An Orthogonal Spectrum Sharing Scheme for Cognitive LTE Networks

A. V. Padaki, A. Sengupta, M. Abdelbar, J. H. Reed, W. H. Tranter

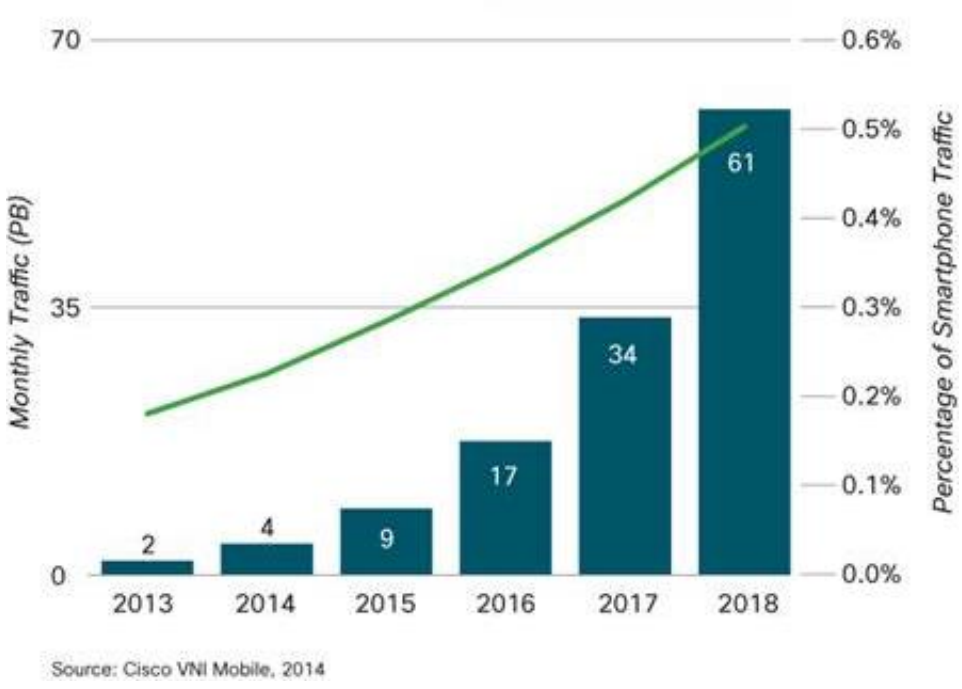
Department of Electrical and Computer Engineering,

Virginia Tech, Blacksburg, VA USA.

Wireless @ Virginia Tech

SDR WInnComm 2014

The Need for Spectrum Sharing

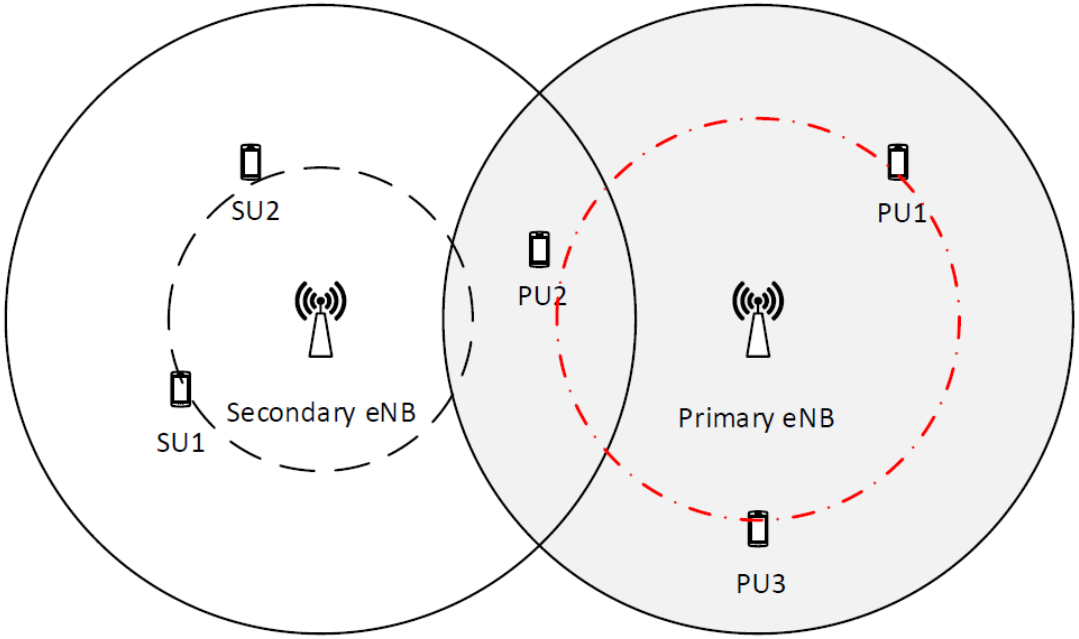


- Global mobile data traffic rapidly increasing
- Need for new and innovative technologies
- Spectrum Sharing is one such promising technique
- Spectrum sharing among cellular operators is explored in this paper

