Power Control for Cognitive Radio Ad Hoc Networks

Lijun Qian and John Attia
Dept. of ECE, Prairie View A&M University
Texas A&M University System

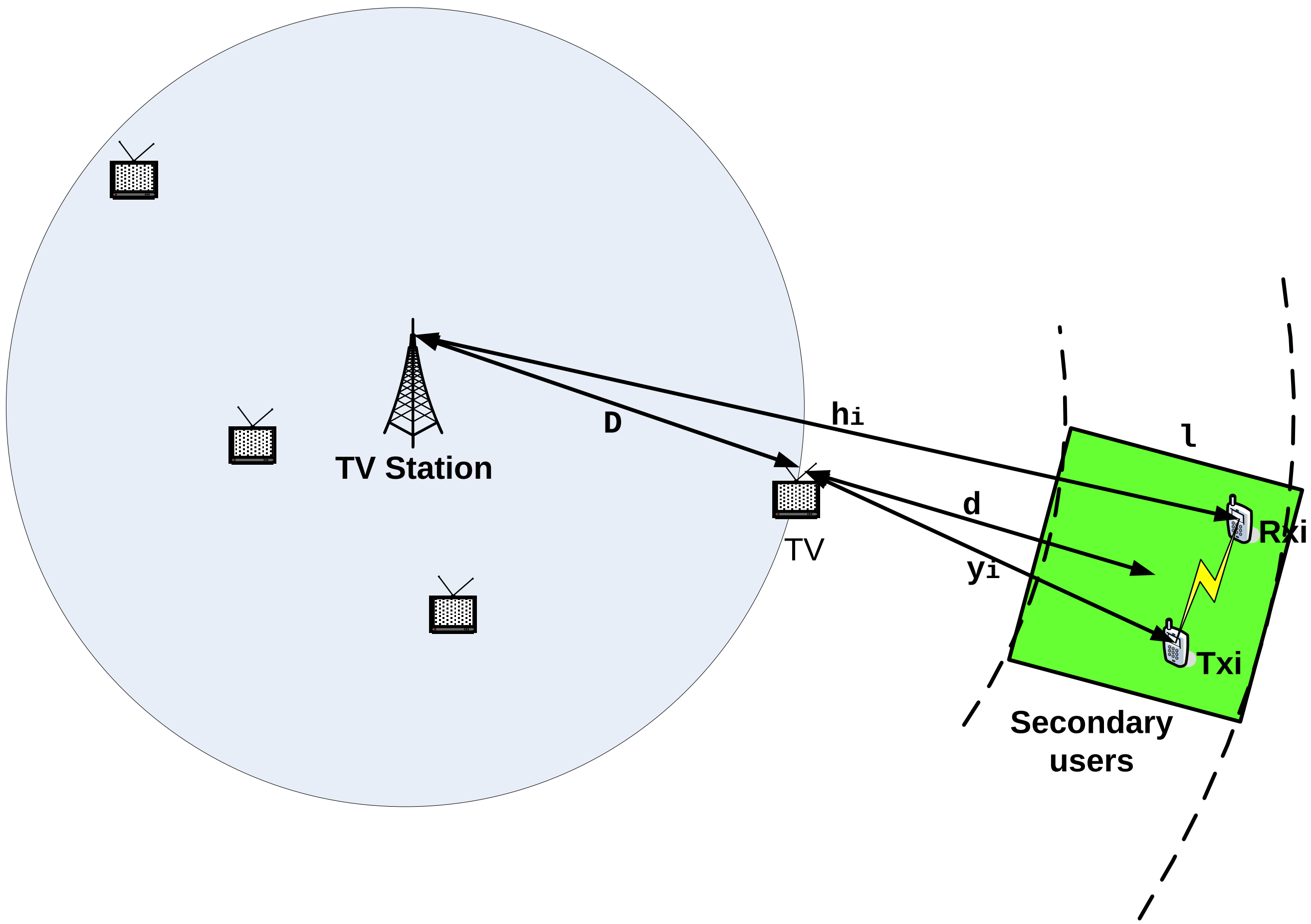
Xiangfang Li and Zoran Gajic
WINLAB, Rutgers University

Cognitive Radio Network

"spectrum access is a more significant problem than physical scarcity of spectrum, in large part due to legacy command-and-control regulation that limits the ability of potential spectrum users to obtain such access" – FCC ET Docket no. 02-135.

