Interference Alignment in Heterogeneous Networks with Macro-to-Picocell Offloaded Users

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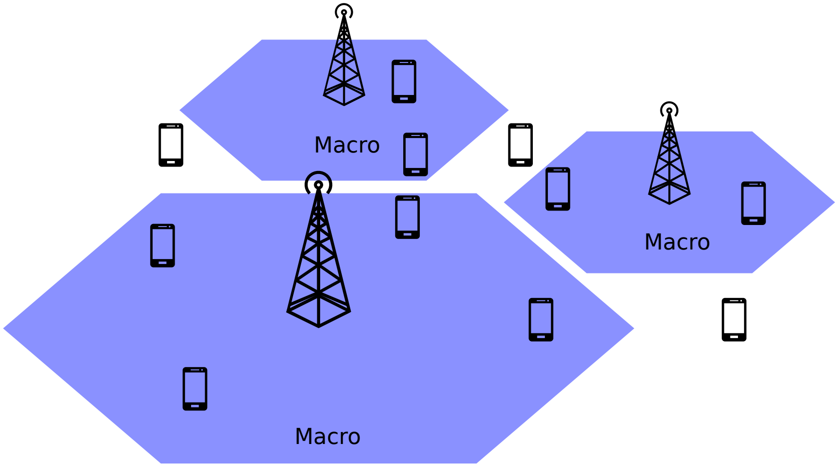
Evolution to Heterogeneous Networks

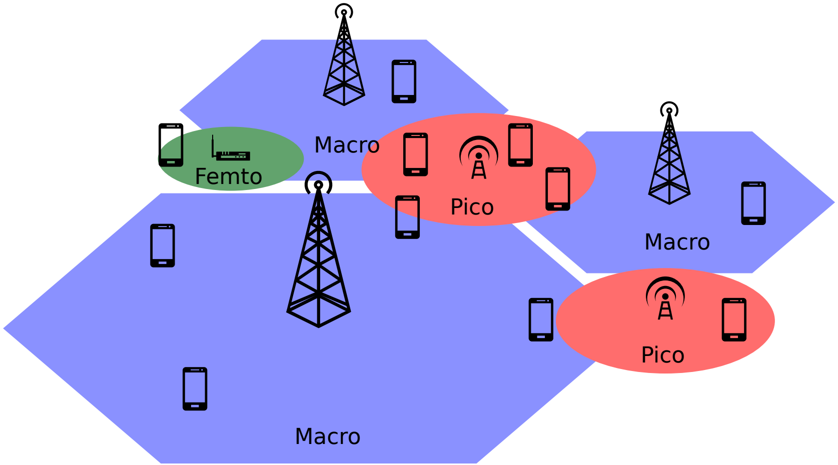
Goals:

- Higher throughput
- Increase spectral efficiency
- Connect more devices

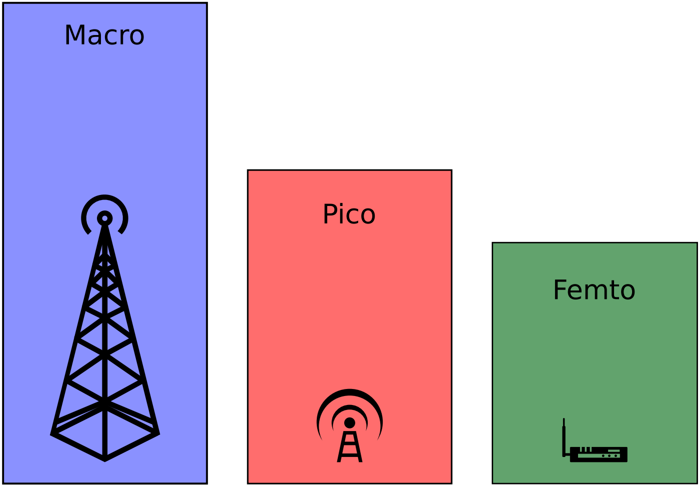
Evolution to Heterogeneous Networks



Evolution to Heterogeneous Networks



Macrocells Compared to Small Cells



Macro	Pico	Femto
$P \approx 46dBm$	$30 < P < 23dBm$	$P < 23dBm$
$1km < r < 20km$	$r < 300m$	$r < 50m$