In this paper…

- Novel Framework for inter-operator spectrum sharing
  - Spectrum cost based rate maximization
  - Assumption: No frequency reuse (orthogonal scheme)
- Optimal Resource Allocation for Users
  - Problem formulation for simple framework
  - Analytical solutions and cost factor analysis
- Extension for multiuser LTE system
  - Problem formulation based on Physical Resource Blocks (PRB)
  - Numerical solution and network simulation for a LTE
- Conclusions and Future Work

System Model (1/2)



System Model from the perspective of one operator

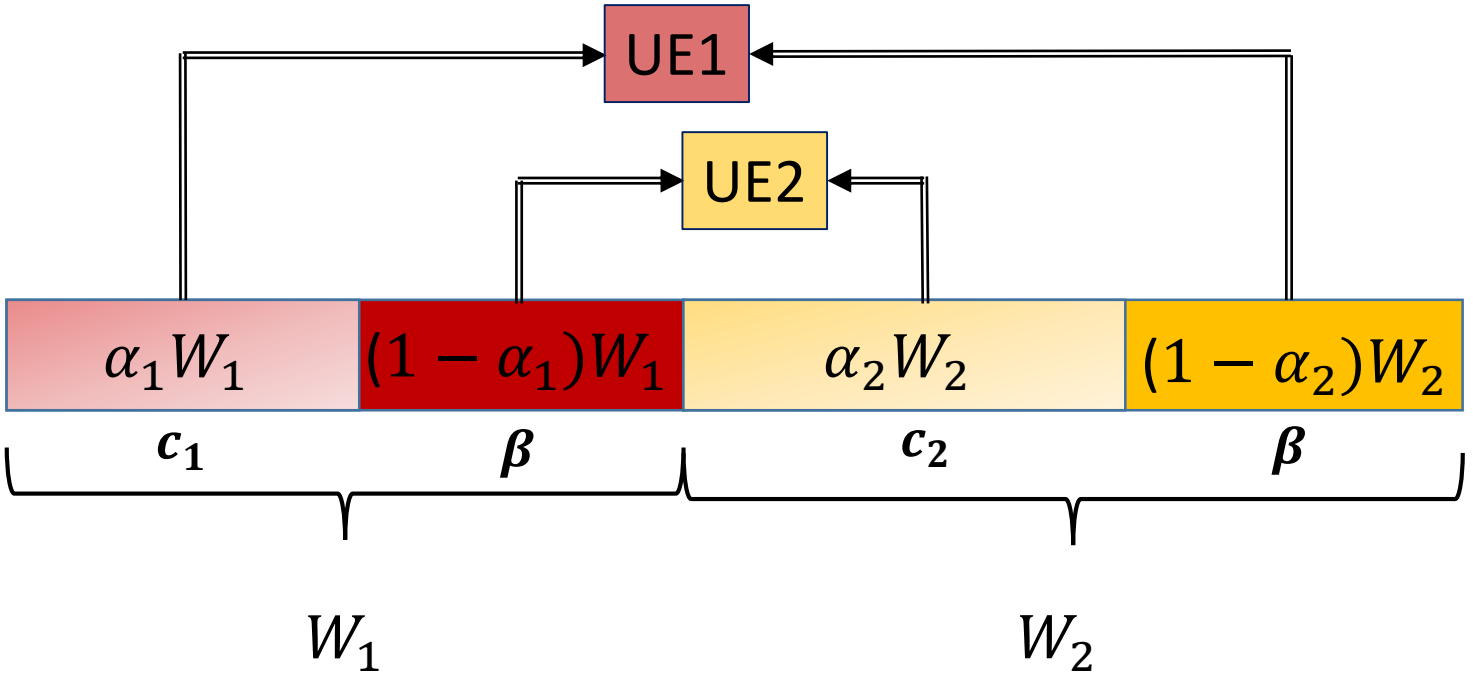
In our Problem…

OP1, OP2 – Two operators

UE1, UE2 – Two Users

- Different costs to access different spectrum
- Based on the costs, resource allocations are made to users
- Minimum rate constraint to ensure fairness

System Model (2/2)



- **Normalized Cost Metric** $- c_i \propto \frac{1}{\text{cost incurred to allocate unit BW}}$
- c_1, c_2 $-$ cost metric for accessing parent spectrum
- β $-$ cost metric for accessing secondary spectrum

In this paper…

- Novel Framework for inter-operator spectrum sharing
  - Spectrum cost based rate maximization
  - Assumption: No frequency reuse (orthogonal scheme)
- Optimal Resource Allocation for Users
  - Problem formulation for simple framework
  - Analytical solutions and cost factor analysis
- Extension for multiuser LTE system
  - Problem formulation based on Physical Resource Blocks (PRB)
  - Numerical solution and network simulation for a LTE
- Conclusions and Future Work

