

# A Competitive and Dynamic Pricing Model for Secondary Users in Infrastructure based Networks

Soumitra Dixit, Shalini Periyalwar, and Halim Yanikomeroglu

Broadband Communications and Wireless Systems (BCWS) Centre,  
Department of Systems and Computer Engineering,  
Carleton University, ON Canada

September 08, 2010



# Outline

- Spectrum underutilization and Dynamic Spectrum Access (DSA)
- Distributed framework for Secondary User (SU) access
- Dynamic pricing model for SUs
- Multiple Wireless Service Providers (WSPs) and competitive SU pricing
- Achieving competitive yet dynamic SU pricing:  
Non-cooperative game theoretic analysis
- Dual benefits for SUs and WSPs

# Spectrum underutilization and DSA

- **Spectrum occupancy field measurements:** Underutilization of the radio spectrum in the spatial and temporal domains [Spectrum measurements, M. A. McHenry et al., '06].
- **Dynamic Spectrum Access (DSA):** Intelligent and efficient use of the radio spectrum by allowing opportunistic SU(*unsubscribed*) access.
- **Software Defined Radios (SDRs) or Cognitive Radios (CRs):** envisioned to be enablers for DSA with the ability for **cognition and reconfigurability**.
- **For infrastructure based networks:** Potential for WSPs to gain additional profits by providing access to SUs.

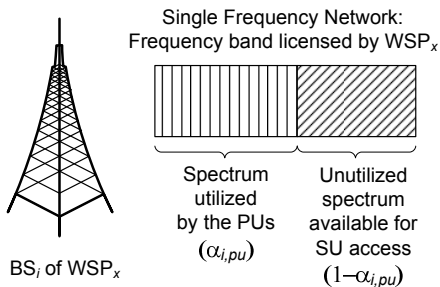
## Previous Works

- Focus on **centralized system framework** with a **Centralized Mediating Entity (CME)** acting as a spectrum manager/broker/negotiator to pool the spectrum and manage the exchange of spectrum among WSPs and to SUs [Spectrum pooling: T. Weiss and F. Jondral '04].
  - Dimsumnet architecture: Co-ordinated access band (spectrum pool) with 'spectrum broker' for spectrum management [M. Buddhikot et al. '05].
  - Spectrum Policy Server (SPS): negotiate spectrum on behalf of WSPs to SUs [O. Ileri et al. '05].
  - Cognitive Pilot Channel (CPC): CPC manager for information exchange [J. Perez-Romero et al. '07].
- Competitive SU pricing and microeconomic models: [D. Niyato, E. Hussein, '07].

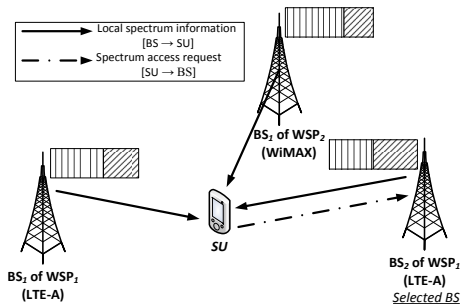
# Distributed System Framework

- Distributed Framework: Base Station(BSs) and not Wireless Service Providers(WSPs) individually advertise and sell their local unutilized spectrum to Secondary Users (SUs) [S. Dixit, S. Periyalwar, H. Yanikomeroglu, '09].
  - Harmonious operation of Primary Users (PUs) and SUs at the same BS at equivalent power levels on different frequencies.
  - Prioritized PU-SU scheduling: SU service subject to instantaneous spectrum availability after PUs have been served.
  - SUs provided the freedom to select their preferred BS based on variety of parameters (i.e., price/service class, signal strength).
  - Dynamic pricing model: SU price depends on spectrum resources utilized at the BS by its subscribers, i.e., PUs.