Advantages and Challenges of HetNets

Advantages

- Reduced distances
- Economy
- Autonomous deployment

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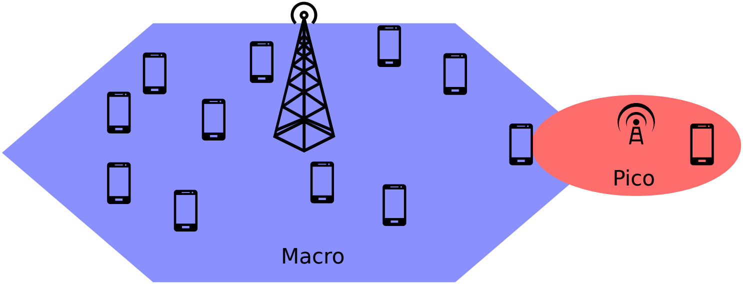
Challenges

- Autoconfiguration
- Handover
- Backhaul limitations
- **INTERFERENCE**

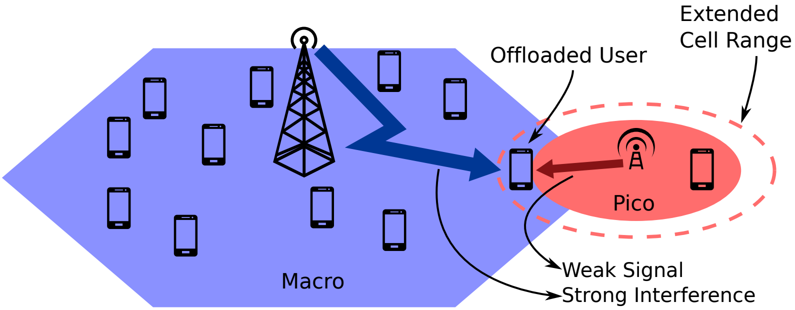
A Challenging Interference Scenario

Cell Range Extension



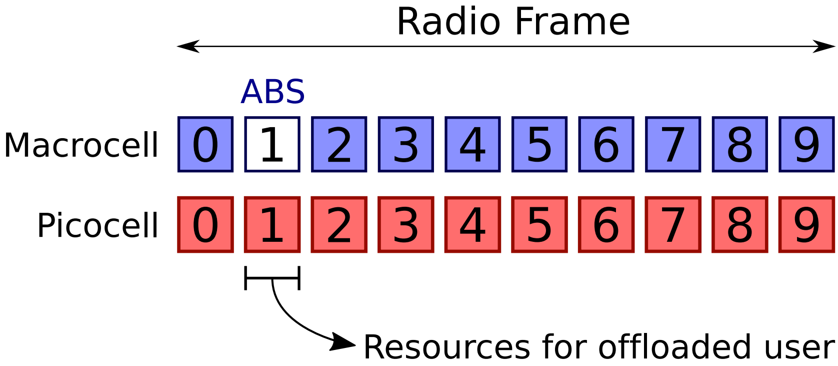
A Challenging Interference Scenario

Cell Range Extension



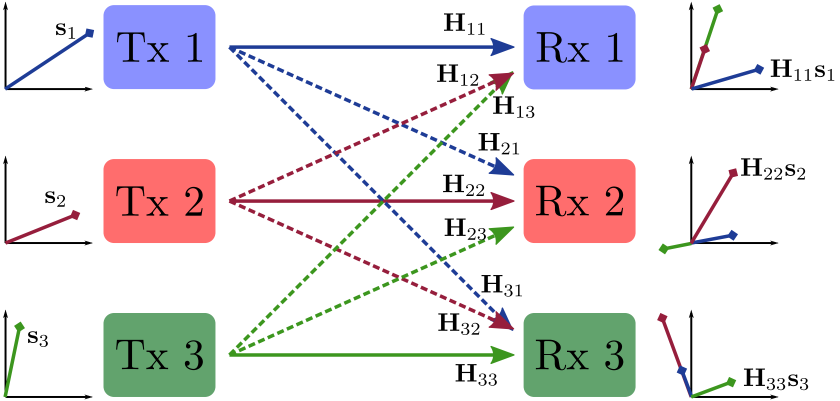
LTE-Advanced Solution

Almost Blank Subframes (eICIC)



Concept of Interference Alignment

Signal and Interference Subspaces



Ideally, the rate grows linearly with the number of users!!!
[S. Jafar, 2011.]