- Spectrum sensing
- Spectrum allocation
- Spectrum sharing

An Example

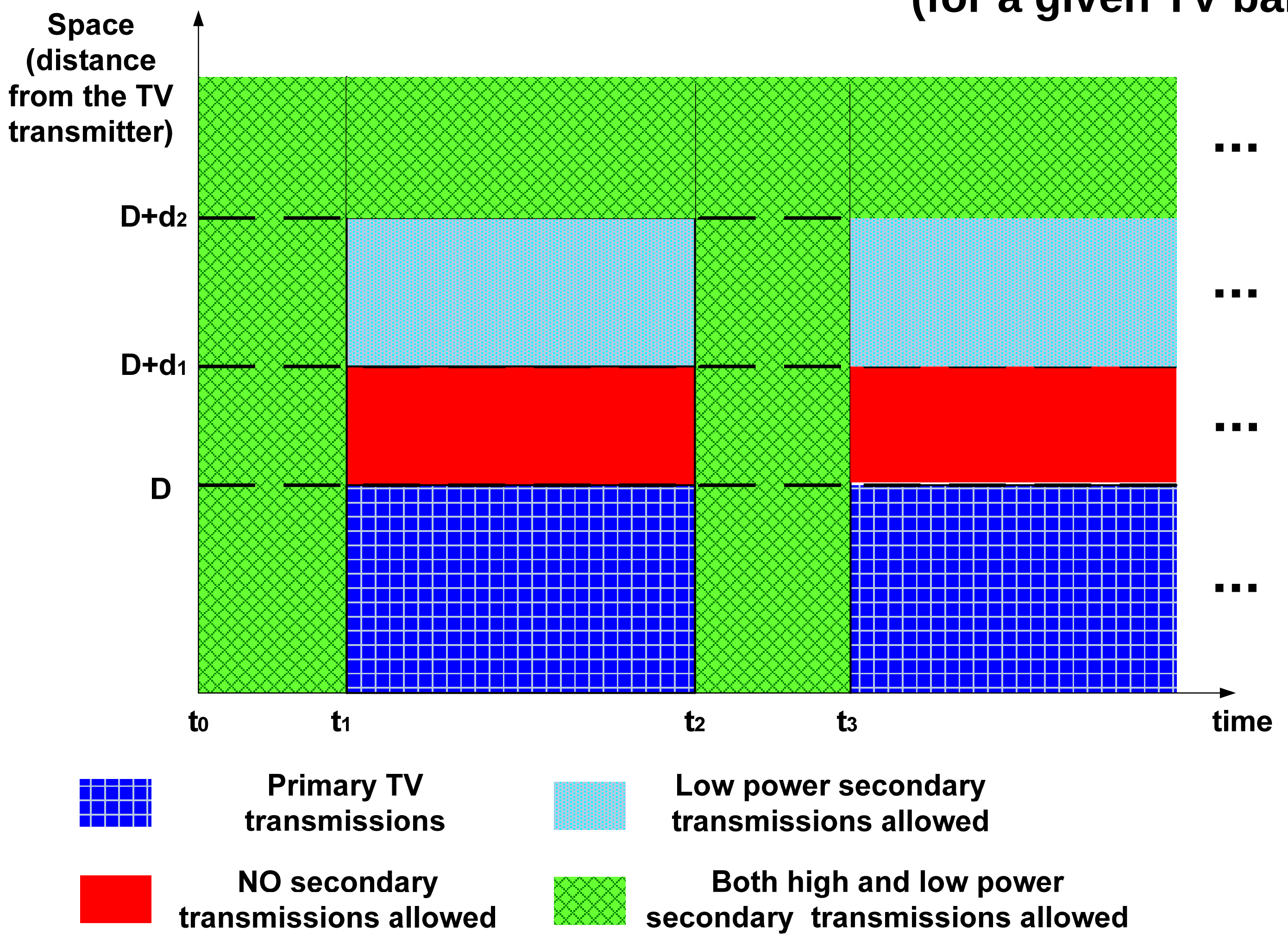


Spectrum Sharing

- Temporal spectrum sharing
  - Periodically sense the spectrum and find spectrum “holes”
  - Occupy spectrum holes when primary user is not present
  - Retreat quickly when primary user returns
- Spatial spectrum sharing
  - Power control is a critical function of cognitive radio
  - QoS assurance of the primary users
  - QoS assurance of the secondary users

