Limited Feedback Spectrum Sharing for Cognitive MIMO Radio

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Outline

- Background and Motivation
- Cognitive MIMO Radio
- Spectrum Sharing Model
- Game-theoretic Formulation
- Summary and Trends

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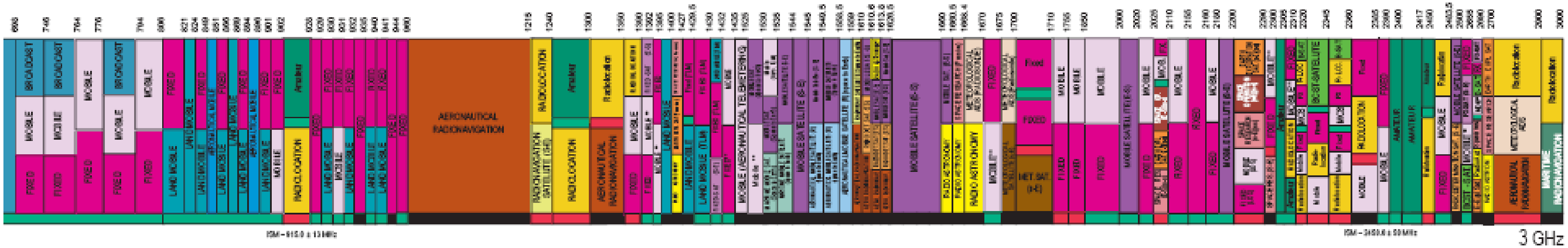
Background and Motivation

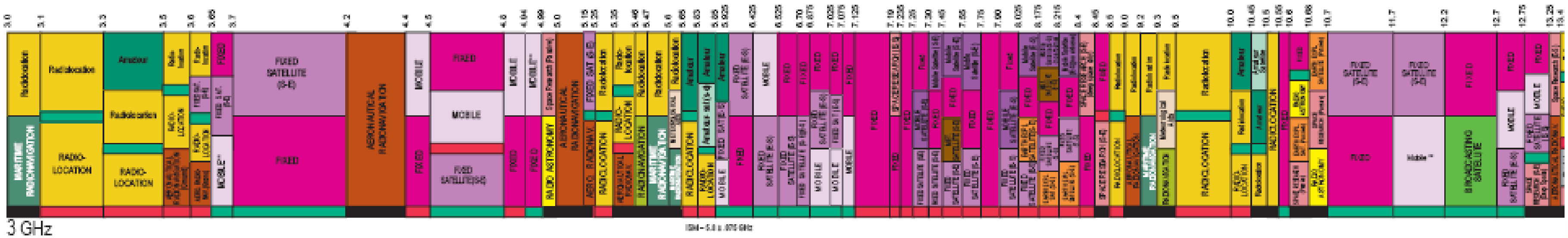
- High data rate communication is demanded

Background and Motivation

- Spectrum Scarcity
  - Most of the frequency spectrum resource has been allocated. **[U.S. FA Chart]**



