Dynamic Fractional CoMP for Advanced Cellular Networks

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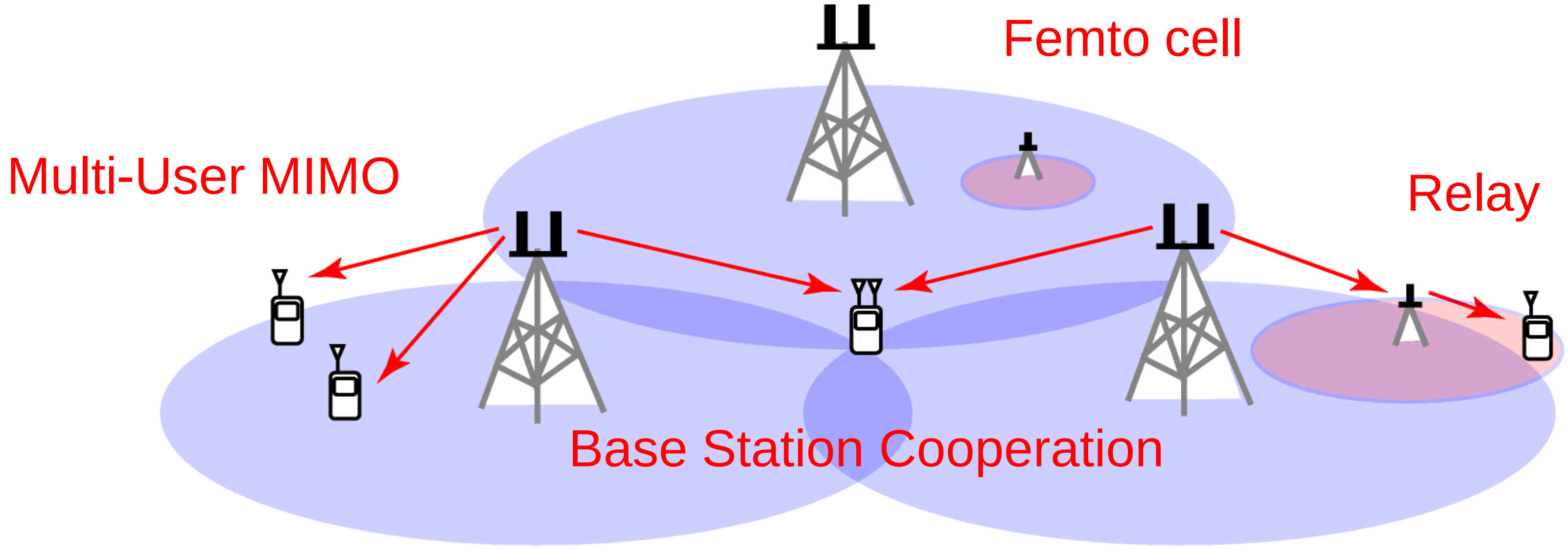
Advanced Cellular Networks

Cell throughput improvement

- Spatial spectrum sharing via Multi-User MIMO and Femto Cell

User throughput improvement

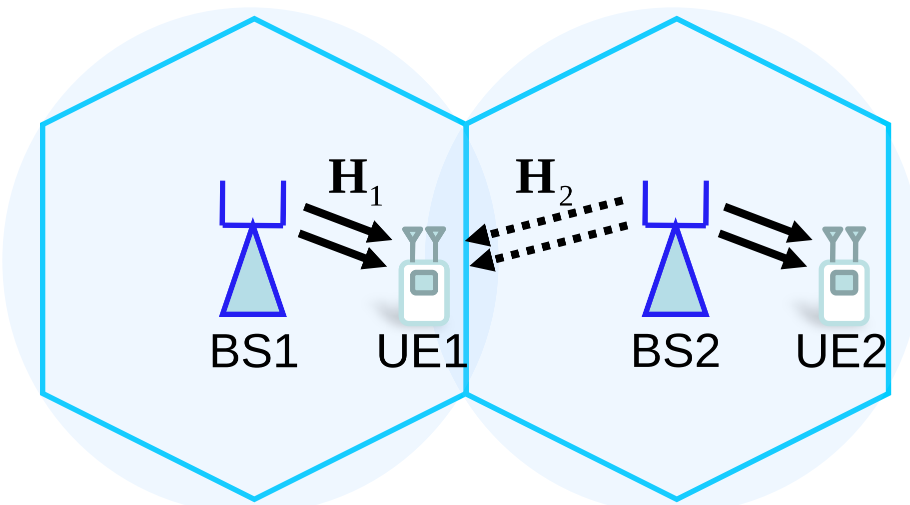
- Pathloss compensation via Relay
- Interference Management via Base Station Cooperation



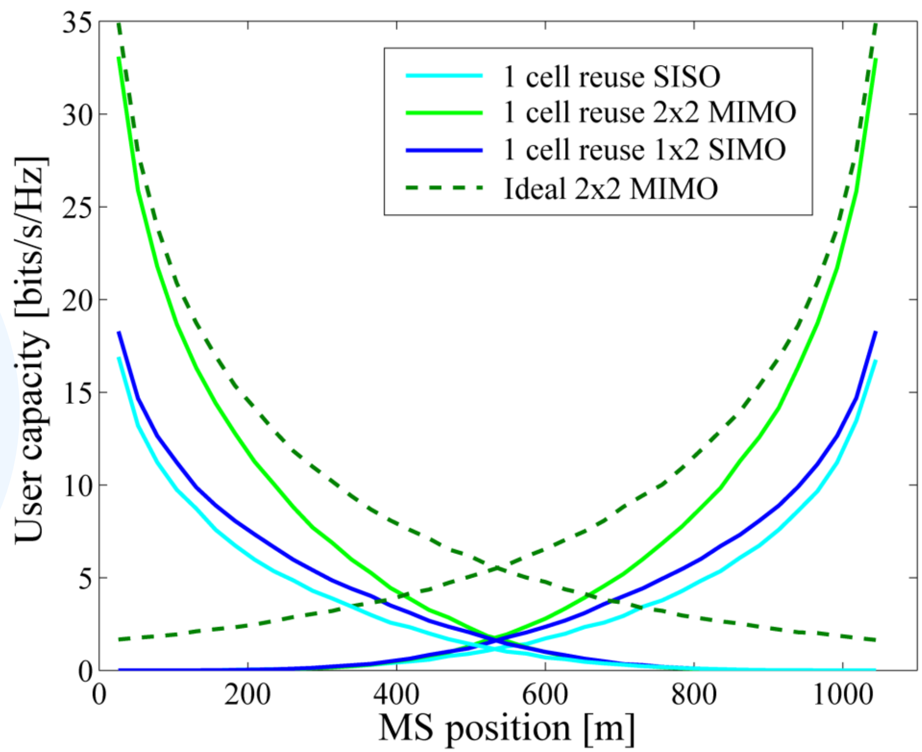
Cell-edge Problem

- Worst SINR due to high pathloss and strong interference from adjacent BS
- Reduced MIMO multiplexing gain due to low SINR
- Further degradation due to higher spatial correlation at BSs

Single Cell Single User MIMO



Spectral efficiency

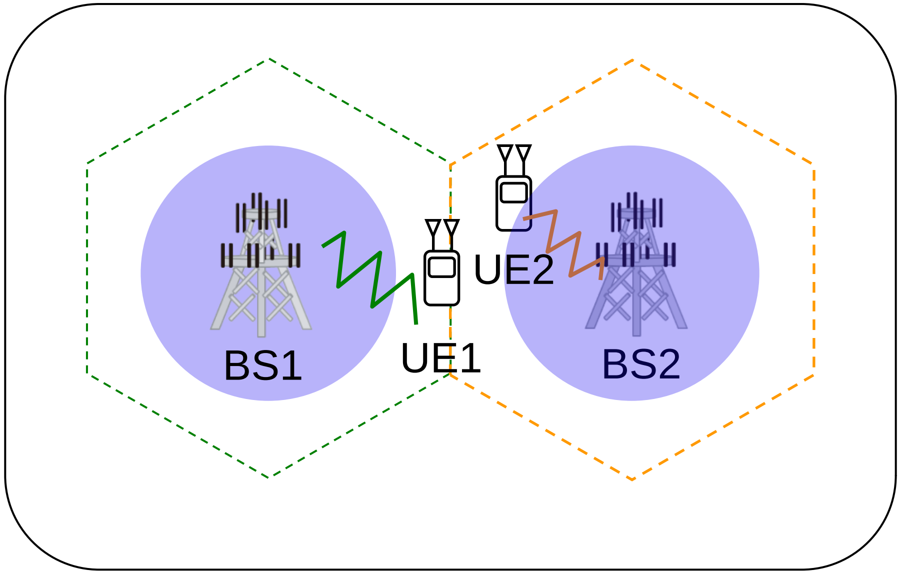


Base Station Cooperation

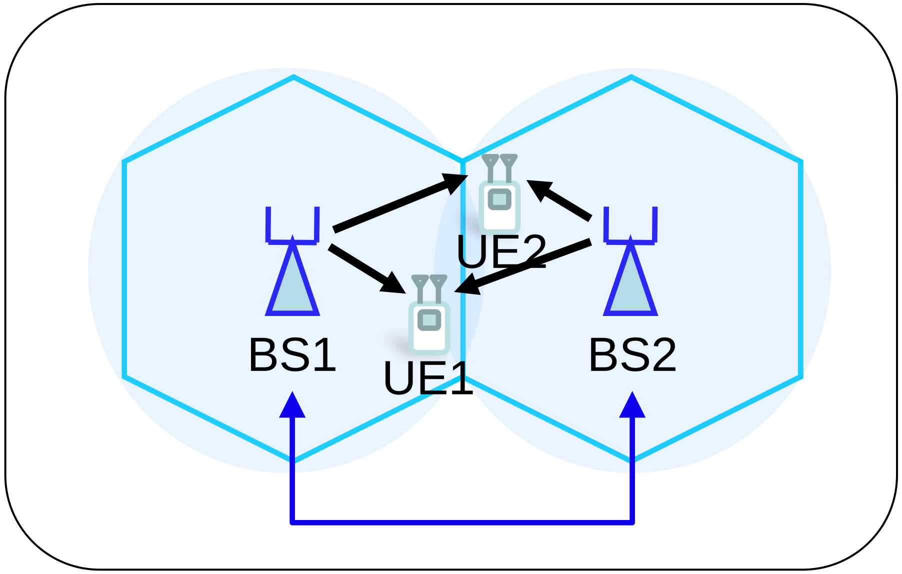
Cooperation between adjacent BSs for interference management

- without data sharing → Coordinated Scheduling / Beamforming
- with data sharing → Base Station Cooperation MIMO (CoMP JT)