Temporal vs. Spatial Spectrum Sharing

(for a given TV band)



Motivation and Rational

- Spectrum sensing is a tough problem
- High transmission power may not be necessary for peer-to-peer or multi-hop ad hoc networks

Spatial spectrum sharing between legacy systems and cognitive radio ad hoc networks (users equipped with low power personal/portable device) via ***power control***

Power Control Problem

(P.1)

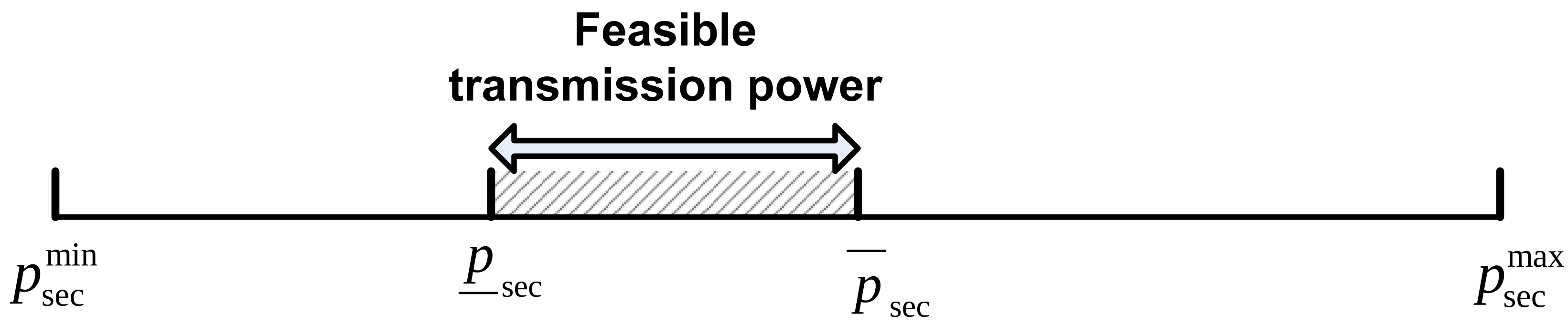
Objective: $$\min \sum_{i=1}^{N} p_{i,\sec}$$

QoS requirement (primary): $$\gamma_{m,TV} \geq \gamma_{TV}^{tar} \quad \forall m$$

QoS requirement (secondary): $$\gamma_{i,\sec} \geq \gamma_{i,\sec}^{tar} \quad \forall i$$

Power constraint: $$p_{\sec}^{\min} \leq p_{i,\sec} \leq p_{\sec}^{\max} \quad \forall i$$