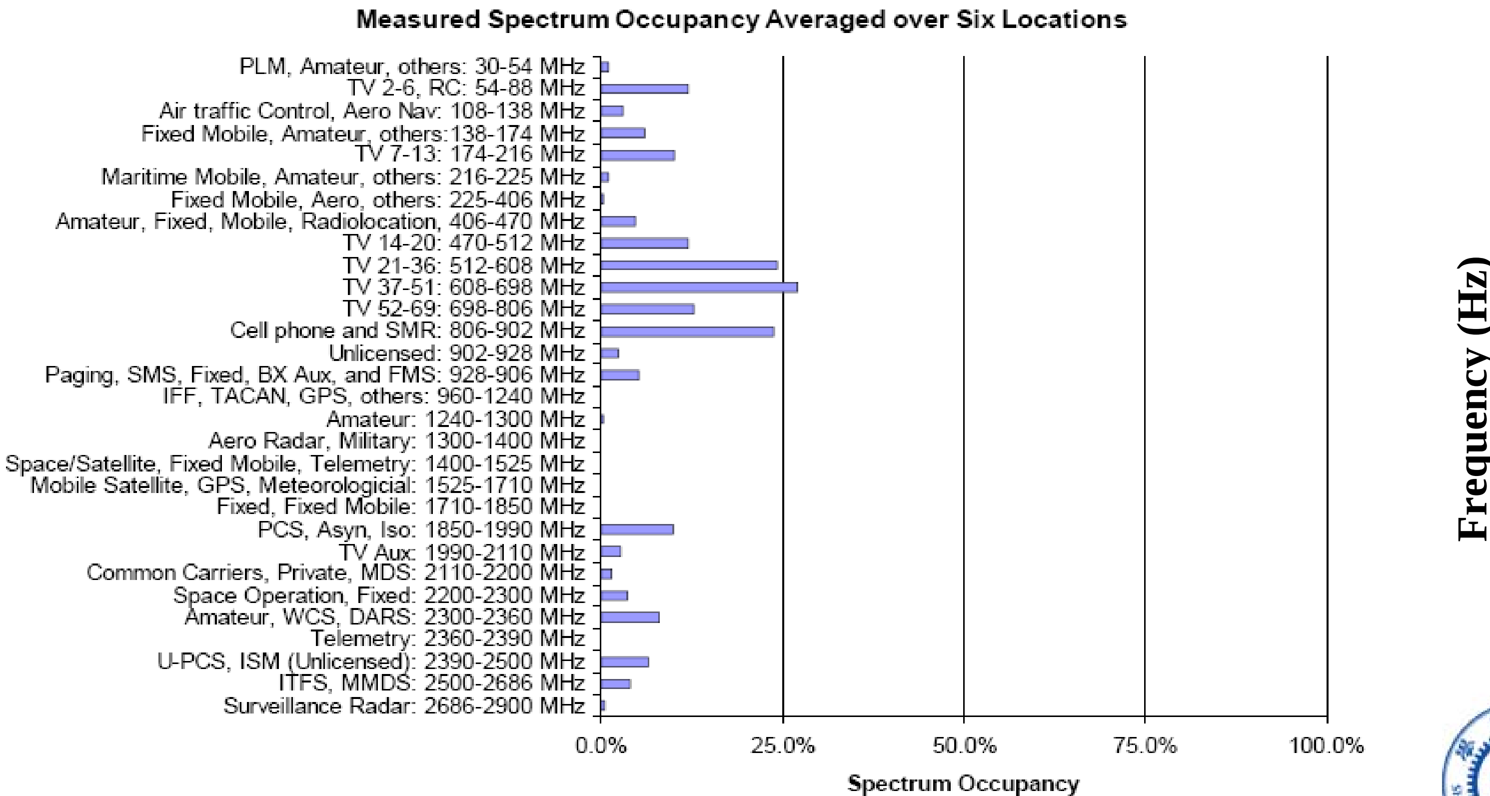
700MHz 3GHz



3GHz 5GHz 13GHz

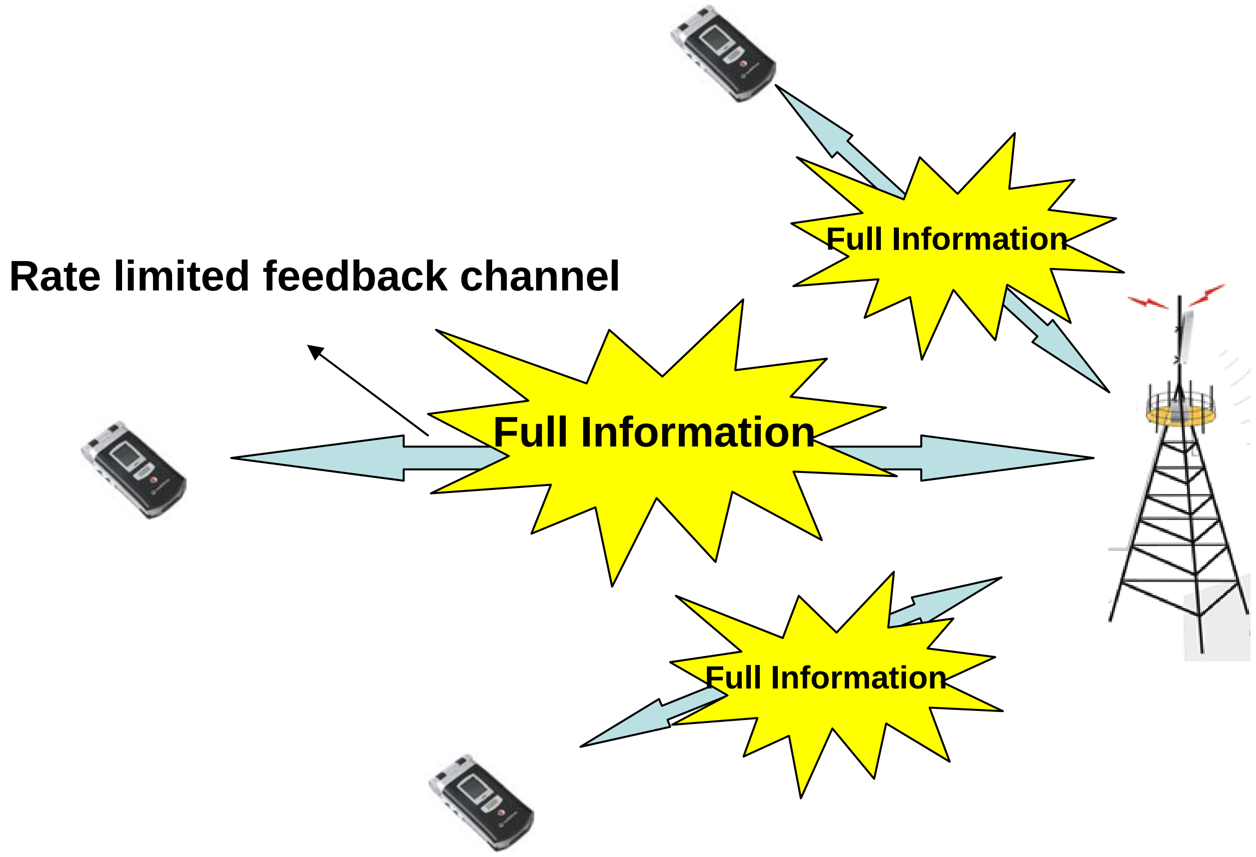
Background and Motivation

- Spectrum Inefficient Utilization