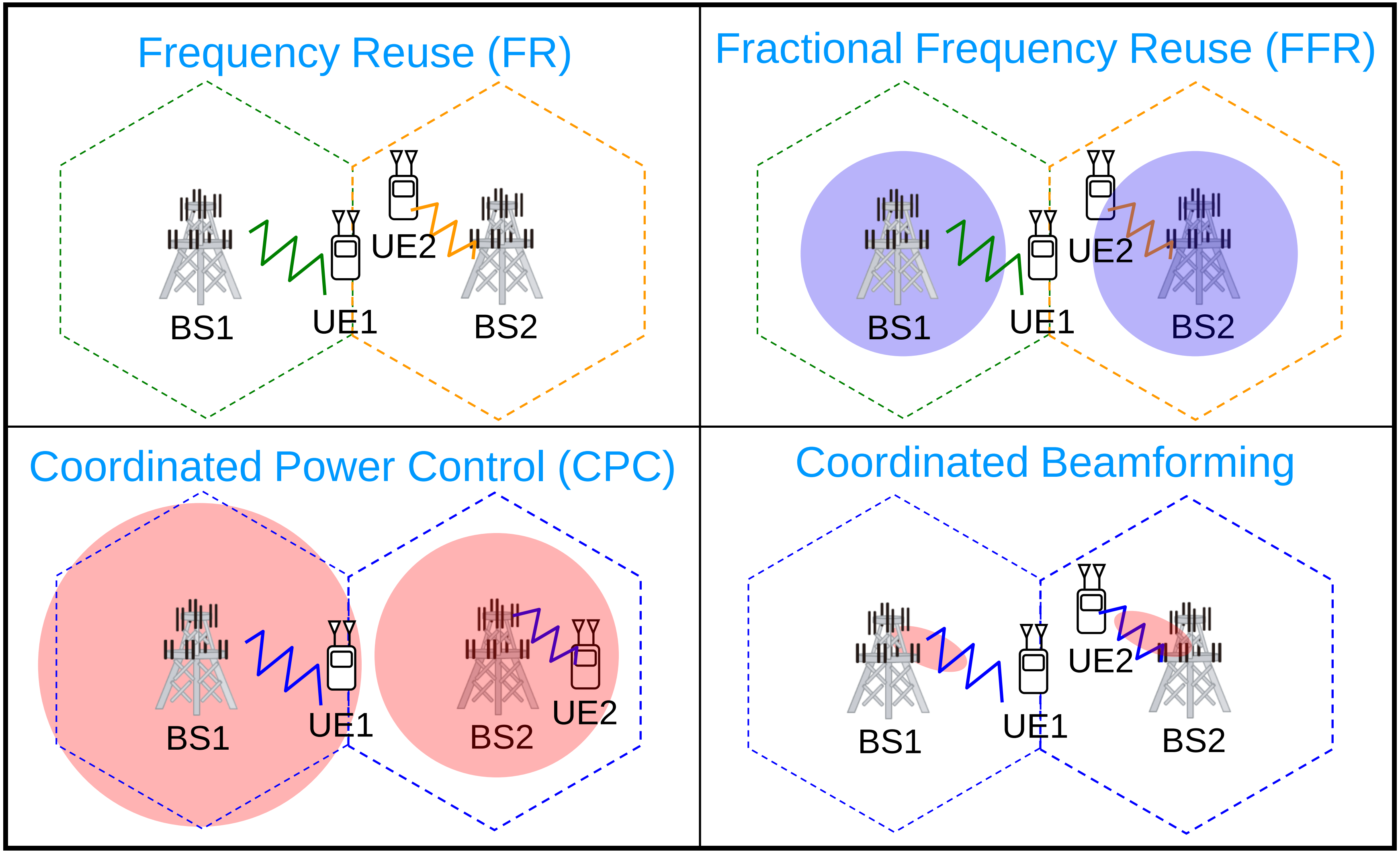
Coordinated Scheduling / Beamforming



Base Station Cooperation



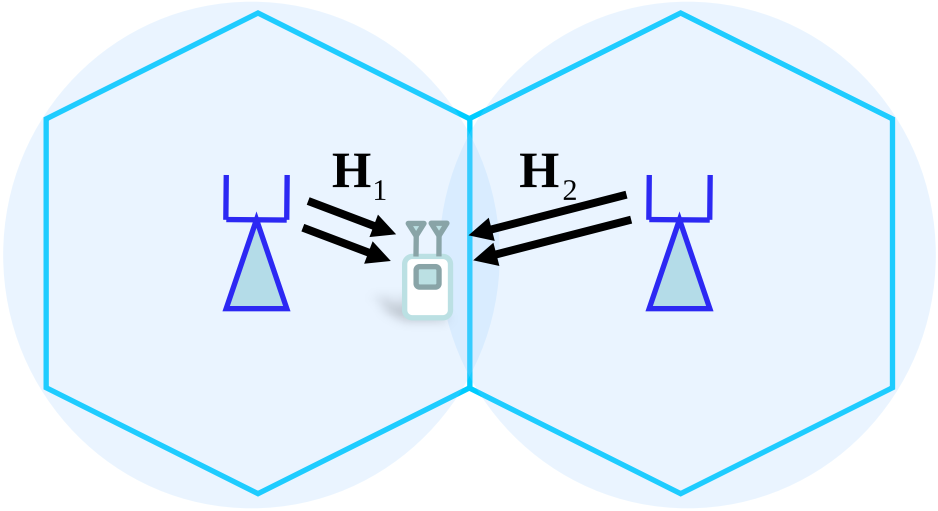
Coordinated Scheduling / Beamforming



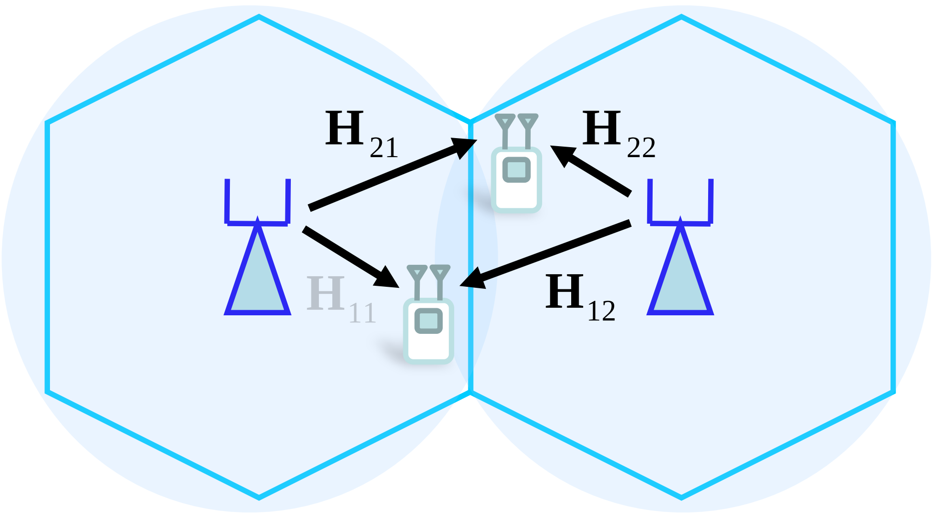
Base Station Cooperation MIMO (CoMP JT)

- Data streams are shared by both BSs to perform distributed MIMO
- BSC SU-MIMO improves user spectral efficiency via macro-diversity and cooperative multiplexing gain
- BSC MU-MIMO improves both user and cell spectral efficiency by additional cooperative user multiplexing gain

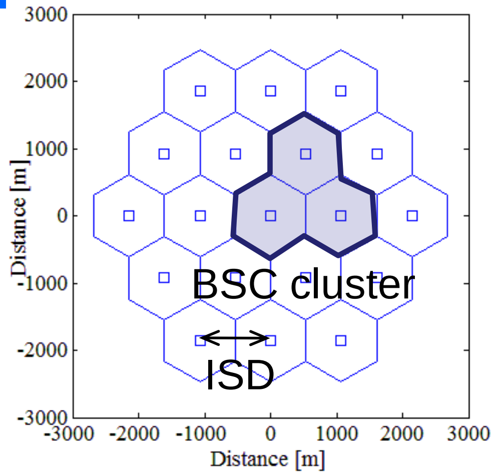
BSC SU-MIMO



BSC MU-MIMO



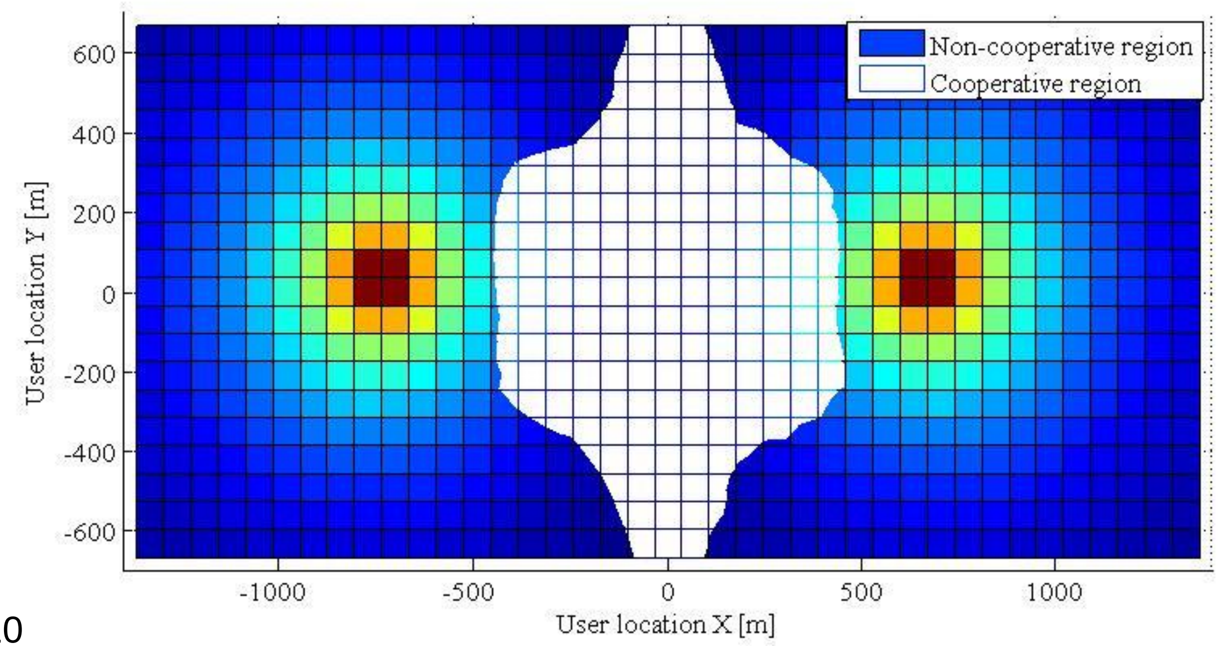
Open Problem in BSC



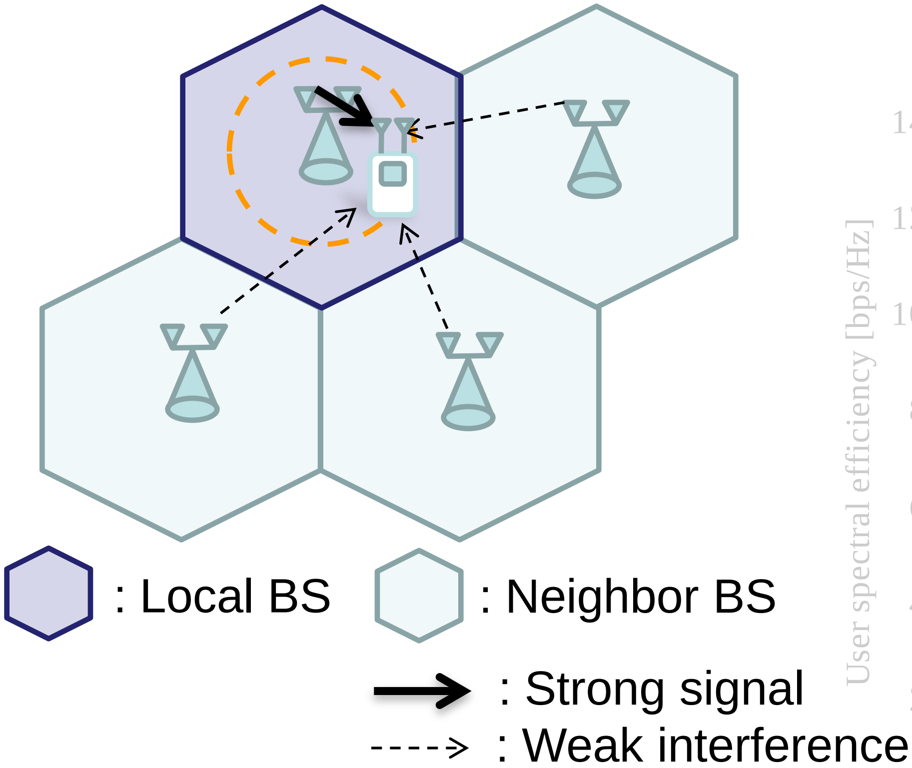
- **Clustering**
  Cooperative BS set selection to perform effective BSC MIMO (static clustering or dynamic clustering)
- **Backhaul architecture**
  Smart backhaul architecture to share data streams with low latency by using X2 interface and/or Remote Radio Head (RRH)
- **Cell planning scheme**
  Innovation from non-overlapped to overlapped cell planning by controlling Inter Site Distance (ISD) or BS antenna down tilting
- **Feedback scheme**
  Codebook based digital precoding is not enough for BSC MU-MIMO and additional feedback is needed (digital or analog)

