Fractional Base Station Cooperation Cellular Network

Naoki Kusashima

Tokyo Institute of Technology,

Department of Electrical and Electronic Engineering,

Araki-Sakaguchi Laboratories.

Contents

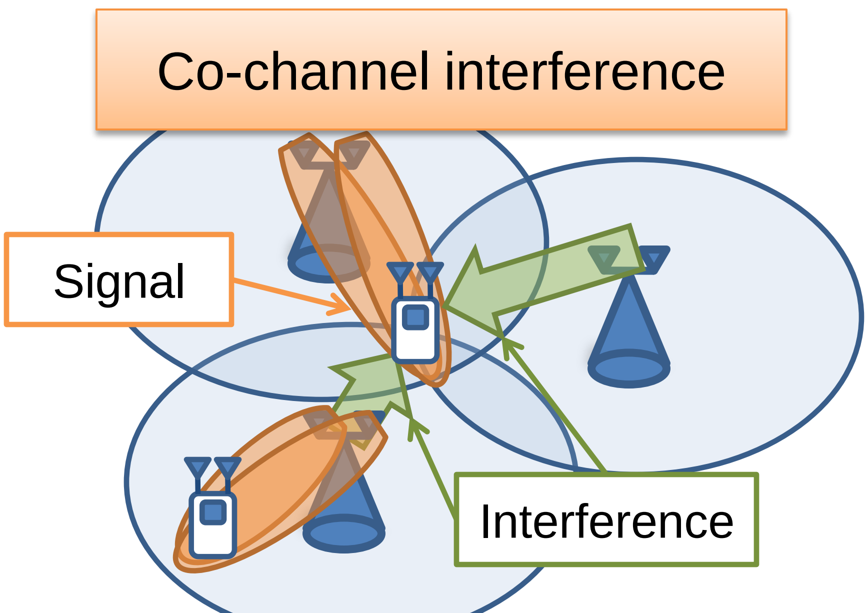
- **Background**
  - Cell-edge problem
  - Conventional solution for the cell-edge problem
  - Base station cooperation
- **Base station cooperation block diagonalization multi-user MIMO**
  - Combination of multi-user
  - Cooperative region
- **Fractional base station cooperation cellular network**
  - Fractional Base Station Cooperation
  - Dynamic clustering
- **Numerical simulation**
- **Conclusion**

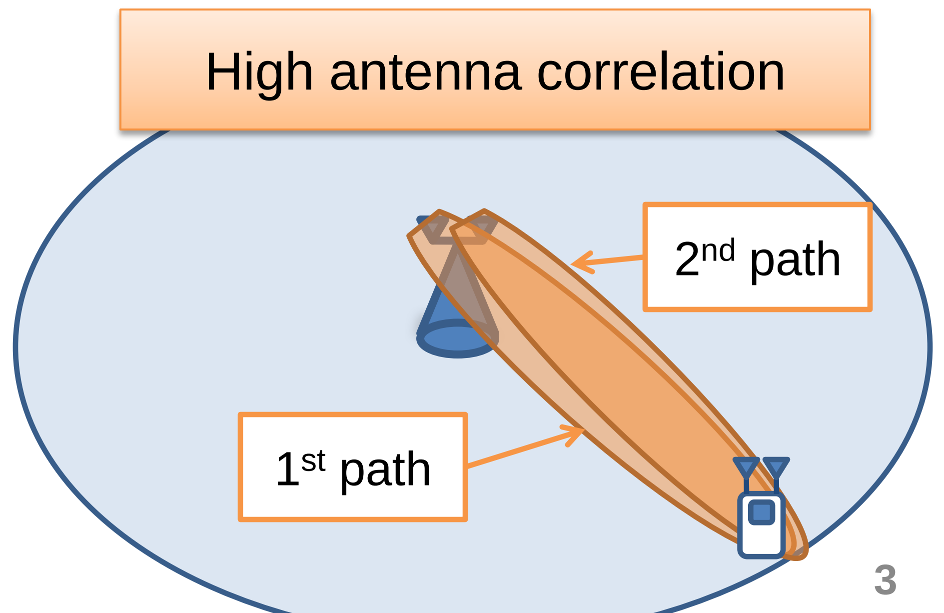
Cell-edge problem

- **If user at the cell-edge location**
  - Low SNR
  - Co-channel interference from adjacent BSs
  - High antenna correlation

  → **Low user throughput**

→ Cell-edge problem



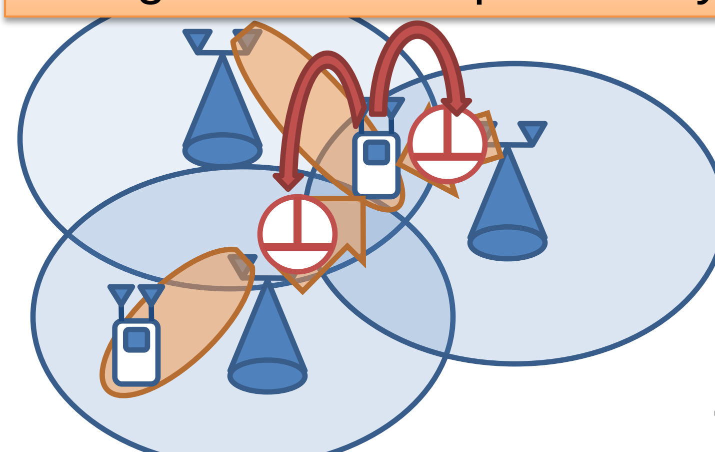


Conventional solution for cell-edge problem

- **Conventional solution**
  - Frequency reuse
    - Each BSs uses different frequency channel from surrounding cells.
    - ✗ It causes degrading of system throughput.
  - Interference cancellation using terminal adaptive array
    - cancels interference by terminals.
    - ✗ It requires many antennas to perform multiplexing and cancellation at the same time.