  - Spectrum utilization depends strongly on time and place. **[NSF-0335272]**



Background and Motivation

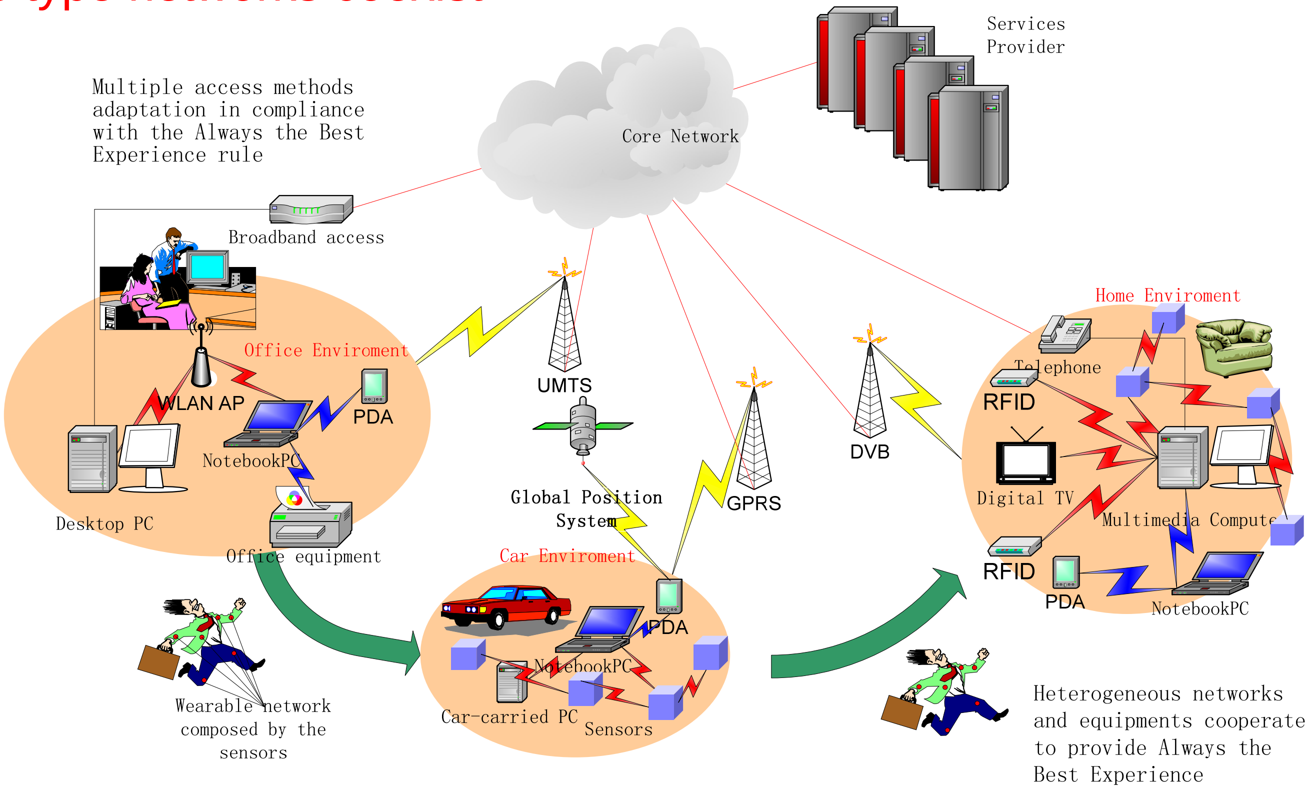
- Optimal transmission strategy is usually difficult to be obtained and impractical