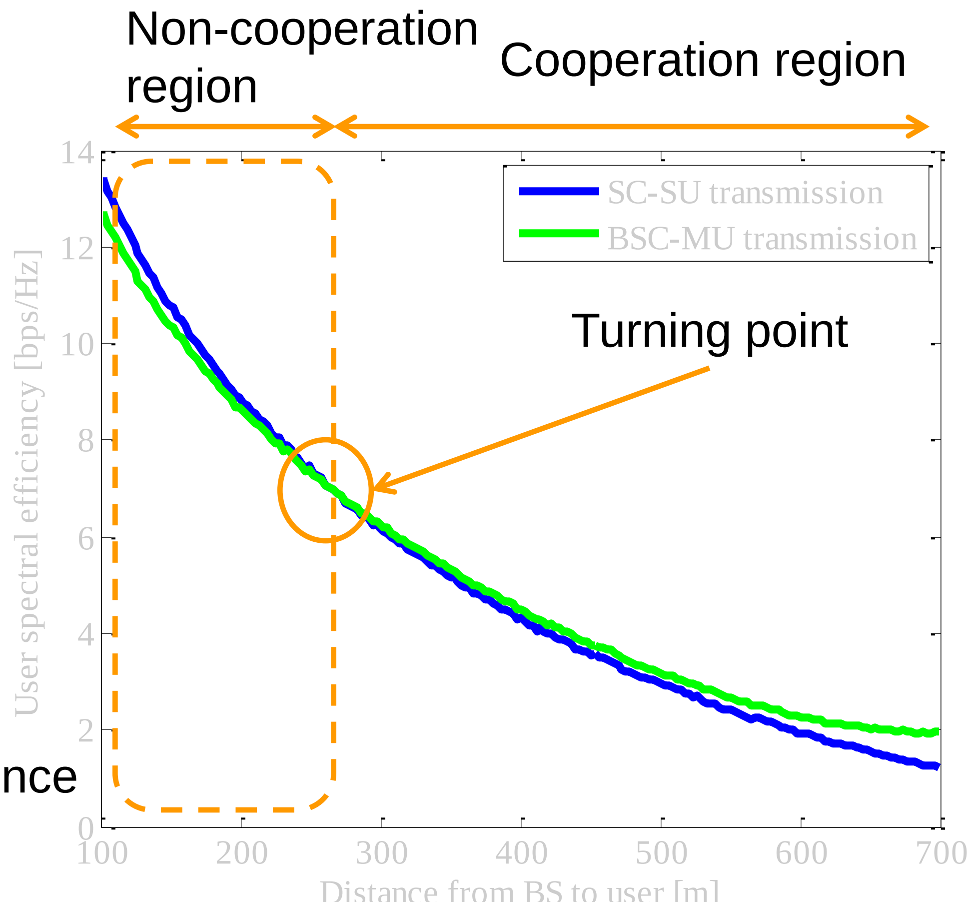
Cooperation Region

- Cell-inner (non-cooperative region)
  - BSC MIMO is not effective due to unbalanced pathloss (high SIR)
  - Single-cell MIMO is efficient at cell-inner
- Cell-edge (cooperative region)
  - BSC MIMO is effective at cell-edge due to balanced pathloss (low SIR)



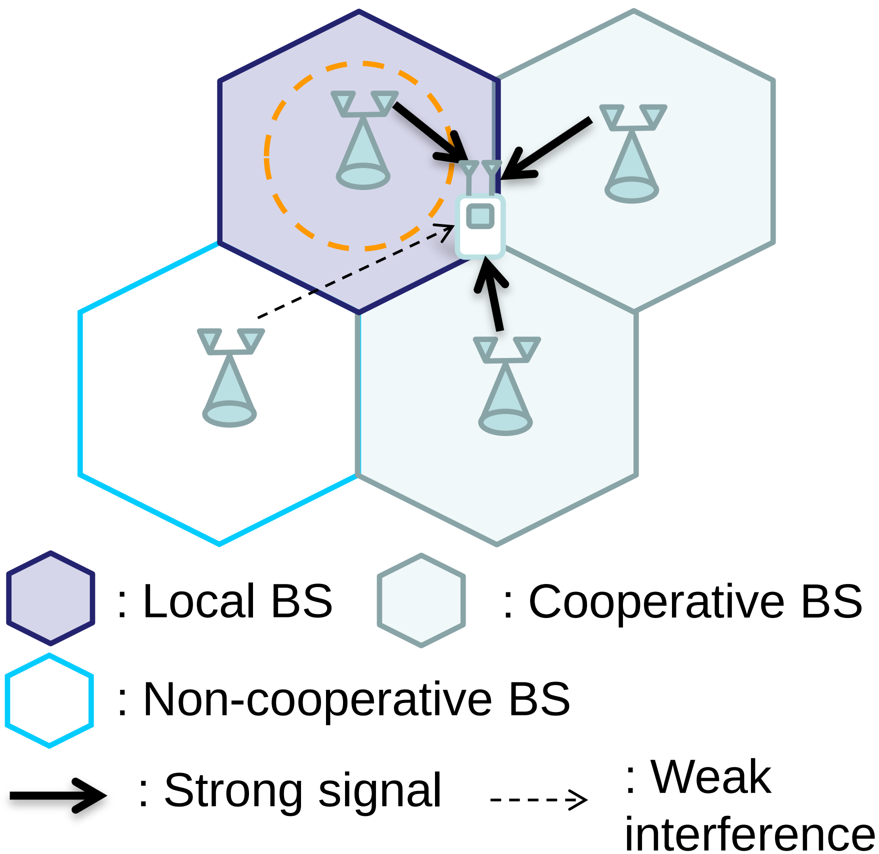
Fractional CoMP

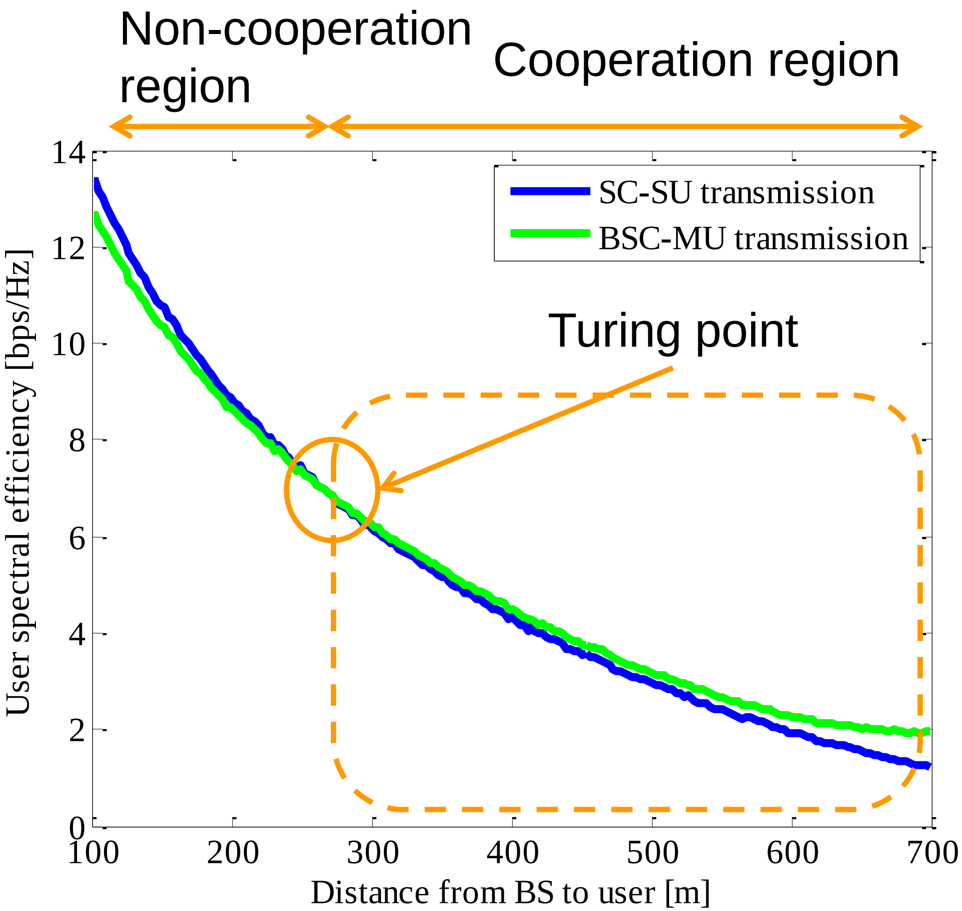




- Non-cooperation region
  - Single Cell Single User (SC-SU) MIMO transmission from local BS is efficient

Fractional CoMP

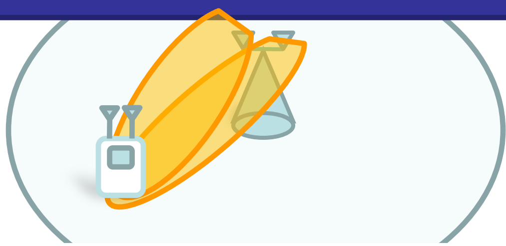




- Cooperation region
  - BSC Multi-User (BSC-MU) MIMO by local and cooperative BSs is effective