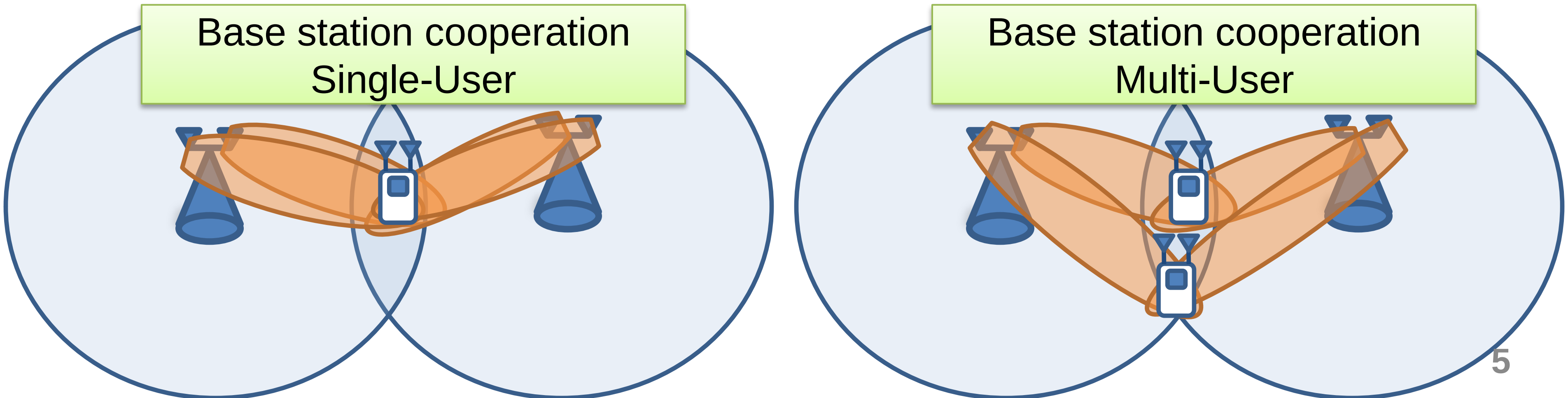
Frequency reuse

Interference cancellation using terminal adaptive array



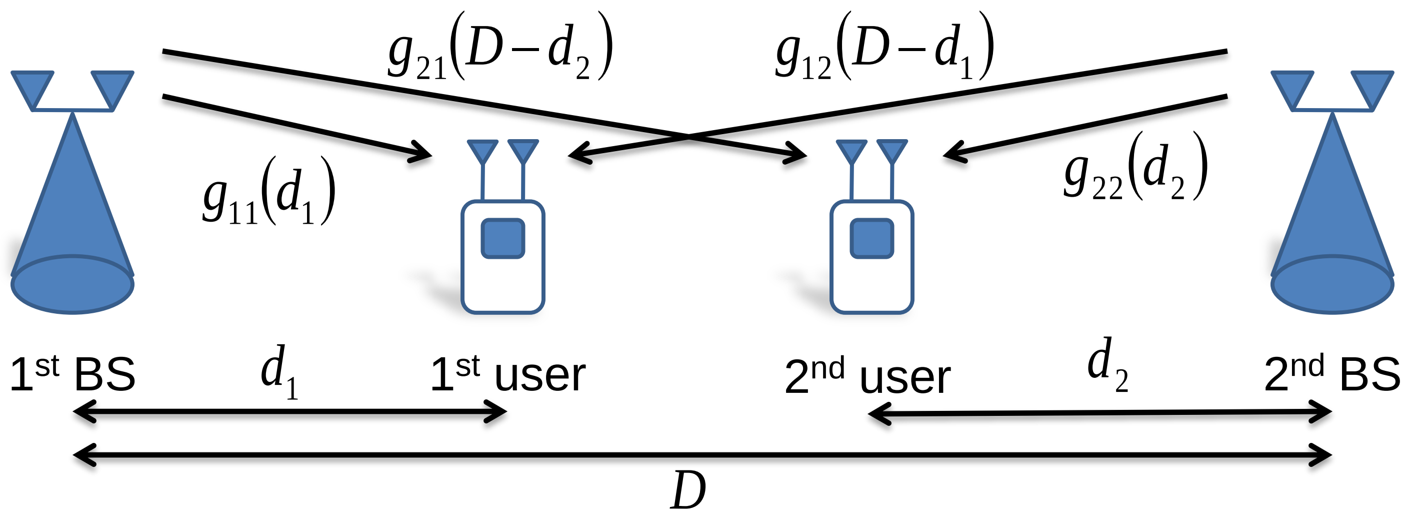
Base station cooperation

- **Base Station Cooperation (BSC)**
  - BSC transmits multiple streams to cooperate with adjacent BSs.
  - There are no problems of nor inter-cell interference nor high antenna correlation.
  - ➢ BSC single-user (BSC-SU)
    - For single user
    - ✗ BSC-SU wastes many resources to a user.
  - ➢ BSC multi-user (BSC-MU)
    - For multiple users
    - ✓ BSC-MU uses resource more efficient than BSC-SU.



Base station cooperation block diagonalization multi-user MIMO

- **Transmission model of (K_{BS},M)×(K_{MS},N) BSC-MU-MIMO**



d_i : distance between *i*th BS and *i*th user

g_{ij} : pathloss between *j*th BS and *i*th user

- **Receive signal of *i*th user**

$$\mathbf{y}_i = \mathbf{H}_{i1}\mathbf{x}_{i1} + \mathbf{H}_{i2}\mathbf{x}_{i2} + \cdots + \mathbf{H}_{iK_{BS}}\mathbf{x}_{iK_{BS}} + \mathbf{n}_i = \mathbf{H}_i\mathbf{Q}_i\tilde{\mathbf{V}}_i\mathbf{s}_i + \mathbf{n}_i$$

$\mathbf{y}_i$: receive signal vector

$\mathbf{x}_{ij}$: transmit signal vector

$\mathbf{s}_i$: transmit data signal vector

$\mathbf{H}_{ij}$: channel matrix

$\mathbf{n}_i$: noise vector

$\mathbf{Q}_i$: precoding matrix of block diagonalization

$\tilde{\mathbf{V}}_i$: precoding matrix of SVD-MIMO

Base station cooperation block diagonalization multi-user MIMO

- **Precoding matrix Q**

$$\left[\mathbf{H}_1^T,\ldots,\mathbf{H}_{i-1}^T,\mathbf{H}_{i+1}^T,\ldots,\mathbf{H}_{K_{\mathrm{MS}}}^T\right]^T=\mathbf{H}_{\backslash i} \qquad \mathrm{svd}\left(\mathbf{H}_{\backslash i}\right)=\mathbf{U}\left[\Sigma \quad \mathbf{O}\right]\left[\mathbf{V}_{\backslash i}^{\parallel} \quad \mathbf{Q}_i\right]^{\mathrm{H}}$$

- **Block diagonalization**

$$\begin{bmatrix}\mathbf{y}_1\\ \vdots \\ \mathbf{y}_{K_{\mathrm{MS}}}\end{bmatrix}=\begin{bmatrix}\mathbf{H}_1\mathbf{Q}_1\tilde{\mathbf{V}}_1 & \cdots & \mathbf{H}_1\mathbf{Q}_{K_{\mathrm{BS}}}\tilde{\mathbf{V}}_{K_{\mathrm{BS}}}\\ \vdots & \ddots & \vdots \\ \mathbf{H}_{K_{\mathrm{MS}}}\mathbf{Q}_1\tilde{\mathbf{V}}_1 & \cdots & \mathbf{H}_{K_{\mathrm{MS}}}\mathbf{Q}_{K_{\mathrm{BS}}}\tilde{\mathbf{V}}_{K_{\mathrm{BS}}}\end{bmatrix}\begin{bmatrix}\mathbf{s}_1\\ \vdots \\ \mathbf{s}_{K_{\mathrm{BS}}}\end{bmatrix}+\begin{bmatrix}\mathbf{n}_1\\ \vdots \\ \mathbf{n}_{K_{\mathrm{MS}}}\end{bmatrix}$$

$$=\begin{bmatrix}\tilde{\mathbf{H}}_1\tilde{\mathbf{V}}_1 & \cdots & \mathbf{O}\\ \vdots & \ddots & \vdots \\ \mathbf{O} & \cdots & \tilde{\mathbf{H}}_{K_{\mathrm{MS}}}\tilde{\mathbf{V}}_{K_{\mathrm{BS}}}\end{bmatrix}\begin{bmatrix}\mathbf{s}_1\\ \vdots \\ \mathbf{s}_{K_{\mathrm{BS}}}\end{bmatrix}+\begin{bmatrix}\mathbf{n}_1\\ \vdots \\ \mathbf{n}_{K_{\mathrm{MS}}}\end{bmatrix}$$

$$\mathbf{H}_j\mathbf{Q}_i=\begin{cases}\tilde{\mathbf{H}}_i & (j=i)\\ \mathbf{O} & (j\neq i)\end{cases}$$