Background and Motivation

- Convergence of the heterogeneous networks

Multiple type networks coexist



White paper, FuTure Forum

Background and Motivation

- Improve the spectrum efficiency
- Dynamic spectrum sharing
- Limited feedback communication
- Distributed optimization

Distributed Limited feedback cognitive radio networks

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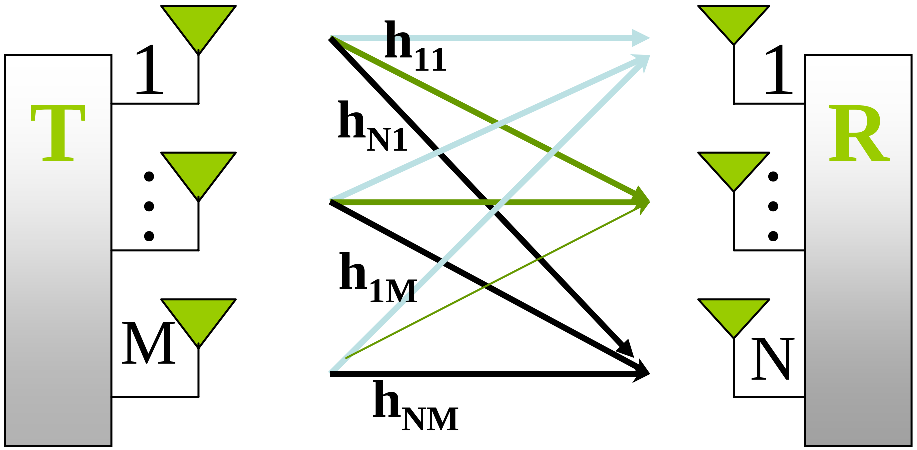
Cognitive MIMO Radio

- MIMO
  - Advantage:
    1. Provide dramatic capacity gain
    2. Increase spectrum efficiency
  - Disadvantage:

    Costly in terms of size, power and hardware. Complex in signal processing.



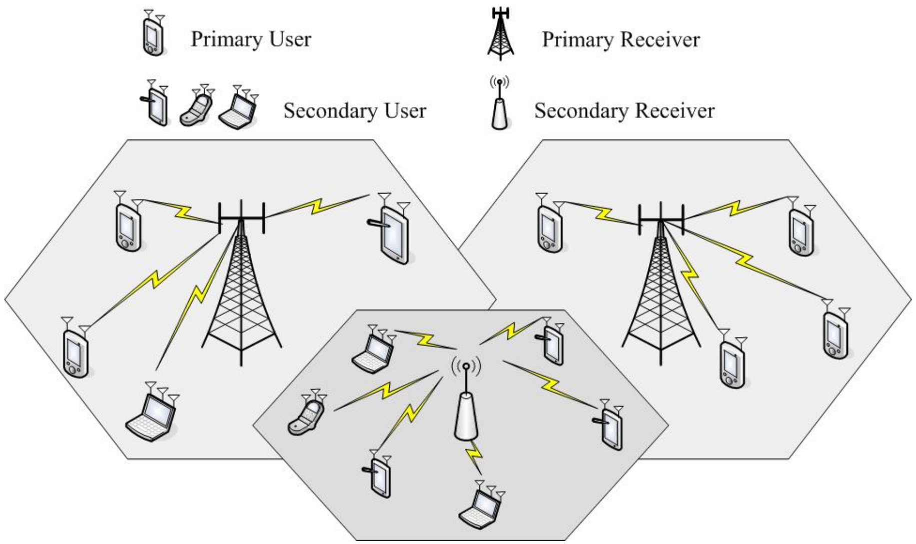
$$\mathbf{H}^{(t)} = \begin{bmatrix} h_{11}{}^{(t)} & h_{12}{}^{(t)} & \cdots & h_{1M}{}^{(t)} \\ h_{21}{}^{(t)} & h_{22}{}^{(t)} & \cdots & h_{2M}{}^{(t)} \\ \vdots & \vdots & \ddots & \vdots \\ h_{N1}{}^{(t)} & h_{N2}{}^{(t)} & \cdots & h_{NM}{}^{(t)} \end{bmatrix}_{N \times M}$$

Cognitive MIMO Radio

MIMO

Cognitive Radio

→ **Cognitive MIMO Radio**



Further improve the utilization of the spectrum

Cognitive MIMO Radio

- **MIMO has been adopted in many wireless standards.**
- **Users and base stations may equipped with multiple antennas in future.**