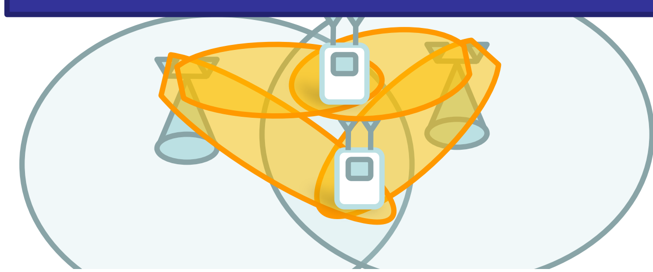
Fractional CoMP

SC-SU MIMO



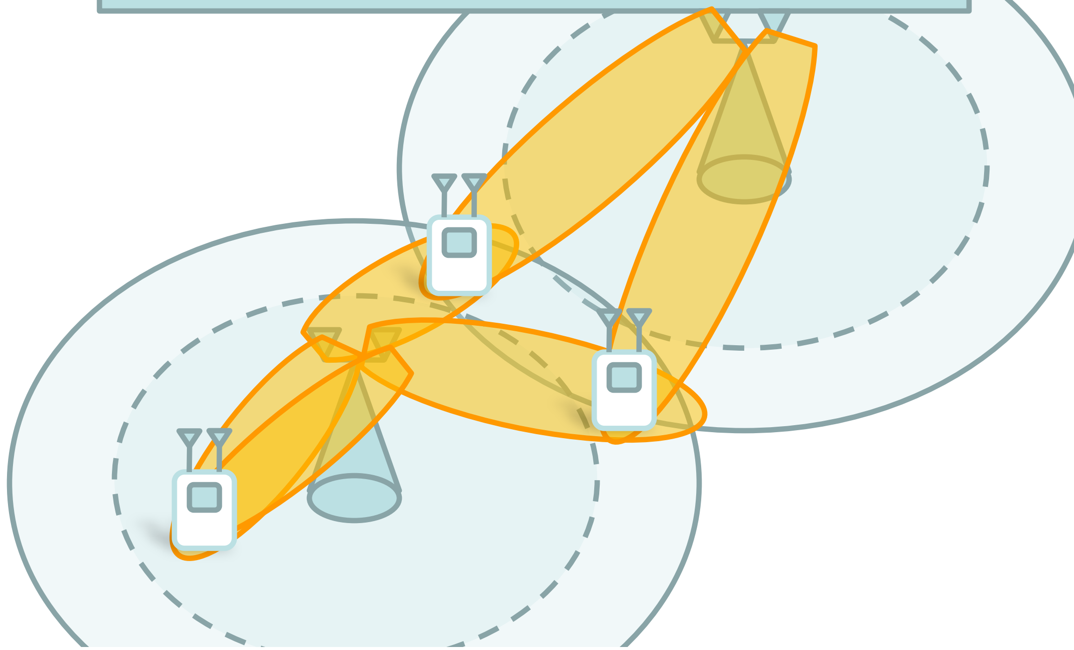
Cell-inner : Good   Cell-edge : NG

BSC-MU MIMO



Cell-inner : NG   Cell-edge : Good

Fractional CoMP



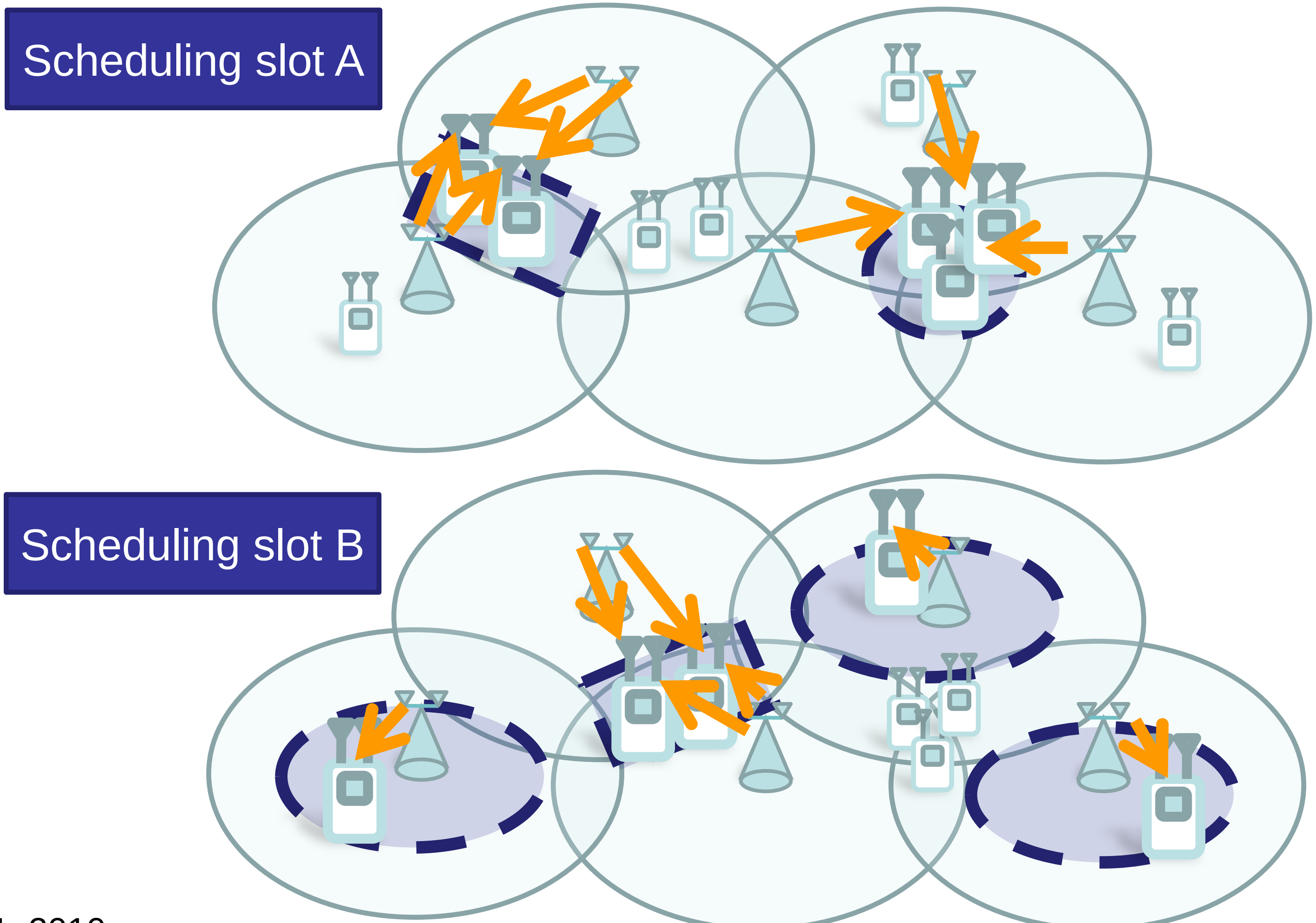
- **Fractional CoMP dynamically selects effective transmission schemes according to UE locations**

  non-cooperative region : SC-SU MIMO

  cooperative region : MC-MU MIMO

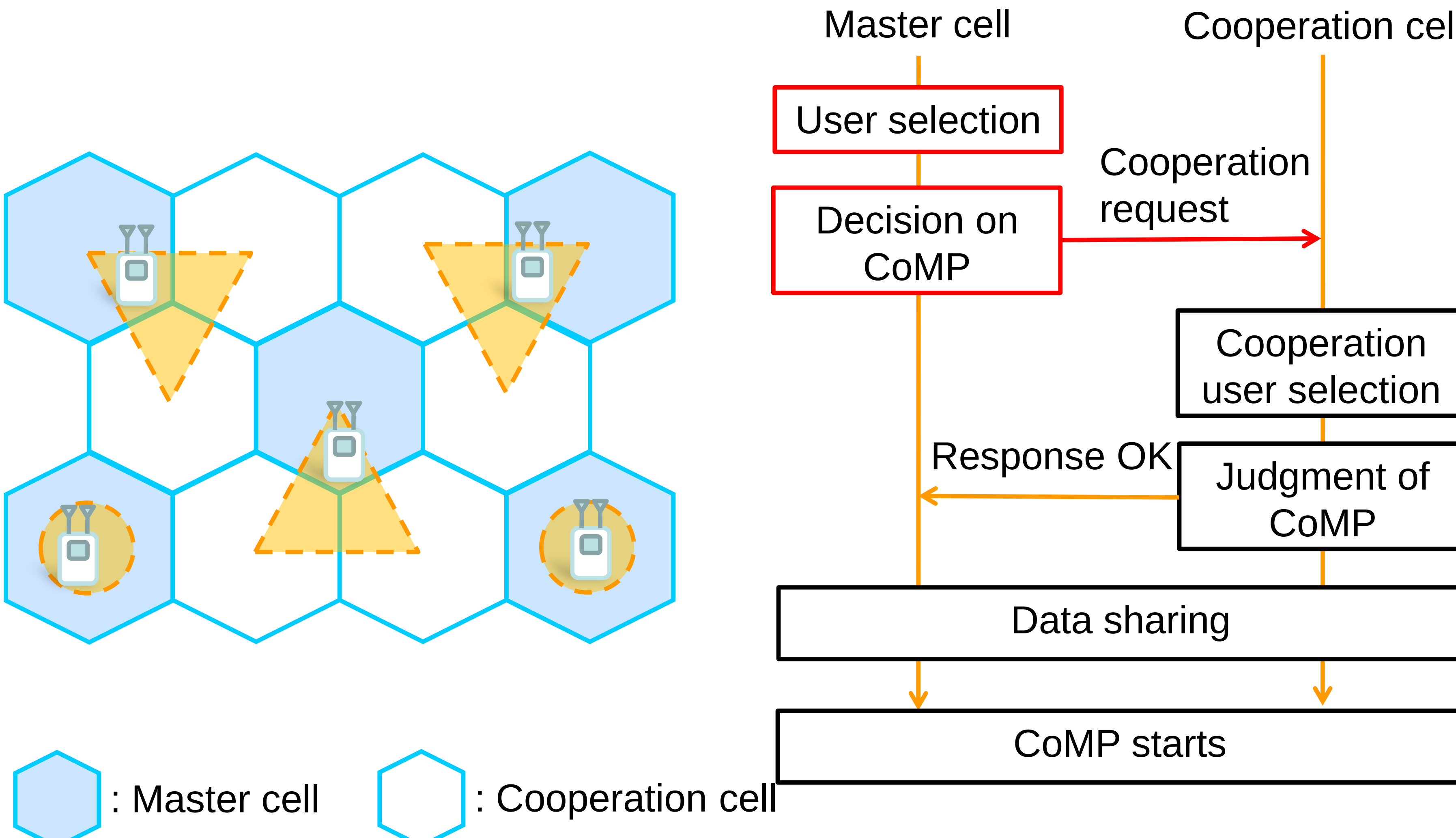
Dynamic Clustering/Scheduling

- Sets of cooperative BSs (incl. SC) are dynamically selected for each scheduling slot (resource block)



Distributed Clustering

- Dynamic clustering algorithm by using distributed cooperative controller



Distributed Clustering

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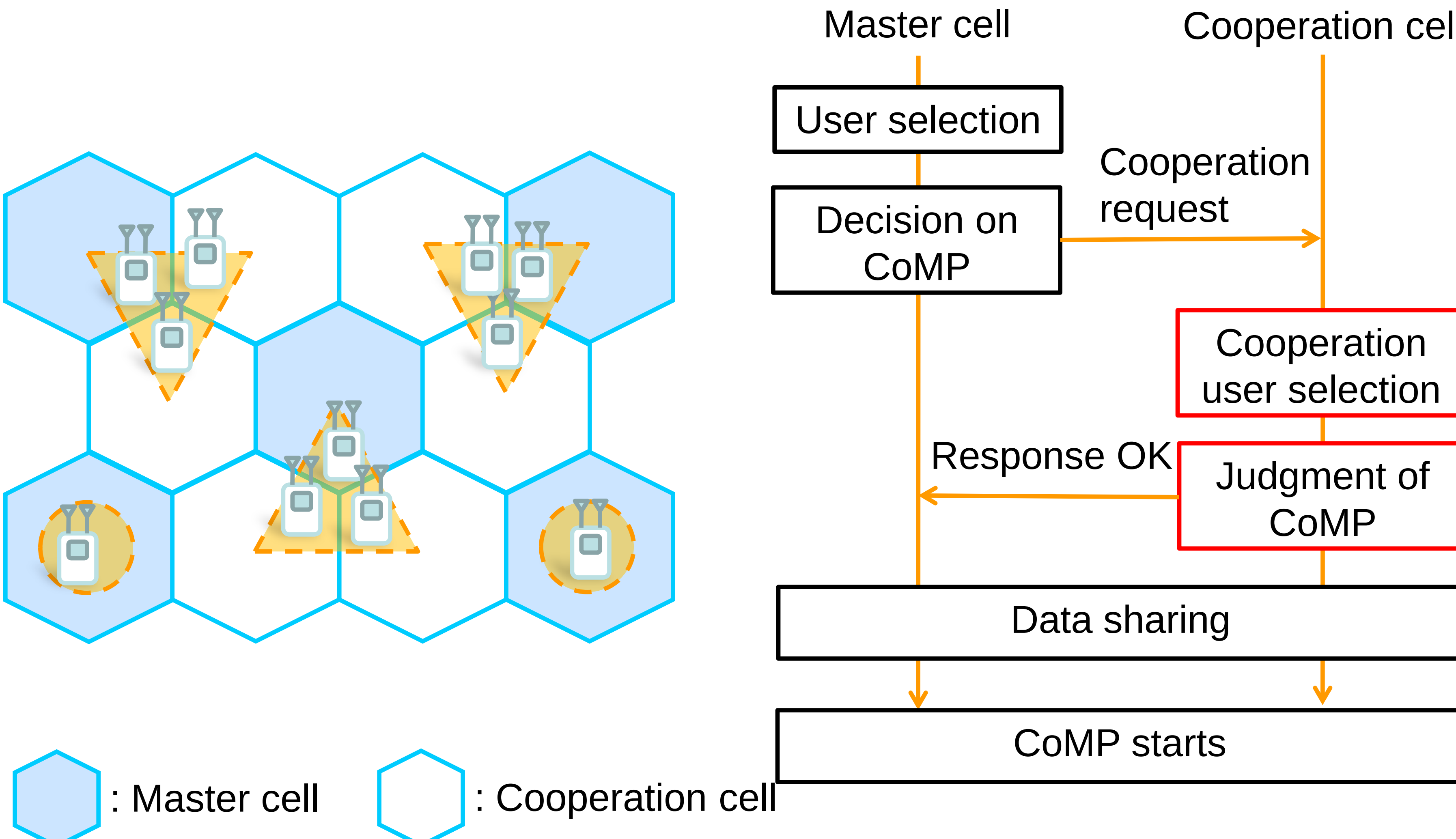
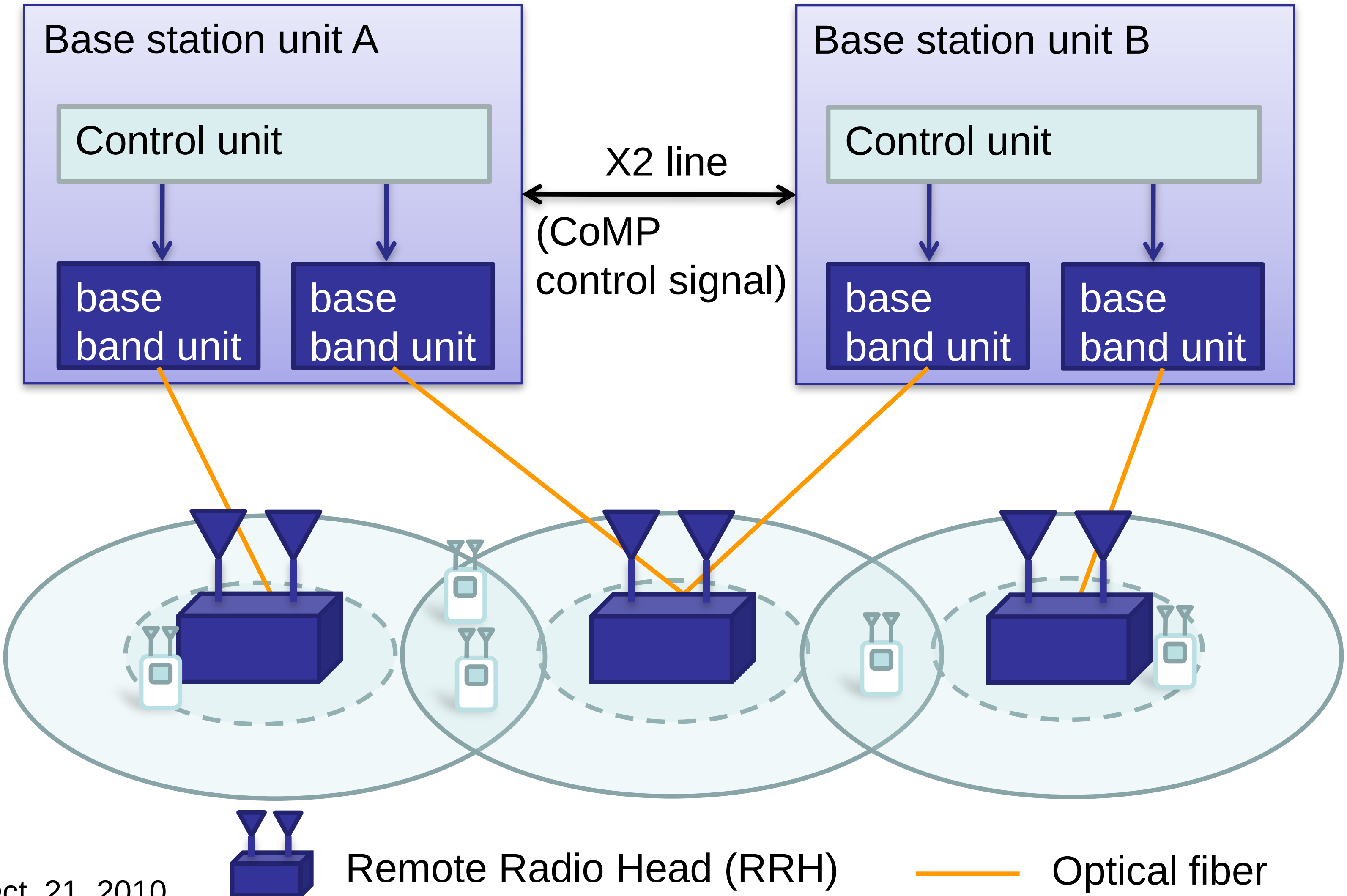


