Sensing-based Resource Allocation In Cognitive Radio Networks

Nafiseh Janatian

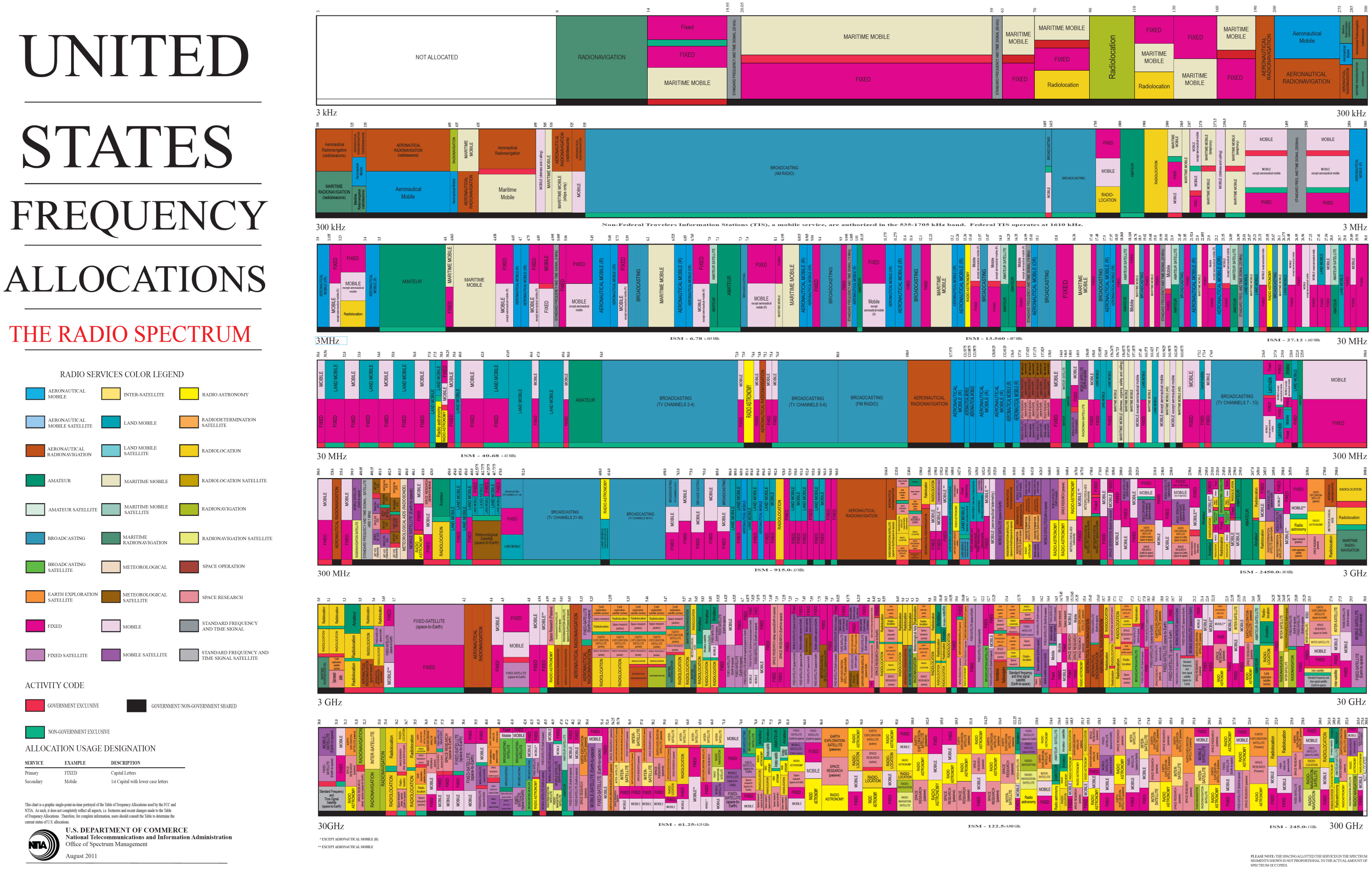
Mostly based on

N. Janatian, S. Sun, and M. Modarres Hashemi, "Joint Optimal Spectrum Sensing and Power Allocation in CDMA-based Cognitive Radio Networks," IEEE Trans. Veh. Technol., vol. 64, no. 9, pp. 3990-3998, 2014.

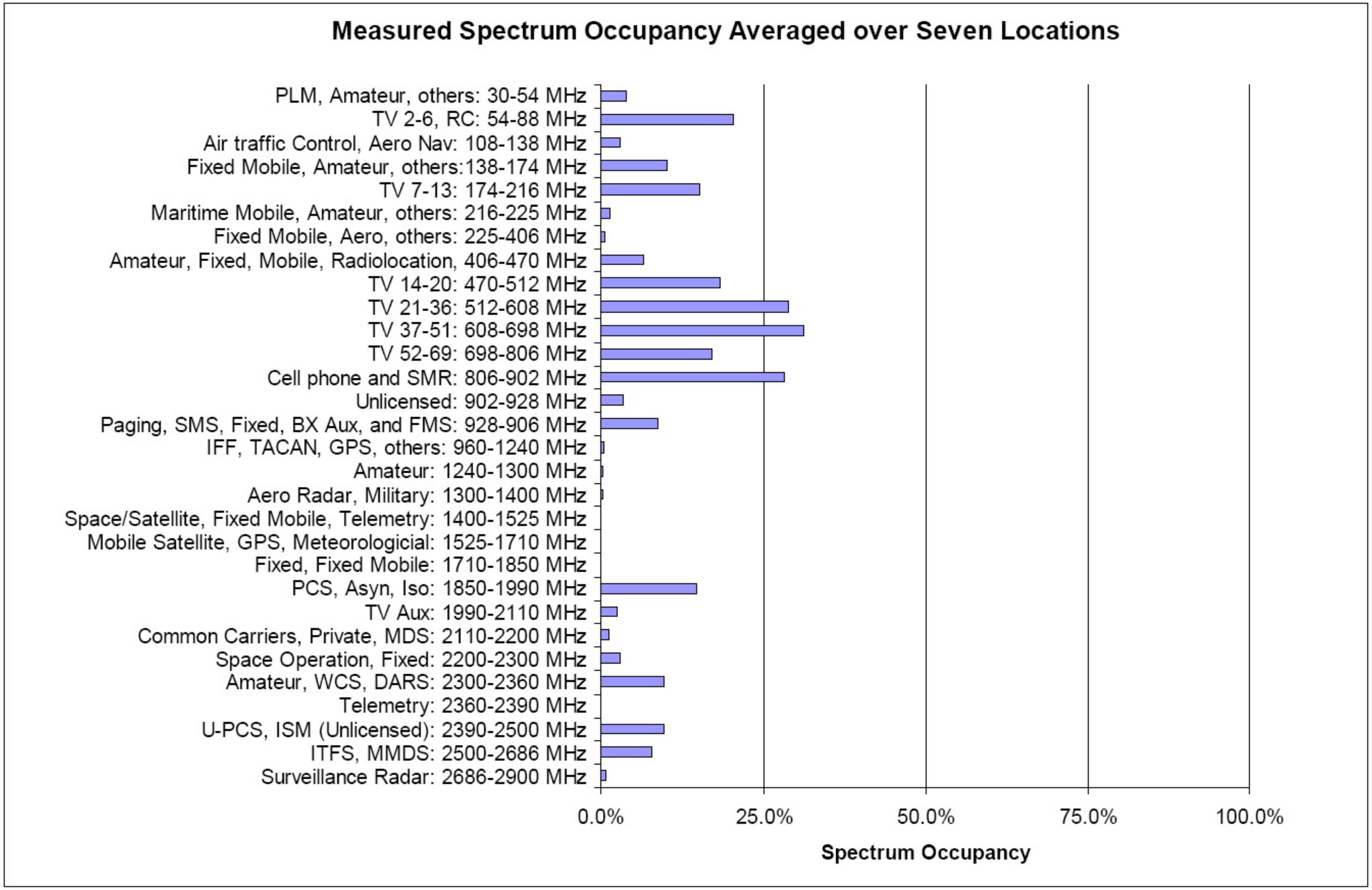
Outline

- Cognitive radio concept
- Two important topics in cognitive radio networks
    - Spectrum sensing
    - Resource allocation
- Sensing based resource allocation in
    - ✔ CDMA-based cognitive radio networks
    - ✘ OFDMA-based cognitive radio networks
- Conclusion and suggestions