Feasibility Power for a single Secondary Tx-Rx

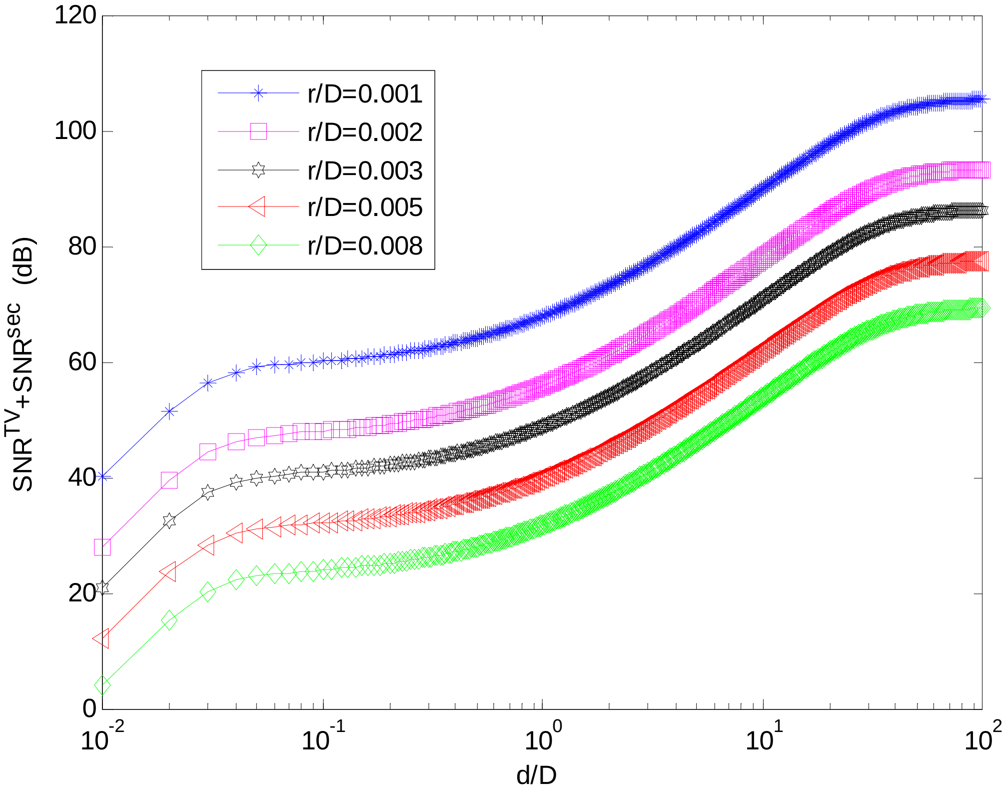


$$\max\{p_{\sec}^{\min}, \underline{p}_{\sec}\} \le p_{\sec} \le \min\{\overline{p}_{\sec}, p_{\sec}^{\max}\}$$

$$\gamma_{\sec} = \frac{p_{\sec} / r^{\alpha_2}}{\frac{f_1 p_{TV}}{h^{\alpha_1}} + \sigma^2} \ge \gamma_{\sec}^{tar} \Rightarrow p_{\sec} \ge \underline{p}_{\sec} = \left(\frac{f_1 p_{TV}}{h^{\alpha_1}} + \sigma^2\right)\gamma_{\sec}^{tar} r^{\alpha_2}$$

$$\gamma_{TV} = \frac{\frac{p_{TV}}{D^{\alpha_1}}}{f_2 p_{\sec} / y^{\alpha_2} + \sigma^2} \ge \gamma_{TV}^{tar} \Rightarrow p_{\sec} \le \overline{p}_{\sec} = \left(\frac{p_{TV}}{D^{\alpha_1}\gamma_{TV}^{tar}} - \sigma^2\right)\frac{y^{\alpha_2}}{f_2}$$

Feasibility Study (a single Tx-Rx)