Channel matrix is block diagonalized

Base station cooperation block diagonalization multi-user MIMO

- **We decompose the channel matrix into fading matrix and pathloss matrix**

$$\mathbf{H}_i = \begin{bmatrix} \mathbf{H}_{i1} & \mathbf{H}_{i2} \end{bmatrix} = \begin{bmatrix} \mathbf{H}_{i1}^{\mathrm{iid}} & \mathbf{H}_{i2}^{\mathrm{iid}} \end{bmatrix} \begin{bmatrix} \mathbf{G}_{i1} & \mathbf{O} \\ \mathbf{O} & \mathbf{G}_{i2} \end{bmatrix} = \mathbf{H}_i^{\mathrm{iid}} \mathbf{G}_i$$

$\mathbf{H}_{ij}^{\mathrm{iid}}$: fading matrix

$$\mathbf{G}_{ij} = \sqrt{g_{ij}}\,\mathbf{I}$$

- **Block diagonalization precoding matrix of BSC**

$$\mathbf{Q}_i = \mathbf{H}_{j\neq i}^{\perp} = \frac{1}{\left\| \mathbf{G}_{j\neq i}^{-1} \right\|_F} \mathbf{G}_{j\neq i}^{-1} \left(\mathbf{H}_{j\neq i}^{\mathrm{iid}} \right)^{\perp}$$

$$\mathbf{H}_{j\neq i}^{\mathrm{iid}} \left(\mathbf{H}_{j\neq i}^{\mathrm{iid}} \right)^{\perp} = \mathbf{O} \quad \Rightarrow \quad \mathbf{H}_i \mathbf{Q}_{j\neq i} = \mathbf{O}$$

- **Receive signal of *i*th user**

$$\mathbf{y}_i = \mathbf{H}_i \mathbf{Q}_i \tilde{\mathbf{V}}_i \mathbf{s}_i + \mathbf{n}_i = \tilde{\mathbf{H}}_i \tilde{\mathbf{V}}_i \mathbf{s}_i + \mathbf{n}_i$$

$$\tilde{\mathbf{H}}_i = \mathbf{H}_i \mathbf{Q}_i = \frac{1}{\left\| \mathbf{G}_{j\neq i}^{-1} \right\|_F} \mathbf{H}_i^{\mathrm{iid}} \mathbf{G}_i \mathbf{G}_{j\neq i}^{-1} \left(\mathbf{H}_{j\neq i}^{\mathrm{iid}} \right)^{\perp} = \sqrt{\frac{g_{11} g_{22} + g_{12} g_{21}}{g_{j\neq i1} + g_{j\neq i2}}}\, \tilde{\mathbf{H}}_i^{\mathrm{iid}}$$

$\tilde{\mathbf{H}}_i^{\mathrm{iid}}$: The equivalent fading matrix of *i*th user

Base station cooperation block diagonalization multi-user MIMO

- **Transmit power from *j*th BS**

$$P_j = E\left[\mathbf{x}_j^H \mathbf{x}_j\right] \leq \Omega P$$

Ω : power normalization factor

P : maximum BS transmit power

$\mathbf{x}_j = \left[\mathbf{x}_{1j}, \ldots, \mathbf{x}_{K_{\mathrm{MS}}j}\right]$

: transmit signal of *j*th BS

- **Power normalization factor**
  - Ω regulates the transmit power

$$\Omega = \begin{cases} \dfrac{1}{\dfrac{g_{12}}{g_{11}+g_{12}} + \dfrac{g_{22}}{g_{21}+g_{22}}} & d_1 \geq d_2 \\ \dfrac{1}{\dfrac{g_{11}}{g_{11}+g_{12}} + \dfrac{g_{21}}{g_{21}+g_{22}}} & d_1 \leq d_2 \end{cases}$$

- **Average receive SNR of *i*th user**

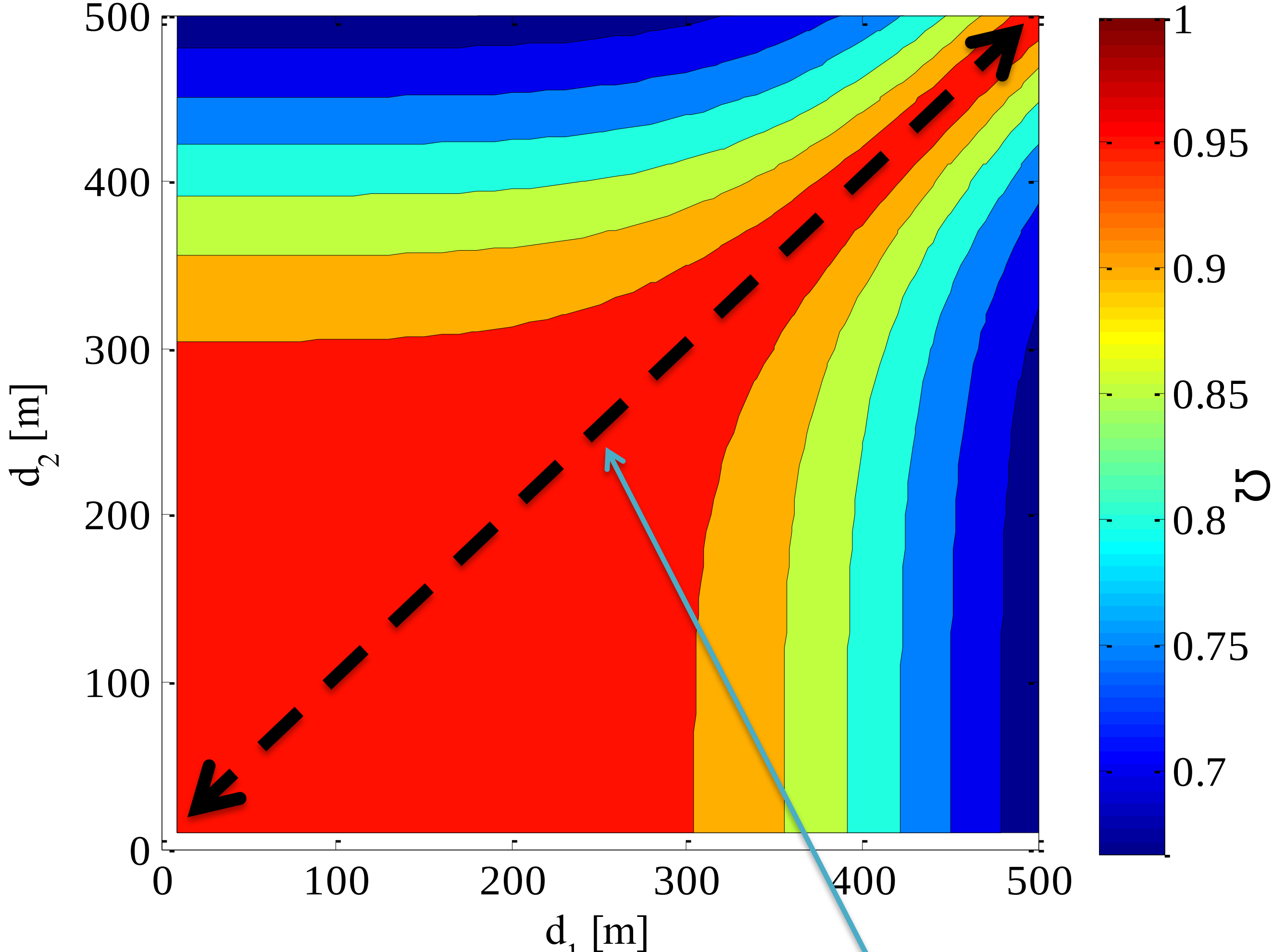
$$\gamma_i = \frac{E\left[\left|\tilde{\mathbf{H}}_i \tilde{\mathbf{V}}_i \mathbf{s}_i\right|^2\right]}{M\sigma^2} = \frac{g_{11}g_{22} + g_{12}g_{21}}{g_{j\neq i1} + g_{j\neq i2}} \frac{\Omega P}{\sigma^2}$$