The Optimization Problem

- Capacity, $R = 1 + \log(1 + \gamma_{ij})$, γ_{ij} – SINR
- Constrained Rate Maximization

$$\max_{\alpha_1,\alpha_2} \quad \mathcal{J} = \alpha_1 c_1 W_1 \log(1+\gamma_{11}) + \longrightarrow \text{UE1-OP1}$$

$$(1-\alpha_2)\beta W_2 \log(1+\gamma_{12}) + \longrightarrow \text{UE1-OP2}$$

$$\alpha_2 c_2 W_2 \log(1+\gamma_{22}) + \longrightarrow \text{UE2-OP2}$$

$$(1-\alpha_1)\beta W_1 \log(1+\gamma_{21}) \longrightarrow \text{UE2-OP1}$$

s.t.

$$\alpha_1 c_1 W_1 \log(1+\gamma_{11}) + (1-\alpha_2)\beta W_2 \log(1+\gamma_{12}) \geqslant R_1$$

$$\alpha_2 c_2 W_2 \log(1+\gamma_{22}) + (1-\alpha_1)\beta W_1 \log(1+\gamma_{21}) \geqslant R_2$$

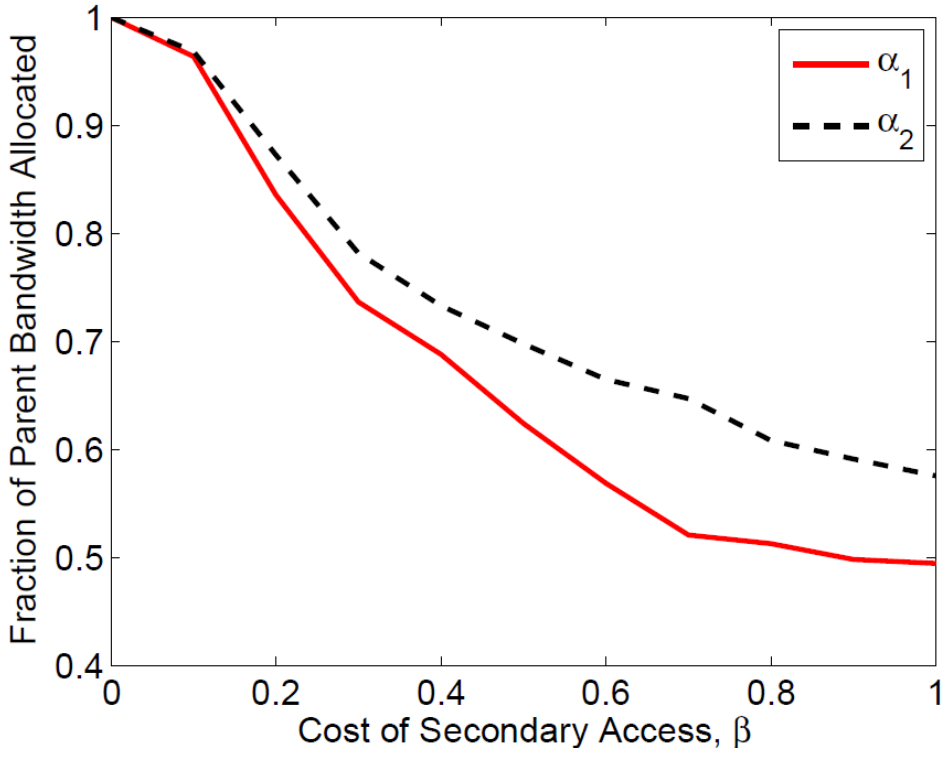
$$0 \leq \alpha_1 \leq 1$$

$$0 \leq \alpha_2 \leq 1$$

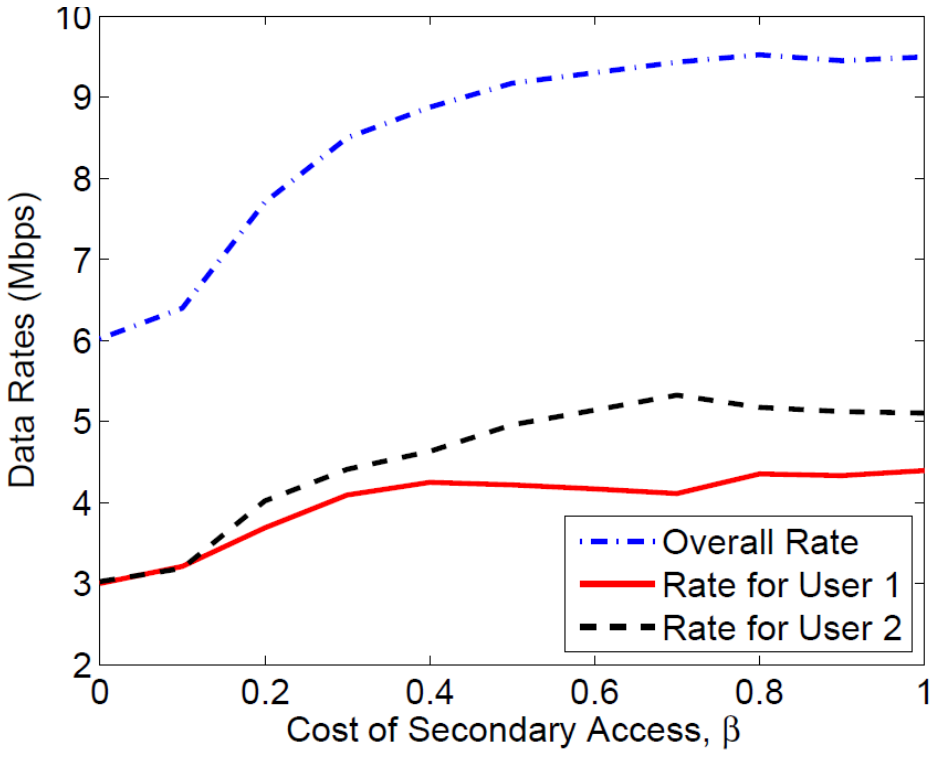
$$(\alpha_1^*, \alpha_2^*) = \psi_i \in \Psi : \arg\max_{\forall \Psi} \mathcal{J}$$