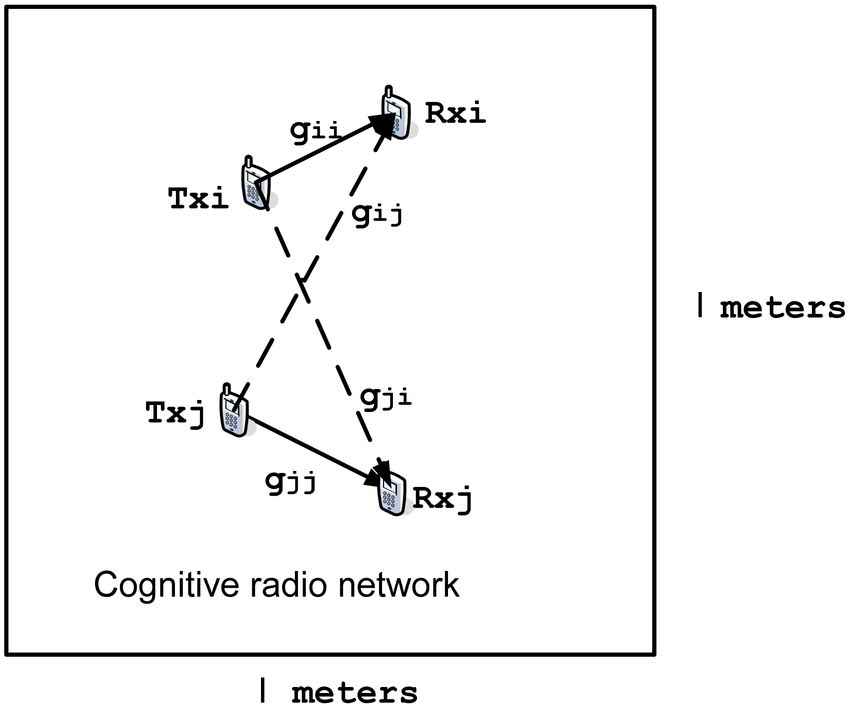


Interference dominant: $\gamma_{TV}^{dB}+\gamma_{\sec}^{dB}\approx\alpha_1\frac{h}{D}+\alpha_2\frac{y}{r}-(f_1+f_2)$ [dB]

$(\frac{r}{D}, \frac{d}{D})$

$$\approx 2\alpha\frac{d}{D}-\alpha\frac{r}{D}-(f_1+f_2) \text{ [dB]}$$

Multiple CR Tx-Rx



$$\gamma_{TV} = \frac{\dfrac{p_{TV}}{D^{\alpha_1}}}{f_2 \sum_{i=1}^{N} \dfrac{p_{i,\sec}}{y_i^{\alpha_2}} + \sigma^2} \geq \gamma_{TV}^{tar}$$

$$\gamma_{i,\sec} = \frac{g_{ii} p_{i,\sec}}{\sum_{\substack{j=1 \\ j \neq i}}^{N} g_{ij} p_{j,\sec} + \dfrac{f_1 p_{TV}}{h_i^{\alpha_1}} + \sigma^2} \geq \gamma_{i,\sec}^{tar}$$

Centralized Solution

$$\vec{p}_{\text{sec}}^{\,*} = [I - \Gamma_{\text{sec}}^{tar} Z]^{-1} \vec{u}$$

$$u_i = \gamma_{i,\text{sec}}^{tar} \eta_i^2 / g_{ii}$$

$$\eta_i^2 = \frac{f_1 p_{TV}}{h_i^{\alpha_1}} + \sigma^2 \qquad i = 1,2,\cdots,N.$$

$$\Gamma_{\text{sec}}^{tar} = \begin{bmatrix} \gamma_{1,\text{sec}}^{tar} & & & & \\ & \gamma_{2,\text{sec}}^{tar} & & & \\ & & \ddots & & \\ & & & \ddots & \\ & & & & \gamma_{N,\text{sec}}^{tar} \end{bmatrix}$$