Proposal

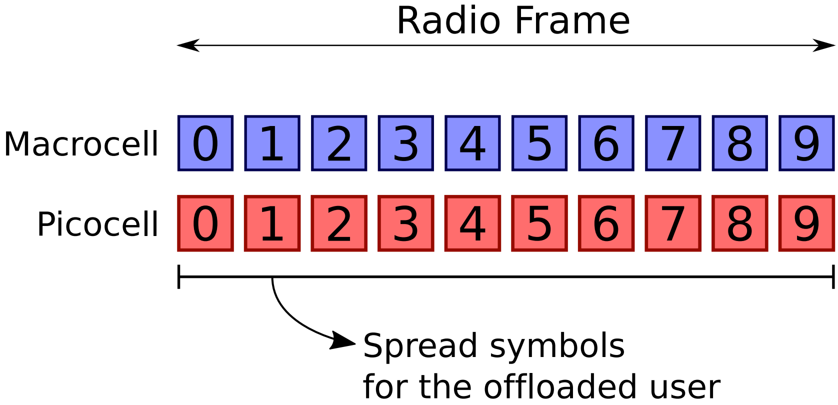
- Evolution from ABS's
- Use OFDM symbols to achieve IA

Signal Model

$$
\begin{aligned}
\hat{\mathbf{S}}^{(\hat{j},\hat{k})} &= \mathbf{A}^{(\hat{j},\hat{k})H}\left(\mathbf{Y}^{(\hat{k})} + \mathbf{Z}\right)\mathbf{B}^{(\hat{j},\hat{k})} \\
&= \mathbf{A}^{(\hat{j},\hat{k})H}\mathbf{H}^{(\hat{j},\hat{k})}\mathbf{P}^{(\hat{j},\hat{k})}\mathbf{S}^{(\hat{j},\hat{k})}\mathbf{Q}^{(\hat{j},\hat{k})}\mathbf{B}^{(\hat{j},\hat{k})} \\
&+ \mathbf{A}^{(\hat{j},\hat{k})H}\mathbf{H}^{(\hat{j},\hat{k})}\sum_{k\neq\hat{k}}\mathbf{P}^{(\hat{j},k)}\mathbf{S}^{(\hat{j},k)}\mathbf{Q}^{(\hat{j},k)}\mathbf{B}^{(\hat{j},k)} \\
&+ \mathbf{A}^{(\hat{j},\hat{k})H}\left(\mathbf{H}^{(j,\hat{k})}\sum_{j\neq\hat{j}}^{J}\sum_{k=1}^{K_j}\mathbf{P}^{(j,k)}\mathbf{S}^{(j,k)}\mathbf{Q}^{(j,k)} + \mathbf{Z}\right)\mathbf{B}^{(\hat{j},\hat{k})}
\end{aligned}
$$

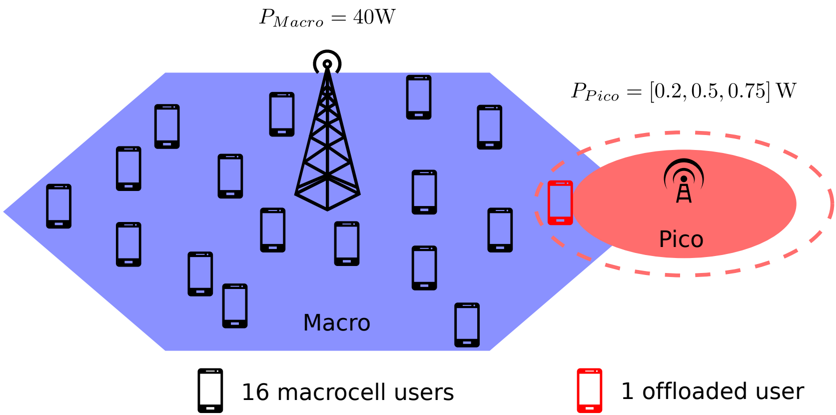
Symbol-Spreading Interference Alignment

- The macrocell uses all time resources
- Symbols for the offloaded user are spread over the frame



