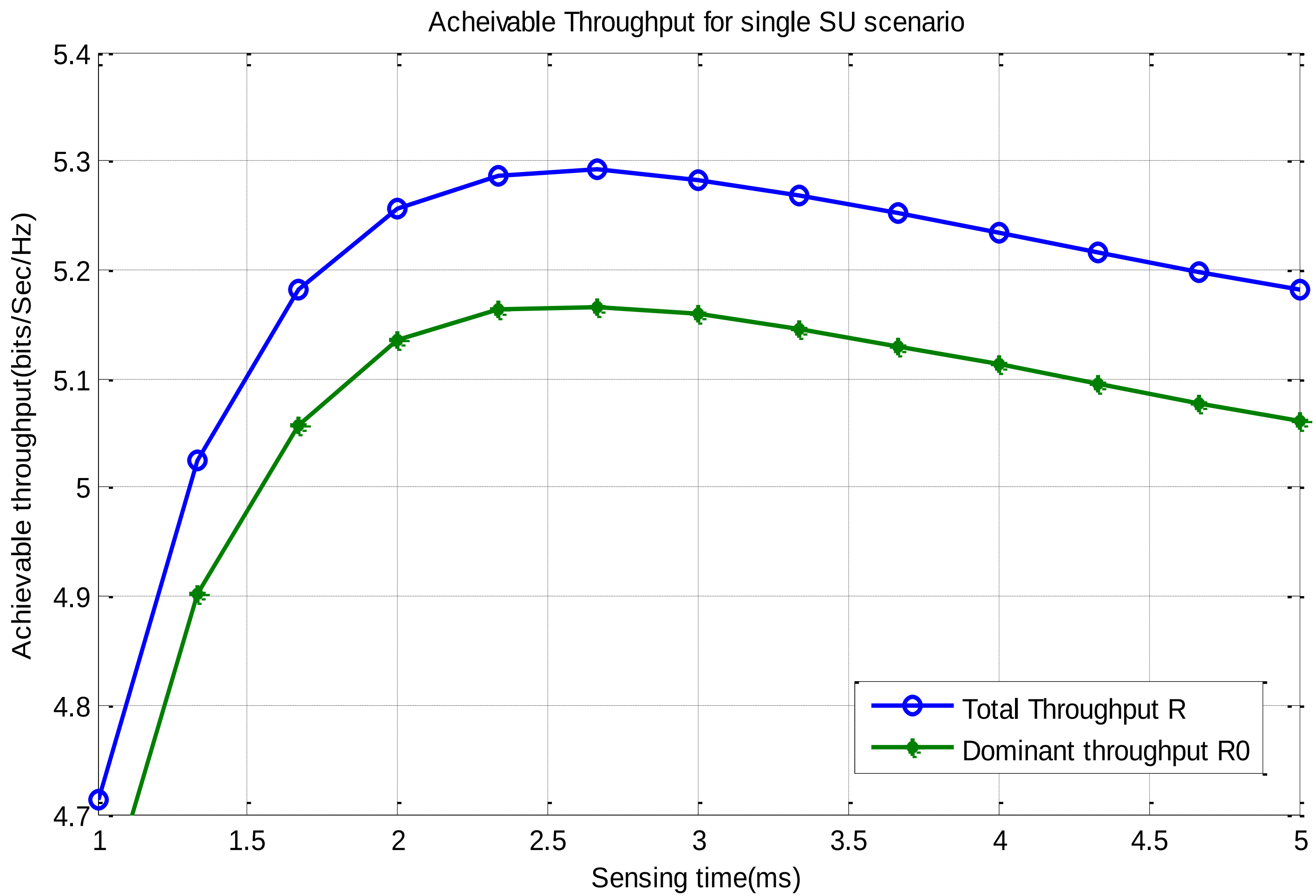
$$(1 - P_d)P(H_1)$$

- Then, SU throughput be