We consider cognitive MIMO radio

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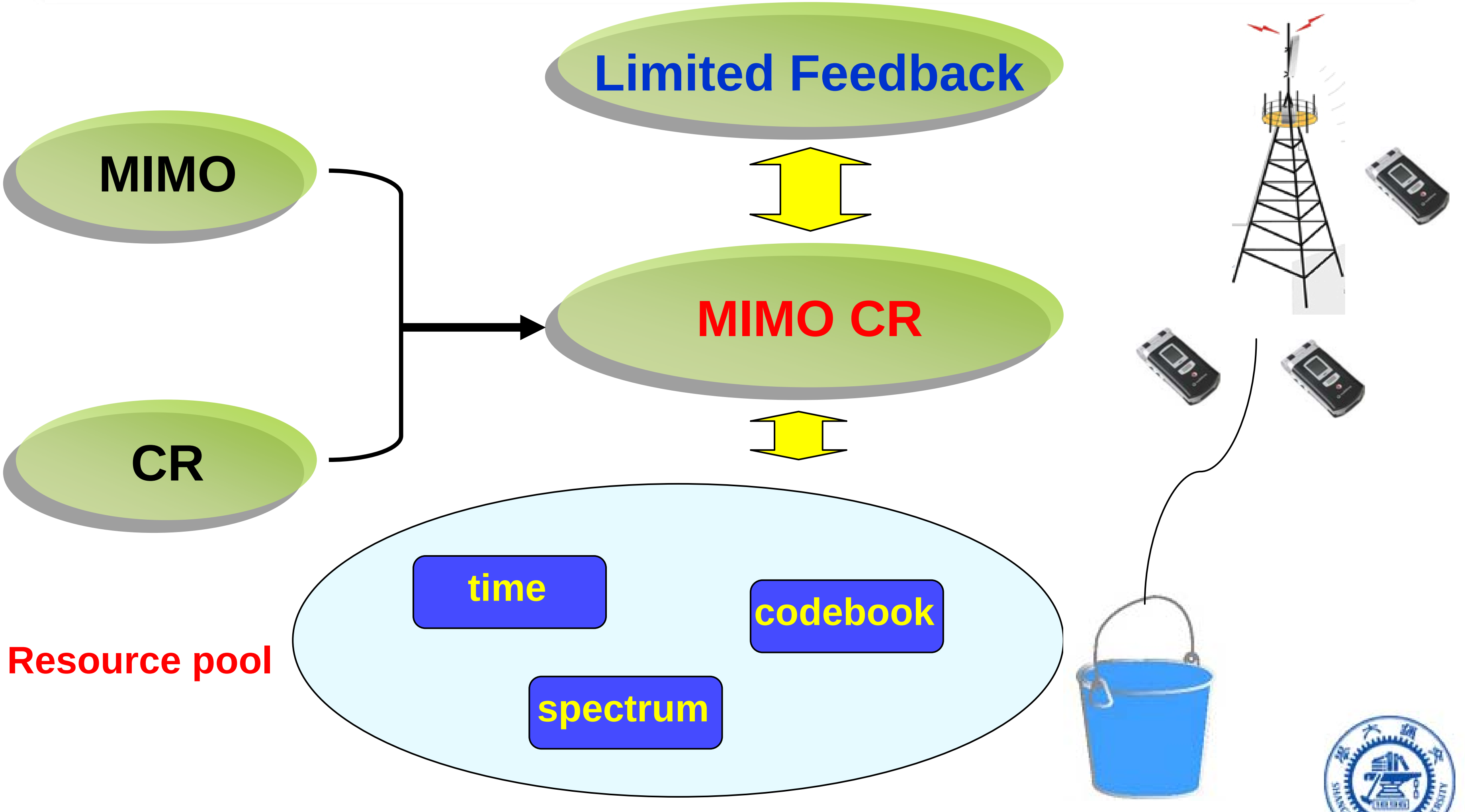
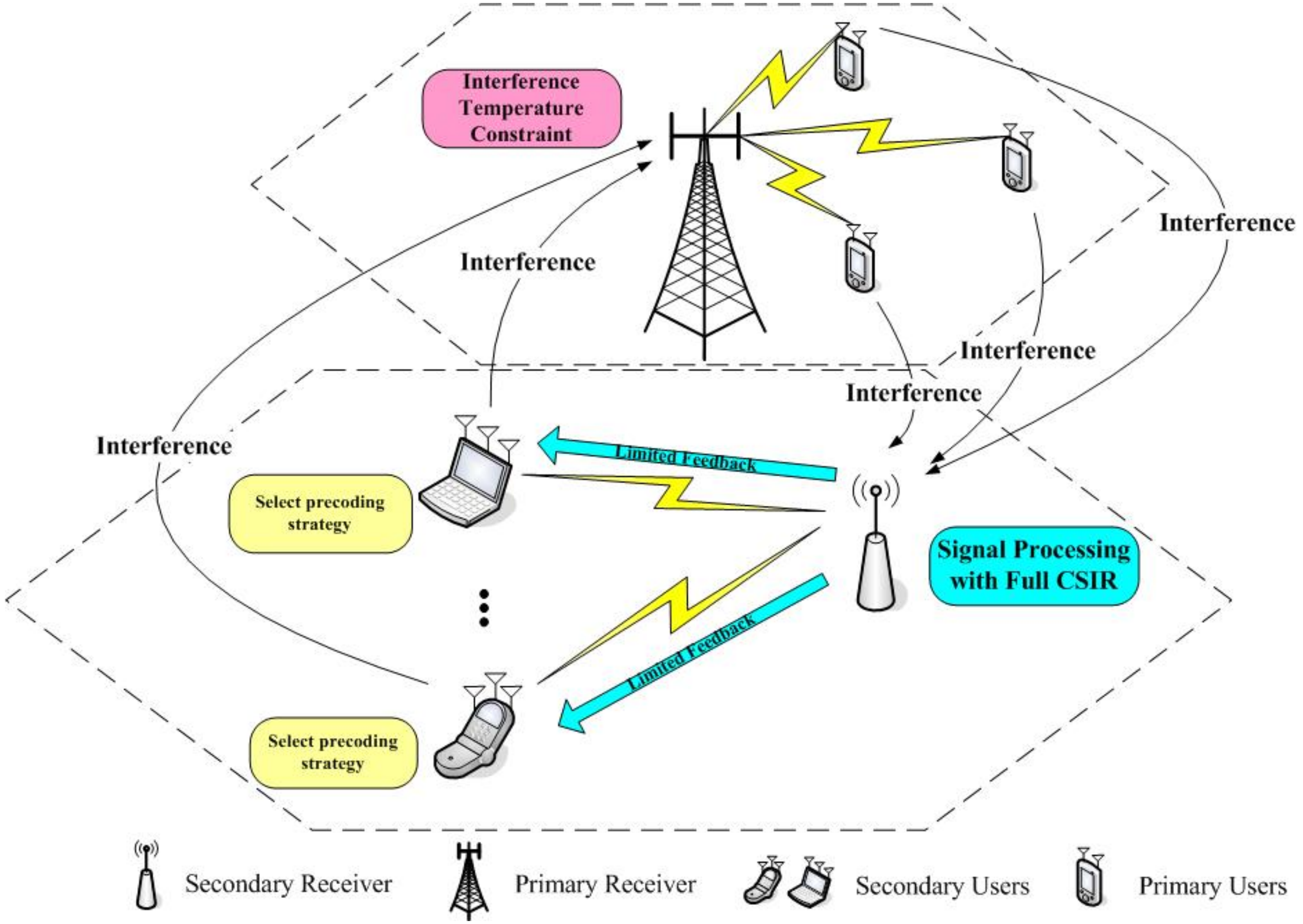
Spectrum Sharing Model