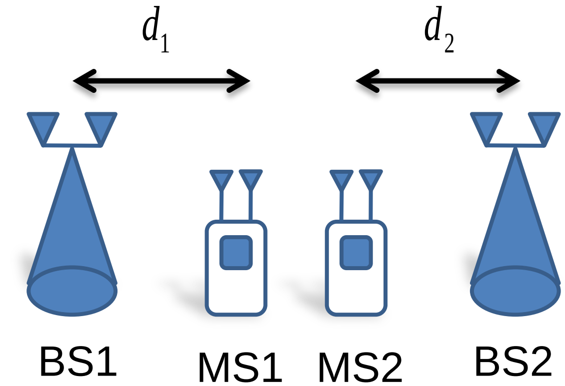
- **Capacity of *i*th user**

$$C_i = \sum_{k=1}^{2} \log_2\left(1 + \lambda_k \gamma_i\right)$$

λ_k : *k*th eigenvalue of equivalent channel

Power normalization factor Ω





- $\mathbf{d_1 = d_2}$

  $\Omega_{max}=1$

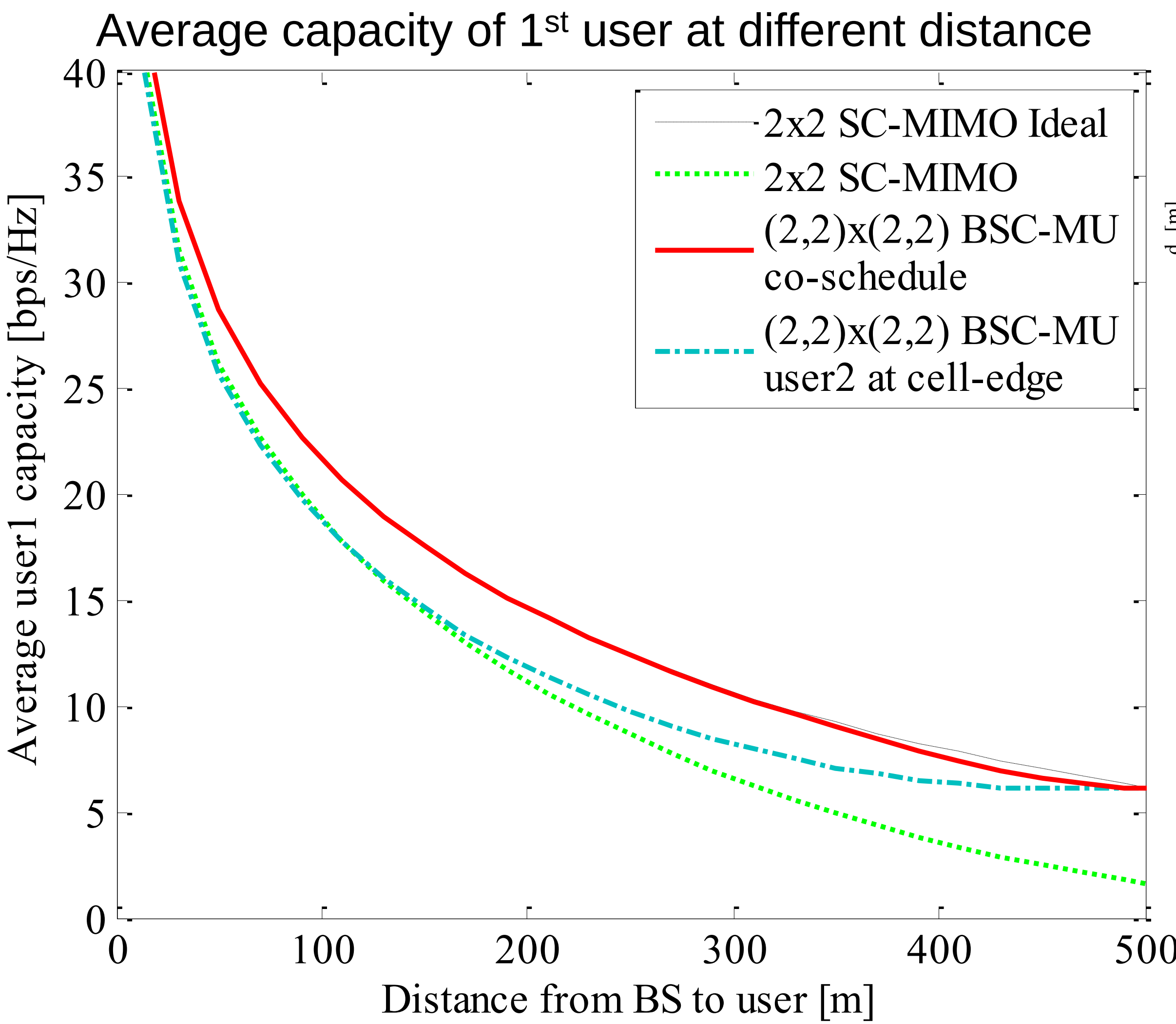
- $\mathbf{d_1 >> d_2,\ d_1 << d_2}$

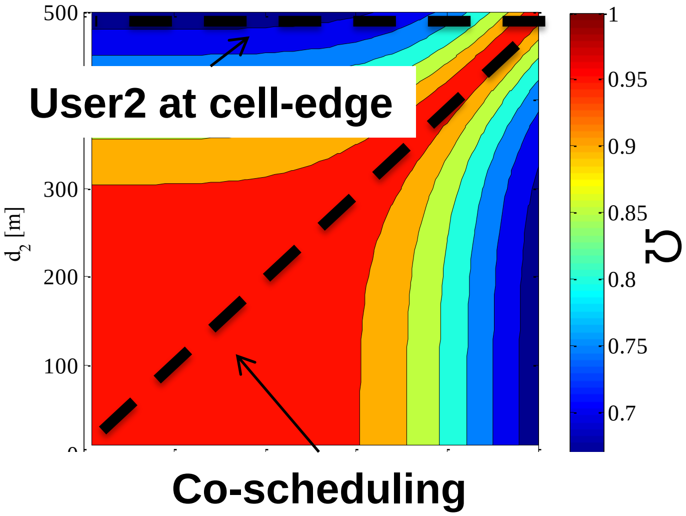
  $\Omega_{min}=2/3$

Co-scheduling

The BSs select users with the same SINR

Capacity of (2,2)x(2,2) BSC-MU-MIMO





- **Co-scheduling**

  BSC-MU is almost the same capacity as 2x2 SC-MIMO ideal

- **User2 at cell-edge**

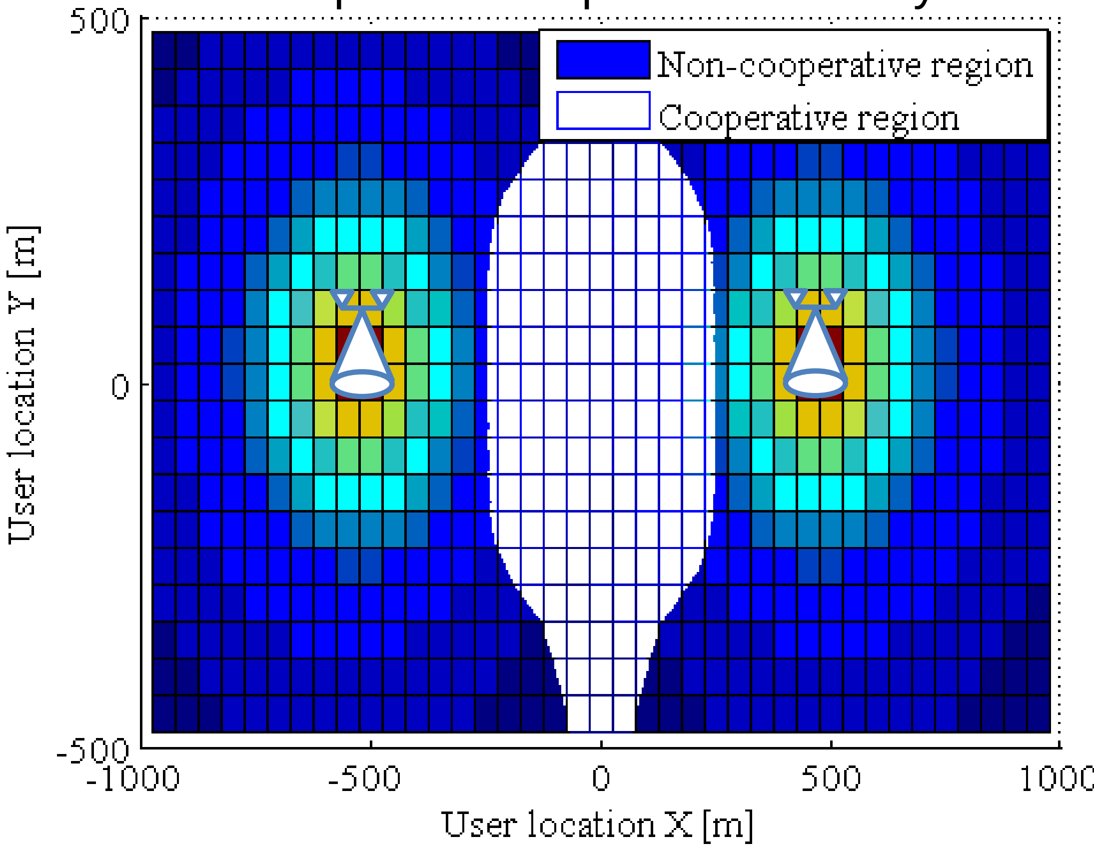
  Capacity is decreased about 3bps where distance is from 100m to 300m

Co-scheduling is the optimal user selection

Cooperative region