# Distributed Framework and Network Scenario

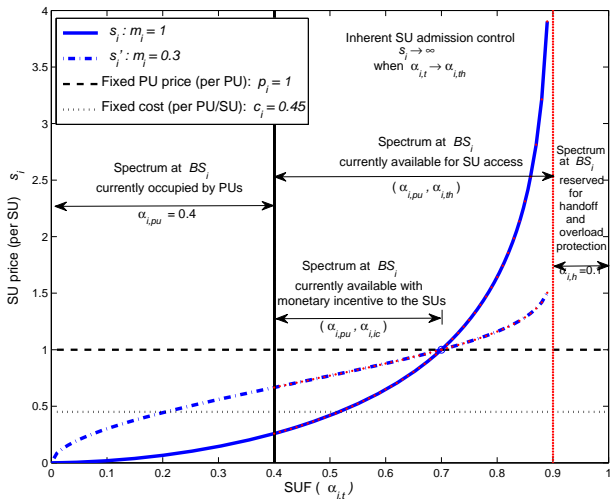


- Snapshot of current spectrum utilization at a particular BS.



- Network scenario with a SU requesting temporary wireless access from the BSs in the area.

# Dynamic Nature of SU Pricing: Terminology



## Dynamic Incentive based SU Pricing Model

- $\alpha_{i,h}$ : Spectrum reserved for handoff;  $\alpha_{i,th} = 1 - \alpha_{i,h}$ .
- $\alpha_{i,su}$ : Spectrum at BS<sub>*i*</sub> occupied by SUs;  $\alpha_{i,su}$  iff  $\alpha_{i,pu} < \alpha_{i,th}$ .
- $\alpha_{i,t}$ : Spectrum Utilization Factor (SUF);  $\alpha_{i,t} = \alpha_{i,pu} + \alpha_{i,su}$ .
- $\alpha_{i,ic}$ : Incentive cutoff limit beyond which  $s_{i,j} > p_{i,j}$ .

SU Price ( $s_i$ ) w.r.t. PU price ( $p_i$ ) and SUF ( $\alpha_{i,t}$ ) at the BS

$$\bar{s}_i = (f_i(\alpha_{i,t}))^{m_i} \times p_i, \quad (1)$$

where  $s_i, p_i, (f_i(\alpha_{i,t}), m_i)$  are non negative real numbers.

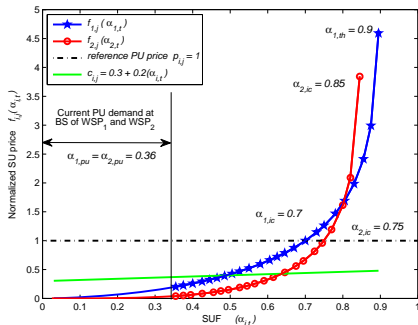
$m_i$ : Price Leveling Factor (PLF) - additional pricing flexibility.

Normalized SU price

$$f_i(\alpha_{i,t}) = \begin{cases} -\ln \left( 1 - \left( \frac{\alpha_{i,t}}{\alpha_{i,th}} \right)^{n_i} \right), & \text{if } 0 \leq \alpha_{i,t} < \alpha_{i,th}, \\ \infty, & \text{if } \alpha_{i,th} \leq \alpha_{i,t} \leq 1. \end{cases} \quad (2)$$



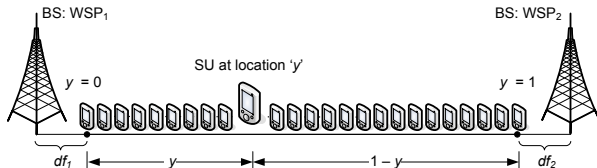
# Competitive Pricing among Multiple WSPs



- **Multiple WSPs:** Aim to maximize individual WSP profits from SUs, while competing on prices.

- Achieving competitive pricing with dynamic SU prices: prohibitively complex.
- For competitive dynamic pricing:
  - 1) Use static SU prices ( $S_i$ ).
  - 2) Find equilibrium static SU prices.
  - 3) Implement on dynamic model using  $PLF(m_i)$ .
- Tools (in step 2):  
Non-cooperative game theoretic analysis with SU service based differentiation.

## Two WSPs and the Differentiation of SU service



- Identical service: high competition, low or zero profits.
- Differentiation of service: low competition, higher profits.
- Differentiation of the SU wireless service: using Dissatisfaction Price ( $\zeta$ ) based on the variance of the wireless channel ( $\sigma_i$ );  $\zeta = K_1 K_2$  (\$), where  $K_1 = 1$  (\$);  $K_2 = (\frac{\sigma_1 + \sigma_2}{2})$ .
- Perceived price to each SU:  $U_i(y) = S_i + (\zeta \times y)$  (\$).