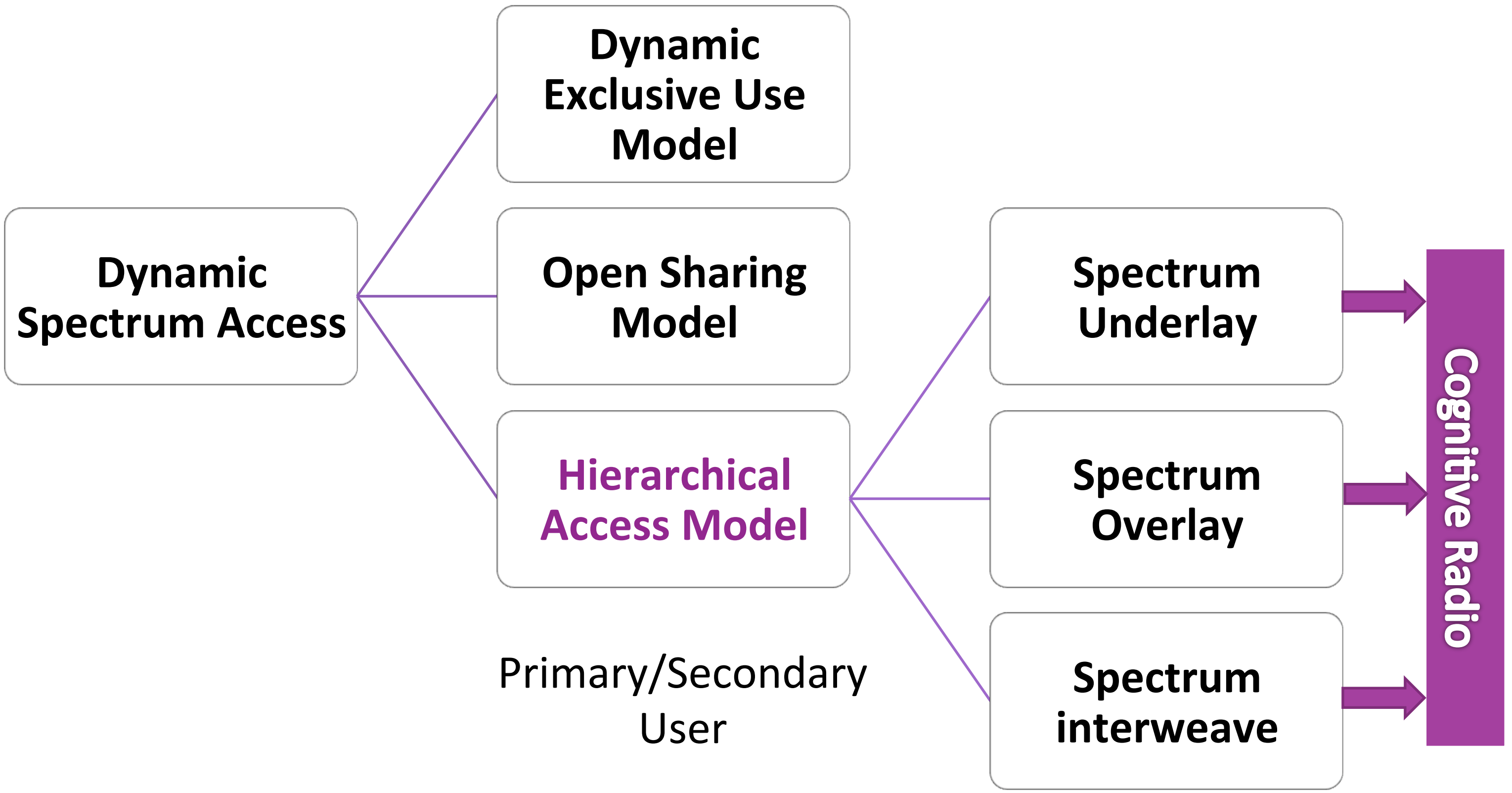
Motivation


UNITED STATES FREQUENCY ALLOCATIONS
THE RADIO SPECTRUM
RADIO SERVICES COLOR LEGEND
ACTIVITY CODE
ALLOCATION USAGE DESIGNATION
U.S. DEPARTMENT OF COMMERCE
National Telecommunications and Information Administration
Office of Spectrum Management
August 2011
3 kHz
300 kHz
3 MHz
30 MHz
300 MHz
3 GHz
30 GHz
30GHz
300 GHz
NOT ALLOCATED
RADIONAVIGATION
MARITIME MOBILE
FIXED
BROADCASTING
AMATEUR
MOBILE