Numerical Results (1/4)

Case 1: $c_1 = 0.5, c_2 = 0.7$, $W_1 = W_2 = 3$ MHz.



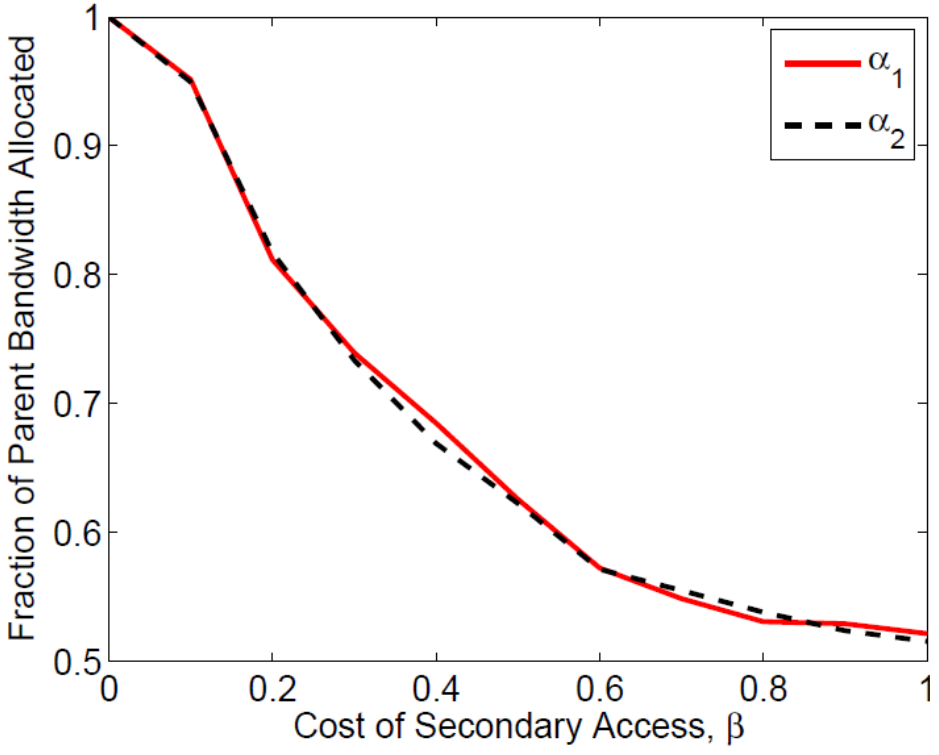
Variation of α's with cost of secondary spectrum



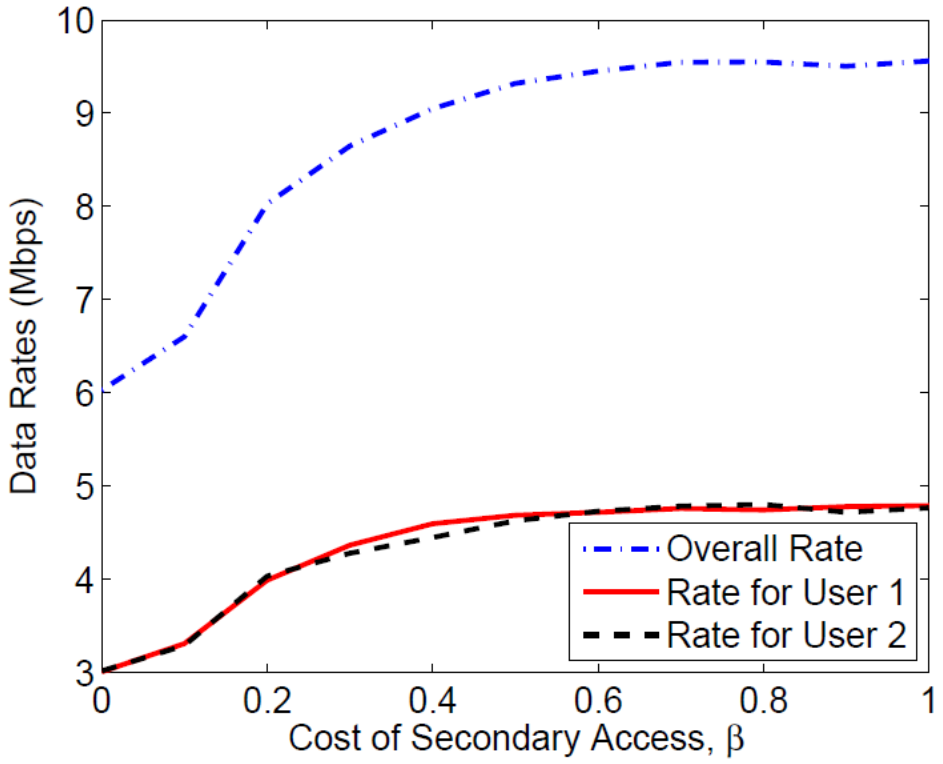
Variation of data rate with cost of secondary spectrum