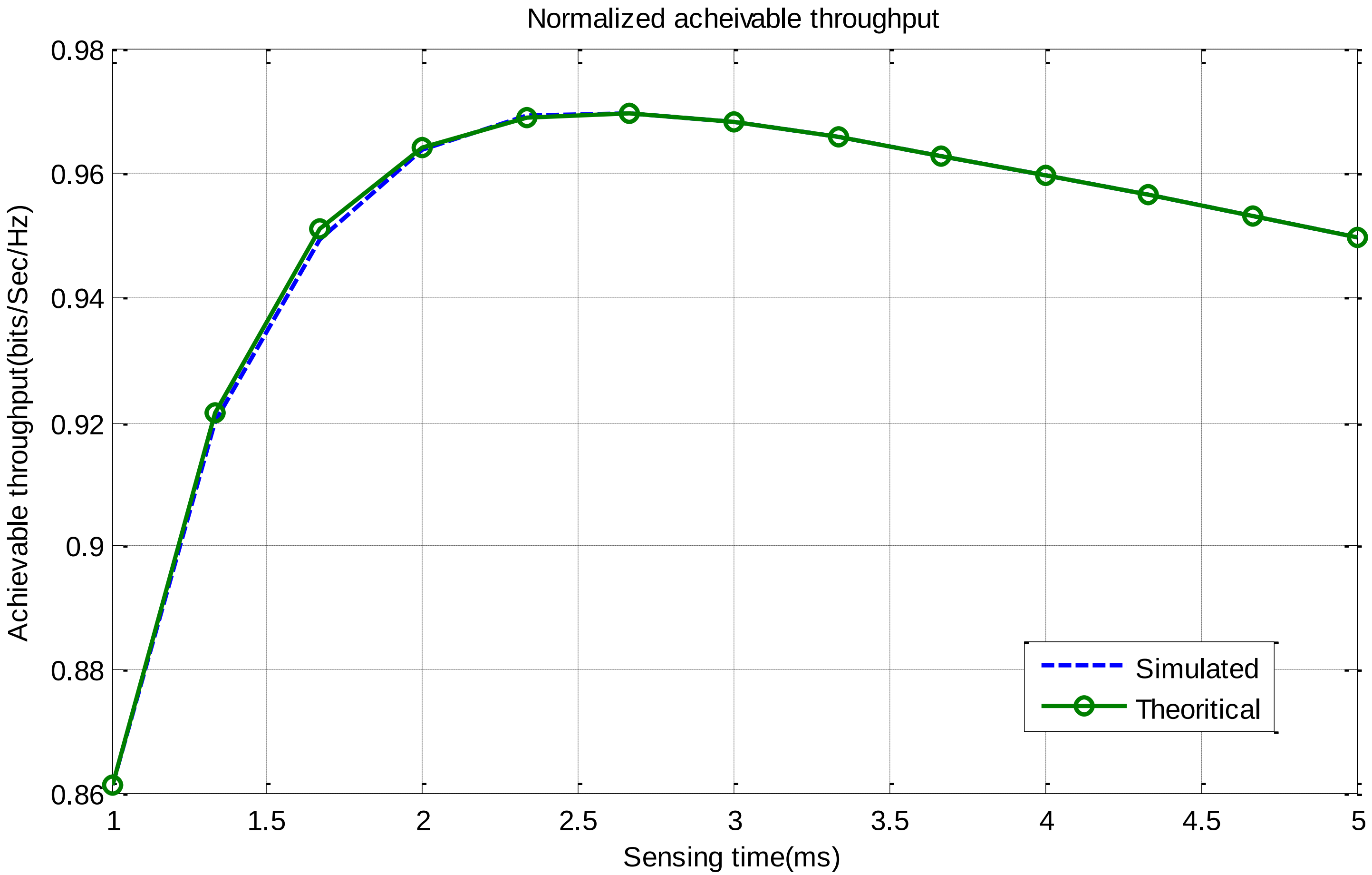
$$R_1(\tau) = \frac{T - \tau}{T}(1 - P_d)P(H_1)C_1$$