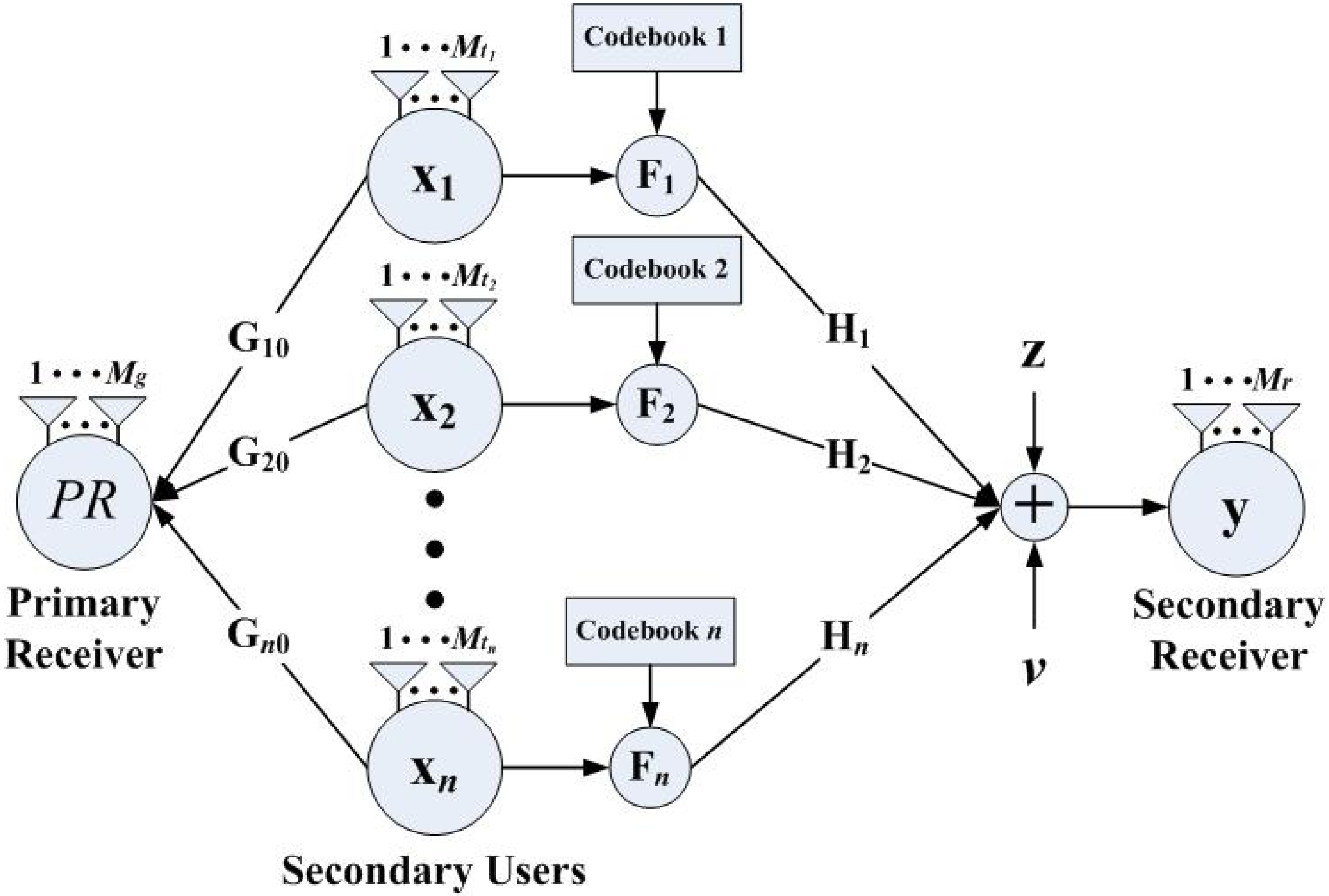
Spectrum Sharing Model

- Cognitive MIMO MAC system model



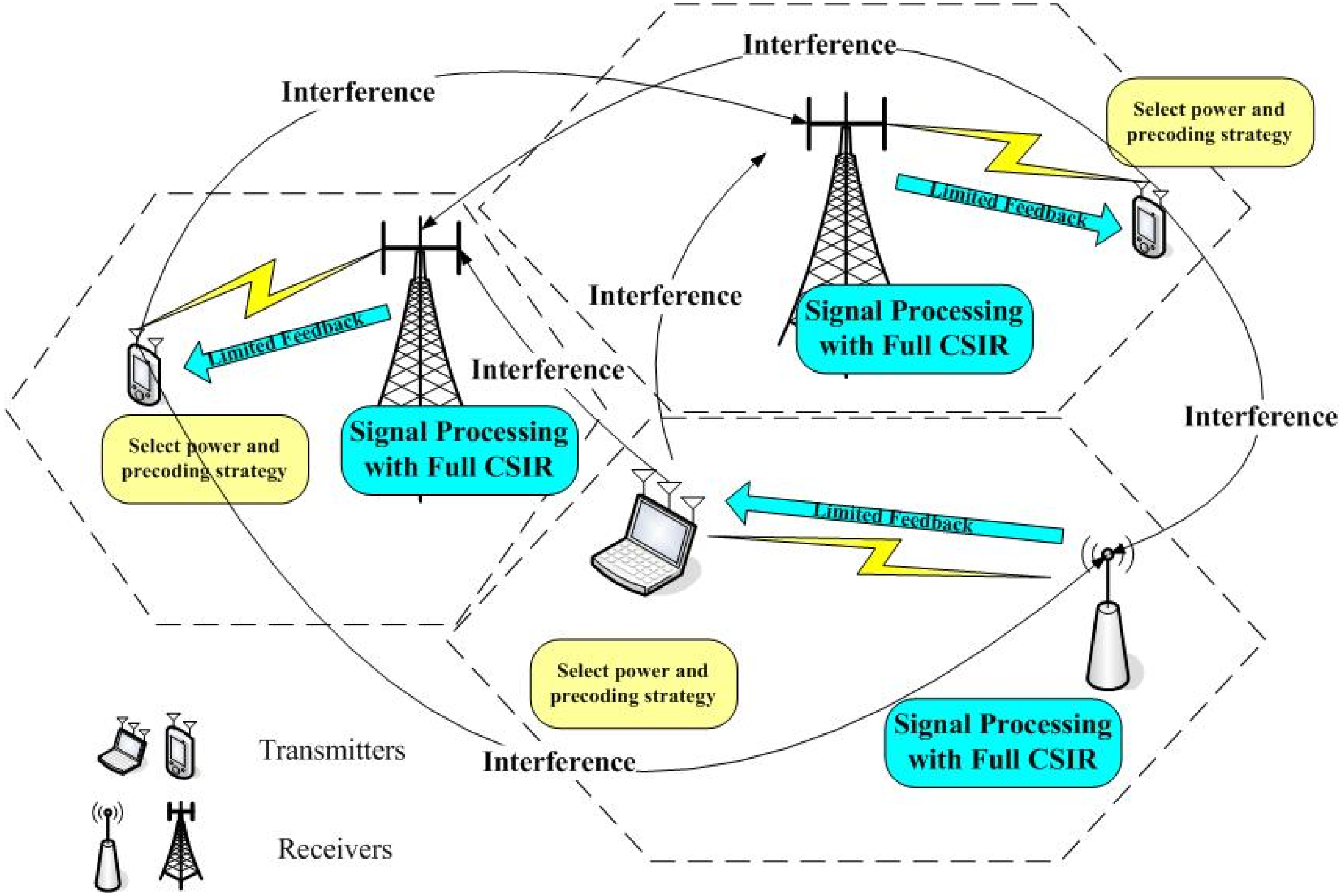
Spectrum Sharing Model

- Cognitive MIMO MAC system model



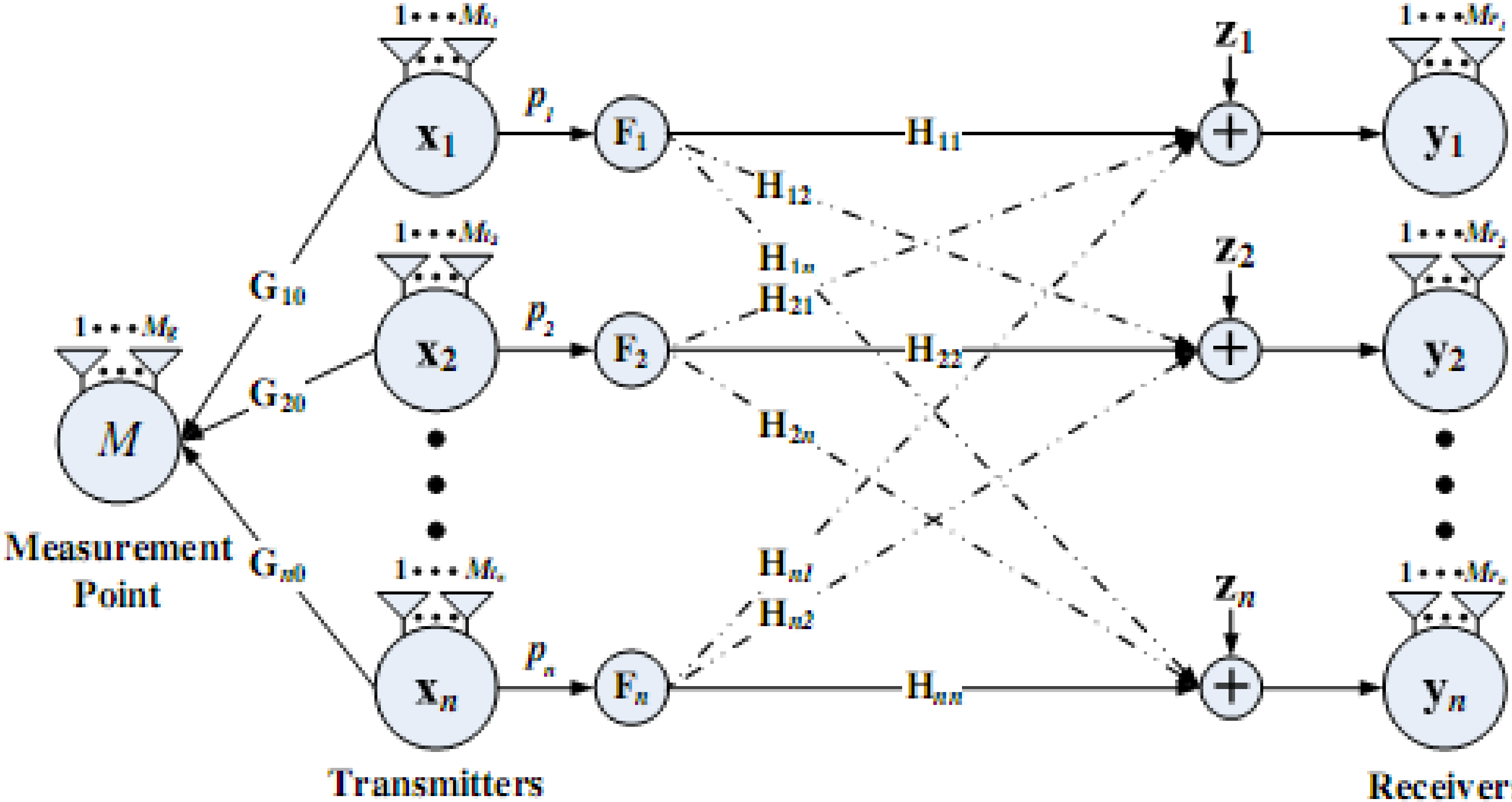
Spectrum Sharing Model

- Cognitive MIMO INT system model



Spectrum Sharing Model

- Cognitive MIMO INT system model



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Game Theoretic Formulation

Why game theory?

Game Theoretic approach

The study of <u>mathematical models</u> of <u>conflict and cooperation</u> between <u>intelligent rational</u> <u>decision-makers</u>

- Distributed
- Self-organized
- Discrete optimization
  – *convex optimization theory cannot be used*
- Feasible – some strategy profiles cannot satisfy the constraints
- Scalable – network is dynamic

Game Theoretic Formulation

- Cognitive MIMO MAC

Precoding matrix

Interference from PU

$$\mathbf{y} = \sum_{i=1}^{N} \mathbf{H}_i \mathbf{F}_i \mathbf{x}_i + \mathbf{z} + v = \sum_{i=1}^{N} \tilde{\mathbf{H}}_i \mathbf{x}_i + \mathbf{z} + v$$

Receive signal vector

Channel matrix

Noise

Game Theoretic Formulation

- Game formulation

Players ⟺ **Rational secondary users currently in the system**