Backhaul for Distributed Clustering

- High speed smart backhaul network composed of RRH and X2



Backhaul for Distributed Clustering

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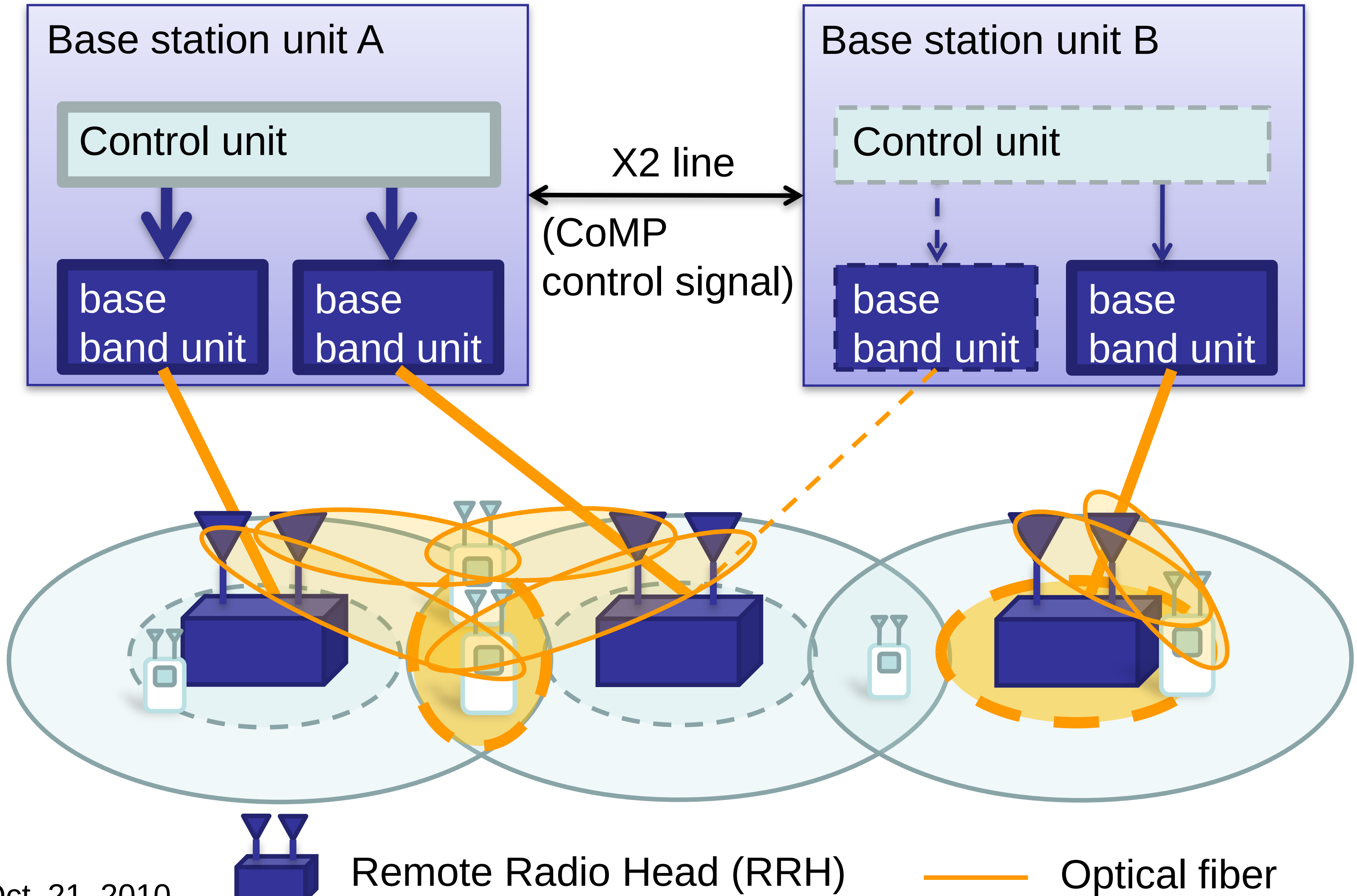
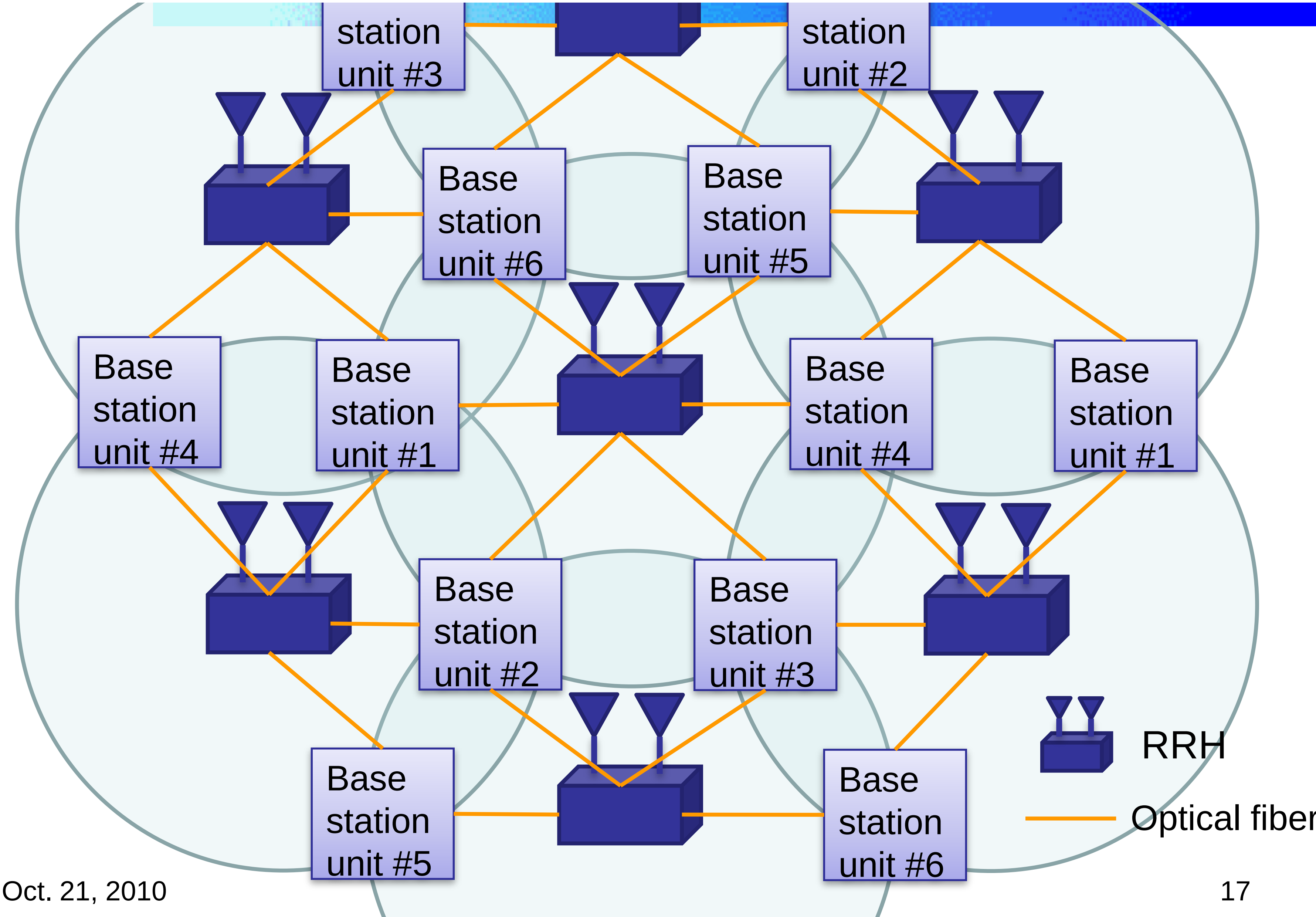