So, the total throughput is $R(\tau) = R_0(\tau) + R_1(\tau)$

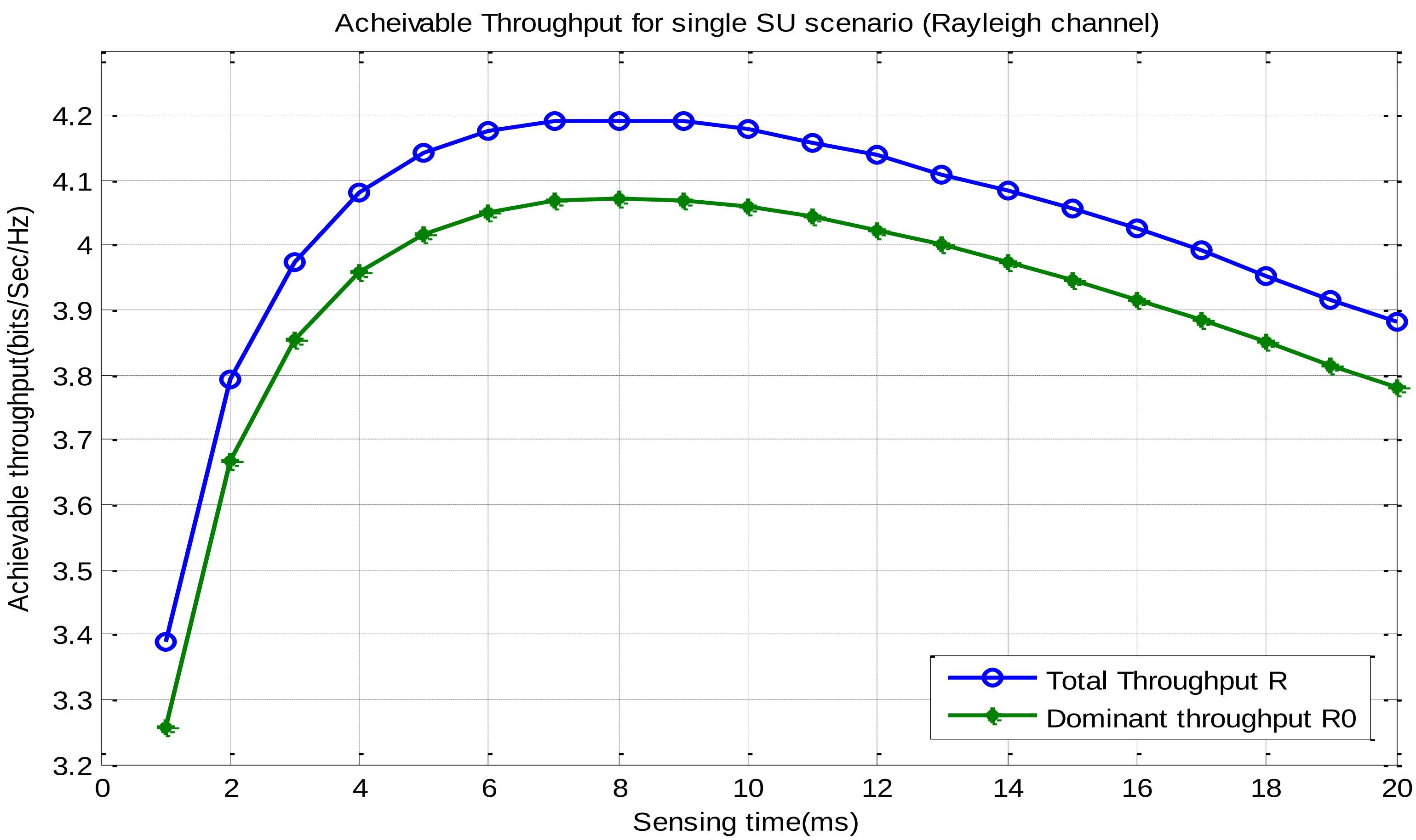
The achievable throughput (AWGN cahnnel)