Actions ⟺ **Multimode precoding strategies**

Payoff function: **Indication function**

$$u_i = R_i + \beta^P \Theta\left(\rho^{th} - B\right) + \beta^M \Theta\left(M_r - M_{total}\right)$$

where $$R_i = \frac{1}{2}\log_2\left|\frac{\rho_i}{L_i}\tilde{\mathbf{H}}_i\tilde{\mathbf{H}}_i^\dagger + \mathbf{N}_i\right| - \frac{1}{2}\log_2\left|\mathbf{N}_i\right|$$

$$\mathbf{N}_i = \sum_{j \neq i} \frac{\rho_j}{L_j}\tilde{\mathbf{H}}_j\tilde{\mathbf{H}}_j^\dagger + \mathbf{I} + \boldsymbol{V}$$

Game Theoretic Formulation

- Game formulation

$\Theta(s)$ is defined as $\Theta(s) = s$ for $s < 0$ and $\Theta(s) = 0$ otherwise, β^P and β^M are non-negative scalars, the second term in (6) is an indication of the interference temperature constraint, the third term in (6) is an indication of the maximum transmission number constraint.

$$\max_{\mathbf{F}_i \in \mathcal{F}_i} u_i\left(\mathbf{F}_i, \mathbf{F}_{-i}\right) \quad for\ all\ i \in \mathcal{N}$$

Game Theoretic Formulation

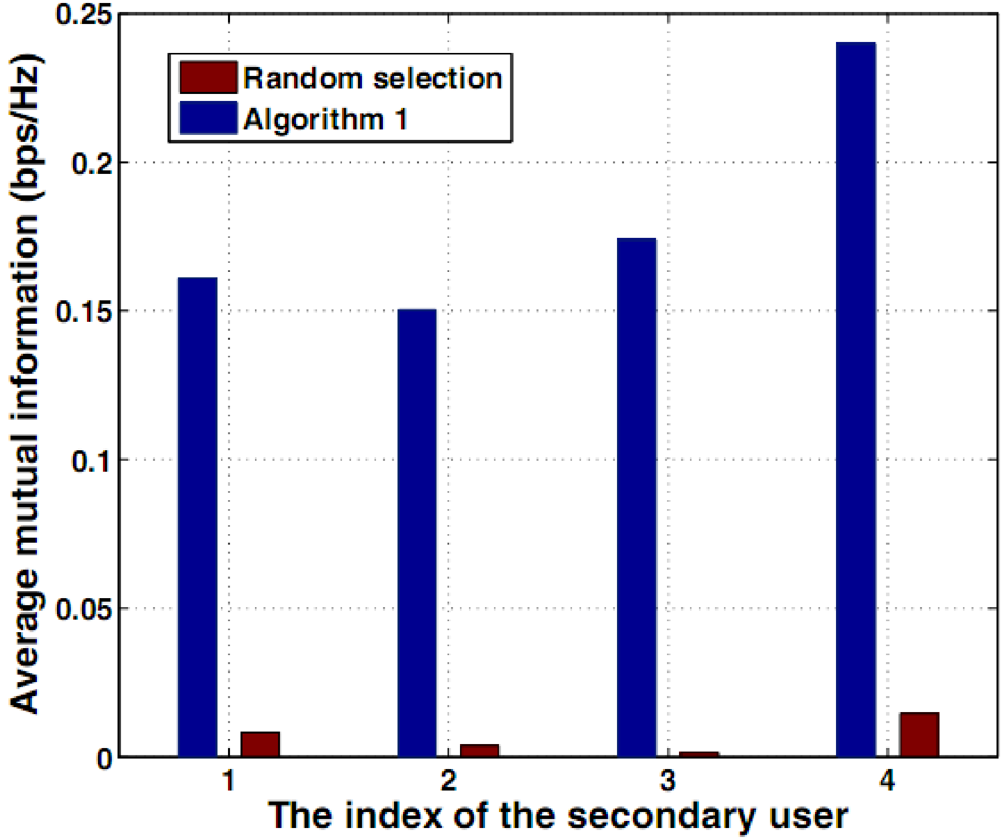


Fig. 2. The average valid mutual information of different secondary users when SNR=10dB (1000 channel realizations) under Co.1 and Co.2.