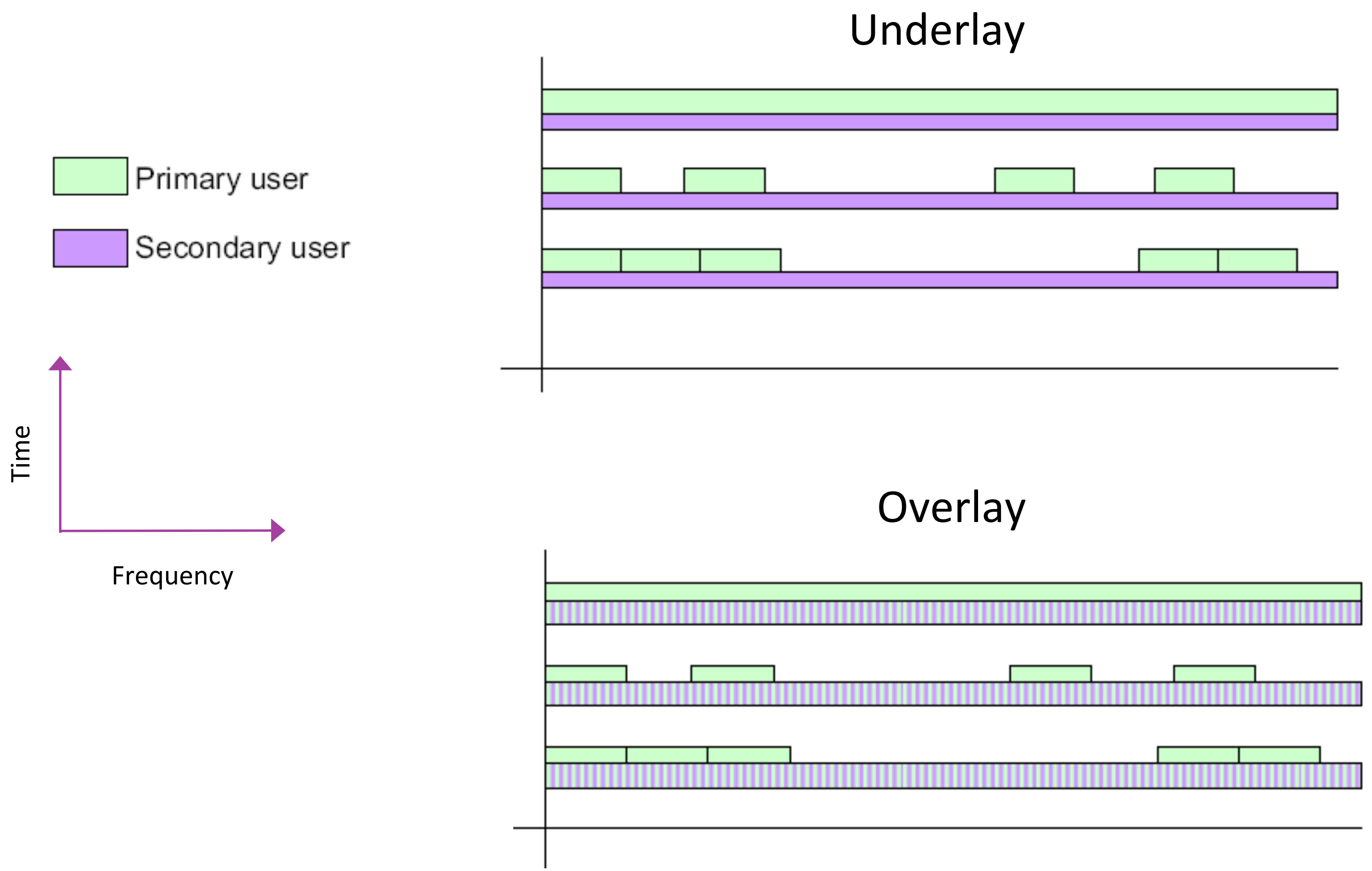
Motivation


Measured Spectrum Occupancy Averaged over Seven Locations
PLM, Amateur, others: 30-54 MHz
TV 2-6, RC: 54-88 MHz
Air traffic Control, Aero Nav: 108-138 MHz
Fixed Mobile, Amateur, others:138-174 MHz
TV 7-13: 174-216 MHz
Maritime Mobile, Amateur, others: 216-225 MHz
Fixed Mobile, Aero, others: 225-406 MHz
Amateur, Fixed, Mobile, Radiolocation, 406-470 MHz
TV 14-20: 470-512 MHz
TV 21-36: 512-608 MHz
TV 37-51: 608-698 MHz
TV 52-69: 698-806 MHz
Cell phone and SMR: 806-902 MHz
Unlicensed: 902-928 MHz
Paging, SMS, Fixed, BX Aux, and FMS: 928-906 MHz
IFF, TACAN, GPS, others: 960-1240 MHz
Amateur: 1240-1300 MHz
Aero Radar, Military: 1300-1400 MHz
Space/Satellite, Fixed Mobile, Telemetry: 1400-1525 MHz
Mobile Satellite, GPS, Meteorologicial: 1525-1710 MHz
Fixed, Fixed Mobile: 1710-1850 MHz
PCS, Asyn, Iso: 1850-1990 MHz
TV Aux: 1990-2110 MHz
Common Carriers, Private, MDS: 2110-2200 MHz
Space Operation, Fixed: 2200-2300 MHz
Amateur, WCS, DARS: 2300-2360 MHz
Telemetry: 2360-2390 MHz
U-PCS, ISM (Unlicensed): 2390-2500 MHz
ITFS, MMDS: 2500-2686 MHz
Surveillance Radar: 2686-2900 MHz
0.0%
25.0%
50.0%
75.0%
100.0%
Spectrum Occupancy

Dynamic Spectrum Access

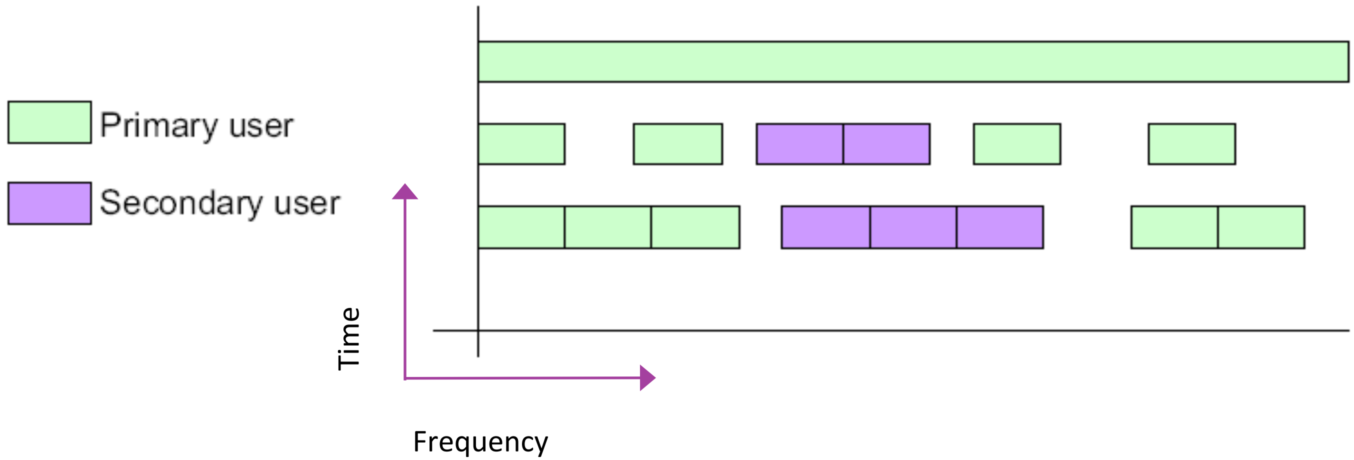


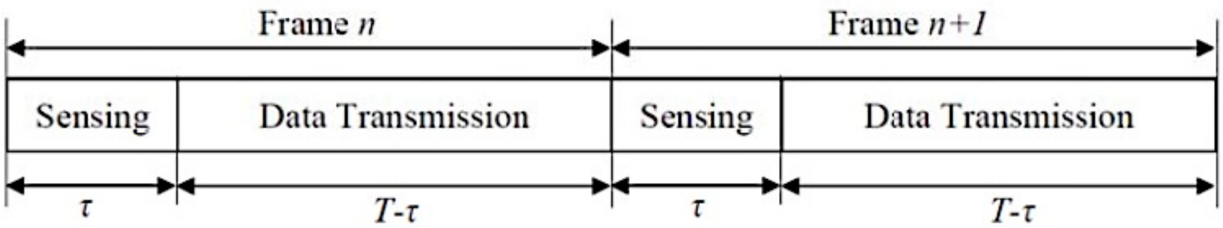
CRN Operation Models



CR Operation Models

Interweave Paradigm





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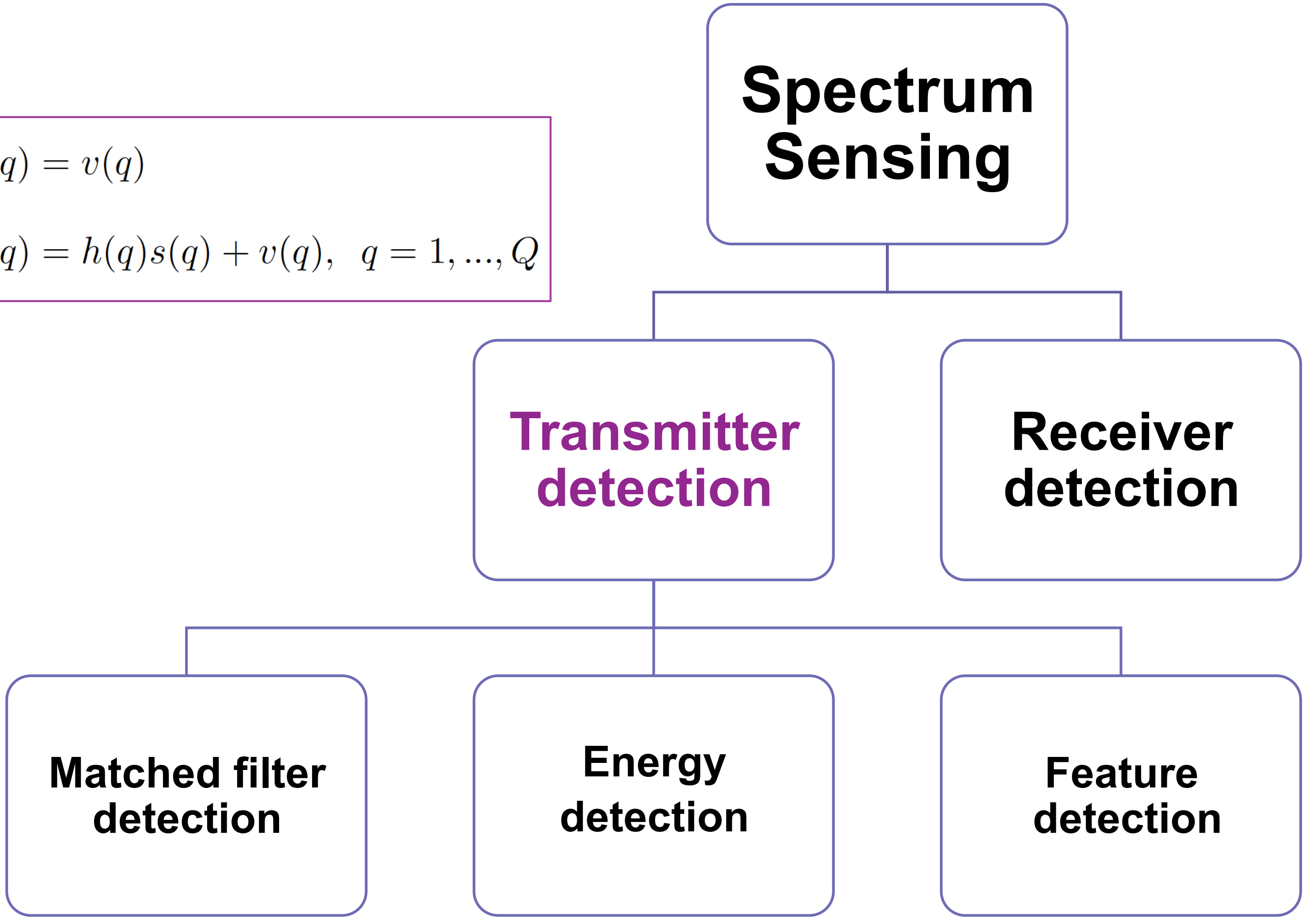
Spectrum sensing