- **Analysis considering overhead is necessary**
  – Overhead : the cost of resource for transmission (ex. Reference signal, guard band, cyclic prefix)

Comparison of spectral efficiency



- **Spectral efficiency**

$$R^{SC} = \chi_{SU} C^{SC}$$
$$R^{MC} = \chi_{MU} C^{MC}$$

χ : bandwidth inefficiencies considering overhead

- **Cell-inner**
  – Non-cooperative region
    - Single-cell MIMO is efficient at cell-inner
- **Cell-edge**
  – Cooperative region
    - BSC MIMO is efficient at cell-edge

Fractional Base Station Cooperation

- **Single-cell MIMO** (conventional cellular system)
  - Cell-inner : efficient
  - Cell-edge : not efficient
- **Base station cooperation MIMO**
  - Cell-inner : not efficient
  - Cell-edge : efficient

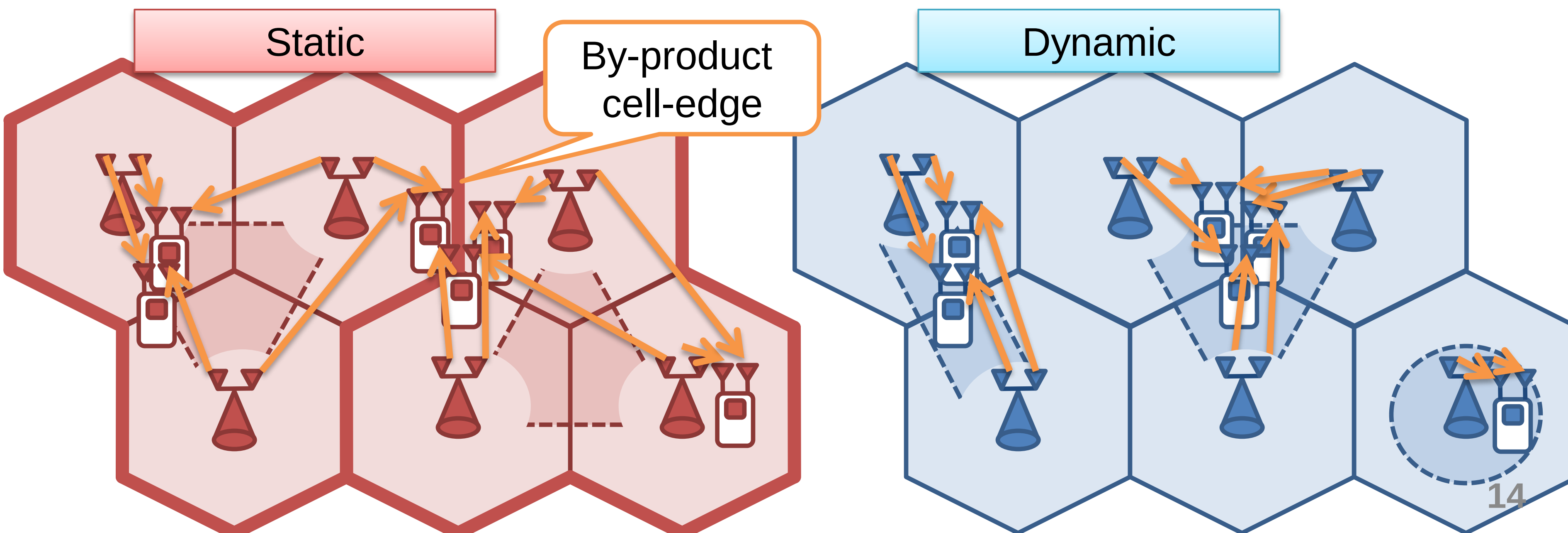
Fractional Base Station Cooperation (FBSC)