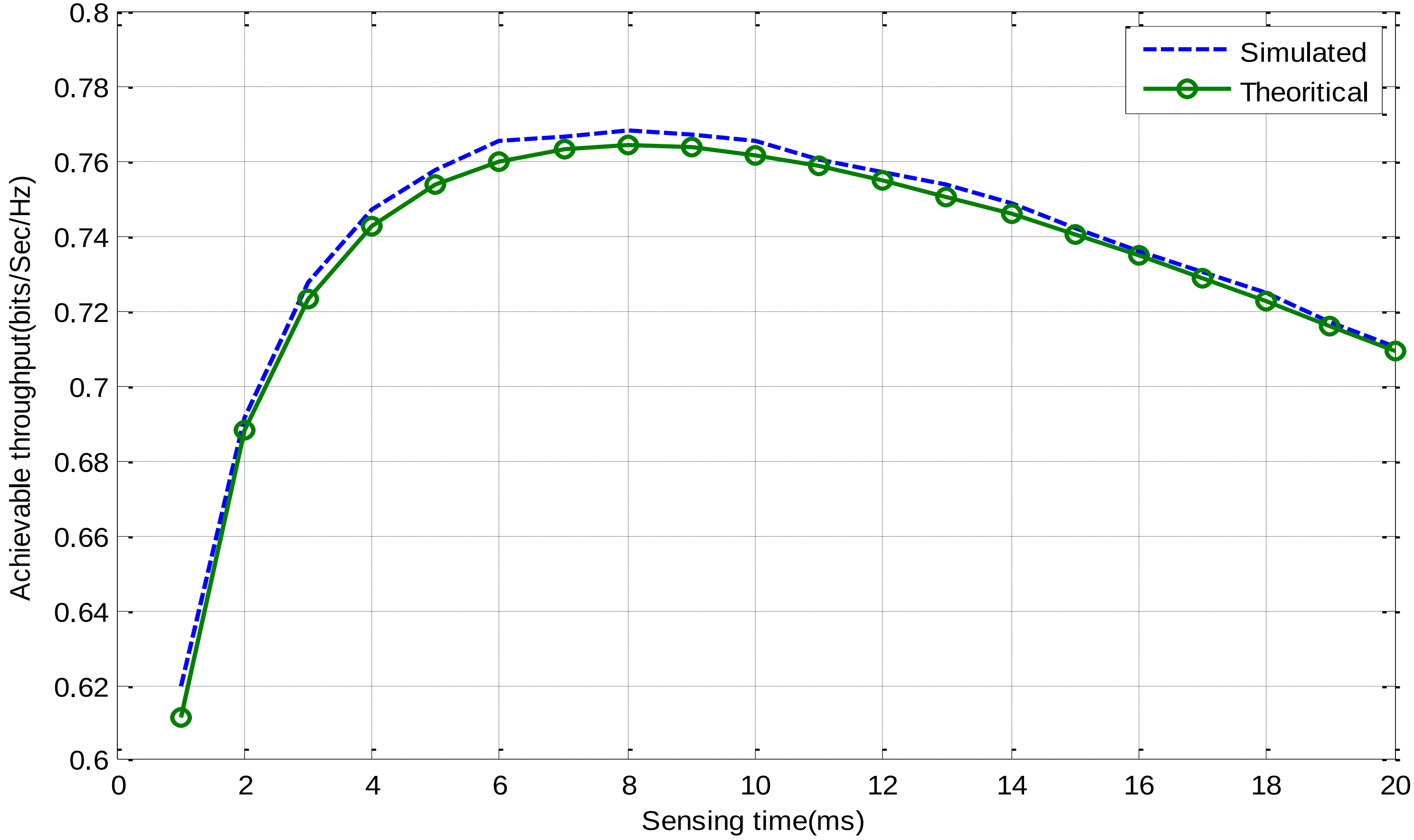
The Normalized throughput (AWGN)



