# Interference Management in Femto/Small Cell and Macro Environments

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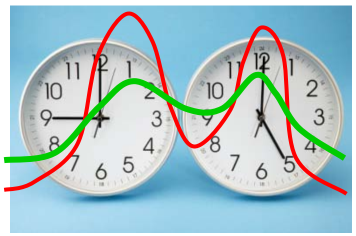
Joint Work with Alexander Stolyar

May, 2010

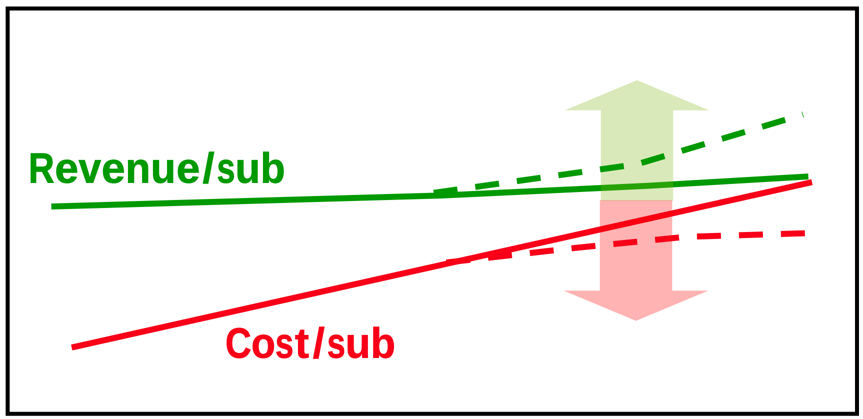
# Where is the next 10X coming from?

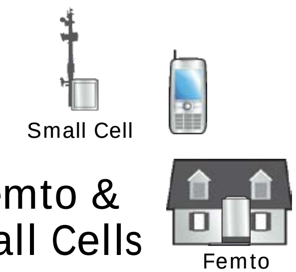
Off-Peak Downloading/ Sideloading

maximize content delivery by smoothing peaks

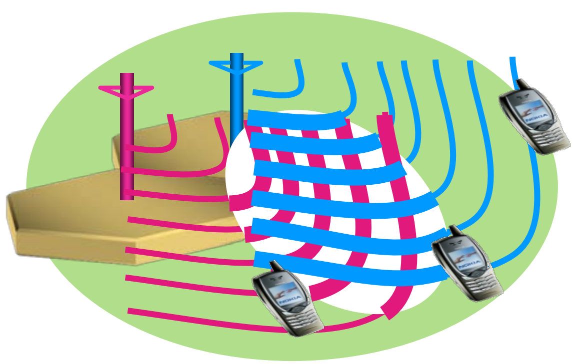


WiFi Offloading



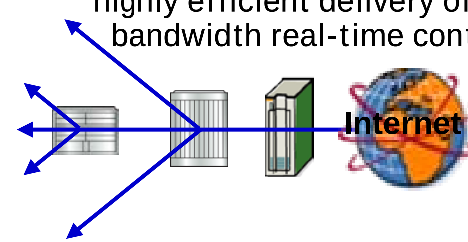

Femto & Small Cells



Interference Mitigation and network MIMO

Network Multicasting

highly efficient delivery of high bandwidth real-time content





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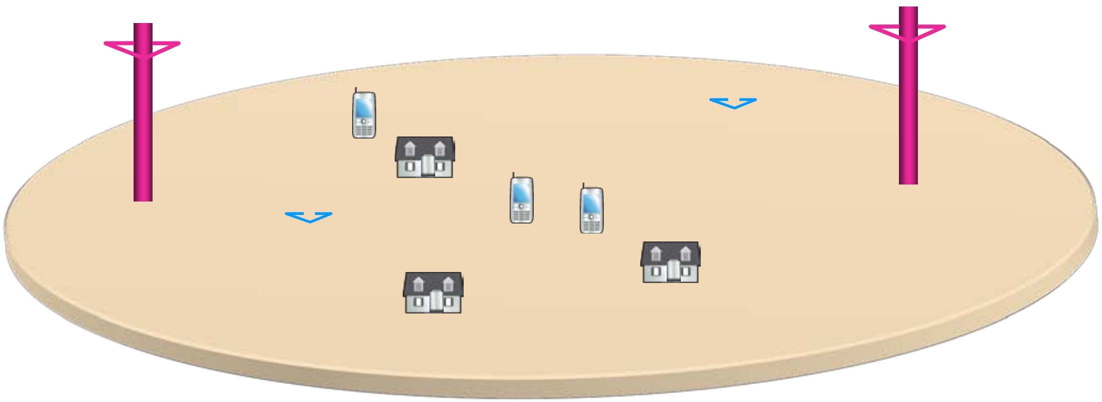
# Emerging Deployment Scenarios