$$H_0 : \; x(q) = v(q)$$

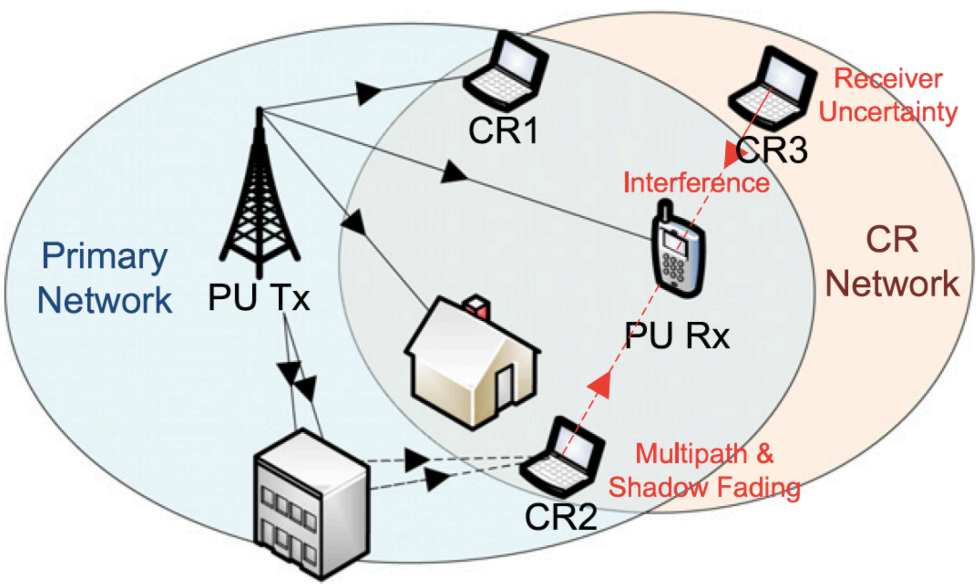
$$H_1 : \; x(q) = h(q)s(q) + v(q), \quad q = 1, \ldots, Q$$



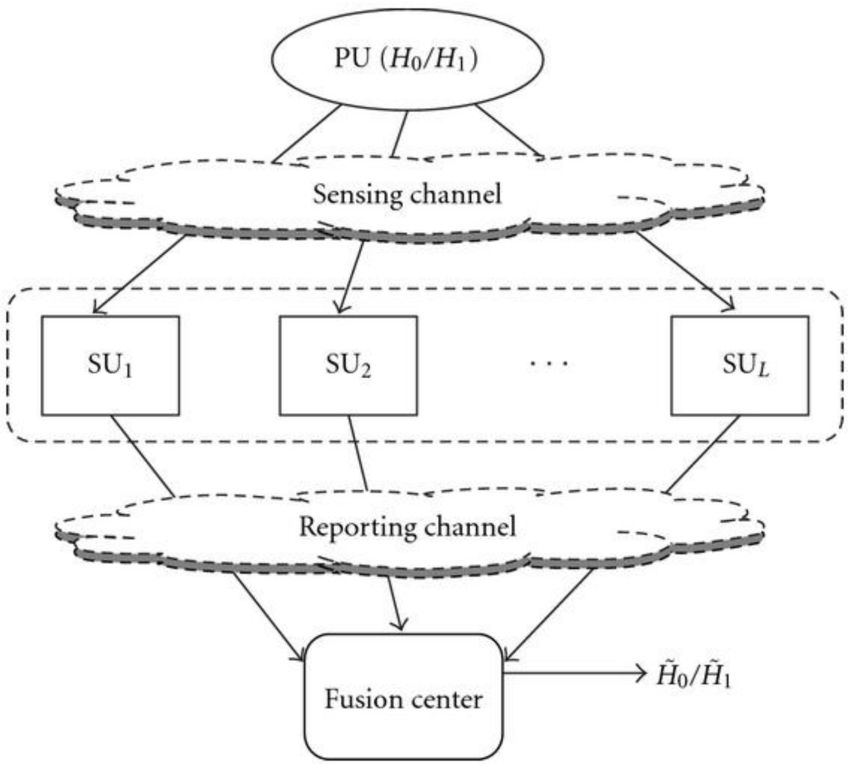
Spectrum sensing

- Performance of Spectrum sensing
  - Pd: Detection probability
  - Pf: False alarm probability

- Spectrum sensing challenges



Cooperative spectrum sensing



- CSS challenges
  - Non ideal Sensing and Reporting channels
  - Resource efficiency in CSS

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Resource Allocation (RA) in CRNs

- Wireless Resources depending on the technology
  - Frequency bands
  - Time slots
  - Orthogonal codes
  - Transmit power

- RA in **interweave CRNs**
  - **Sensing based Resource Allocation**
    - Maximize the throughput
    - ✓Minimize the energy consumption
    - Maximize the energy efficiency metric

Energy Consumption Minimization

- Transmit power allocation in a multicarrier-CDMA network with known sensing parameters.

$$\underset{P_i}{\text{Minimize}} \quad \sum_{i=1}^{N} \sum_{k=1}^{A_i} P_i^{(k)}$$

$$\text{subject to} \quad (1) \sum_{k=1}^{A_i} P_i^{(k)} \leq P_{max}, \; i = 1, ..., N$$

$$(2) \sum_{k=1}^{A_i} b_i^{(k)} \geq R_i, \; i = 1, ..., N$$

$$(3) \; |F_i| = A_i, \; i = 1, ..., N$$

Q. Qi, L. B. Milstein, and D. Vaman, "Cognitive radio based multi-user resource allocation in mobile adhoc networks using multi-carrier CDMA modulation," IEEE J. Sel. Area Comm. , vol. 26, no. 1, pp.70–82, 2008.

Energy Efficiency Maximization

- Sub-channel assignment in CRN consisting M SUs and N sub-channels, with known sensing parameters.

$$\underset{x_{m,n}}{\text{Maximize}} \quad \eta = \frac{R}{E}$$

$$\text{subject to} \quad (1) \sum_{n=1}^{N} x_{m,n} \leq 1, \; m = 1, ..., M$$

$$(2) \sum_{m=1}^{M} x_{m,n} \leq 1, \; n = 1, ..., N$$

$$(3) \; x_{m,n} \in \{0 \; , \; 1\}$$

S. Bayhan and F. Alagoz, "Scheduling in centralized cognitive radio networks for energy efficiency," IEEE Trans. Veh. Technol. , vol. 62, no. 2, pp. 582 – 595, Oct. 2013.