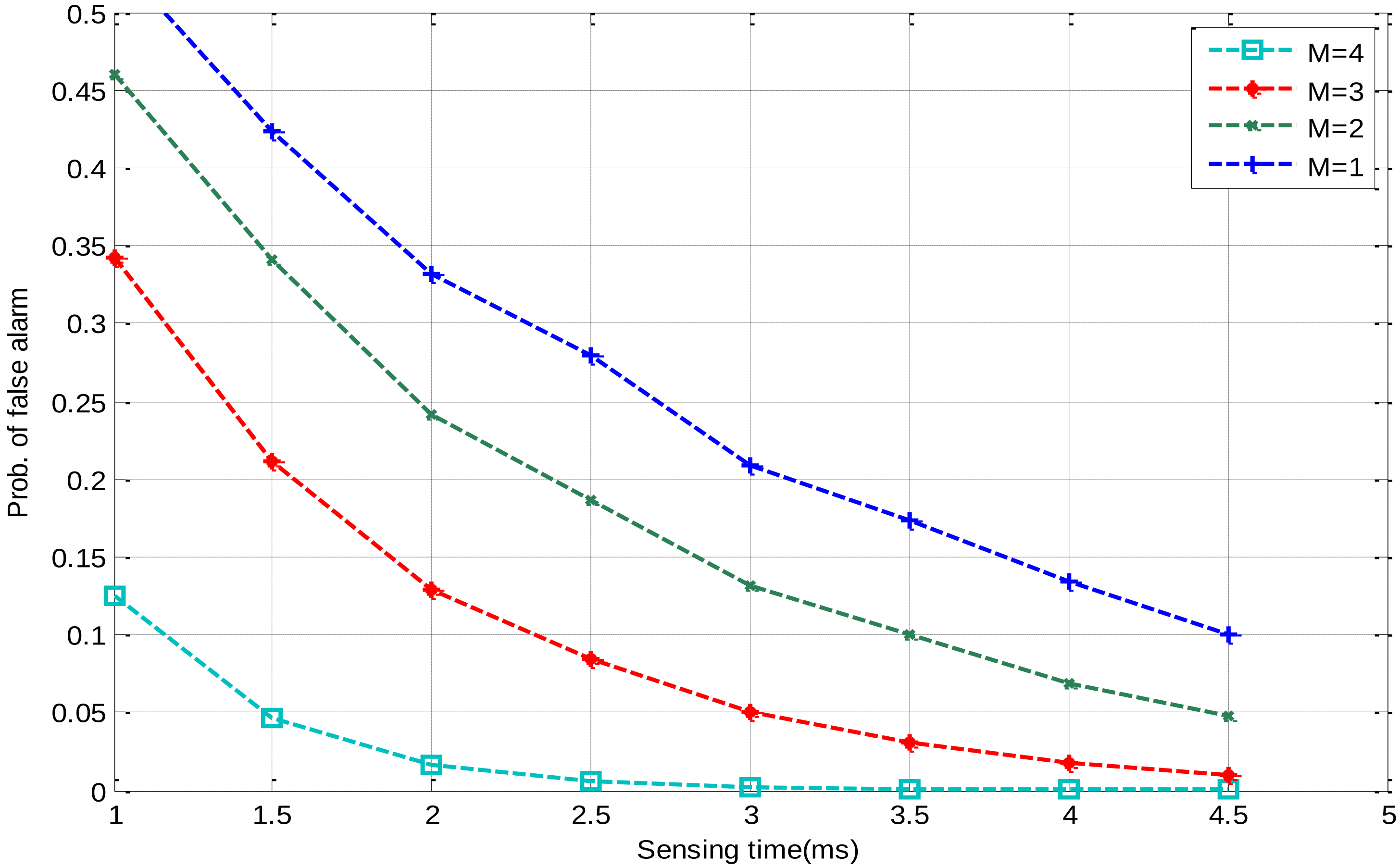
The achievable throughput (Rayleigh Channel)