**HetNets**

- Outdoor Hotzones/RRH
- Home Femtos
- Relays
- Enterprise Femto/Pico

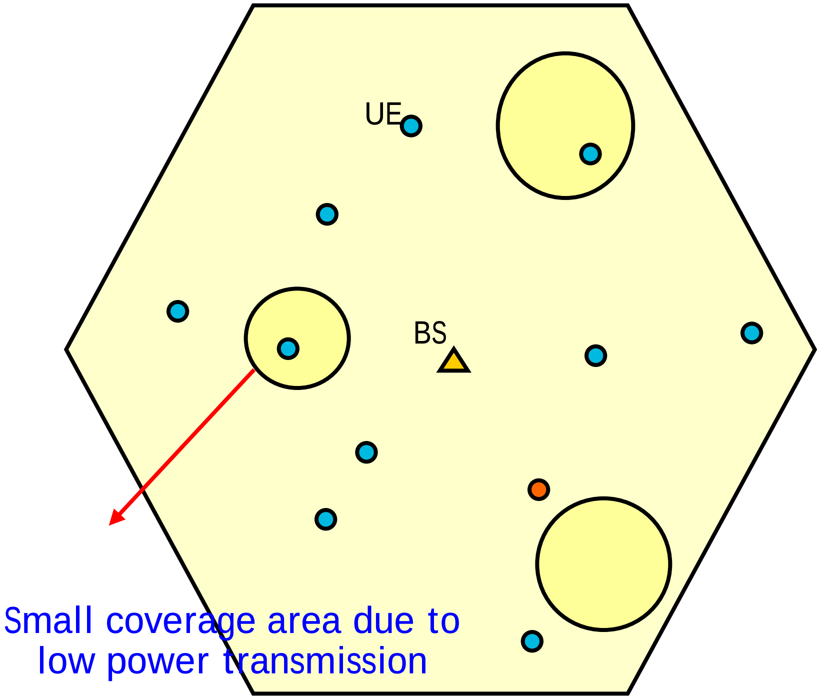
**Targeted and Effective**

Cells deployed only where additional capacity or coverage is needed or there are opportunities for offloading

**Less predictable Interference patterns because of unplanned deployment and bursty traffic**

**Self-organizing, self-optimizing solutions**

# Interference management Issues - I




- **Downlink interference from Macro shrinks coverage of low power small cells for signal strength based association**
- **Alternate cell selection schemes also driven by backhaul congestion and load balancing**
- **Consequence**
  - **Users in very low geometries or high interference conditions are served**
  - **In the uplink, the users connected to the macro BS in proximity of small cell severely interfere with the users in the small cell**
  - **Control channel interference**
  - **Creation of more cell "edges"**



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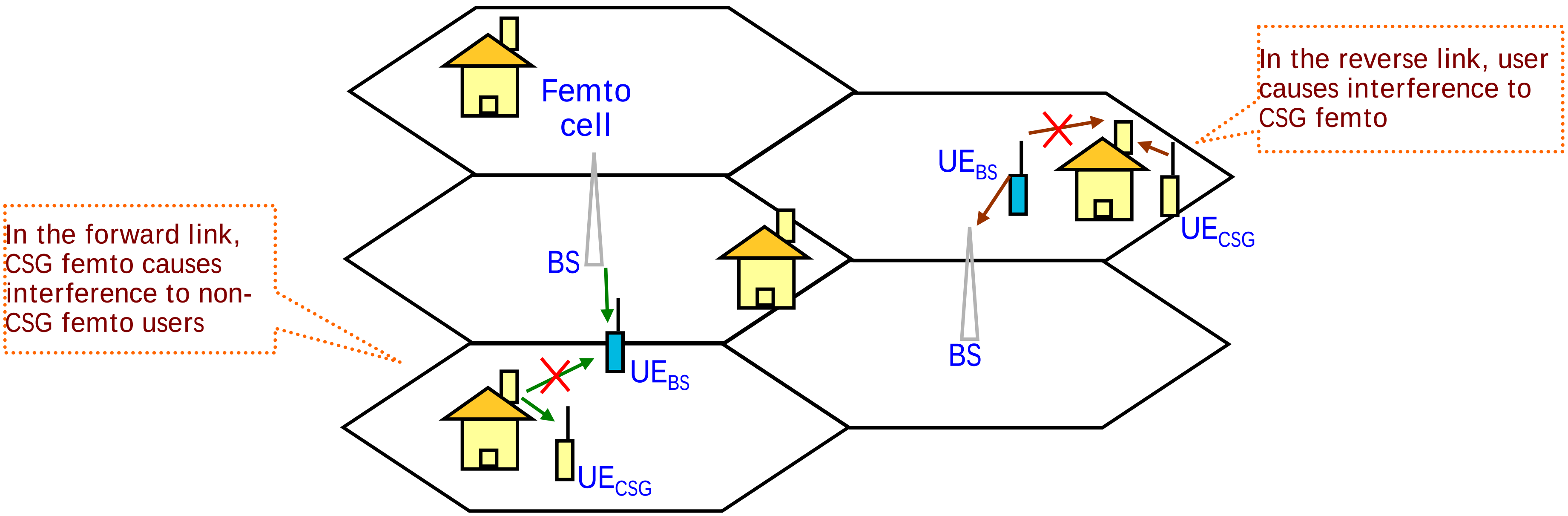
# Interference management issues - II




Interference from Closed Subscriber Group (CSG) femto cell

- UE cannot associate with femto cell even if it has good connectivity to it
- Forward link -> UE suffers interference from such CSG femto cell
- Reverse link -> CSG femto cell sees interference from non-CSG UE