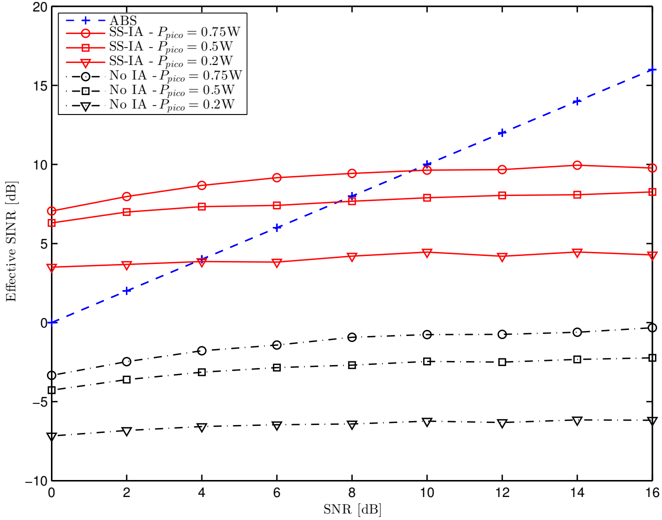
Simulation Results

Simulated Scenario



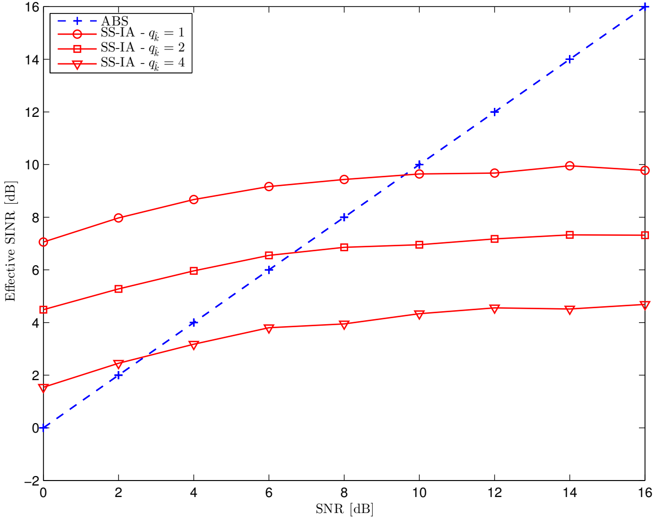
Effective SINR vs SNR for the Offloaded User

$P_{pico} = [0.75, 0.5, 0.2]$ W



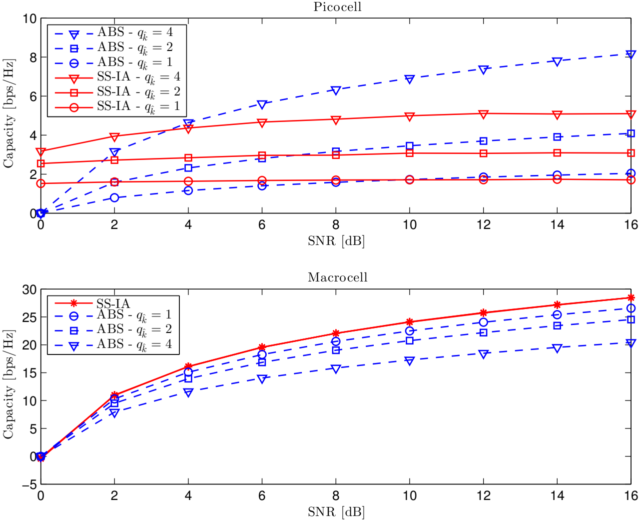
Effective SINR vs SNR for the Offloaded User

$q_{\hat{k}} = [1, 2, 4]$



Average Capacity per Radio Frame vs SNR

$q_{\hat{k}} = [1, 2, 4]$



Conclusions

Some Conclusions and Extensions

- IA concept is applicable to existing systems
- The proposed system outperforms current techniques in LTE-A
- There are many opportunities to optimize precoder and receiver matrix designs

¡Thank you!

¿Questions?

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Signal model

Transmitted signal:

$$\mathbf{X}^{(\hat{j},\hat{k})} = \mathbf{P}^{(\hat{j},\hat{k})}\mathbf{S}^{(\hat{j},\hat{k})}\mathbf{Q}^{(\hat{j},\hat{k})}$$

$$\mathbf{S}^{(j,k)} = \left[\mathbf{s}^{(j,k)}\left[p\right], \mathbf{s}^{(j,k)}\left[p+1\right], \ldots, \mathbf{s}^{(j,k)}\left[p+q-1\right]\right]$$