RRH based Backhaul Network

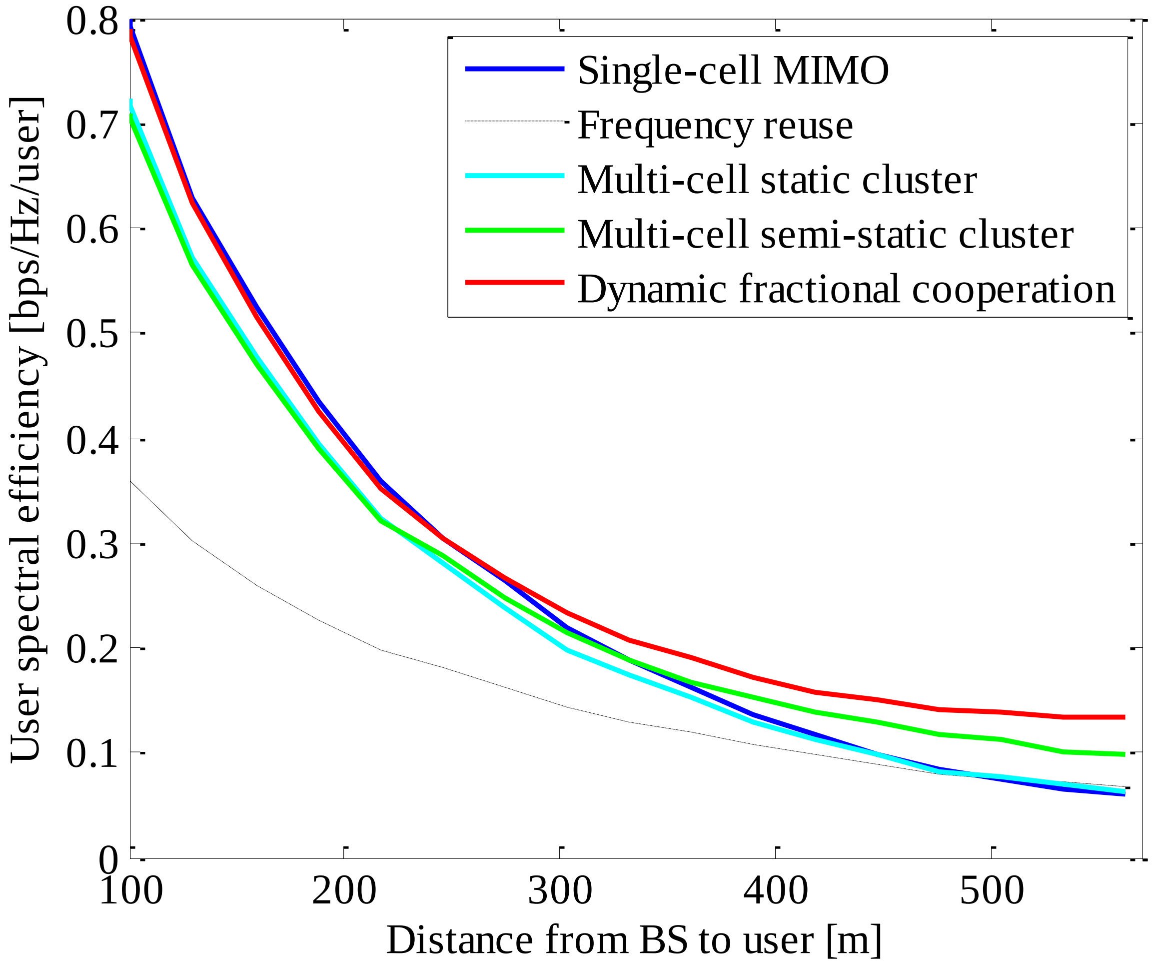


Numerical Examples

Parameter	Value
Number of BS	19
Number of users per cell	10
Number of antennas	2x2
CoMP cooperation set size	3
Transmit power	40dBm
Noise power	-100dBm
Inter site distance	1000m
Pathloss model	$34.5+35\log_{10}(d[m])$ [dB]
Small-scale fading	i.i.d. Rayleigh
Shadow fading standard deviation	8dB
Inter-cell shadow fading correlation	0.5
Scheduling	Round-robin
SU-MIMO scheme	SVD-MIMO
MU-MIMO scheme	Block Diagonalization SVD-MIMO
Overhead of SC-SU MIMO	0.6387 (3GPP R1-093611)
Overhead of BSC-MU MIMO	0.5787 (3GPP R1-093611)

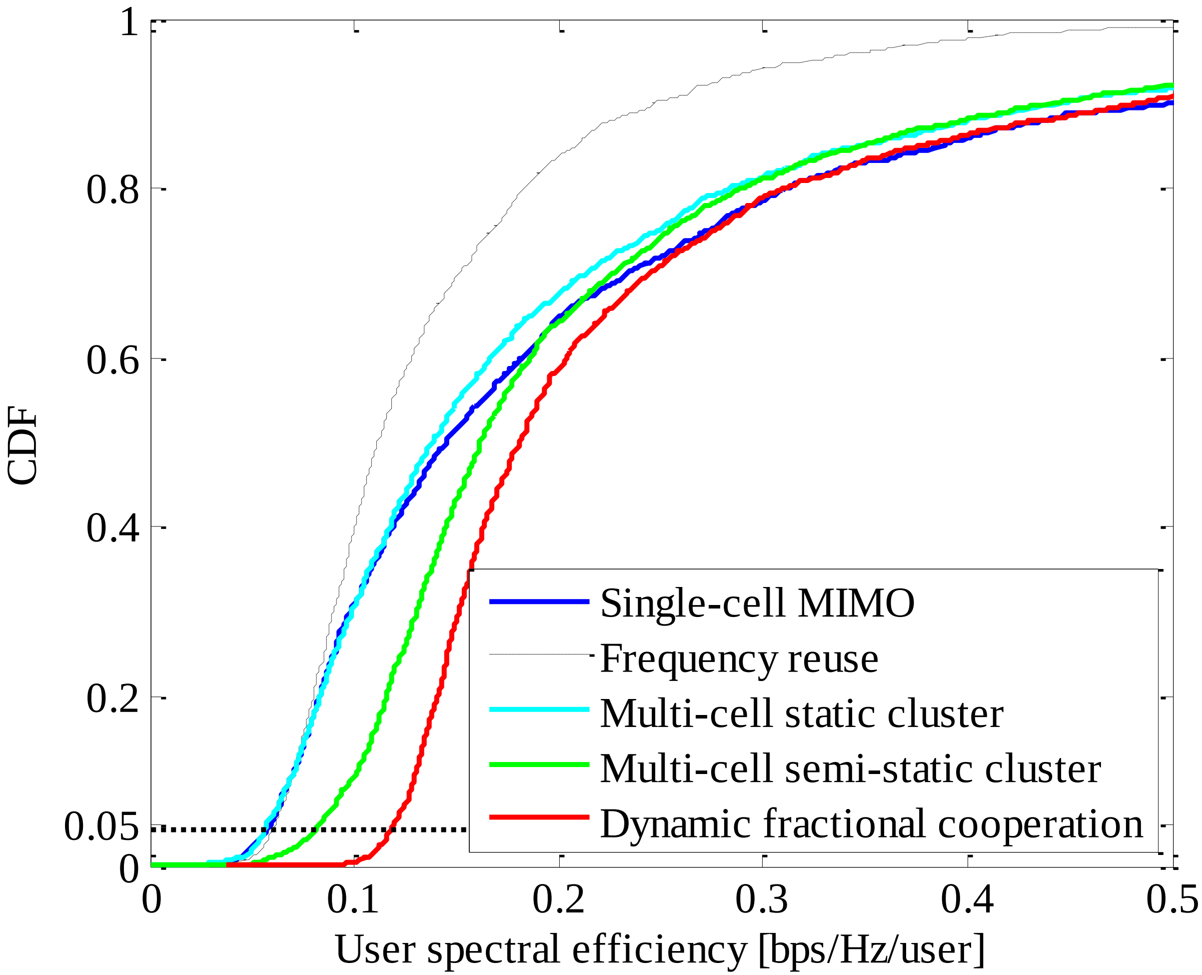
User Spectral Efficiency

- Multi-cell static clustering BSC MIMO is still not effective at cell-edge
- Dynamic fractional cooperation is effective both at cell-inner and cell-edge

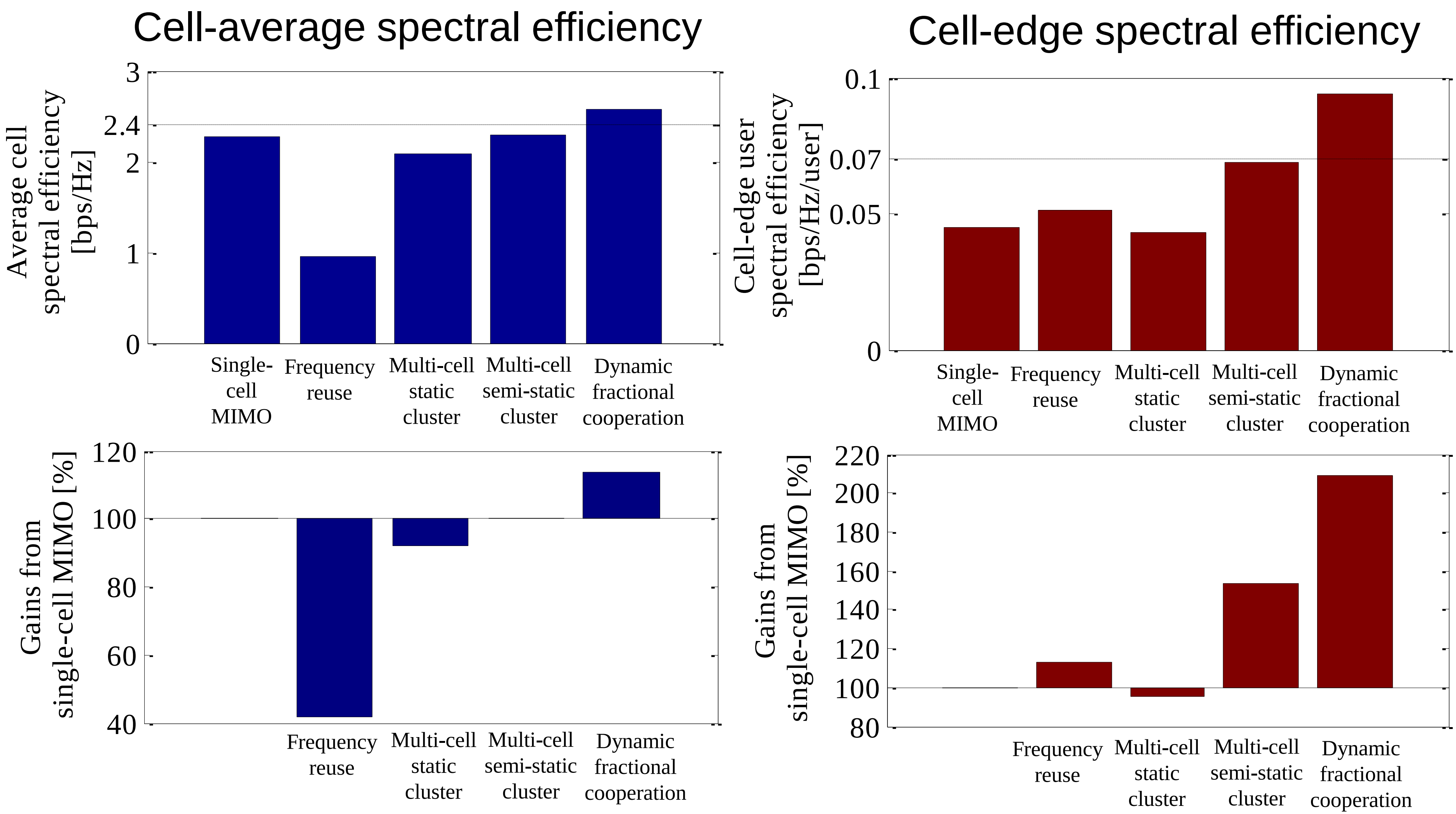


CDF of User Spectral Efficiency

- Both cell-average and 5% cell-edge user spectral efficiency are improved



Cell-average & cell-edge spectral efficiency

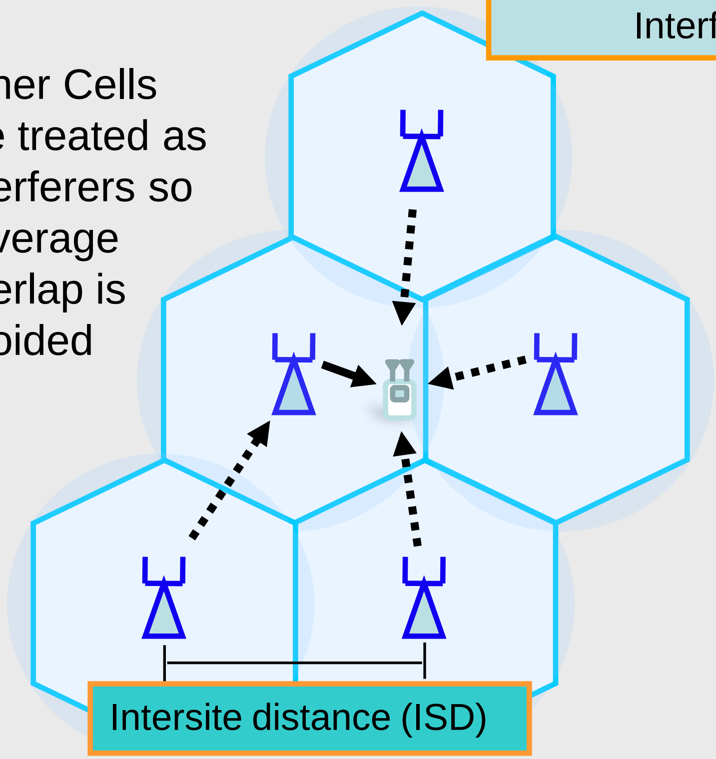


Cell Planning for BSC

- ← Desired Signal
- ←⋯⋯ Interfering Signal
- ← – – Desired for JT CoMP or Interfering for CS/CB