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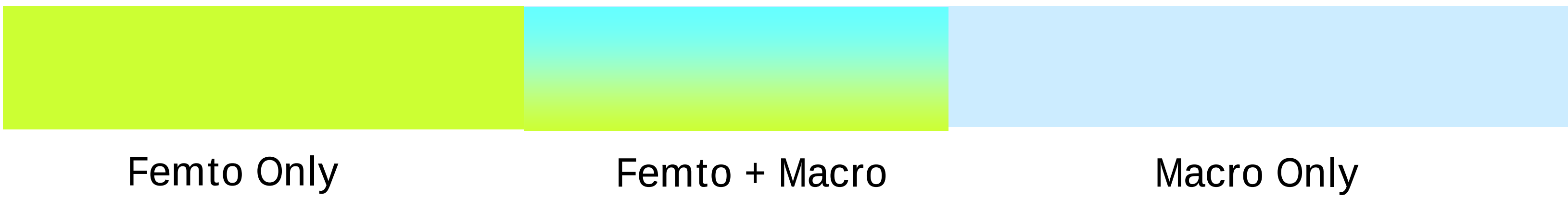
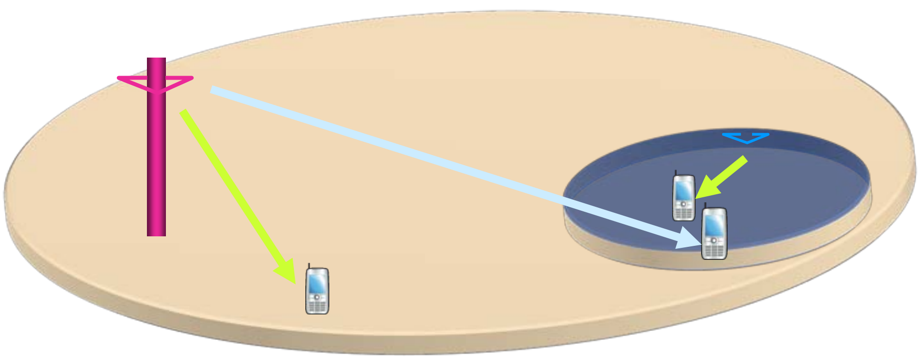
# Dynamic Frequency Allocation



- **Enhanced cell selection**
- **Carrier Aggregation**
- **Dynamic Resource Management**

Distributed with limited message exchange between cells or through devices

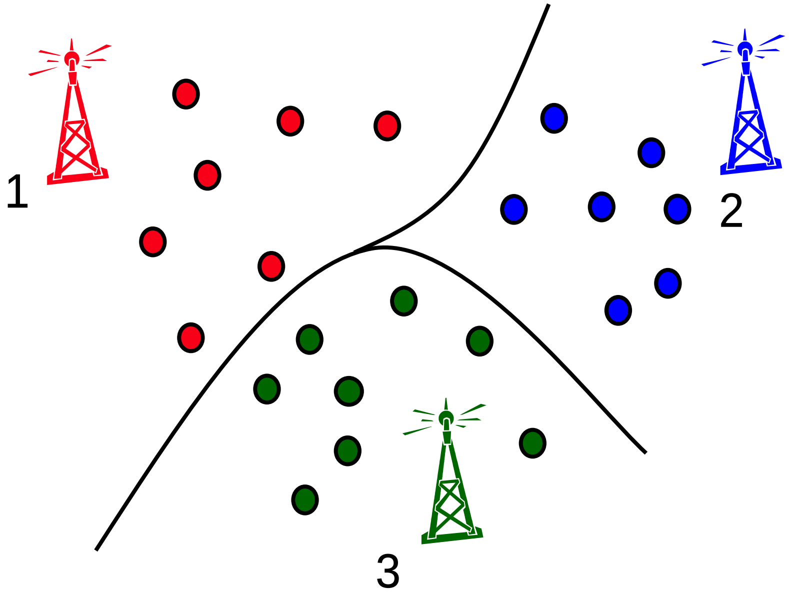
Dynamic sharing to optimize the tradeoff between better SINR and degrees of freedom

Interference Measurement based

Effective use of transmit power on different portions of the spectrum

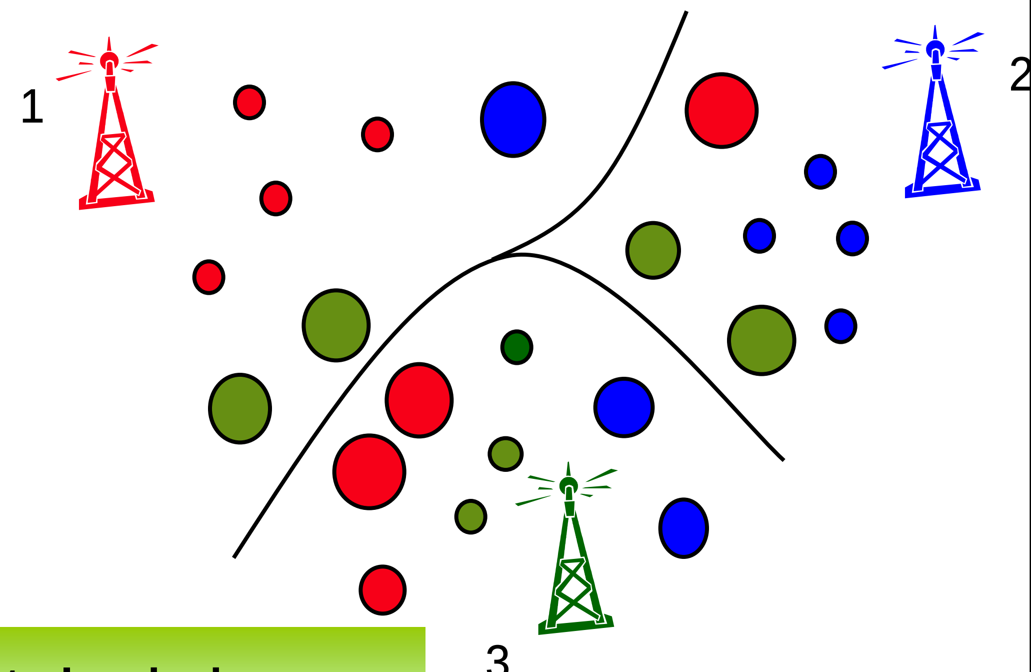
Simple to Implement

# Soft Fractional Reuse




All frequency resources are used in every cell but at different power levels to minimize interference