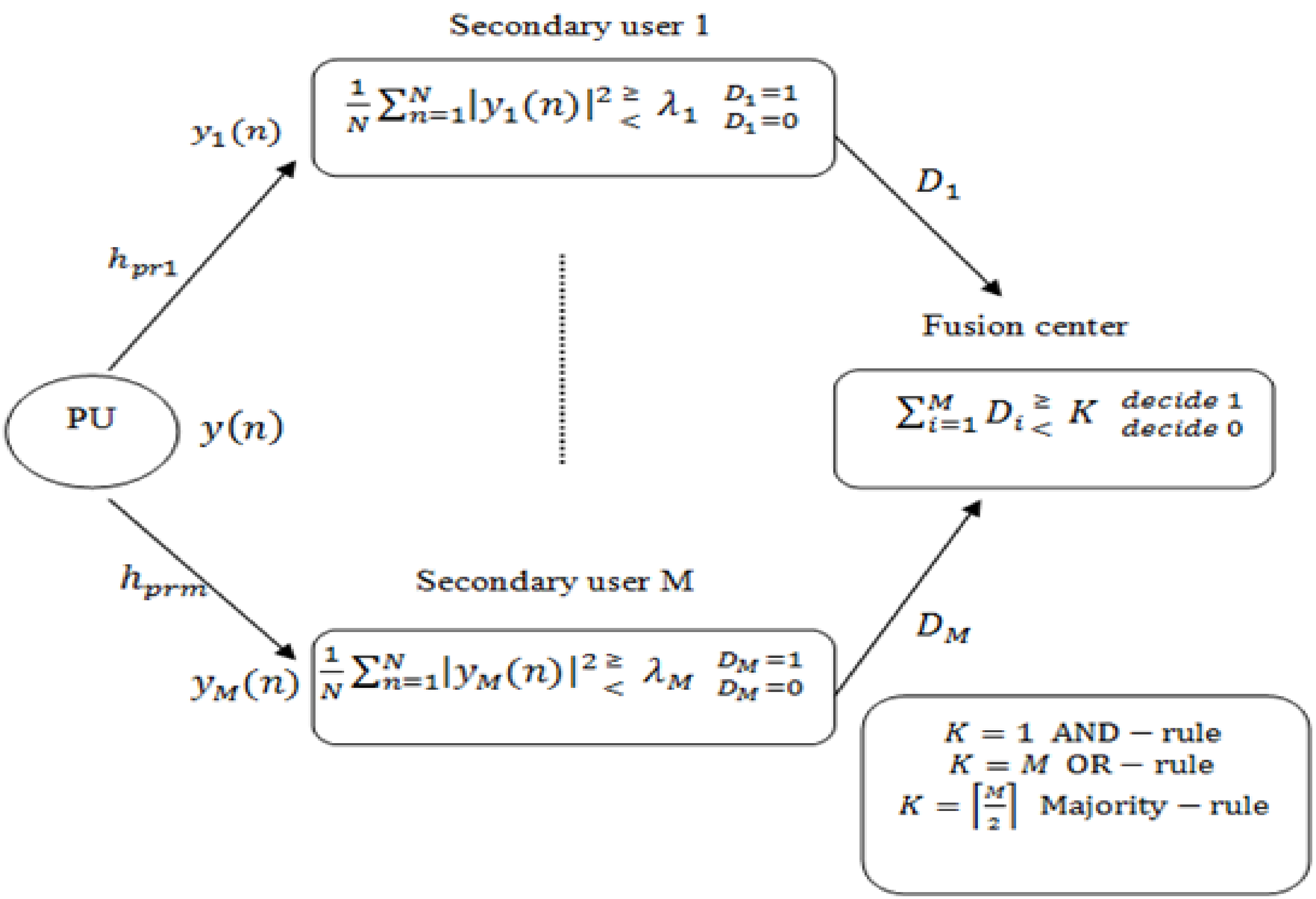
The Normalized throughput (Rayleigh Channel)