Non-BSC Cell Planning

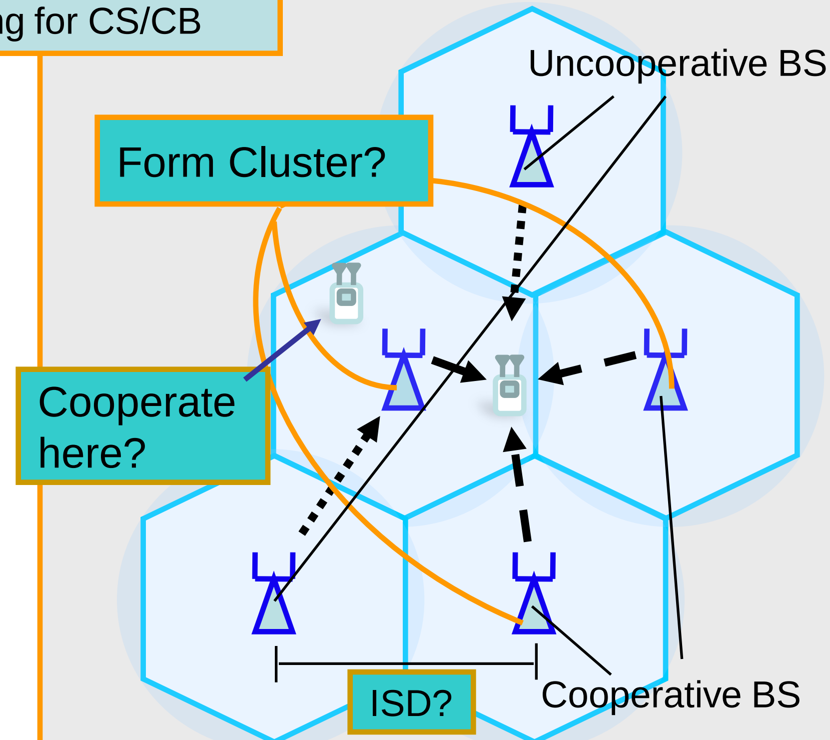
Other Cells are treated as interferers so coverage overlap is avoided



Typical Cell Planning Design
- Inter-site distance? BS Locations?
- Tx powers? Antenna parameters?

**optimum ISD estimate results in optimum network cost estimate*

BSC Cell Planning



BSC Cell Planning Design
- Typical Cell Planning Design

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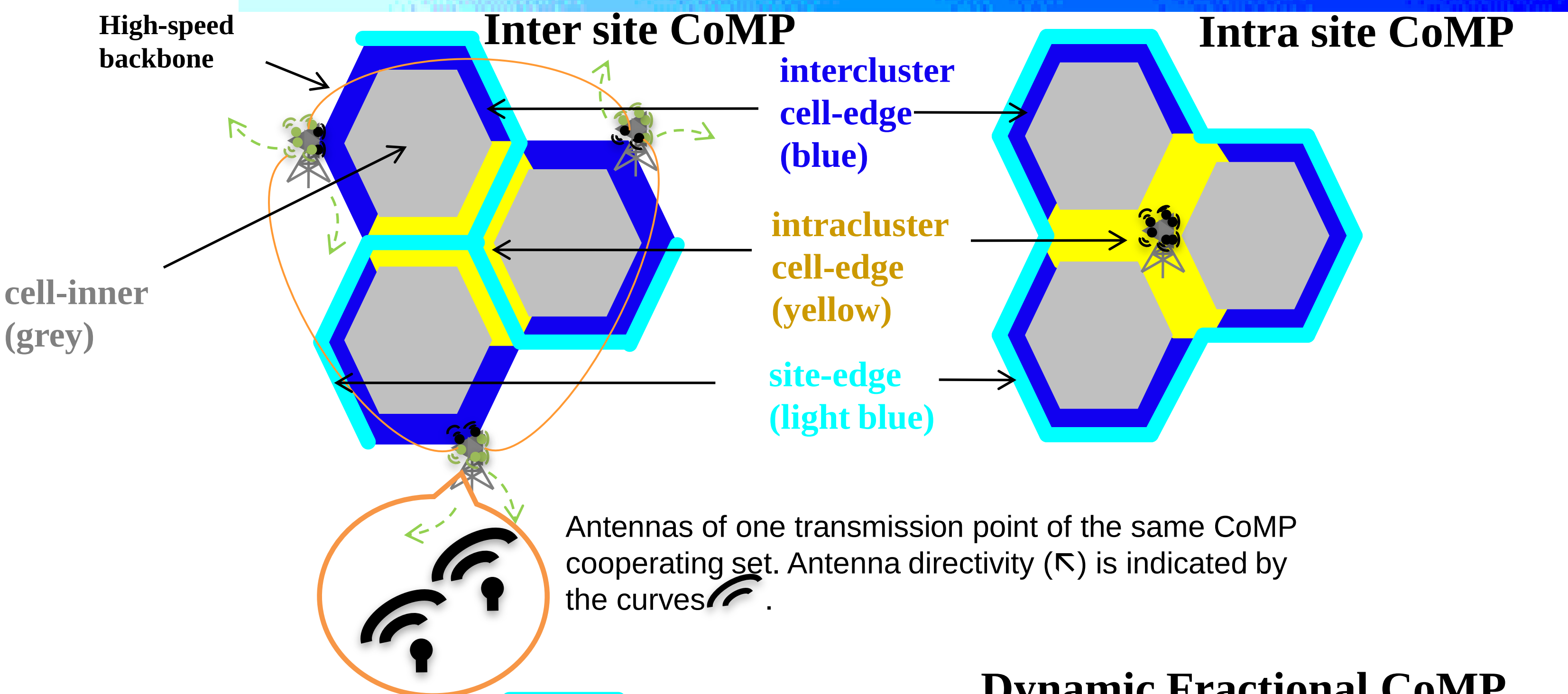
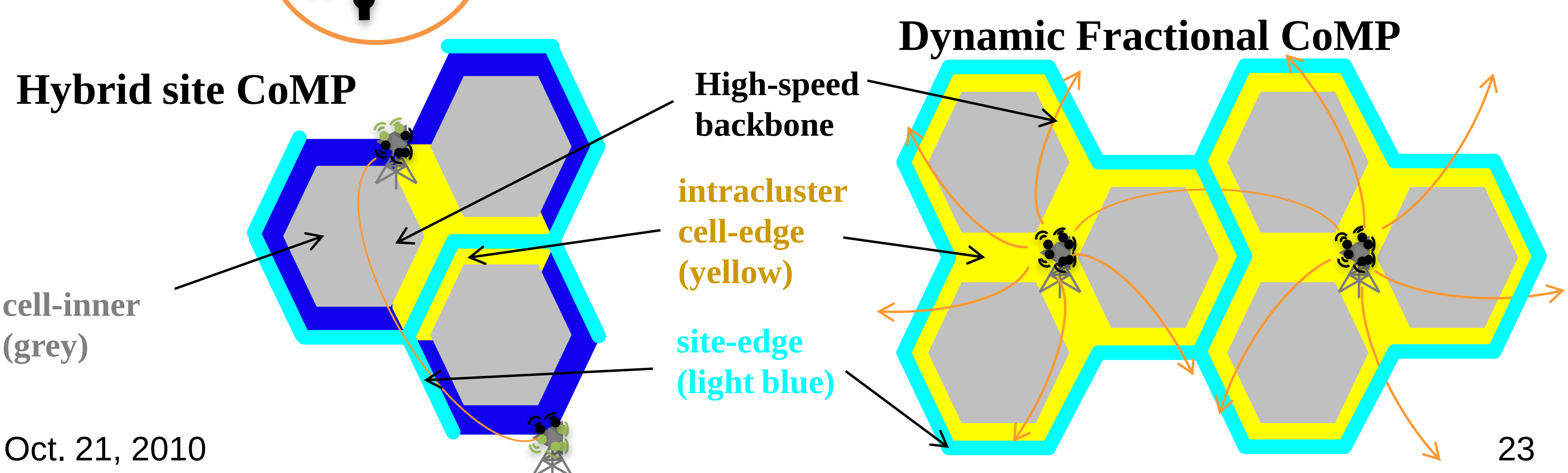
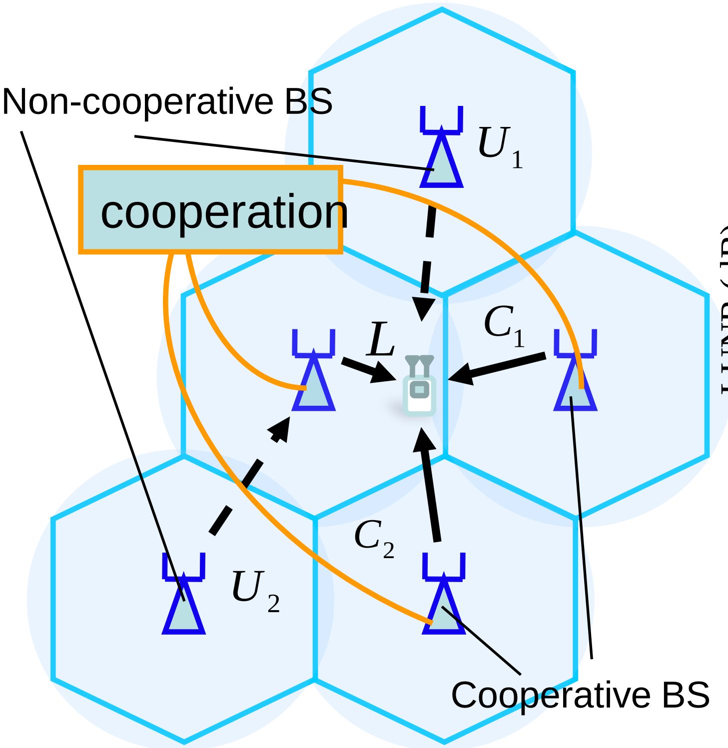
- Cell Partitioning? (Cooperation regions)
- BSC Cluster Partitioning?