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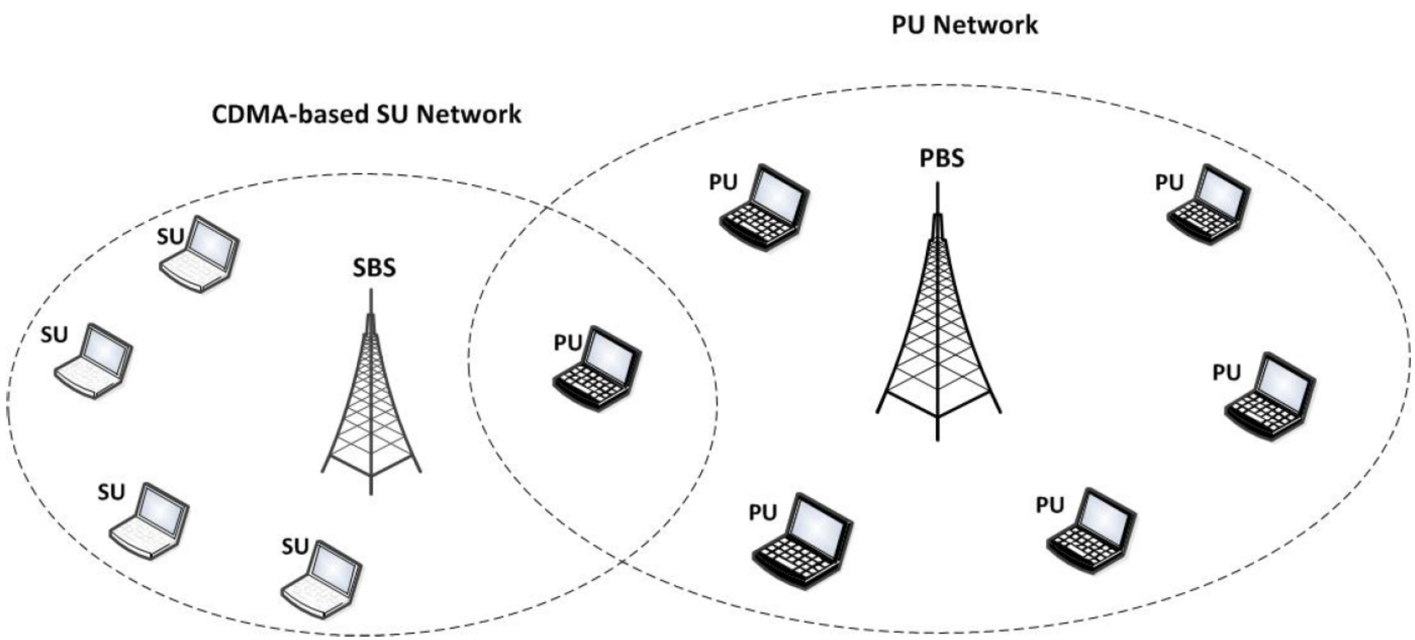
System Model



Sensing	Reporting	Channel access
τ	η	T-τ-η

Spectrum sensing phase

- Hypothesis test at the *i*th SUs

$$x_i(q) \sim \begin{cases} n_i(q) & H_0 \\ n_i(q) + h_i s(q) & H_1 \end{cases}$$

- $s(q)$ is the PU's signal which is assumed to be unknown deterministic
- $n_i(q)$ is the Gaussian noise with zero mean and variance σ_0^2
- $q = 0, \ldots, Q-1$ is the time index, and Q equals τf_s

Spectrum sensing phase

- Energy detector

$$y_i = \frac{1}{\sigma_0^2}\sum_{q=0}^{Q-1}(x_i(q))^2 \sim \begin{cases} \chi_Q^2 & H_0 \\ \chi_Q'^2(Q\gamma_i) & H_1 \end{cases}$$

- On-OFF Censoring

$$u_i = \begin{cases} 1 & y_i \geq \lambda_i \\ \times & y_i < \lambda_i \end{cases}$$