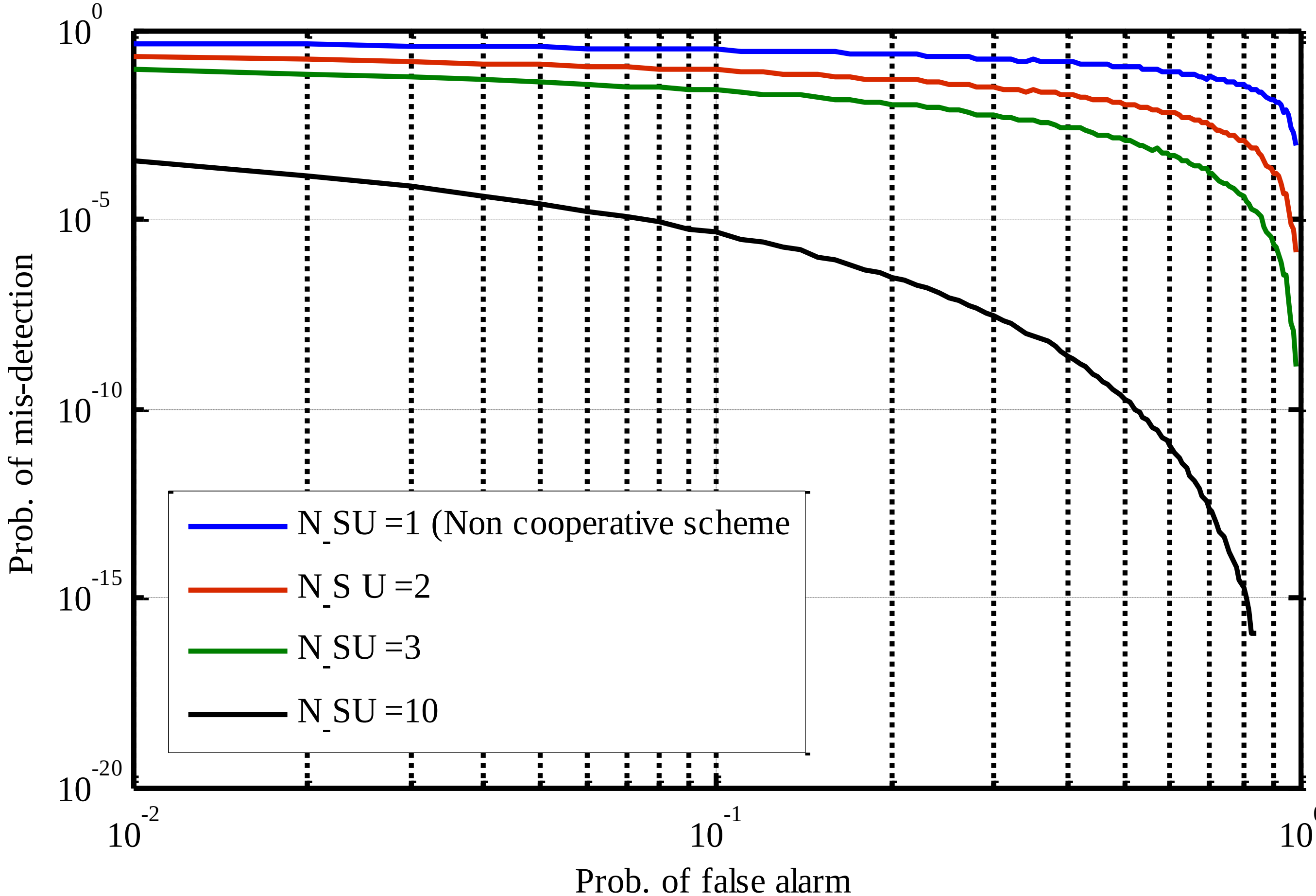
Multi-slot Spectrum Sensing



Decision fusion cooperative sensing scheme



Superiority of cooperative sensing



The ROC curve for OR fusion rule with variable number of users.

Conclusion

- The sensing-throughput trade off problem is highlighted in the AWGN and Rayleigh fading channels.
- The throughput curve in both channels has concave shape so, a unique solution is found.
- Optimal sensing time in AWGN noise channel of 2.667 ms is resulted (For a frame length of 100 ms)
- While, optimal sensing time for Rayleigh fading be 7 ms.
- Also, the Rayleigh fading reduces the SU transmission throughput.
- Multi-slot sensing it a type of time diversity improves the false alarm probability.

Thank You