Numerical Results (2/4)

Case 2: $c_1 = c_2 = 0.5$, $W_1 = W_2 = 3$ MHz



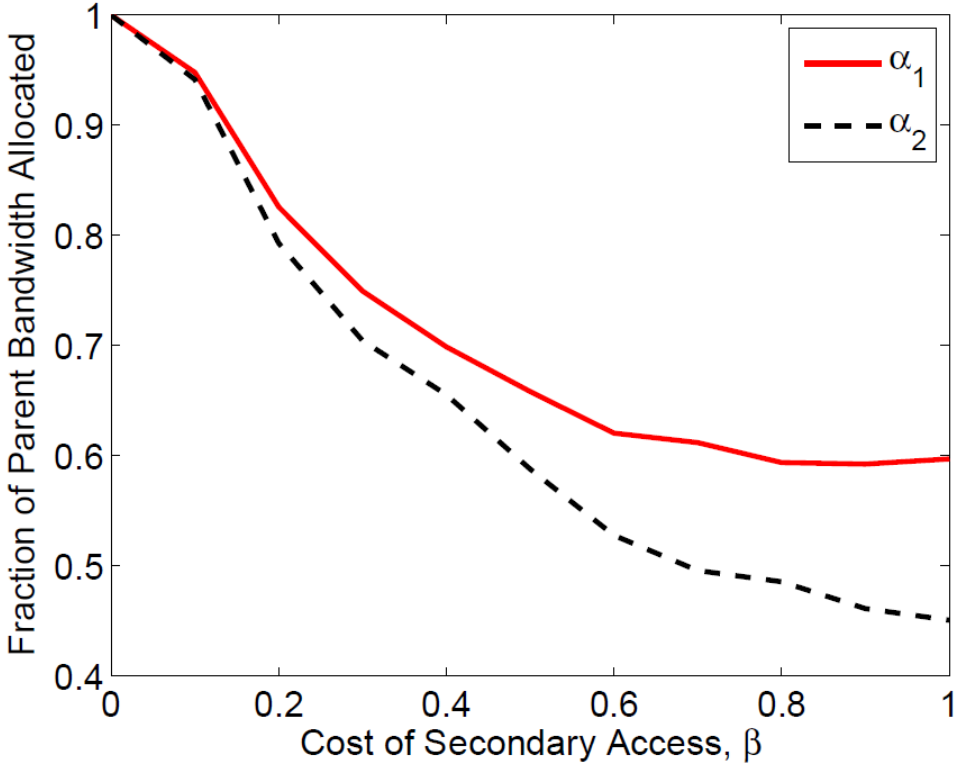
Variation of α's with cost of secondary spectrum



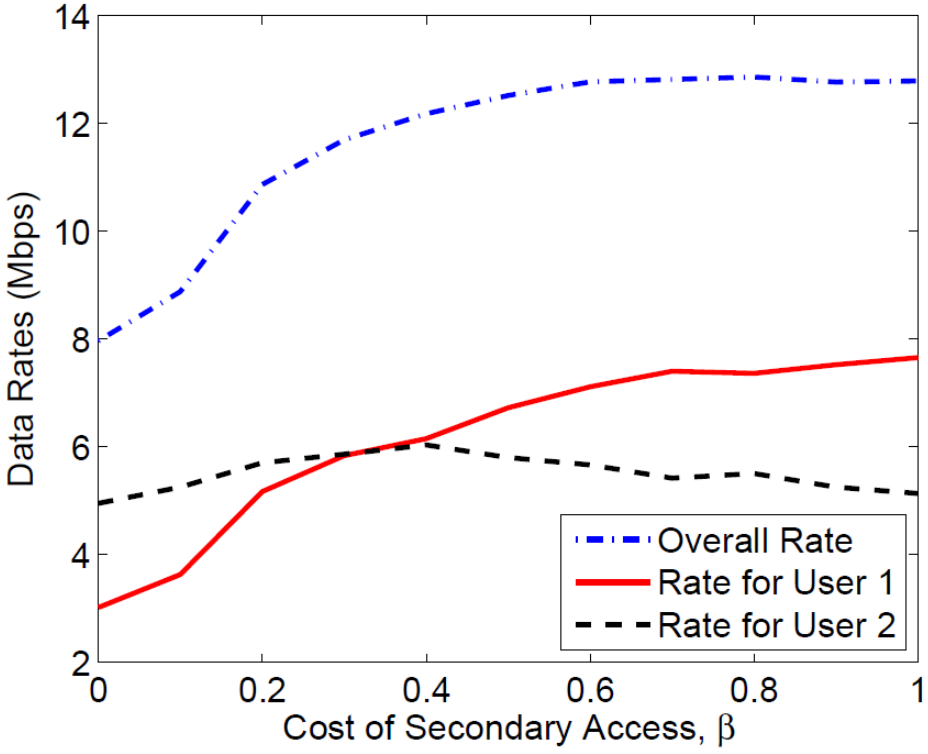
Variation of data rate with cost of secondary spectrum