A set of frequency resources is reserved for each cell in a cluster to achieve interference avoidance




**More sophisticated than separating cell central and edge users**

# Problem

**Focus is on downlink best effort traffic**

$i$ = user index, $X_i$ = average data rate

$k$ = sector index; $P^*$ = sector power limit

$j$ = sub-band index; $P^{(k)}_j$ = power allocated by sector k in sub-band j

Problem: $max_P\ U(X) = \sum log\ X_i$ s.t. $\sum_j P^{(k)}_j \cdot P^*$, 8 k

Given fixed power allocation $P=\{P^{(k)}_j\}$ in the system, each sector k can independently (by doing optimal scheduling) maximize its own utility $U^{(k)}(X) = \sum_{i\ 2\ sector\ k} log\ X_i$

$P$ uniquely determines $X=X(P)$ => The optimization is on the power allocation $P$



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# Multi-cell Gradient (MGR) Algorithm – General Approach

Each sector *k* constantly tries to reallocate (in small increments) its power among sub-bands, to improve the overall system utility *U*.

Reallocation is done based on the partial derivatives of *U* w.r.t. the sector powers $P^{(k)}_j$ :

$$\frac{\partial}{\partial P_j^{(k)}} U = \frac{\partial}{\partial P_j^{(k)}} U^{(k)} + \sum_{m \neq k} \frac{\partial}{\partial P_j^{(k)}} U^{(m)}$$

?

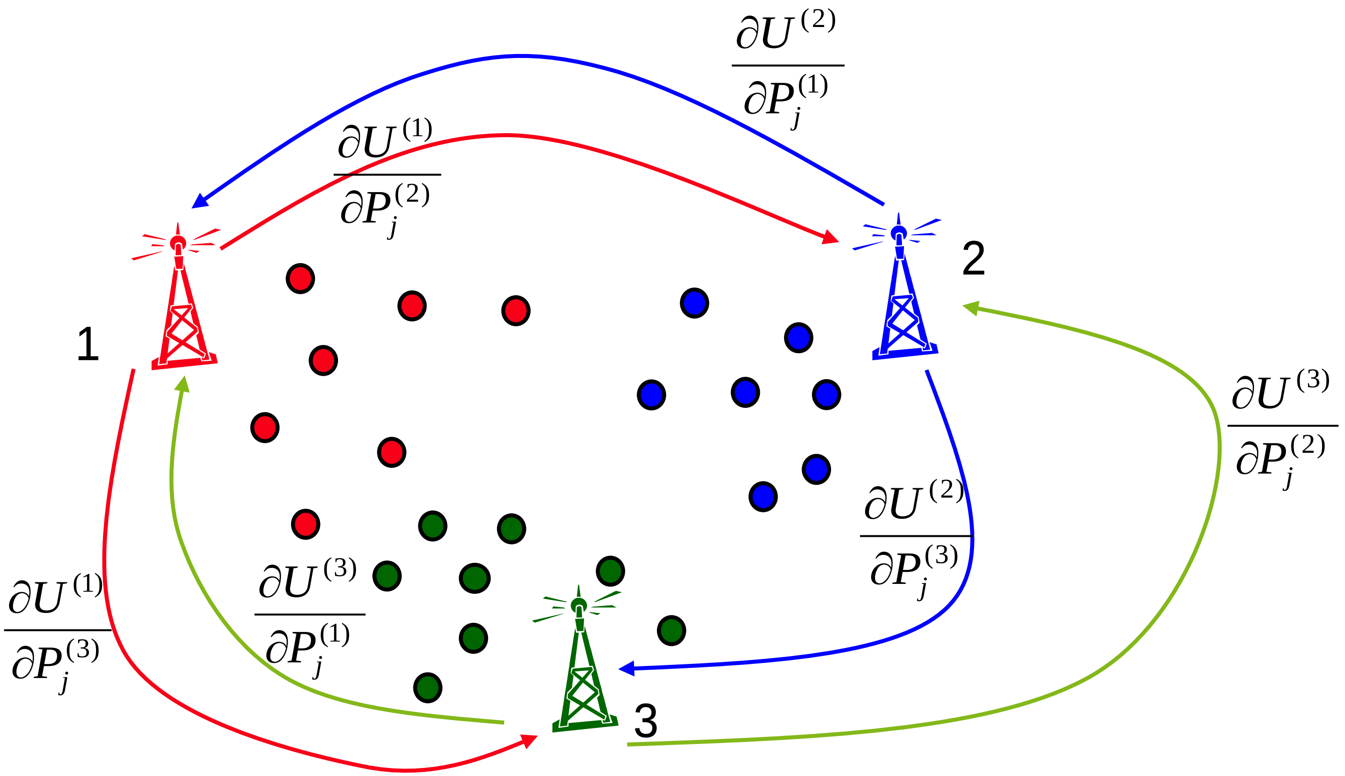
Own Cell

???