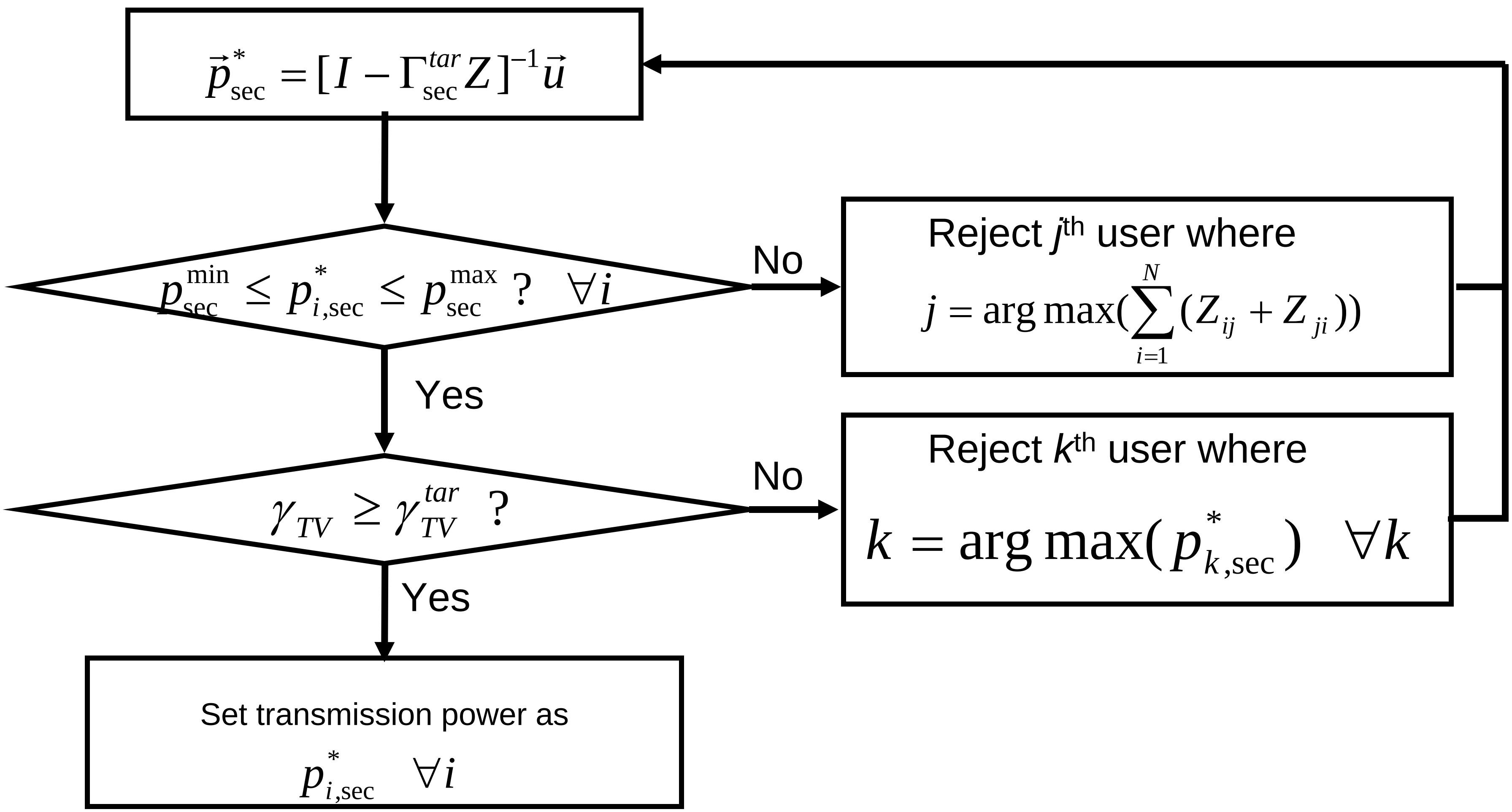
$$Z = \begin{bmatrix} 0 & \frac{g_{12}}{g_{11}} & \cdots & & \frac{g_{1N}}{g_{11}} \\ \frac{g_{21}}{g_{22}} & 0 & & & \frac{g_{2N}}{g_{22}} \\ \vdots & & \ddots & & \vdots \\ & & & 0 & \\ \frac{g_{N1}}{g_{NN}} & \frac{g_{N2}}{g_{NN}} & \cdots & \frac{g_{N,N-1}}{g_{NN}} & 0 \end{bmatrix}$$

Priority of Primary Users

$$\gamma_{TV} = \frac{\dfrac{p_{TV}}{D^{\alpha_1}}}{f_2 \sum_{i=1}^{N} \dfrac{p^*_{i,\sec}}{y_i^{\alpha_2}} + \sigma^2} \geq \gamma_{TV}^{tar} \quad ?$$

→ Admission Control

Joint Power Control and Admission Control



Distributed Implementation

$$p_{i,\sec}(k+1) = \min\{\frac{\gamma_{i,\sec}^{tar}}{\gamma_{i,\sec}(k)} p_i(k),\ \ p_{\sec}^{\max}\} \qquad i = 1,2,\cdots,N.$$

Enforce the QoS guarantee for primary users:

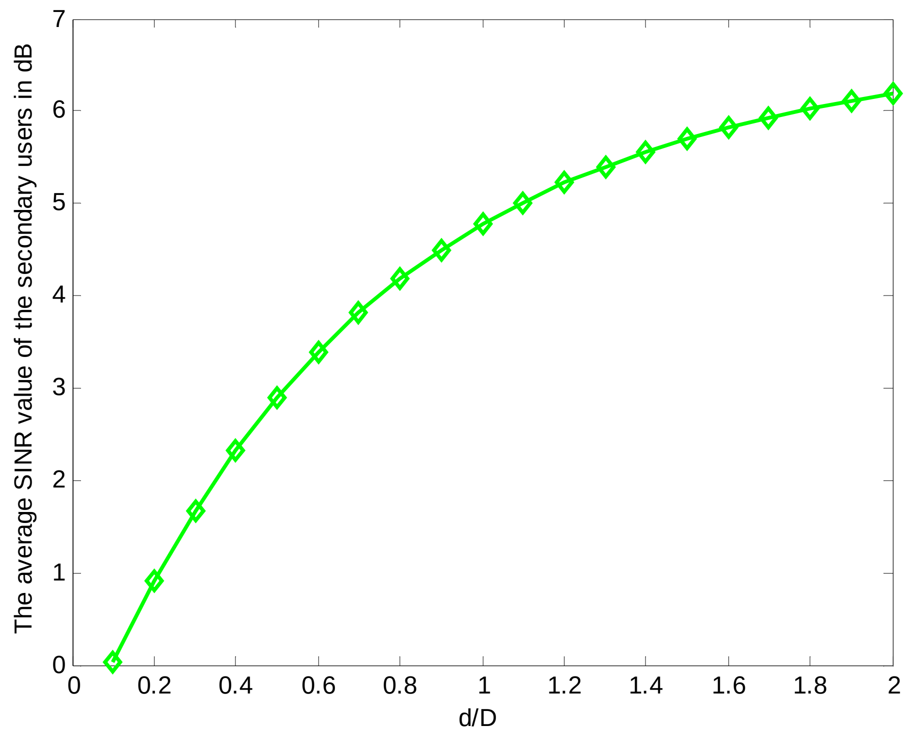
Place a “genie” near the primary receiver at the border of the TV coverage area. The genie will monitor the interference level and inform the secondary users if the QoS of the primary receiver will be violated.

Performance Evaluation (1)

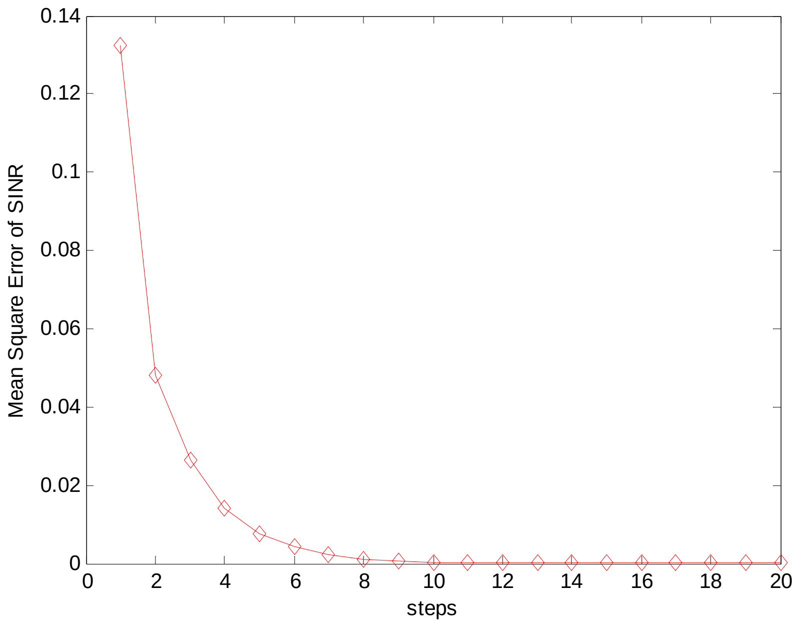
Parameters	Value
p_{TV}	100 kW
γ_{TV}^{tar}	34 dB
p_{sec}^{min}	0 mW
p_{sec}^{max}	100 mW
γ_{sec}^{tar}	3 dB
σ^2	10^{-14}
D	60 km
α_1	3
α_2	4