Estimated signal:

$$\begin{aligned}
\hat{\mathbf{S}}^{(\hat{j},\hat{k})} &= \mathbf{A}^{(\hat{j},\hat{k})H}\left(\mathbf{Y}^{(\hat{k})} + \mathbf{Z}\right)\mathbf{B}^{(\hat{j},\hat{k})} \\
&= \mathbf{A}^{(\hat{j},\hat{k})H}\mathbf{H}^{(\hat{j},\hat{k})}\mathbf{P}^{(\hat{j},\hat{k})}\mathbf{S}^{(\hat{j},\hat{k})}\mathbf{Q}^{(\hat{j},\hat{k})}\mathbf{B}^{(\hat{j},\hat{k})} \\
&+ \mathbf{A}^{(\hat{j},\hat{k})H}\mathbf{H}^{(\hat{j},\hat{k})}\sum_{k\neq\hat{k}}\mathbf{P}^{(\hat{j},k)}\mathbf{S}^{(\hat{j},k)}\mathbf{Q}^{(\hat{j},k)}\mathbf{B}^{(\hat{j},k)} \\
&+ \mathbf{A}^{(\hat{j},\hat{k})H}\left(\mathbf{H}^{(j,\hat{k})}\sum_{j\neq\hat{j}}^{J}\sum_{k=1}^{K_j}\mathbf{P}^{(j,k)}\mathbf{S}^{(j,k)}\mathbf{Q}^{(j,k)} + \mathbf{Z}\right)\mathbf{B}^{(\hat{j},\hat{k})}
\end{aligned}$$

Dominant Macrocell Interference

Dominant interference signal

$$\mathbf{Y}_{int}^{(j,\hat{k})} = \mathbf{H}^{(j,\hat{k})} \sum_{k=1}^{K_j} \mathbf{P}^{(j,k)} \mathbf{S}^{(j,k)} \mathbf{Q}^{(j,k)}$$

SVD:

$$\begin{aligned}\mathbf{Y}_{int}^{(j,\hat{k})} &= \mathbf{U}\mathbf{\Sigma}\mathbf{V}^H \\ &= \begin{bmatrix} \mathbf{u}_1 & \cdots & \mathbf{u}_{(C+L_p)} \end{bmatrix} \begin{bmatrix} \sigma_1 & 0 & \cdots & 0 \\ 0 & \sigma_2 & \cdots & 0 \\ \vdots & \vdots & \ddots & \sigma_q \\ \mathbf{0} & \mathbf{0} & \cdots & \mathbf{0} \end{bmatrix} \begin{bmatrix} \mathbf{v}_1^H \\ \vdots \\ \mathbf{v}_q^H \end{bmatrix}\end{aligned}$$

Receive Matrices

Post-multiplication matrix $\mathbf{B}$: the basis are columns of $\mathbf{V}$ corresponding to the smallest singular values.

$$\mathbf{B} = \begin{bmatrix} 0 & 0 & \cdots & v_{1q} \\ 0 & 0 & \cdots & v_{2q} \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & v_{qq} \end{bmatrix}$$

Pre-multiplication matrix $\mathbf{A}$: the columns of $\mathbf{U}$ corresponding to the smallest singular values belong to the nullspace of $\mathbf{A}$.

$$\mathrm{tr}\left\{ \left(\mathbf{A}^H \mathbf{Y}_{int}^{(j,\hat{k})} \mathbf{B} \right)^H \left(\mathbf{A}^H \mathbf{Y}_{int}^{(j,\hat{k})} \mathbf{B} \right) \right\} =$$
$$= |\sigma_q|^2 \,\mathrm{tr}\left\{ \mathrm{diag}\left\{ \begin{bmatrix} 0 & \cdots & \|\mathbf{A}^H \mathbf{u}_q\|^2 \end{bmatrix} \right\} \right\} = |\sigma_q|^2 \, \|\mathbf{A}^H \mathbf{u}_q\|^2$$

Transmit Matrices

Post-multiplication matrix $\mathbf{Q}$: since receive matrix $\mathbf{B}$ is non-invertible, the condition to satisfy is

$$\mathbf{S}^{(\hat{j},\hat{k})}\mathbf{Q}^{(\hat{j},\hat{k})}\mathbf{B} = \mathbf{S}^{(\hat{j},\hat{k})}$$

$$\mathbf{Q}^{(\hat{j},\hat{k})}\mathbf{B} = \begin{bmatrix} \mathbf{0}_{(q-q_t)\times(q-q_t)} & \mathbf{0}_{(q-q_t)\times(q_t)} \\ \mathbf{0}_{(q_t)\times(q-q_t)} & \mathbf{I}_{(q_t)\times(q_t)} \end{bmatrix}$$

Pre-multiplication matrix $\mathbf{P}$: conventional precoding functions (e.g., multiuser transmissions, MIMO, beamforming).