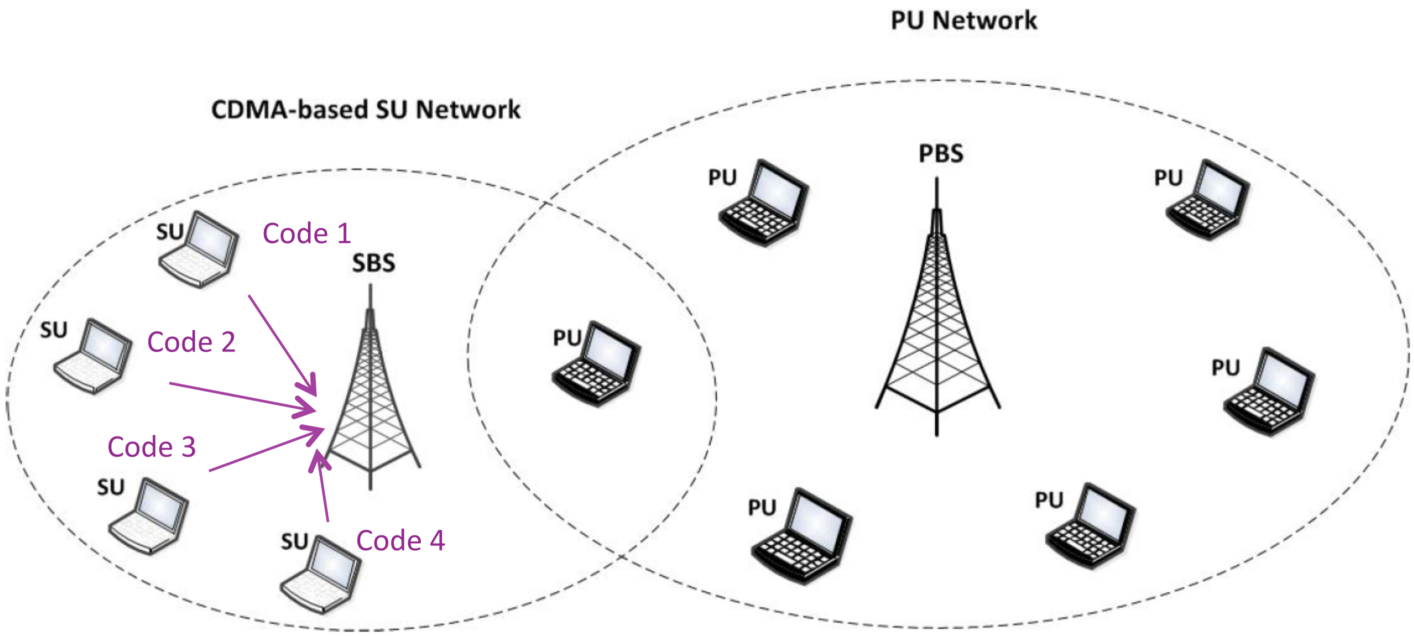
Counting Rule (OR) at Fusion Center

$$P_F = 1 - \prod_{i=1}^{M}((1-p_{f_i})(1-p_{e_i}) + p_{f_i}p_{e_i})$$

$$P_D = 1 - \prod_{i=1}^{M}((1-p_{d_i})(1-p_{e_i}) + p_{d_i}p_{e_i})$$

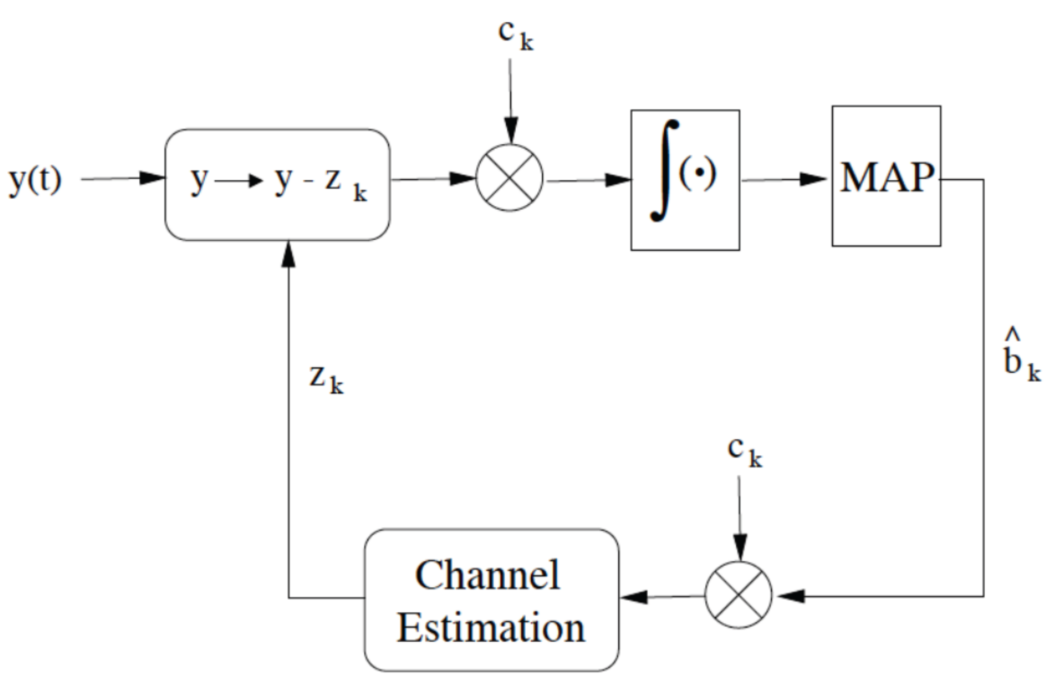
Transmission phase

- Uplink CDMA (Code Division Multiple Access)



Transmission phase

- Conventional single user matched filter
- SIC (Successive Interference Canceller) detector at SBS



Problem Formulation (1)

Joint Optimization of Spectrum Sensing and Power Allocation

Problem P1

$$\underset{\boldsymbol{\Lambda},\boldsymbol{P}}{\text{Minimize}} \quad E_T = \sum_{i=1}^{M}[(\Phi_{s_i}\tau + \Phi_{r_i}\frac{\eta}{M}((1-\rho_{0_i})\pi_0 + (1-\rho_{1_i})\pi_1)]$$

$$+ (T-\tau-\eta)((1-P_F)\pi_0 + (1-P_D)\pi_1)\sum_{i=1}^{M} P_i$$

$$\text{subject to} \quad (1)\ R_i \approx (1-\frac{\tau+\eta}{T})(1-P_F)\pi_0 \log(1+\frac{P_i}{\sum_{k=i+1}^{M} P_k + N_0 W}) \geq \alpha_i$$

$$(2)\ P_D \geq \bar{P}_D$$

$$(3)\ P_F \leq \bar{P}_F$$

$$(4)\ \lambda_i \geq 0, P_i > 0, \quad i = 1, ..., M$$

Joint optimization

- **Problem P2**

$$\underset{p_{f_i}, i=1,\ldots,M}{\text{Minimize}} \quad E_T = \sum_{i=1}^{M} [\Phi_{s_i}\tau + \Phi_{r_i}\frac{\eta}{M}(p_{f_i}\pi_0 + p_{d_i}\pi_1)]$$

$$+ N_0 W(T-\tau-\eta)((1-P_F)\pi_0 + (1-P_D)\pi_1)$$

$$(\exp(\frac{\sum_{i=1}^{M}\alpha_k}{\pi_0(1-\frac{\tau+\eta}{T})(1-P_F)}) - 1)$$

$$\text{subject to} \quad (1)\ P_D \geq \bar{P}_D$$

$$(2)\ P_F \leq \bar{P}_F$$

$$(3)\ 0 \leq p_{f_i} \leq 1, \quad i = 1, \ldots, M$$

- P2 is not convex in general but can be represented as a monotonic optimization problem.

Monotonic Optimization Problem

- Definition :

$$\text{Minimize}\{f(\boldsymbol{z})|\boldsymbol{z} \in \mathcal{G} \cap \mathcal{H}\}$$

$$\mathcal{G} = \{\boldsymbol{z} \in \mathcal{R}_+^n | g(\boldsymbol{z}) \leq 0\}$$

$$\mathcal{H} = \{\boldsymbol{z} \in \mathcal{R}_+^n | h(\boldsymbol{z}) \geq 0\}$$

is a **Monotonic Optimization Problem** **iff**

- $f(\boldsymbol{z}), g(\boldsymbol{z}), h(\boldsymbol{z}) : \mathcal{R}_+^n \rightarrow \mathcal{R}$ **are monotone increasing.**
- $\mathcal{G} \cap \mathcal{H} \subseteq [\mathbf{0}\ ,\ \boldsymbol{b}] \subseteq \mathcal{R}_+^n$ **is a close set.**

Joint optimization

- **Problem P3**

$$\underset{p_{f_i}, i=1,...,M}{\text{Minimize}} \quad \log(E_T) = \log(X_1(\boldsymbol{p_f})) + \log(X_2(\boldsymbol{p_f}))$$

$$\text{subject to} \quad (1)\ P_D \geq \bar{P}_D$$

$$(2)\ P_F \leq \bar{P}_F$$

$$(3)\ 0 \leq p_{f_i} \leq 1, \quad i = 1, ..., M$$

- $X_2(\boldsymbol{p_f})$ is an increasing and $X_1(\boldsymbol{p_f})$ is a decreasing function of $\boldsymbol{p_f} = [p_{f_1} \ ... \ p_{f_M}]$

- Objective of P3 is a difference of increasing functions and can be represented as a monotonic optimization problem.

Joint optimization

- **Problem P4**

$$\underset{t, p_{f_i}, i=1,\dots,M}{\text{Minimize}} \quad t + Y_2(\boldsymbol{p_f})$$

$$\text{subject to} \quad (1)\; t - Y_1(\boldsymbol{p_f}) \geq -Y_1(\mathbf{1})$$

$$(2)\; P_D(\boldsymbol{p_f}) \geq \bar{P}_D$$

$$(3)\; P_F(\boldsymbol{p_f}) \leq \bar{P}_F$$

$$(4)\; 0 \leq p_{f_i} \leq 1, \;\; i = 1, \dots, M, \;\; 0 \leq t \leq Y_1(0) - Y_1(1)$$

- **Polyblock/Copolyblock** algorithms are suggested by **Tuy** for solving monotonic **Maximization/Minimization** problem.

H. Tuy, "Normal sets, polyblocks and monotonic optimization," Vietnam Journal of Mathematics , vol. 27, no. 4, pp. 277–300, 1999.

Problem Formulation (2)

Separate Optimization of Spectrum Sensing and Power Allocation

- **Problem Q1**

$$\underset{p_{f_i}, i=1,\dots,M}{\text{Minimize}} \quad E_{CSS} = \sum_{i=1}^{M} [\Phi_{s_i}\tau + \Phi_{r_i}\frac{\eta}{M}(p_{f_i}\pi_0 + p_{d_i}\pi_1)]$$

$$\text{subject to} \quad (1)\ P_F = 1 - \prod_{i=1}^{M}((1-p_{f_i})(1-p_{e_i}) + p_{f_i}p_{e_i}) \le \bar{P}_F$$

$$(2)\ P_D = 1 - \prod_{i=1}^{M}((1-p_{d_i})(1-p_{e_i}) + p_{d_i}p_{e_i}) \ge \bar{P}_D$$

$$(3)\ 0 \le p_{f_i} \le 1, \quad i = 1, \dots, M$$

- Monotonic Optimization Problem

Separate Optimization

- **Problem Q2**

$$\underset{\boldsymbol{P}}{\text{Minimize}} \quad E_{Trans} = (\sum_{i=1}^{M} P_i)(T - \tau - \eta)((1 - P_F)\pi_0 + (1 - P_D)\pi_1)$$

$$\text{subject to} \quad (1)\ R_i \approx (1 - \frac{\tau + \eta}{T})(1 - P_F)\pi_0 \log(1 + \frac{P_i}{\sum_{k=i+1}^{M} P_k + N_0 W}) \geq \alpha_i$$