- Cell-inner : uses single-cell MIMO
- Cell-edge : uses BSC MIMO

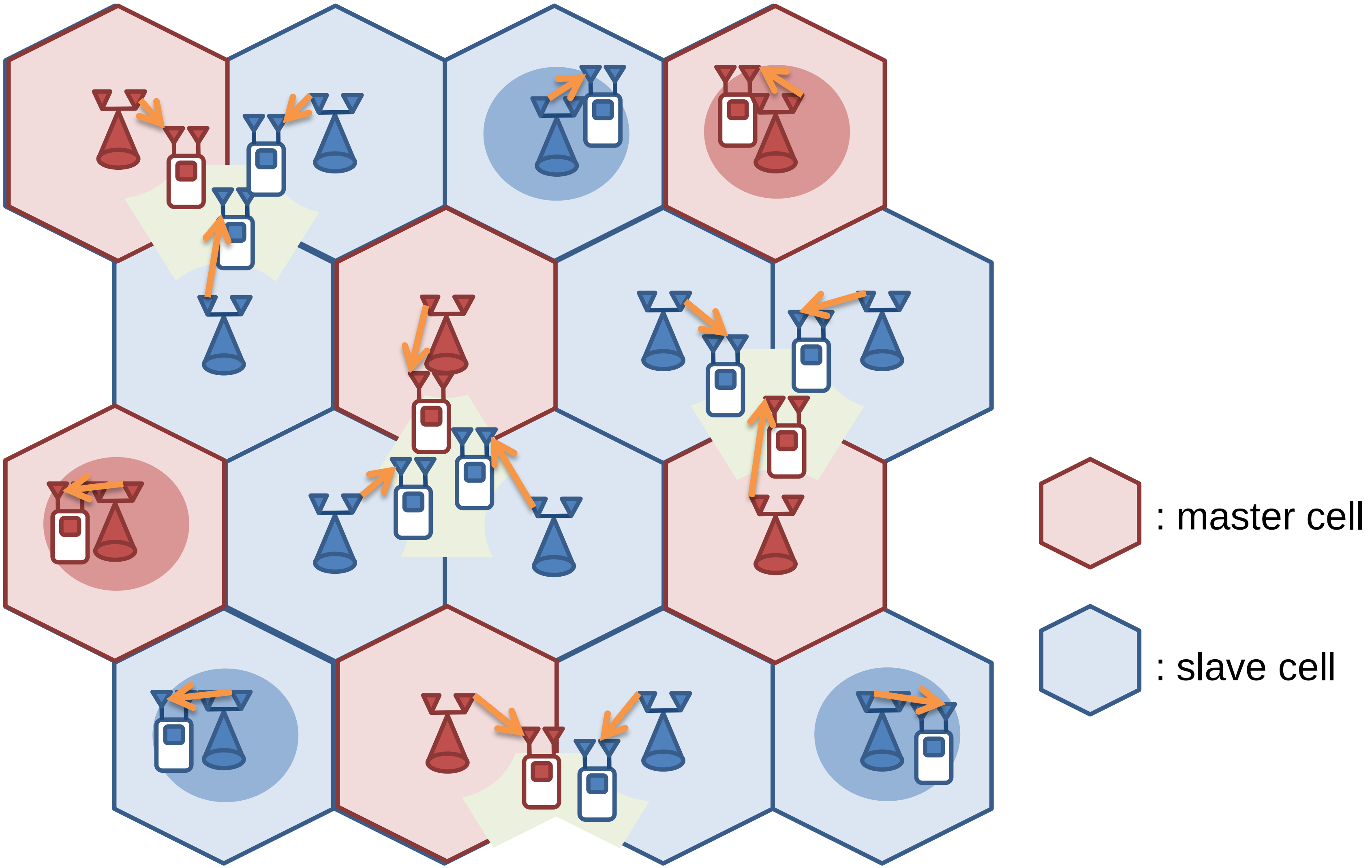
FBSC is performed to achieve gains both at the cell-inner and cell-edge.

Cooperation clustering

- **Clustering**
  - Static clustering
    - Cooperation set is fixed
    - ✗ By-product cell-edge is created.
  - Dynamic clustering
    - makes cooperation set adaptively.
    - ✓ Cooperation is efficient at all cell-edges.



