Non-intrusive cognitive radio networks based on smart antenna technology

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Outline

Introduction

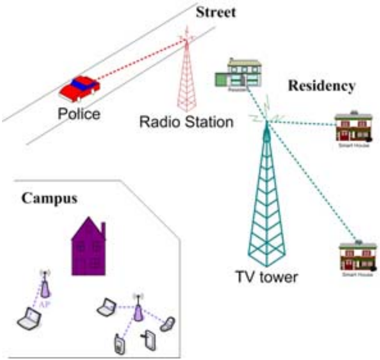
- Spectrum is an ever increasing scarce commodity, worth of billions of dollars (e.g. 4.6 billions bid for 20MHz)
- However, more than 60% of the licensed spectrum is under-utilized
- Therefore, we need more flexible approaches/policies to use the precious spectrum resource
- A promising technique: Cognitive radio
- Cognitive radio permits the opportunistic access of secondary users to primary users' bands

Challenges in cognitive radio network

- Protection of the QoS of primary users
- Cooperation from primary users may not be available
- Cooperation between secondary users may be fragile (lack of fixed spectrum resource for control channel)
- QoS guarantee for secondary users in a dynamically change radio environment

Motivation of our work

- Wireless communication consumes time, frequency, and SPACE



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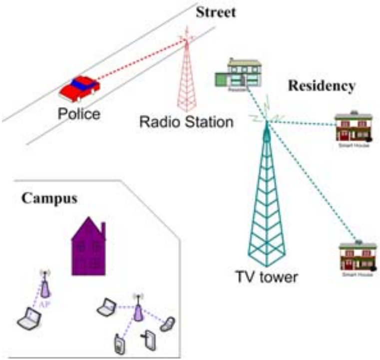
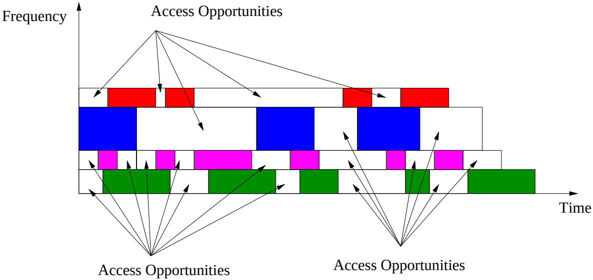


- Question:
  How cognitive radio systems can exploit the opportunities in different dimensions?

Related works

- Most of previous works (e.g., [D. Carbic et al. 2005], [W. Krenik et al. 2005], [N. Nie et al. 2005], and [X. Liu et al. 2006]) focused on detecting/exploiting the spectrum opportunities in the time-frequency domain
  - No simultaneous transmissions for PT and CT
  - No explicit consideration of space diversity



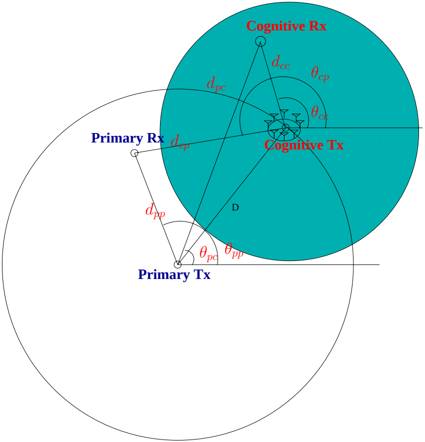
Related works (cont.)

- Works in [N. Devroye el at. 2006] and [H. Islam el at. 2007] enable simultaneous transmission of CT and PT, but
  - Requires primary detector at CT
  - Complicated DPC coding
  - Or requires cooperation from primary network
  - No guarantee on the interference to the primary network

Contributions of our work

- Non-intrusiveness:
  - No cooperation from PT
  - Guarantee on the interference at PR from CT
- Exploit spectrum opportunities in spatial domain
  - Enable-Tech: Smart antenna
  - Considerable spectrum efficiency improvement
- Challenges:
  - Interference from CT to PR
  - Information uncertainty on the locations of PR
  - Interference from PT to CR

System Model



- CT: multiple antennas, CR: single antenna
- Location of CR: known to CT
- Distances between CT and PR: known to CT
- Angle between CT and PR: inaccurate
- PT: omni-directional antenna or multiple antennas

Signal Representations

- Received Signal at PR and CR:

$$y_p = \underbrace{h_{pp} \cdot s_p}_{\text{Desired Signal}} + \underbrace{h_{cp} \cdot s_c}_{\text{Interference}} + n_p$$

$$y_c = \underbrace{h_{cc} \cdot s_c}_{\text{Desired Signal}} + \underbrace{h_{pc} \cdot s_p}_{\text{Interference}} + n_c$$

- Beamforming gain in direction θ:

$$G_i(\theta) = \mathbf{w}_i^H \mathbf{v}_i(\theta), \qquad i = p,\, c.$$

$\mathbf{v}_i(\theta)$: array manifold
$\mathbf{w}_i(\theta)$: beamforming weight vector.

- Channel gain for each pair of Tx/Rx

$$h_{ij} = d_{ij}^{-\alpha} \cdot G_i(\theta), \qquad i,\, j = p,\, c.$$

Signal Representations (cont.)