Out of Cell

$$\overline{P}^{(k)}(t+1) = \overline{P}^{(k)}(t) + \overline{\Delta} \bullet \overline{Q}\left( \left\{ \frac{\partial U}{\partial P_j^{(k)}} \right\} \right)$$

# Coordination




Partial derivates are exchanged with strongest interferers periodically



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## Partial derivatives

Optimal fraction of time user i is scheduled in sub-band j

$$D_j^{(m,k)} \doteq \frac{\partial}{\partial P_j^{(m)}} U^{(k)} = \sum_i \frac{\partial U^{(k)}}{\partial X_i}(X)\phi_{ij} \frac{\partial R_{ij}^{(k)}}{\partial P_j^{(m)}}.$$

?

$$\frac{\partial R_{ij}}{\partial P_j^{(m)}} = \frac{W/\log 2}{1+F_{ij}(P)} \frac{\partial F_{ij}(P)}{\partial P_j^{(m)}}.$$

Fast SNR feedback from users to their BS

Given the form of SNR $F_{ij}$,

$$\frac{\partial F_{ij}(P)}{\partial P_j^{(k)}} = \frac{F_{ij}(P)}{P_j^{(k)}},$$

$$\frac{\partial F_{ij}(P)}{\partial P_j^{(m)}} = -\frac{[F_{ij}(P)]^2}{P_j^{(k)}} \frac{G_i^{(m)}}{G_i^{(k)}}, \quad \text{if } m \neq k.$$

Can be measured by users; SLOW feedback to their BS

# Shadow Scheduling algorithm for the partial derivatives' estimation

Algorithm in each sector *k* runs over virtual time slots, possibly more than 1 per actual time slot

In each virtual slot, we sequentially pick each sub-band j and do the following:

1. Choose user $i^* \in \arg\max_i \frac{\partial U^{(k)}}{\partial X_i}(X) R_{ij}^{(k)}$.

2. Update average rates: $X_{i^*} := \beta_1 J R_{i^*,j}^{(k)} + (1-\beta_1) X_{i^*},$
$X_i := (1-\beta_1) X_i, \quad \text{for all } i \neq i^*.$

Standard scheduling step

3. For each neighbor sector *m* (including self, *m*=*k*), update:

$$D_j^{(m,k)} := \beta_2 \frac{\partial U^{(k)}}{\partial X_{i^*}}(X) \frac{\partial R_{i^*,j}^{(k)}}{\partial P_j^{(m)}} + (1-\beta_2) D_j^{(m,k)}.$$

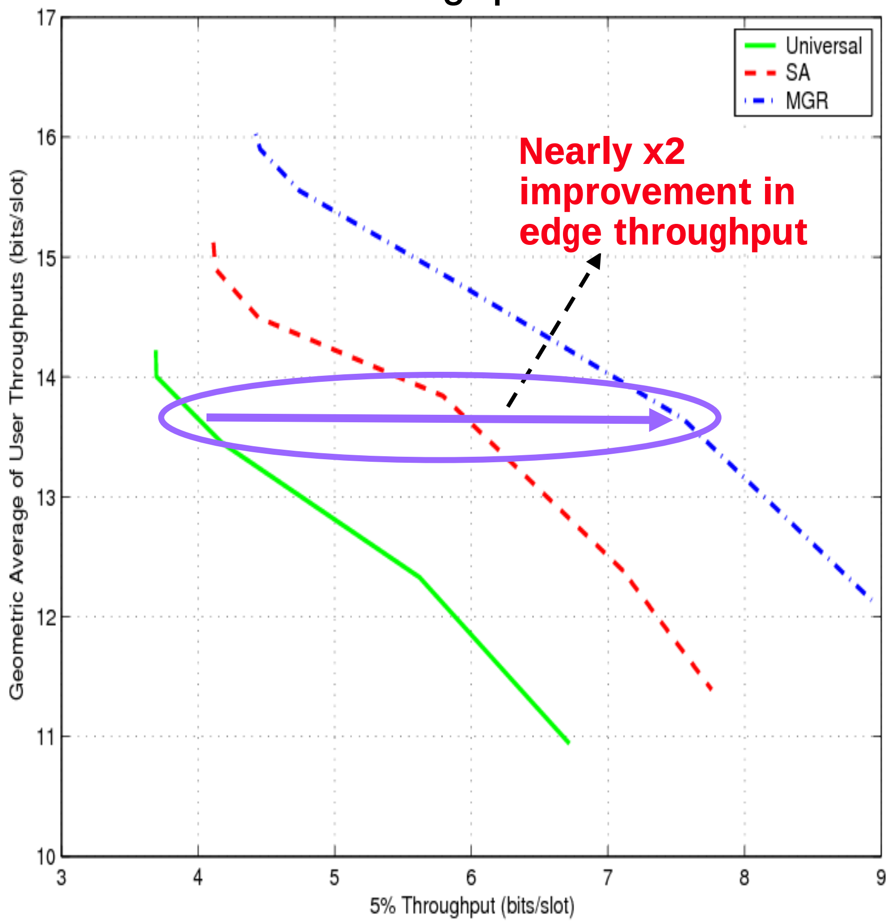
Gradient Update

The algorithm produces asymptotically optimal estimates of $D_j^{(m,k)}$ when parameters $\beta_1,\beta_2 > 0$ are small