Numerical Results (3/4)

Case 3: $c_1 = c_2 = 0.5$, $W_1 = 3\text{MHz}$, $W_2 = 5$ MHz



Variation of α's with cost of secondary spectrum



Variation of data rate with cost of secondary spectrum

In this paper…

- Novel Framework for inter-operator spectrum sharing
  - Spectrum cost based rate maximization
  - Assumption: No frequency reuse (orthogonal scheme)
- Optimal Resource Allocation for Users
  - Problem formulation for simple framework
  - Analytical solutions and cost factor analysis
- **Extension for multiuser LTE system**
  - **Problem formulation based on Physical Resource Blocks (PRB)**
  - **Numerical solution and network simulation for a LTE**
- Conclusions and Future Work

Extension to LTE Networks

- Reformulated as a PRB assignment problem
- Optimization becomes a binary integer program
- Definition of cost metric:

$$\begin{aligned} \mathcal{C}_{i,j} &= c_1 \quad \forall i \in \mathbb{I}_1,\ j \in \mathbb{J}_1 \\ \mathcal{C}_{i,j} &= c_2 \quad \forall i \in \mathbb{I}_2,\ j \in \mathbb{J}_2 \\ \mathcal{C}_{i,j} &= \beta \quad \forall i \in \mathbb{I}_1,\ j \in \mathbb{J}_2 \\ \mathcal{C}_{i,j} &= \beta \quad \forall i \in \mathbb{I}_2,\ j \in \mathbb{J}_1 \end{aligned}$$

where $\mathbb{I}_1, \mathbb{I}_2$ – Set of PRBs in OP1 and OP2's networks respectively

$\mathbb{J}_1, \mathbb{J}_2$ – Set of UEs in OP1 and OP2's networks

Resource Scheduling for LTE (1/2)

- Binary assignment variable :

$$x_{i,j,t} = \begin{cases} 1 & \text{if i}^{\text{th}} \text{ PRB is assigned to j}^{\text{th}} \text{ UE} \\ 0 & \text{if i}^{\text{th}} \text{ PRB is } \textit{not} \text{ assigned to j}^{\text{th}} \text{ UE} \end{cases}$$

- Joint optimization problem:

$$\max_{x_{i,j,t}} \sum_{j=1}^{J} x_{i,j,t} \mathcal{C}_{i,j} R_{i,j,t} \quad \text{s.t.} \quad \sum_{j=1}^{J} x_{i,j,t} \in \{0,1\},$$

$$\sum_{i=1}^{I} (x_{i,j,t} R_{i,j,t}) > R_{j,t}^{\min},$$

Per UE QoS guarantee

$$\sum_{i=1}^{I} (x_{i,j,t} R_{i,j,t}) < R_{j,t}^{\max},$$

Max rate per UE

Resource Scheduling for LTE (2/2)

- Problem can be solved numerically
- Evaluation of spectrum assignment metrics α_1, α_2 :

$$\alpha_1 = \frac{1}{|\mathbb{I}_1|} \cdot \sum_{j \in \mathbb{J}_1} \sum_{i \in \mathbb{I}_1} x_{i,j,t}$$

$$\alpha_2 = \frac{1}{|\mathbb{I}_2|} \cdot \sum_{j \in \mathbb{J}_2} \sum_{i \in \mathbb{I}_2} x_{i,j,t}$$