Game Theoretic Formulation

- Cognitive MIMO INT

$$\mathbf{y}_i = \sum_{j=1}^{n} \mathbf{H}_{ji}\mathbf{F}_j\mathbf{x}_j + \mathbf{z}_i = \sum_{j=1}^{n} \tilde{\mathbf{H}}_{ji}\mathbf{x}_j + \mathbf{z}_i$$

Energy efficiency of secondary user *i*

$$\Gamma_i = \frac{R_i}{p_i} \quad \left(\frac{bits/Hz}{Joule}\right)$$

Mutual information

power

$$u_i(\mathbf{a}_i, \mathbf{a}_{-i}) = \begin{cases} \Gamma_i + \beta^B \Theta(p^{th} - B) + \beta^R \Theta(R_i - R_i^{th}) - c_i p_i, & p_i > 0 \\ 0, & p_i = 0 \end{cases}$$

Indication function

Pricing

Interference temperature

Minimum transmission rate

Game Theoretic Formulation

- Two assumption:

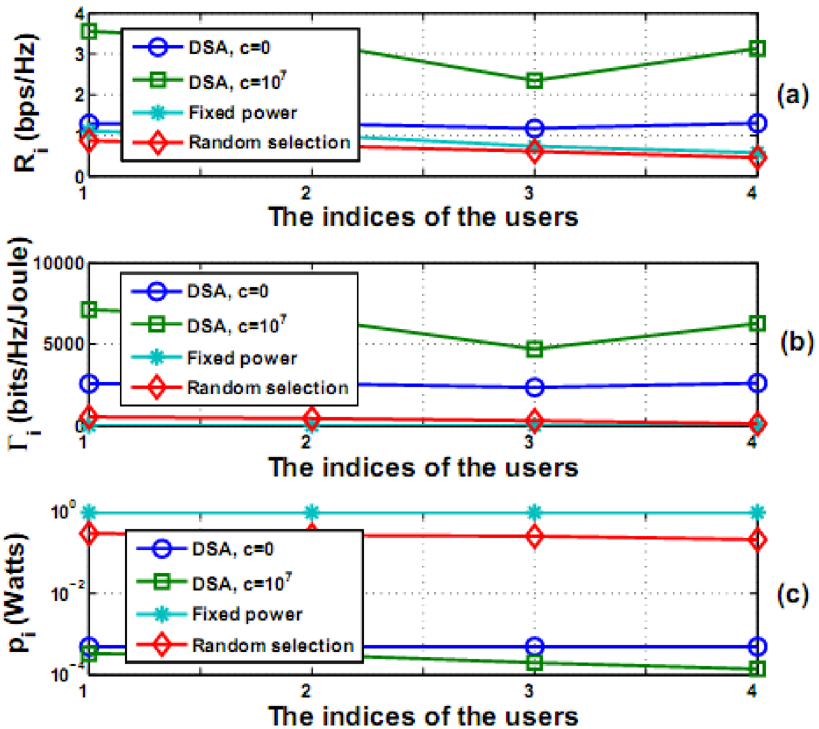
  - A.1: If the Co.1 is not taken into account, $\beta^B = 0$. Otherwise, β^B is chosen to be sufficiently large to ensure that $u_i < 0, \forall i \in \mathcal{N}$ when $B > p^{th}$.
  - A.2: If the Co.2 is not taken into account, $\beta^R = 0$. Otherwise, β^R is assumed to be sufficiently large to guarantee that $u_i < 0, \forall i \in \mathcal{N}$ when $R_i > R_i^{th}$.

$$\max_{\mathbf{a}_i \in \mathcal{A}_i} u_i(\mathbf{a}_i, \mathbf{a}_{-i}), \quad for\ all\ i \in \mathcal{N}.$$

⟺ equivalent

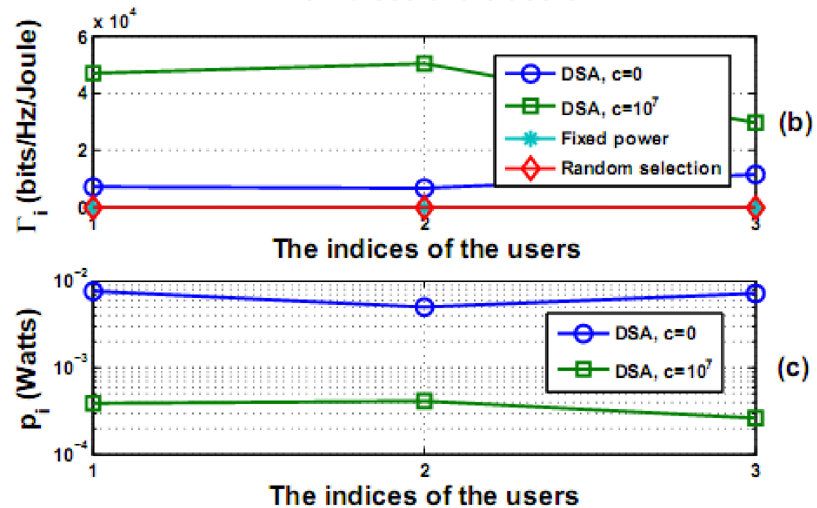
$$\max_{\mathbf{a}_i \in \mathcal{A}_i} \Gamma_i, \quad for\ all\ i \in \mathcal{N}$$
$$s.t.\ R_i \geq R_i^{th}$$
$$B \leq p^{th}.$$

Game Theoretic Formulation



The comparision of different algorithms (case 1)

Four users without constraints



The comparision of different algorithms (case 2)

Three users with constraints

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Summary and Trends

- Limited feedback spectrum sharing techniques can reach near optimal or required performance with relative low complexity, and is hence more practical.

- Game theoretic spectrum sharing algorithm can improve the performance compared to random selection algorithm and always find the feasible strategies with well designed payoff function.

Summary and Trends

- Multi-dimension/jointly radio resource management
  (channel allocation, power, bandwidth…)

- Cross-layer design

- Take economic factors into account
  (price, revenue…)

Thank you!

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