SINR at PR and CR:

$$\mathit{SINR}_p = \frac{P_p \cdot d_{pp}^{-\alpha} \cdot |G_p(\theta_{pp})|^2}{N_0 + P_c \cdot d_{cp}^{-\alpha} \cdot |G_c(\theta_{cp})|^2},$$

$$\mathit{SINR}_c = \frac{P_c \cdot d_{cc}^{-\alpha} \cdot |G_c(\theta_{cc})|^2}{N_0 + P_p \cdot d_{pc}^{-\alpha} \cdot |G_p(\theta_{pc})|^2}.$$

Can be regarded as the average SINR if we consider the small-scale channel fading

Problem Formulation

- Objective: Maximize $SINR_c$, under PR's interference constraint
- Controllable parameters: $\mathbf{w}_c(\theta)$, P_c
- Optimization problem:

$$\max_{\mathbf{w}_c, P_c} SINR_c$$

subject to

Interference Constraint: $P_c \cdot d_{cp}^{-\alpha} \cdot |G_c(\theta_{cp})|^2 \leq I_0$

Side-lobe Constraint: $|G_c(\theta_{cj})| \leq 1/2, \theta_{cj} \notin [\theta_{cc} - \Delta\theta, \theta_{cc} + \Delta\theta]$

Power Constraint: $P_c \leq P_{max} = \gamma_c N_0 d_{cc}^{\alpha},$

Non-intrusive Optimal Beamforming with angle uncertainty

- Uncertainty in angle information $\Rightarrow$ Guarantee worst case interference:

$$P_c \cdot d_{cp}^{-\alpha} \cdot \max_{\theta_{cp}-\Delta\phi \leq \theta \leq \theta_{cp}+\Delta\phi} |G_c(\theta)|^2 \leq I_0$$

- No cooperation from PT, $SINR_c$ limited by P_c, and therefore I_0.
- The optimization problem is transferred to:

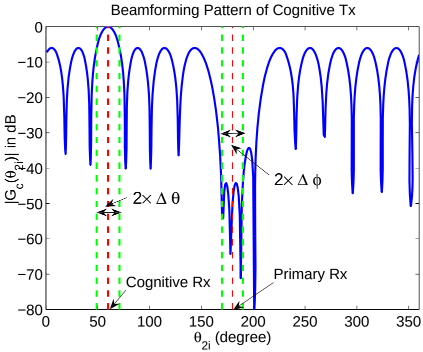
$$\min_{\mathbf{w}_c} \quad \max_{\theta_{cp}-\Delta\phi \leq \theta_{ci} \leq \theta_{cp}+\Delta\phi} \quad |G_c(\theta_{ci})|$$

subject to

$$|G_c(\theta_{cj})| \leq 1/2, \quad \theta_{cj} \notin [\theta_{cc} - \Delta\theta, \theta_{cc} + \Delta\theta].$$

- A convex optimization problem

CT's beamforming pattern



Bounds of Decodable Zone for CR

- Decodable zone:

$$S := \iint_{S:(d_{cc},\theta_{cc}):\mathsf{SINR}_c \geq T} ds,$$

- No transmit power constraint: $P_{max} = \infty$
- Fixed the location of PR, PT uses omni-directional antenna
- Using triangle inequality, we obtained the lower/upper bounds of the border for decodable zones
- Help the deployment of cognitive radio users

Bounds of Decodable Zone for CR (cont.)

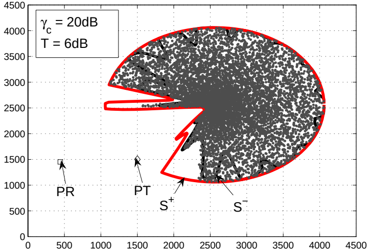


Figure: Decodable Zone of CR when PT uses omni-directional antenna

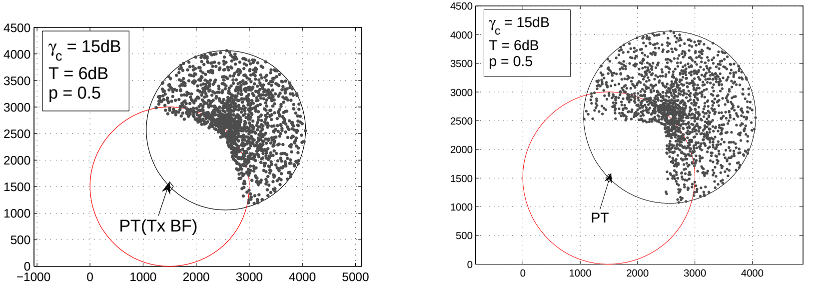
Total Spectrum Efficiency Improvement

- Given location of CR, PR randomly locates over the covered area of PT
- Performance metric of CR: $Pr\{\mathit{SINR}_c \geq T\}$
- Total improvement on spectrum efficiency:

$$\rho_0 = \iint_{A:\{d_{cc}\in[d_{min},d_{max}],\theta_{cc}\in[0,2\pi)\}} \rho(d_{cc},\theta_{cc})\, dA$$

- Evaluated using numerical method: Area of regions with $Pr\{\mathit{SINR}_c \geq T\} > p$
- A lower bound on ρ_0: $\rho_0 = p \times \frac{ShadedArea}{TotalArea}$

Numerical Results for Spectrum Efficiency



(a) PT uses transmit beamforming

(b) PT uses omni-directional antenna

Figure: Regions of CR with $Pr\{SINR_c \geq T\} > p$ for $\gamma_c = 15$dB

- Spectrum efficiency increases at least 45.15% and 40.63%, respectively

Conclusion

- Cognitive radio should exploit the spectrum opportunities in spatial dimension.
- Smart antenna techniques can take advantage of space diversity and spectrum opportunity
- Our scheme enables simultaneous transmissions of CT and PT
- Our scheme handles uncertainty on the location information
- Our scheme improves spectrum efficiency

Future Work

- Time-varying fading channels
- Inaccuracy on distance estimation
- Multiple cognitive radio links
- Hybrid MAC layer protocol
- Handover or frequency switch

Thank you very much!