- Cost optimal spectrum allocation solution

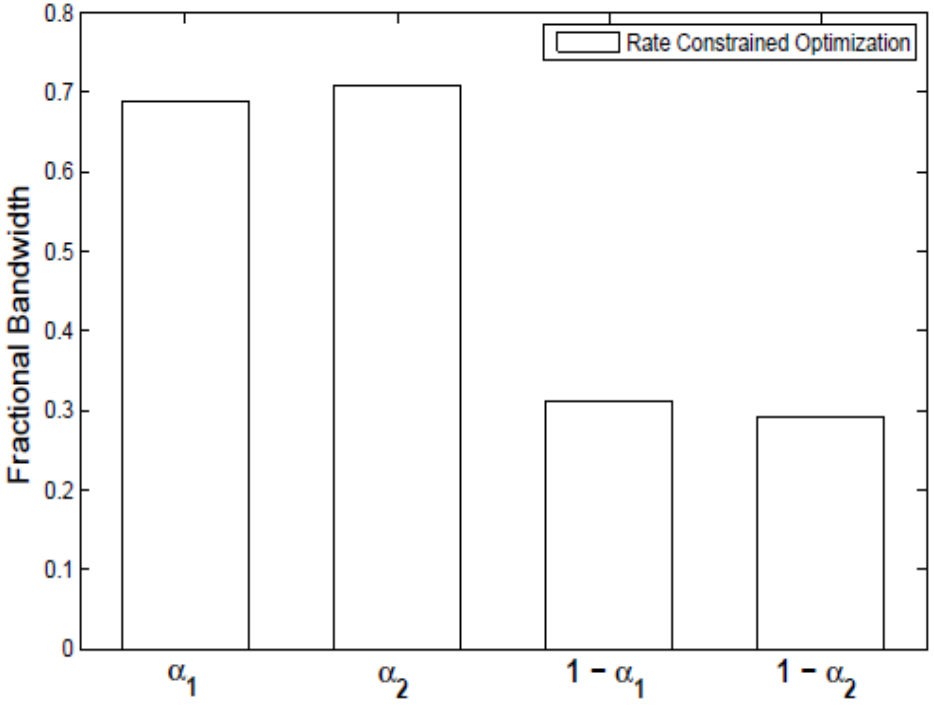
Simulation Results (1/3)

Simulation Parameters

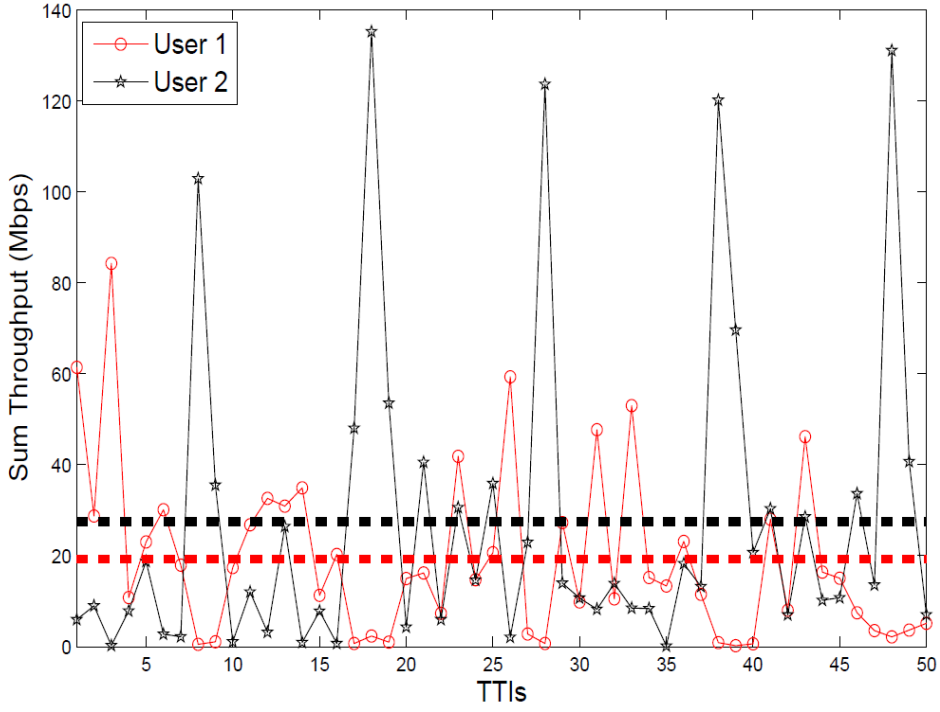
Channel Model	COST-Hata Model
Center Frequency of Operator 1	1800 MHz
Center Frequency of Operator 2	1900 MHz
Sub-carrier separation (Δf)	15 kHz
LTE system bandwidth (Operator 1& 2)	3 MHz (15 PRBs)
Number of cells in network	2
Radius of each cell	2 km
Height of base-station	80 m
Height of UE	10 m
eNB transmit power (maximum)	40 dBm
$\sigma_{\text{Shadowing}}$	7 dB
Simulation time	50 TTIs
Operator 1's cost, c_1	0.5
Operator 2's cost, c_2	0.7
Secondary Access cost, β	0.3
Minimum rate per UE, $R_{j,t}^{\min}$	0.1 Mbps

Simulation Results (2/3)