Dynamic clustering

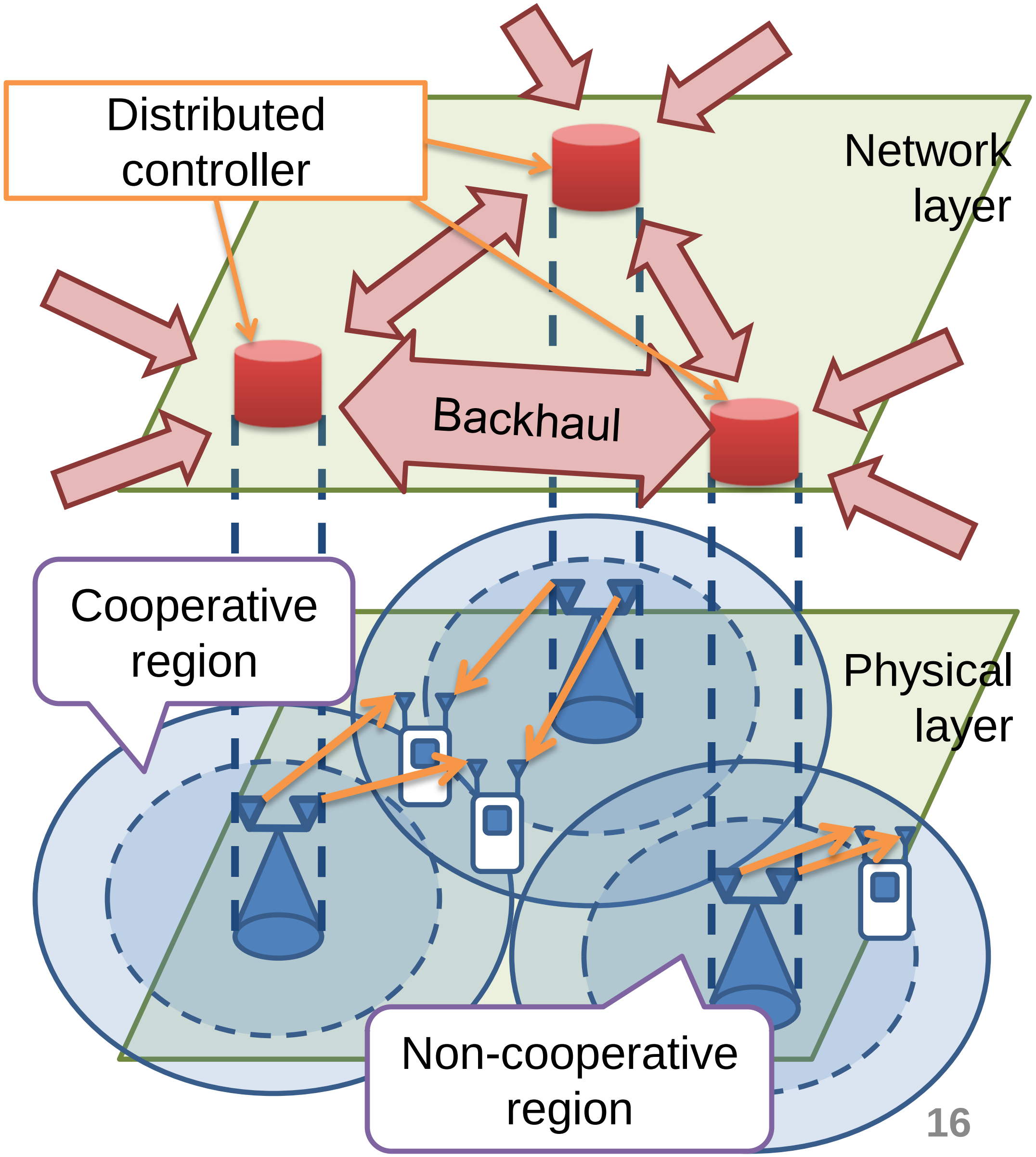


Fractional base station cooperation cellular network

Fractional base station cooperation cellular network

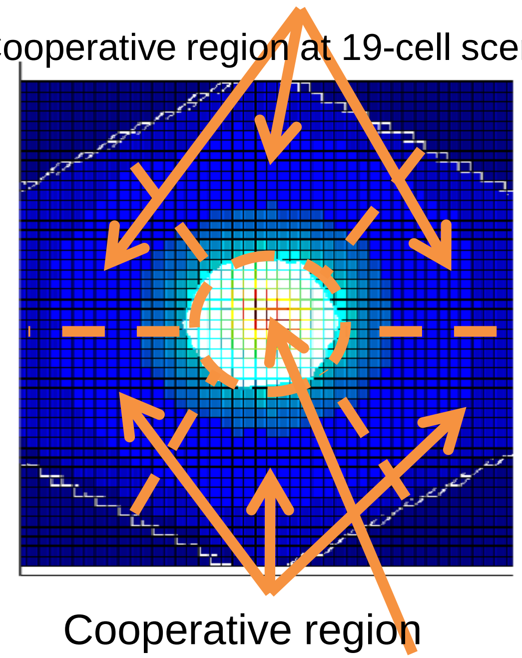
Fractional base station cooperation

Dynamic clustering



Simulation scenario

- **Comparison transmission**
  - Single-cell SISO
  - Single-cell MIMO
    - 2x2 SVD-MIMO
  - Multi-cell static clustering
    - BSC is performed at all locations
    - Static clustering
  - Fractional Base Station Cooperation Cellular Network (FBSC-CN)



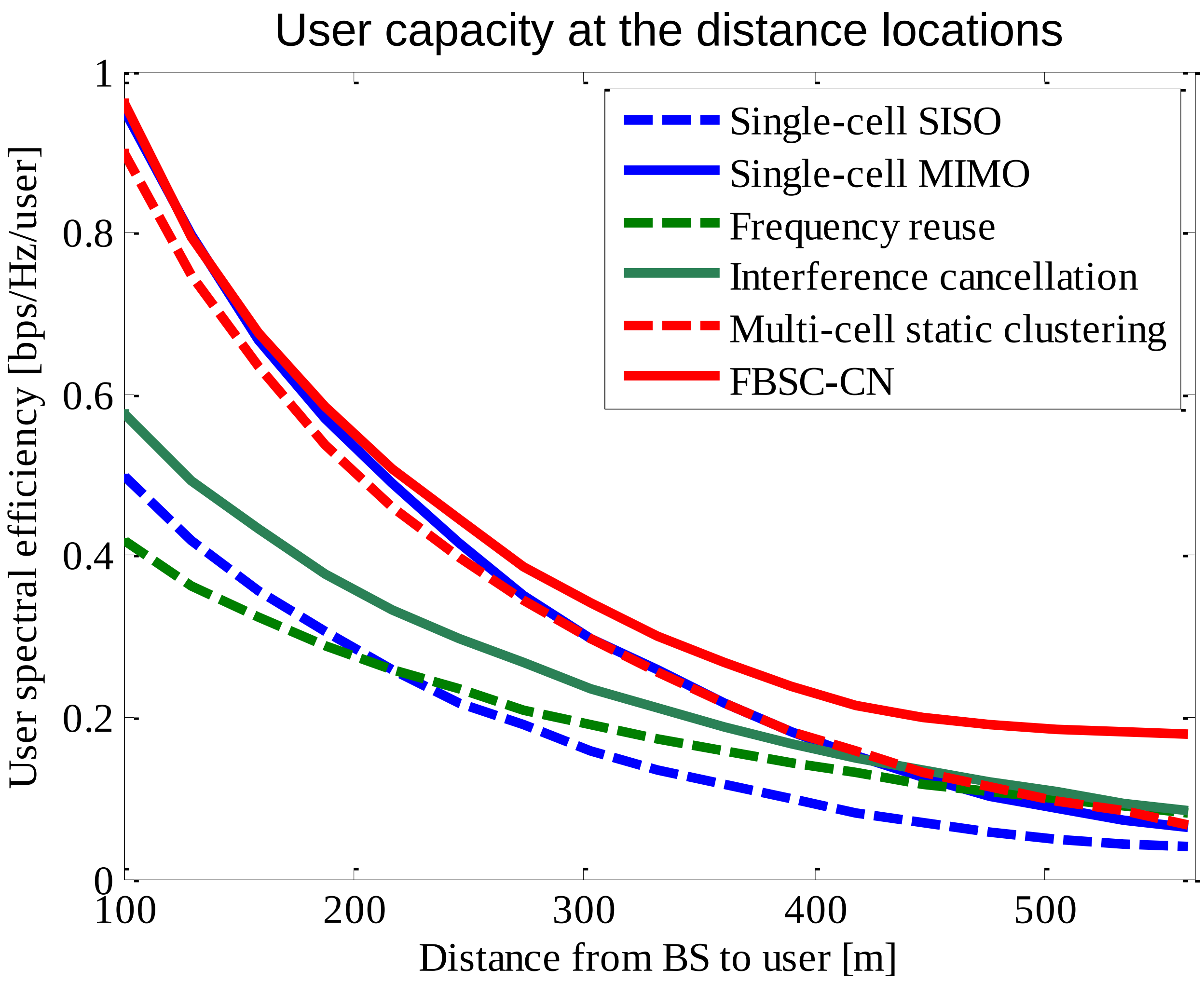
Simulation scenario

Simulation parameter

Parameters	Values
Number of cell	19 cells
Number of user	10 users / cell
Number of cooperation set	3 cells
Number of antenna (BS, user)	1, 1 (SISO) or 2, 2 (MIMO)
Channel model	i.i.d. Rayleigh
Pathloss model	$34.5 + 35\log_{10}(d[\mathrm{m}])$ [dB] (3GPP TR 25.996 : Urban Macro)
Transmit power	40[dBm]
Noise level	-100[dBm]
Site to site distance	1000 m
Scheduler	Round-robin & co-scheduling
Single-user MIMO scheme	SVD-MIMO
Multi-user MIMO scheme	Generalized BD [*]

* V. Stankovic, M. Haardt, "Generalized design of multi-user MIMO precoding matrices," *IEEE Trans. Wireless Commun., vol.7, no.3,* pp.953-961, Mar. 2008.