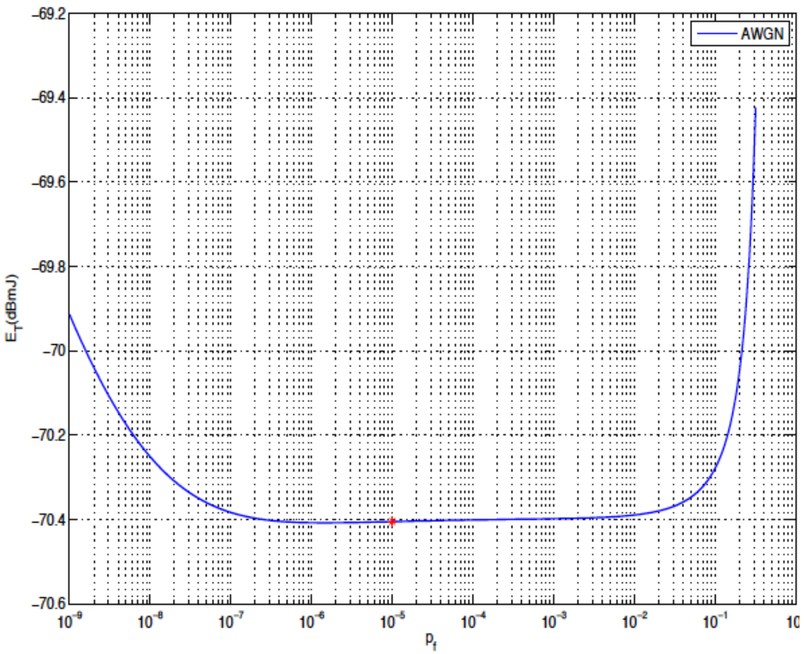
$$(2)\ P_i > 0, \quad i = 1, ..., M$$

- Optimal value happens when

$$R_i^* = \alpha_i \quad i = 1, ..., M$$

Numerical Results

- M=5, $\bar{P}_F$ = 0.5, $\bar{P}_D$ = 0.95
- Effect of sensing parameters on energy consumption,

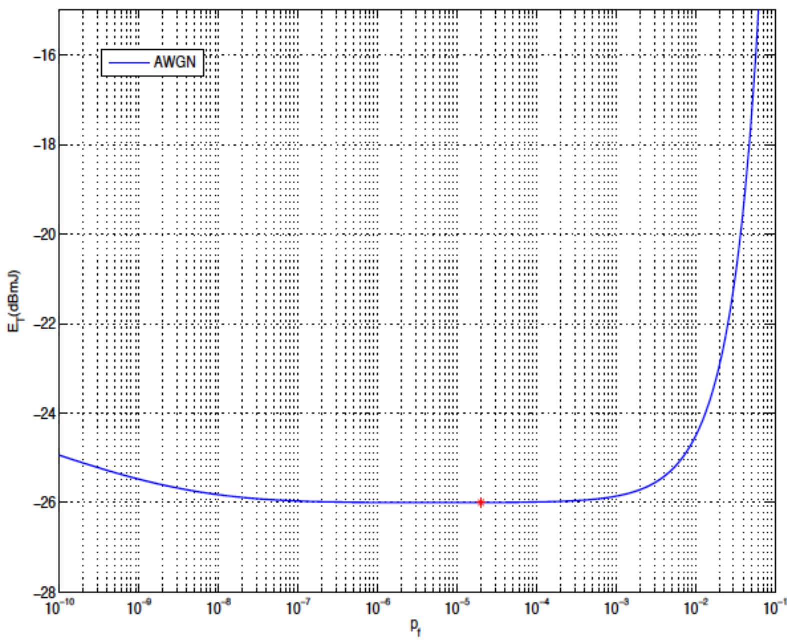


$\gamma = 0$ dB ، $\alpha_i = 0.01$ bit/s/Hz

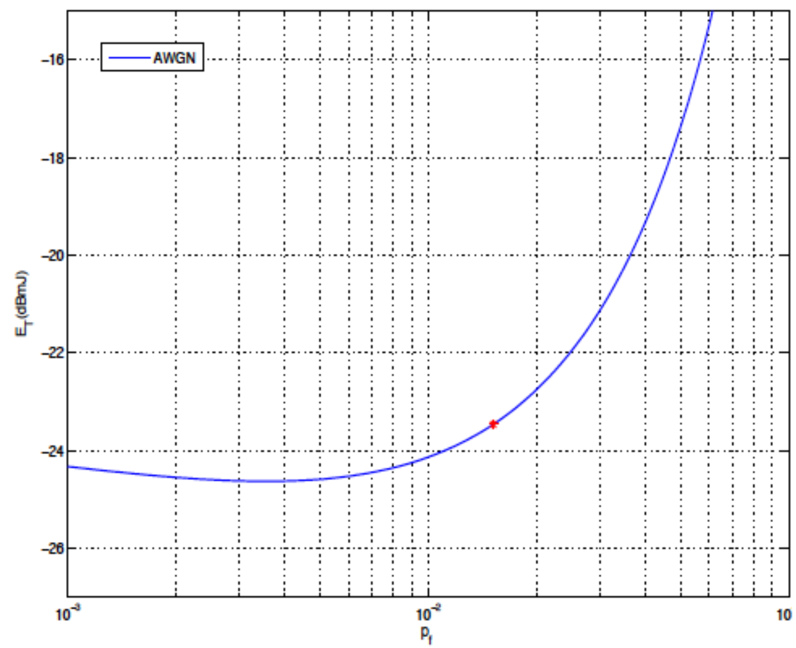
$\gamma = -5$ dB ، $\alpha_i = 0.01$ bit/s/Hz

Numerical Results

- Effect of sensing parameters on energy consumption,



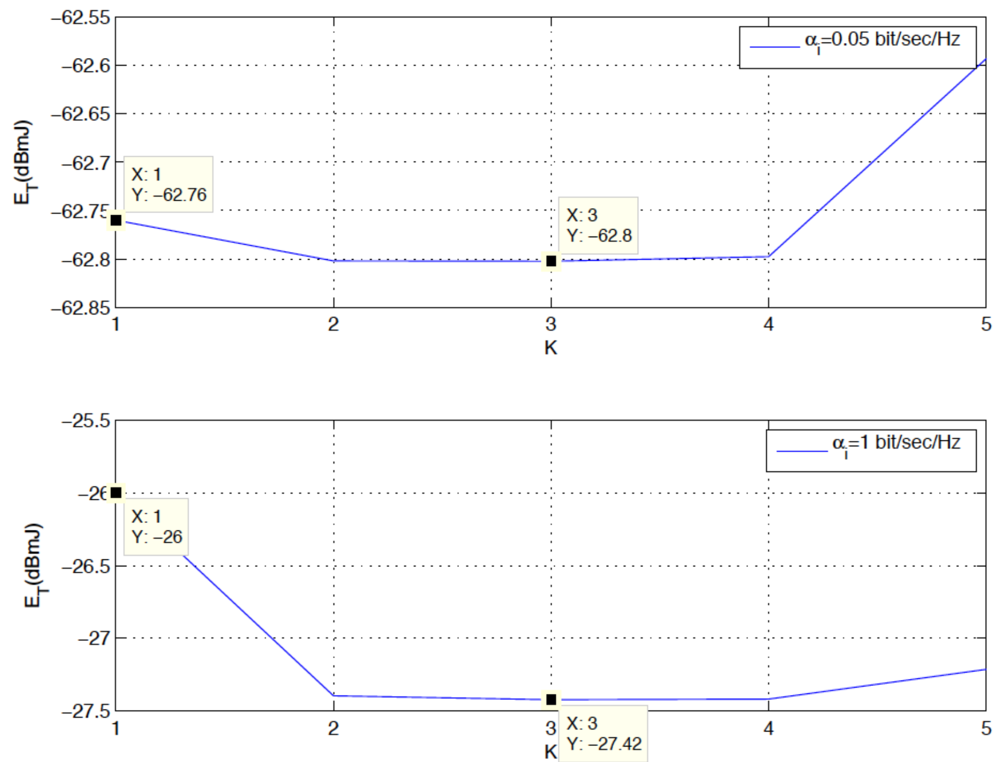
$\gamma = 0$ dB , $\alpha_i = 1$ bit/s/Hz