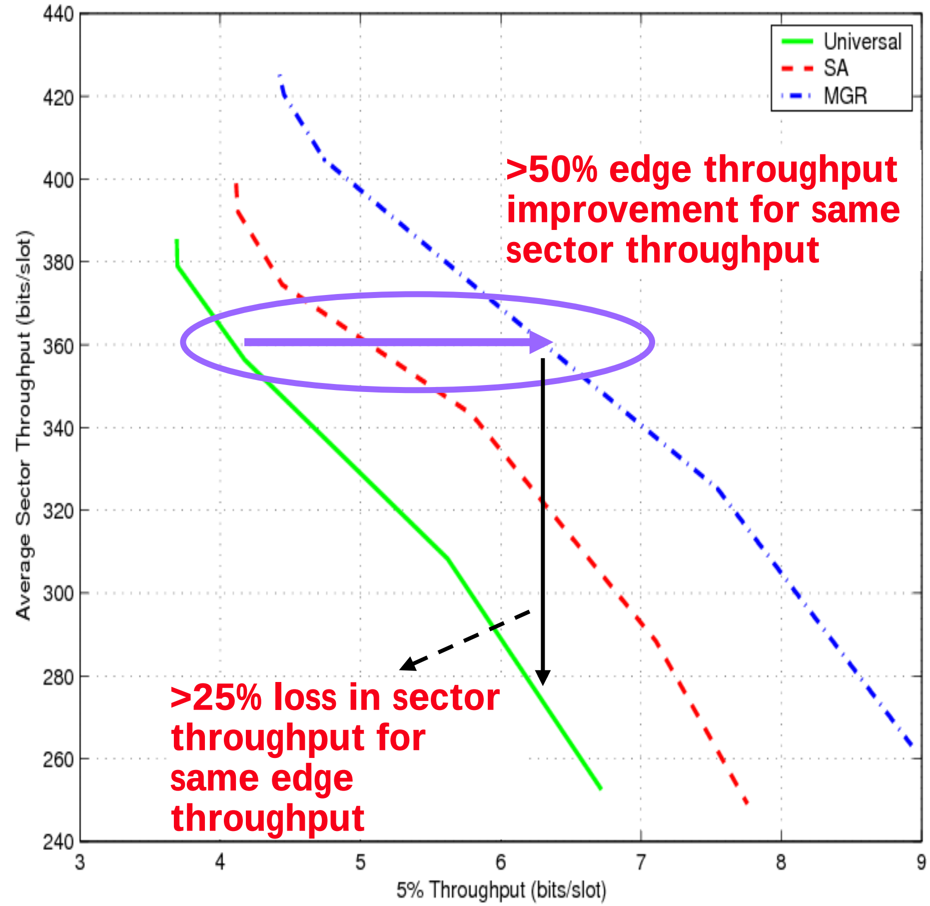
# FL, BE traffic, 57 sectors:

Random uniform user distribution, Full Buffer traffic, Fast fading

## Geometric average of throughputs Vs. Sector edge throughput




## Average sector throughput Vs. Sector edge throughput





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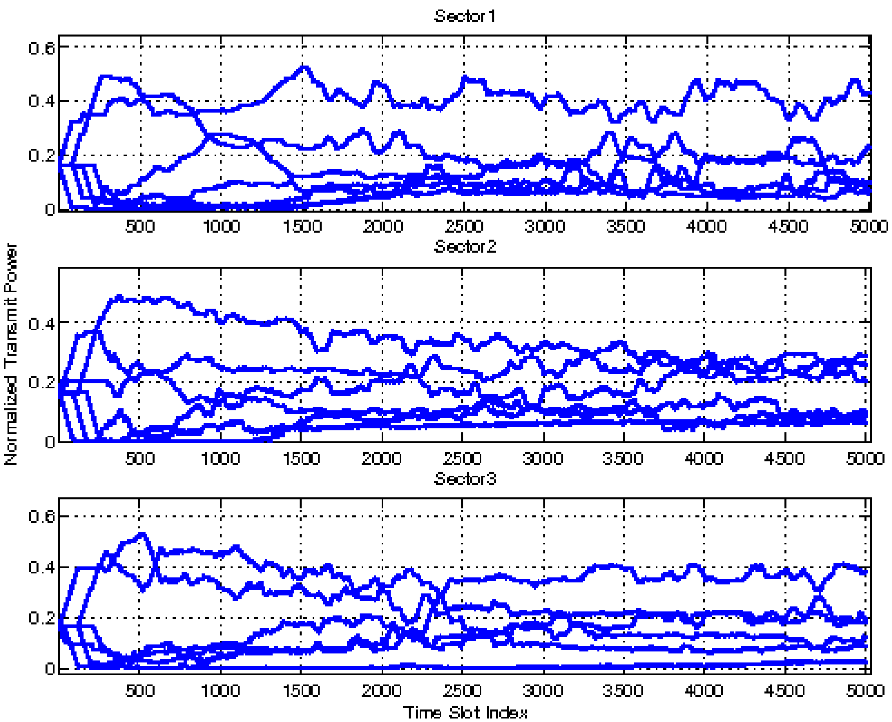
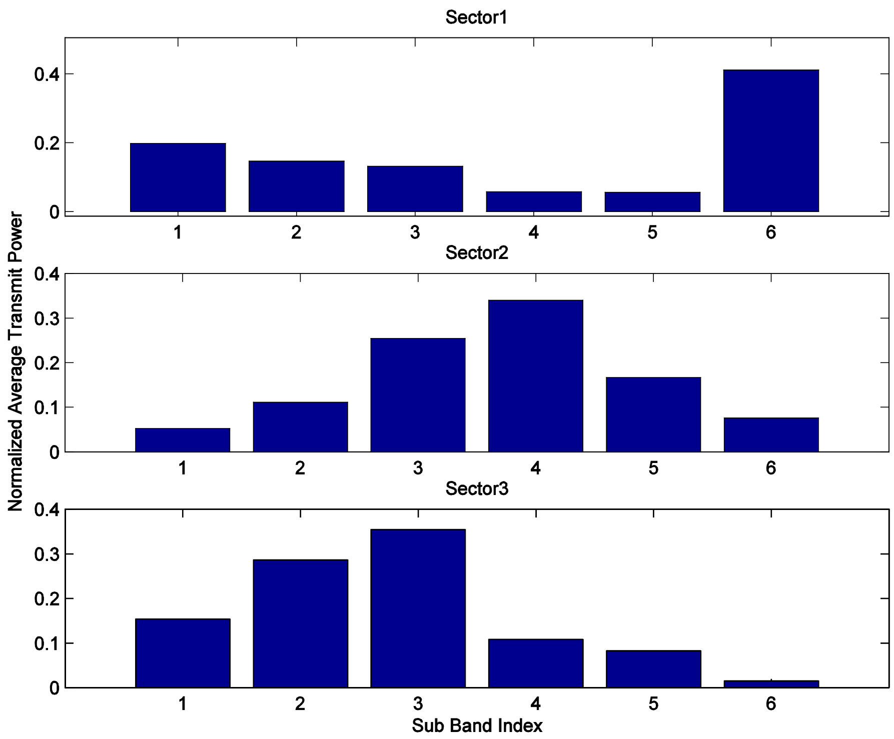
# FL, BE traffic, 57 sectors:
# Random uniform user distribution, Full Buffer traffic, Fast fading