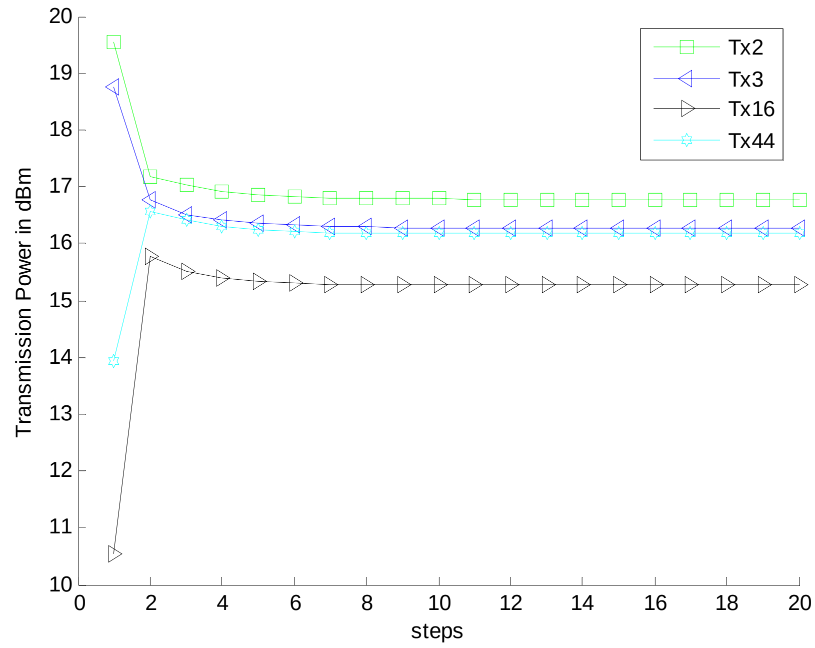
TABLE I

SIMULATION PARAMETERS

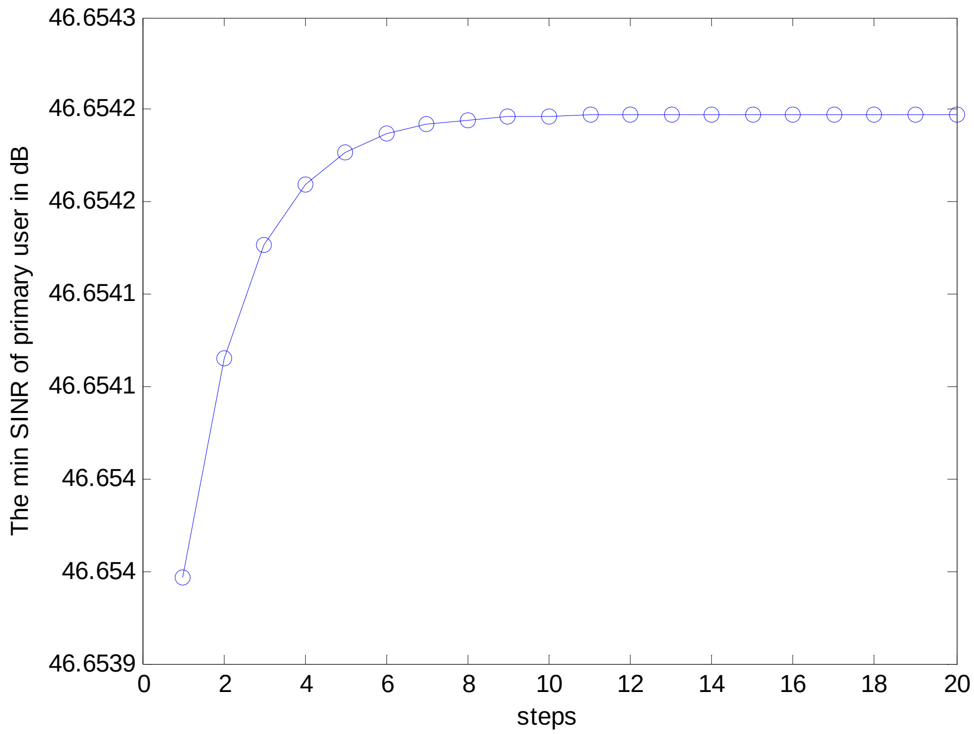


Performance Evaluation (2)





Performance Evaluation (3)



Conclusions

- Results can be directly applied to CR network using CDMA.
- Single Tx-Rx result can be directly applied to CR network using TDMA.
- Combined temporal and spatial spectrum sharing requires joint design of spectrum allocation scheme and power control & admission control scheme.

Extensions

- More results for centralized joint power control and admission control
- A fully distributed implementation
- Effects other than distance (shadowing)
- CR network using OFDMA