$\gamma = -5$ dB , $\alpha_i = 1$ bit/s/Hz

Numerical Results

- Effect of fusion rule on energy consumption

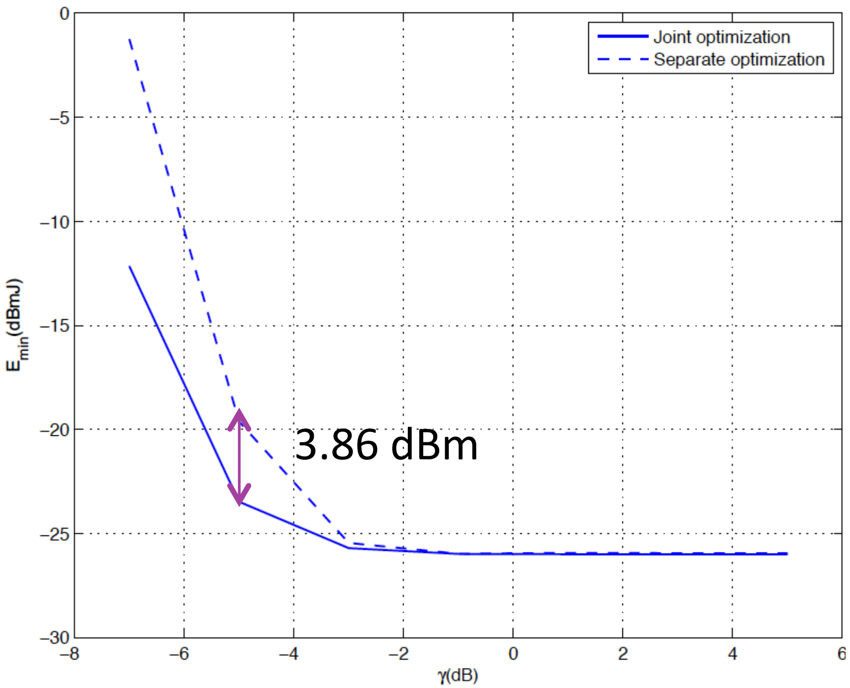


0.04 dBmJ

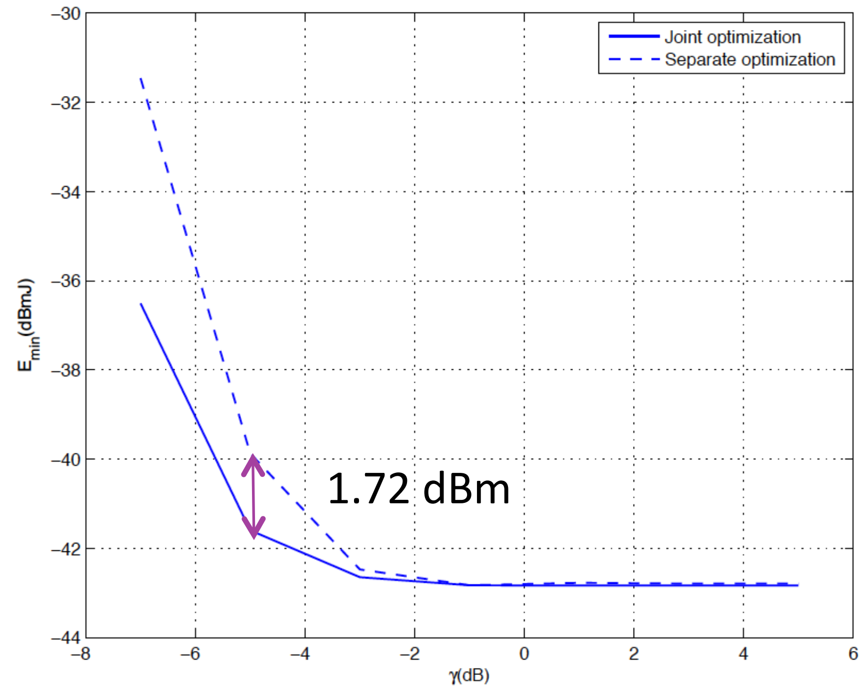
1.42 dBmJ

Numerical Results

- Comparison of joint and separate optimization



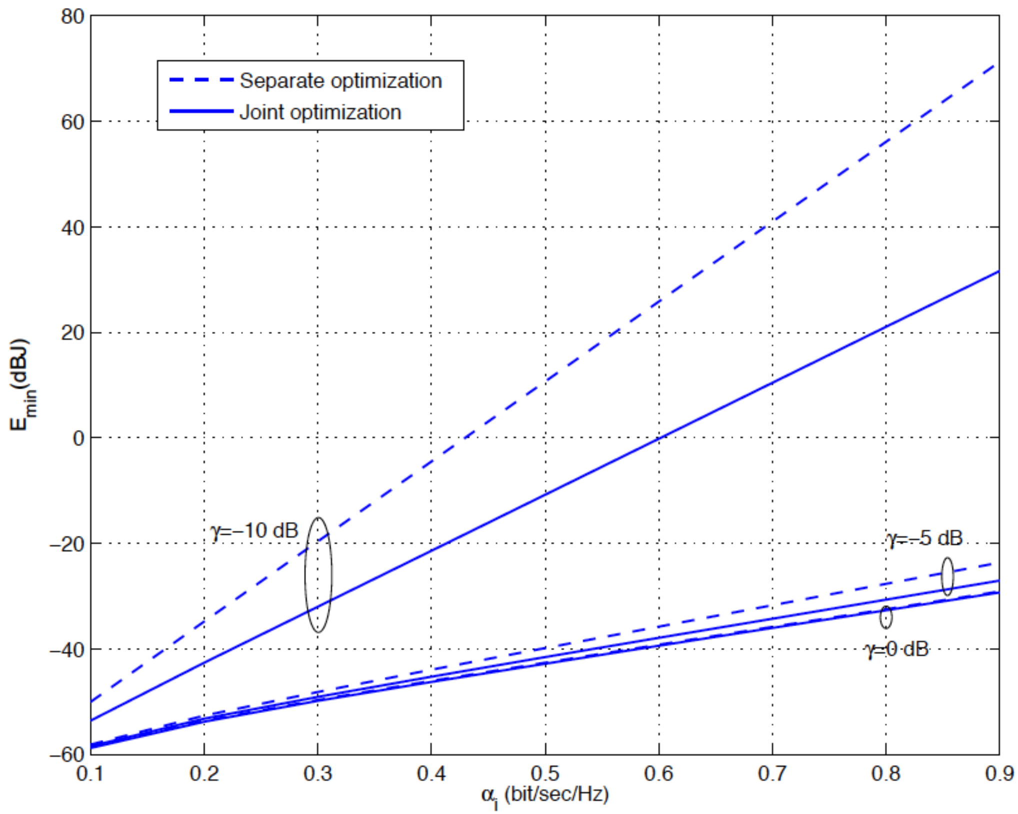
$\alpha_i = 1$ bit/s/Hz



$\alpha_i = 0.5$ bit/s/Hz

Numerical Results

- Comparison of joint and separate optimization



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Conclusion

- Spectrum sensing based resource allocation in CDMA-based cognitive radio networks is considered.
- Joint and separate optimization of sensing parameters and Transmitted powers are studied.
- Numerical results provided suggest that
  - Joint optimization method saves the energy consumption significantly in lower sensing SNRs.
  - It has a very close performance to the separate method in high sensing SNRs

Suggestions

- In this work,
  - uplink power allocation problem for the secondary users,
  - A single channel cognitive radio network with CDMA multiple access of secondary users,
  - Sensing time is fixed.

- Suggestions,
  - The downlink counterpart of the current problem,
  - its extension for the the multi-channel cognitive radio networks,
  - Optimizing the sensing time.

Thanks for your attention!