## Power/sub-band dynamics (MGR)




## Average power/sub-band (MGR)



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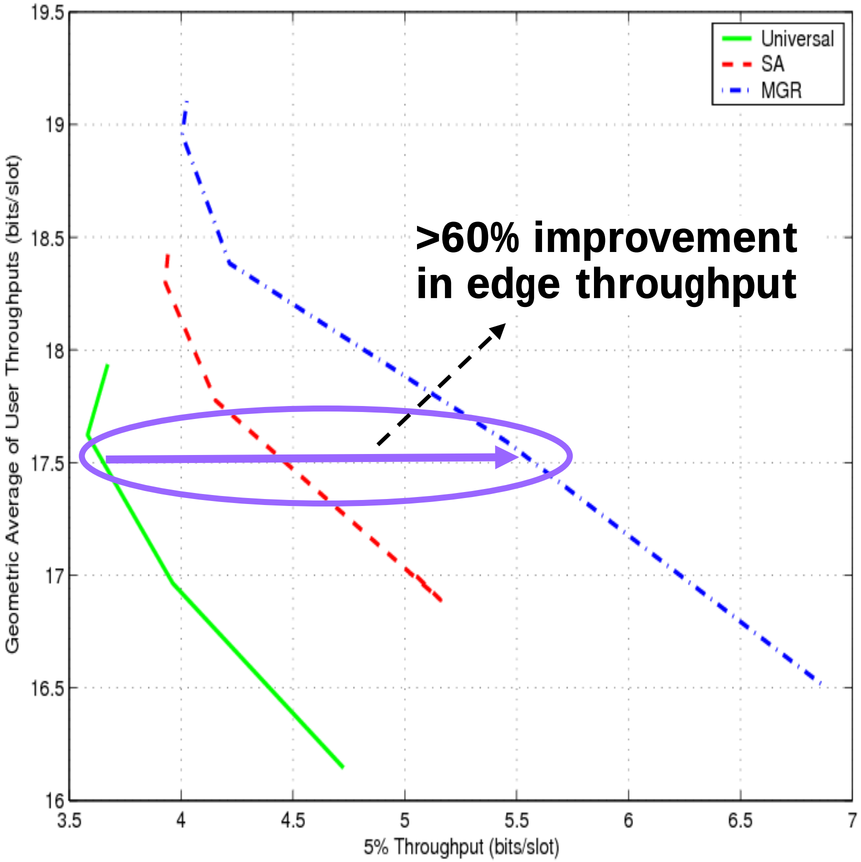
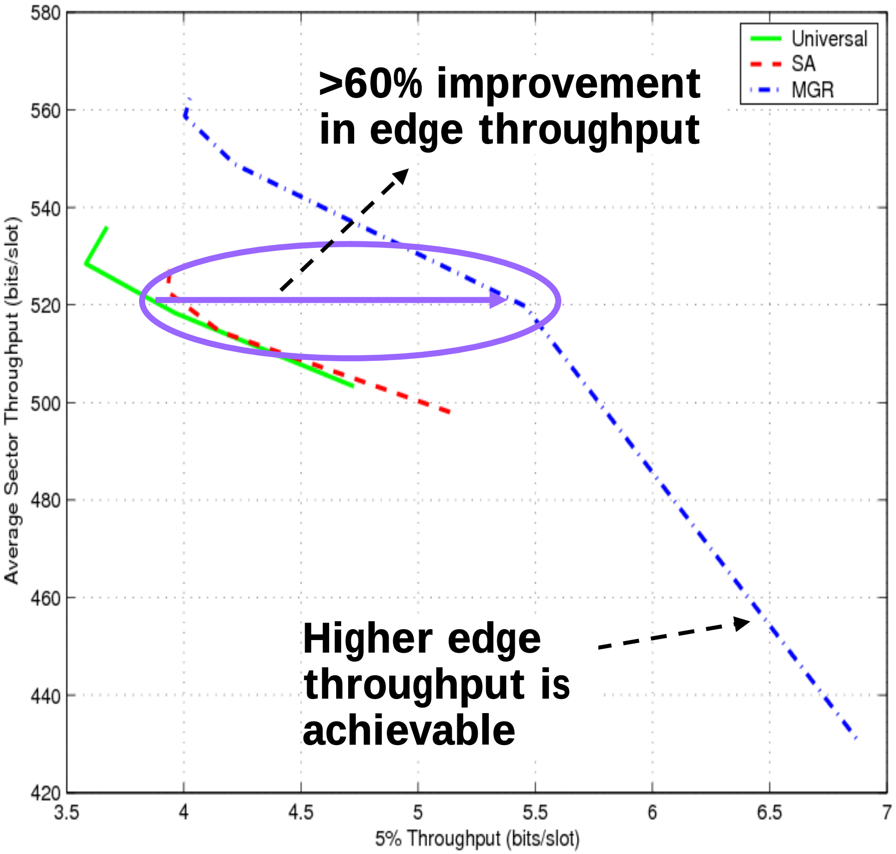
# FL, BE traffic, 57 sectors:

## Random non-uniform user distribution, Full Buffer traffic, Fast fading

Geometric average of throughputs Vs. Sector edge throughput




Average sector throughput Vs. Sector edge throughput




**DFFR automatically adapts to traffic distribution to provide gains**



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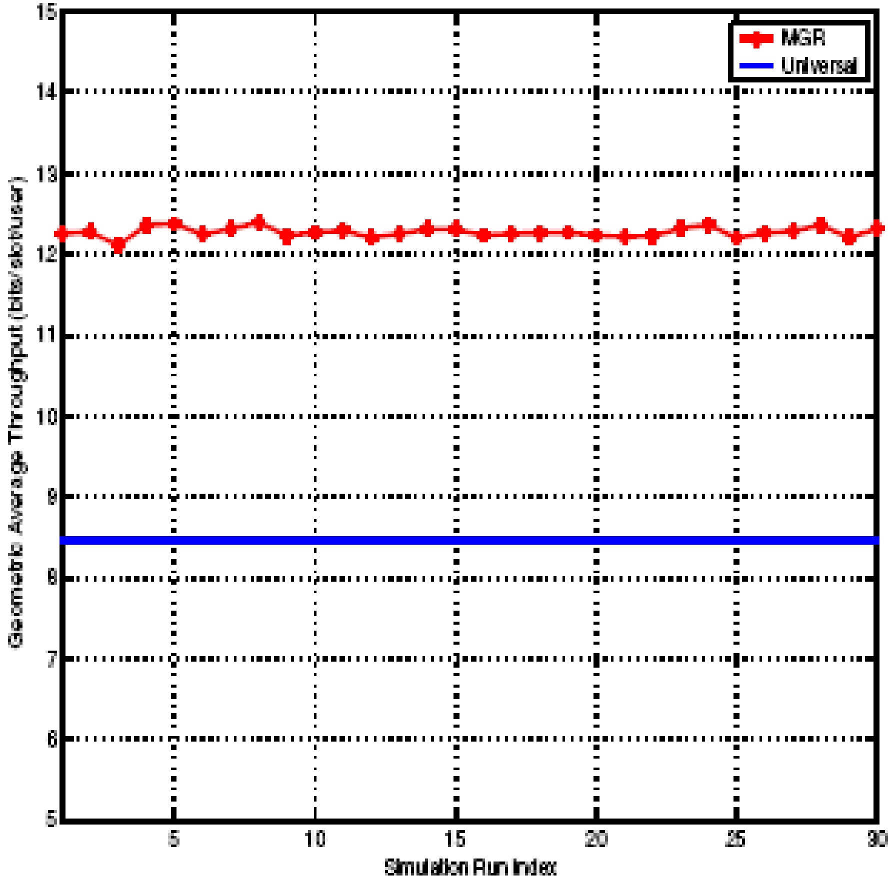
# Global versus Local Optimization

MGR Vs Universal




Performance remains almost the same for 30 different initial conditions of the power values

Benefits are larger with no fast fading

Opportunistic scheduling + Fast fading provide some degree of “automatic” interference avoidance





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## Summary

Efficient FFR pattern is created automatically, and dynamically adapts to traffic load and other changes

Fading provides some interference mitigation benefits without FFR

Significant performance improvement for cell edge users

**References**

Uplink Best Effort


- B. Rengarajan, A.L. Stolyar, H. Viswanathan, **A Semi-autonomous Algorithm for Self-organizing Dynamic Fractional Frequency Reuse on the Uplink of OFDMA Systems**, *CISS 2009*


Downlink Best Effort


- A.L. Stolyar, H. Viswanathan, **Self-organizing Dynamic Fractional Frequency Reuse for Best-Effort Traffic Through Distributed Inter-cell Coordination** , *INFOCOM'2009*


Downlink VoIP


- A.L. Stolyar, H. Viswanathan, **Self-organizing Dynamic Fractional Frequency Reuse in OFDMA Systems** , INFOCOM 2008.






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