Single User Case: One user in each OP



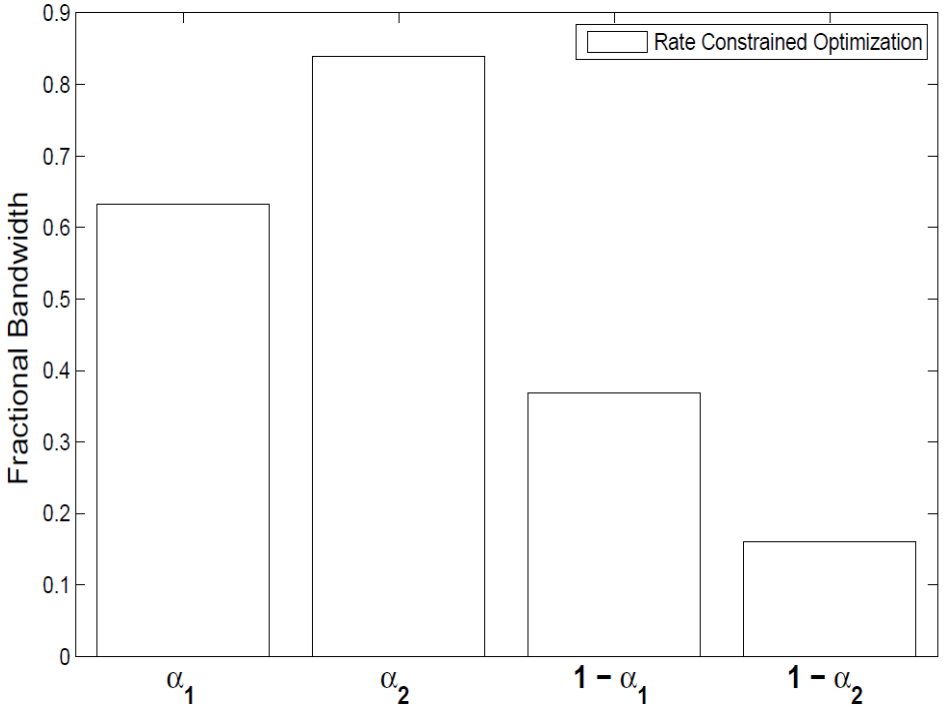
Average α factors for OP1 and OP2 over 50 TTIs



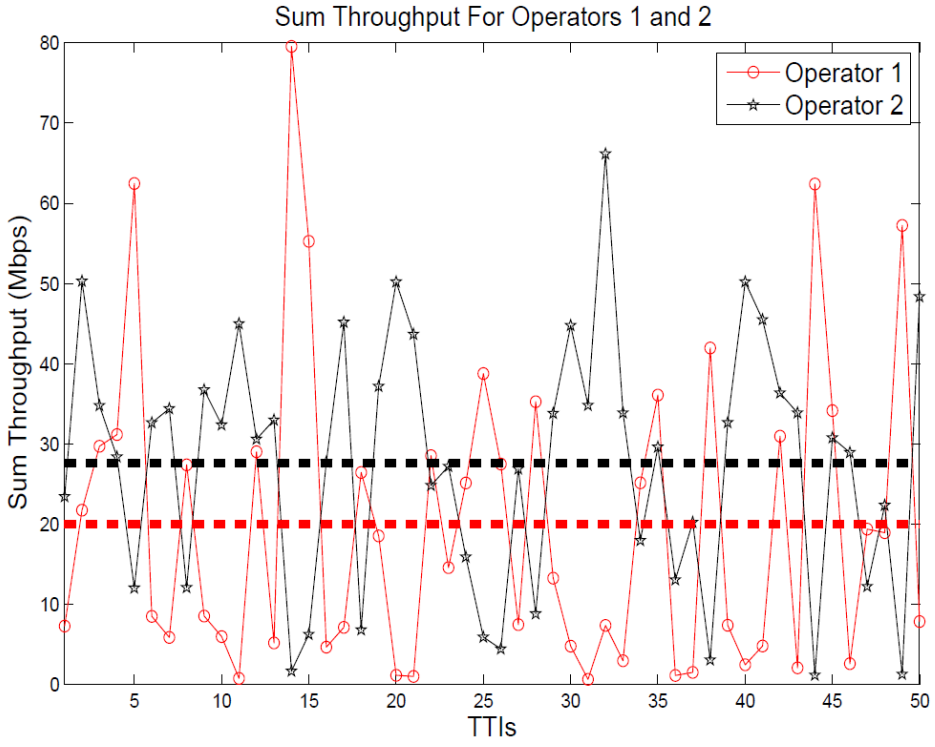
Sum Throughputs of UE1 and UE2 over 50 TTIs

Simulation Results (3/3)

Multiple User Case: 2 UEs in each OP



Average α factors for OP1 and OP2 over 50 TTIs



Sum Throughputs of UEs of OP1 and OP2 over 50 TTIs

In this paper…

- Novel Framework for inter-operator spectrum sharing
  - Spectrum cost based rate maximization
  - Assumption: No frequency reuse (orthogonal scheme)
- Optimal Resource Allocation for Users
  - Problem formulation for simple framework
  - Analytical solutions and cost factor analysis
- Extension for multiuser LTE system
  - Problem formulation based on Physical Resource Blocks (PRB)
  - Numerical solution and network simulation for a LTE
- **Conclusions and Future Work**

Conclusions and Future Work

- Model for multi-operator spectrum sharing
- Solution – Weighted linear optimization
- Price of spectrum access modeled into formulation
- Trade-off of secondary spectrum cost vs. data rate investigated and mutually beneficial strategy discussed
- Extended to LTE networks
- Future Work –
  - Analyze a non-orthogonal sharing model
  - Design of power control for more efficient resource utilization
  - Optimal mode selection between orthogonal and non-orthogonal modes based on system conditions

Thank You!

Questions?