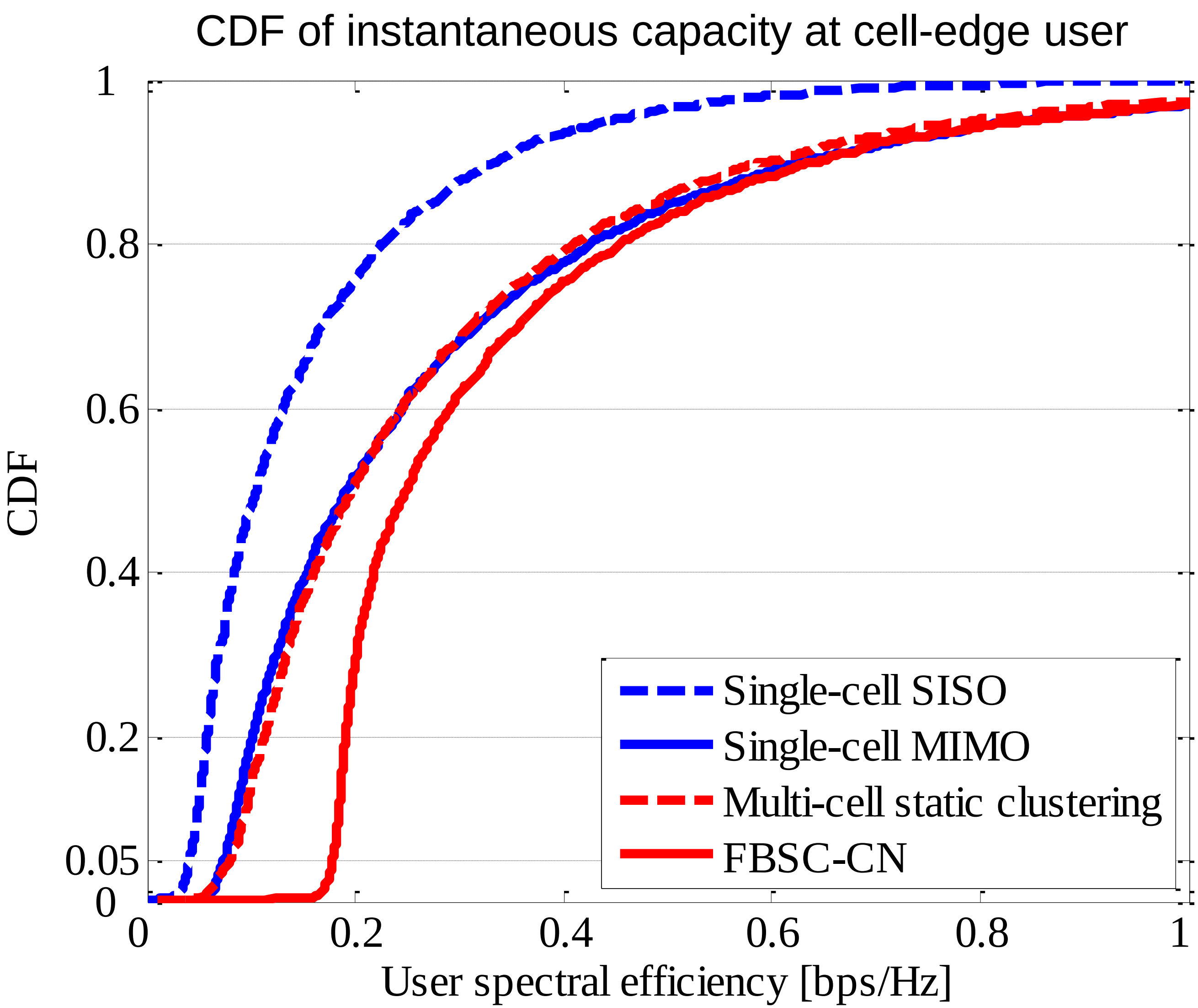
Simulation result



Fractional BSC

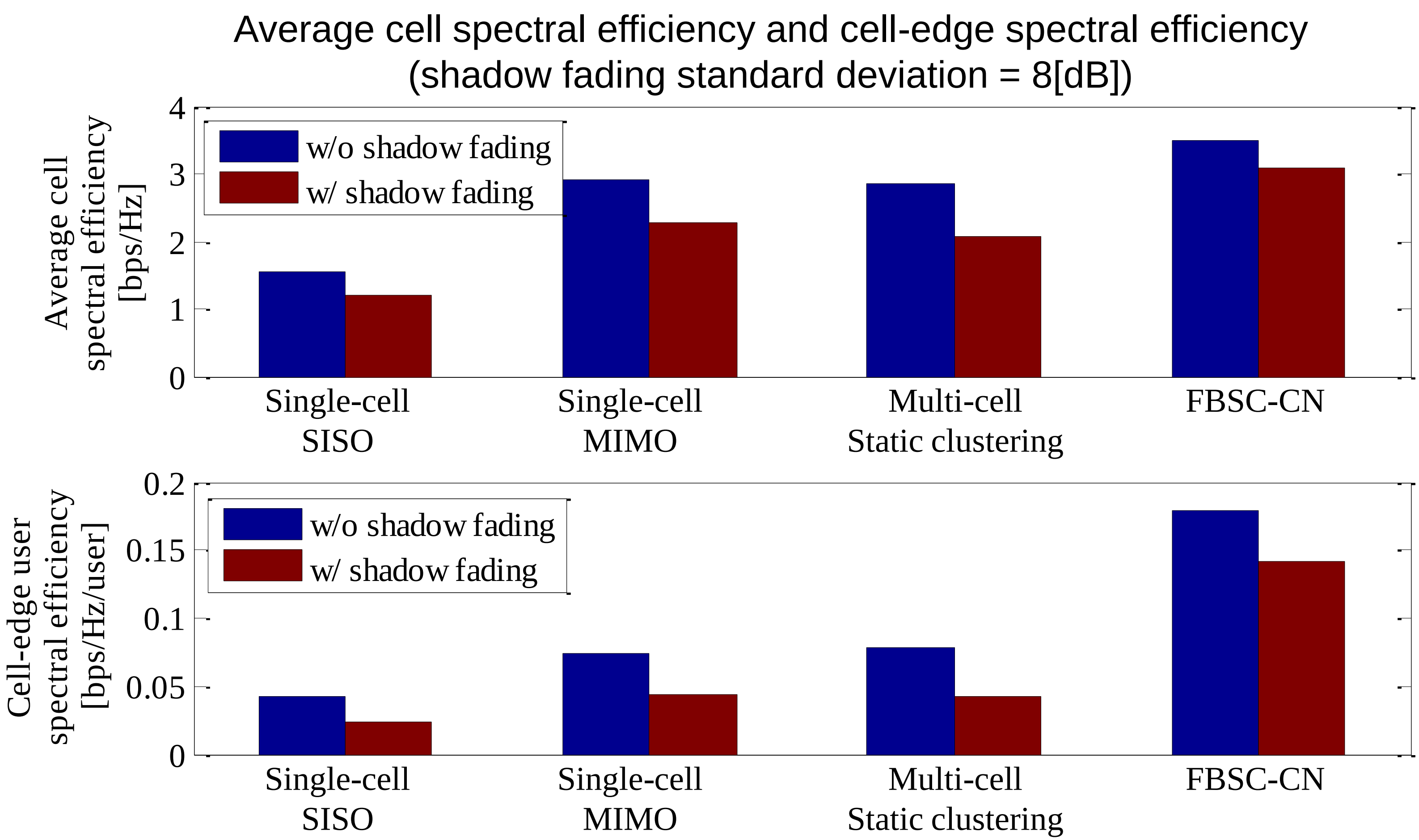
- User capacity at the cell-inner is as high as Single-cell MIMO
- User capacity at the cell-edge is almost the same with BS cooperation

Simulation result



- FBSC is higher capacity than other scheme at all probability

Simulation result



- The average cell spectral efficiency of FBSC is slightly improved than single-cell MIMO
- The cell-edge user spectral efficiency of FBSC is 2.4 times as high as that of single-cell MIMO

Conclusion

- **BSC solves the cell-edge problem.**
- **Fractional BSC is proposed.**
  - FBSC performs to achieve gains both at the cell-inner and cell-edge.
- **FBSC cellular network is proposed.**
  - In FBSC-CN, cooperation sets are constructed dynamically.
- **Numerical simulation shows that FBSC performs efficiently both at cell-inner and cell-edge.**

Thank you for your attention.