# Transformation for Achieving Competitive Pricing

Nash Equilibrium (NE) SU price  $S_i^*$

$$S_i^* = C_i + \zeta, \quad (3)$$

where  $C_i$  is the fixed cost considering static SU pricing.

SU Pricing w.r.t. PU price and SUF at the BS

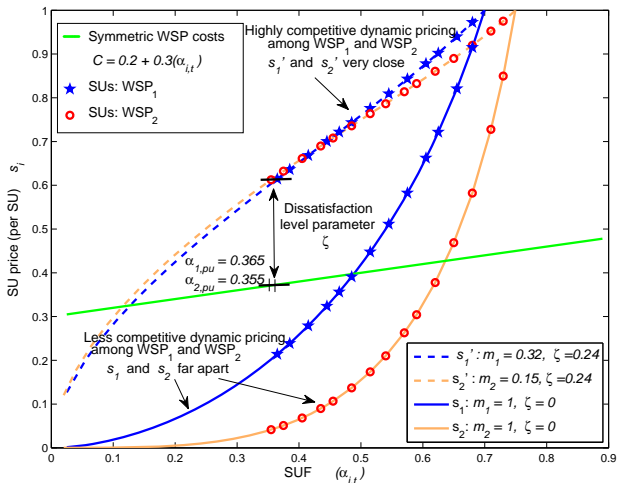
$$s'_i = (f_i(\alpha_{i,t}))^{m_i} \times p_i. \quad (4)$$

- Mapping:  $s'_i = S_i^*$ , i.e., **Static SU price mapped to first SU entering the BS** at  $\alpha_{i,t} = \alpha_{i,pu}$ .

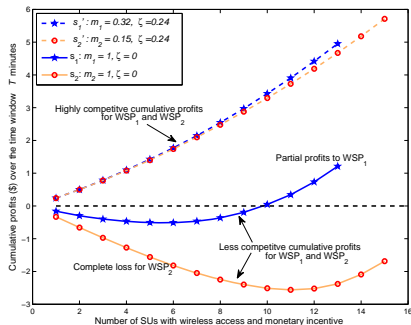
Value of  $m_i$

$$m_i = \frac{\ln\left(\frac{S_i^*}{p_i}\right)}{\ln(f_i(\alpha_{i,pu}))}. \quad (5)$$

# Competitive Dynamic SU Pricing



# Competitive WSP Profits



- To quantify the competitive nature: **Competitiveness Metric** ( $\psi_{s_1, s_2}$ ).

- Competitiveness Metric:**  

$$\psi_{s_1, s_2} = \text{VAR}(\Lambda),$$
 where  $\Lambda = |\hat{s}_1(L_1) - \hat{s}_2(L_2)|$
- $\hat{s}_1(L_1) = \{s_1(1), s_1(2), \dots, s_1(L_1)\}$ .  
 $L_i$ : Total number of SUs with WSP  $i$ .
- $psi_{s_1, s_2} = 5.24 \times 10^{-2}$ ,  
 $psi_{s'_1, s'_2} = 3.44 \times 10^{-4}$ .
- Competitiveness improvement:**  
**factor of 100 !**

# Conclusions and Future Work

- **BS-centric distributed framework** demonstrating the profitability potential for the WSPs and opportunistic temporary wireless access for SUs is presented.
- Methodology to achieving **competitive yet dynamic SU pricing without co-operation** among WSPs was elaborated.
- **Non-cooperative game theoretic analysis** with the **SU wireless service differentiated based on the wireless channel** was used to achieve competitive yet dynamic SU pricing.
- The competitive dynamic SU price set by the BS for direct temporary SU access was observed to depend upon:
  - Wireless environment,
  - Spectrum utilization (PUs + SUs) at the BS,
  - Incentives provided by WSPs through their BSs,
  - Current PU demand and the PU price.
- **Future Work:** Resource Allocation, and Relay Networks perspective.