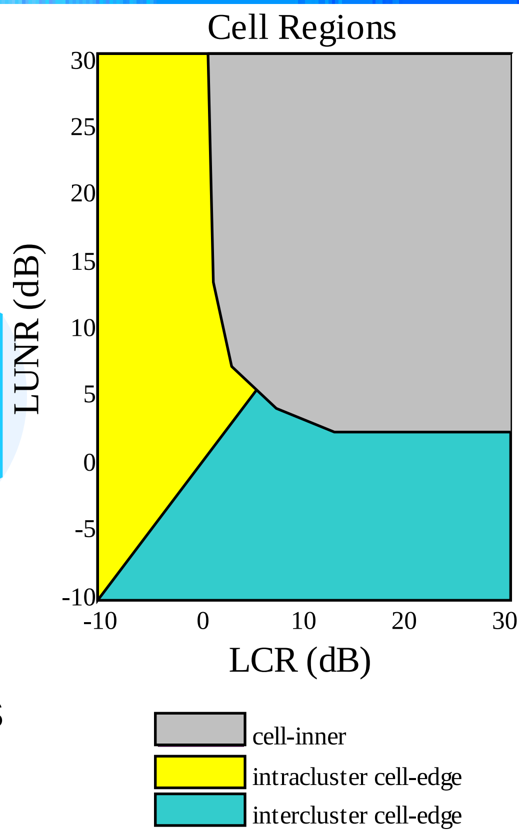
BSC Cluster Types

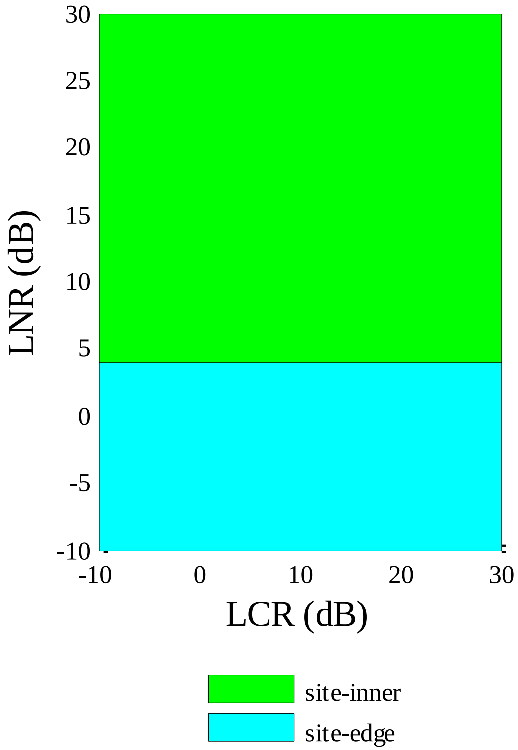




Cell Regions according to LUNR and LCR







$$\text{LUNR} = \frac{L}{U+N}$$

$$\text{LCR} = \frac{L}{C}$$

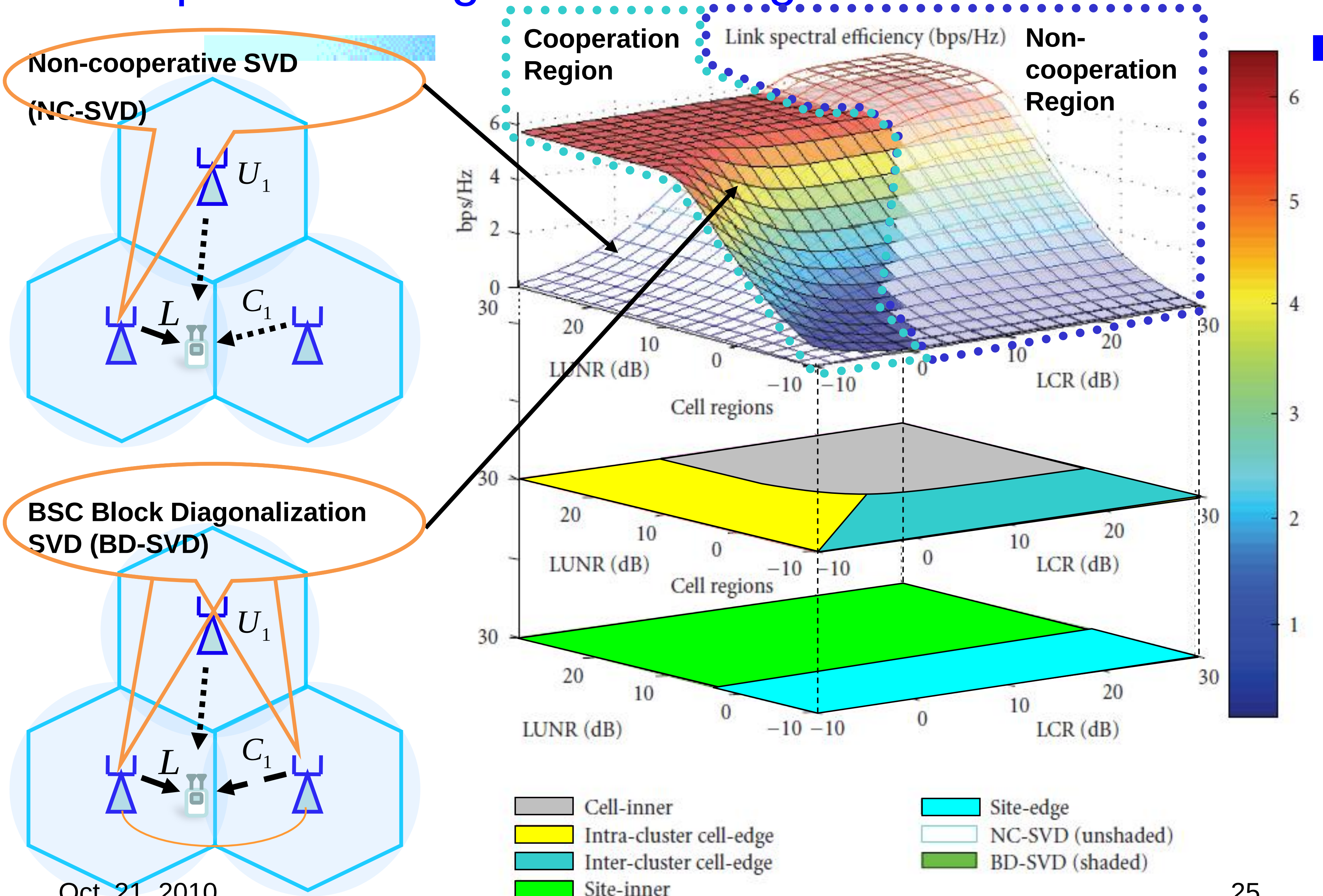
L is the Rx power from local BS

$C = C_1 + C_2$ is the total Rx power from cooperative BSs

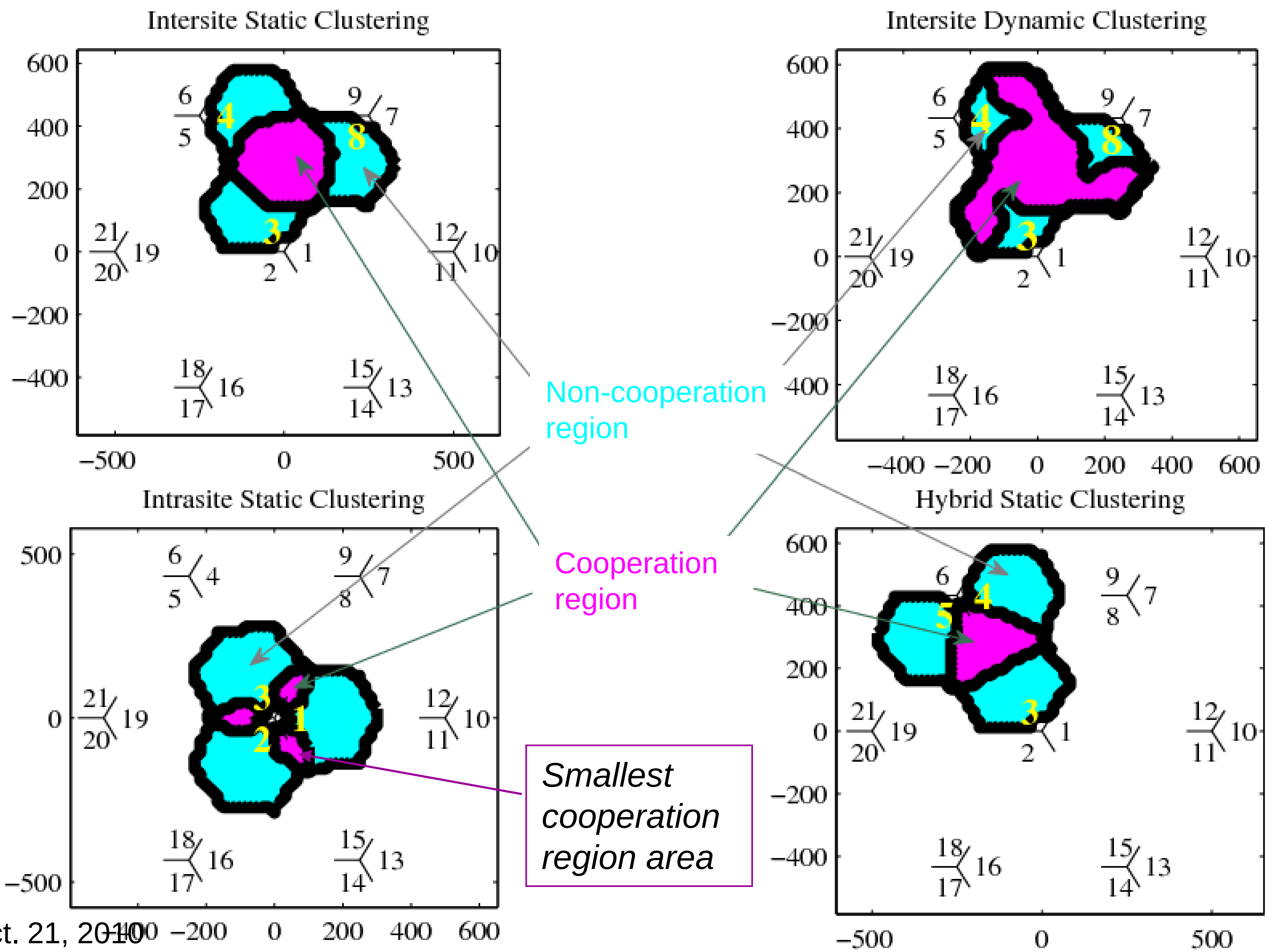
$U = U_1 + U_2$ is the total Rx power from non-cooperative BSs

N is the noise power

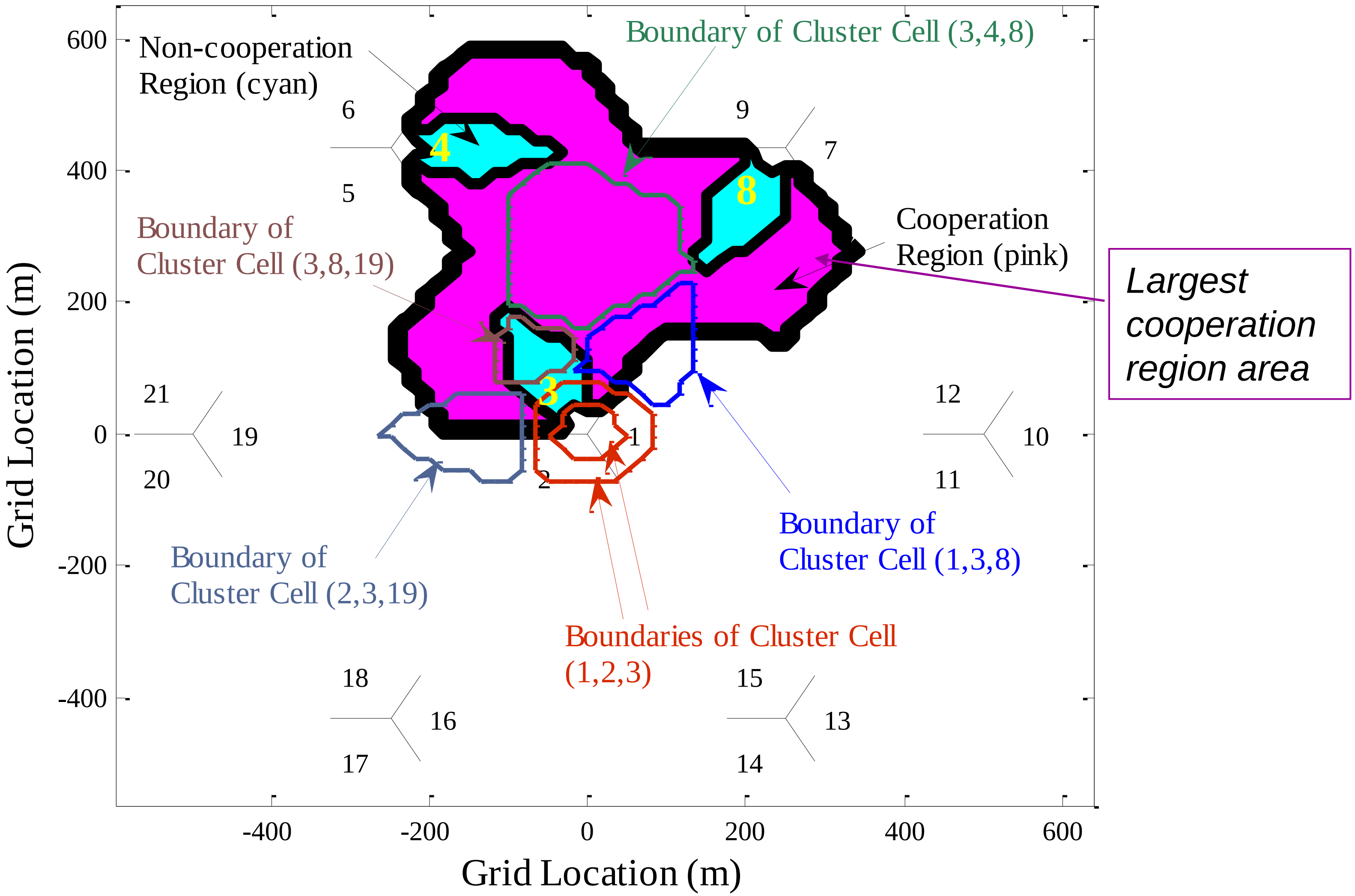
Cooperation Region according to LUNR and LCR



Cooperation Regions of BSC Clusters



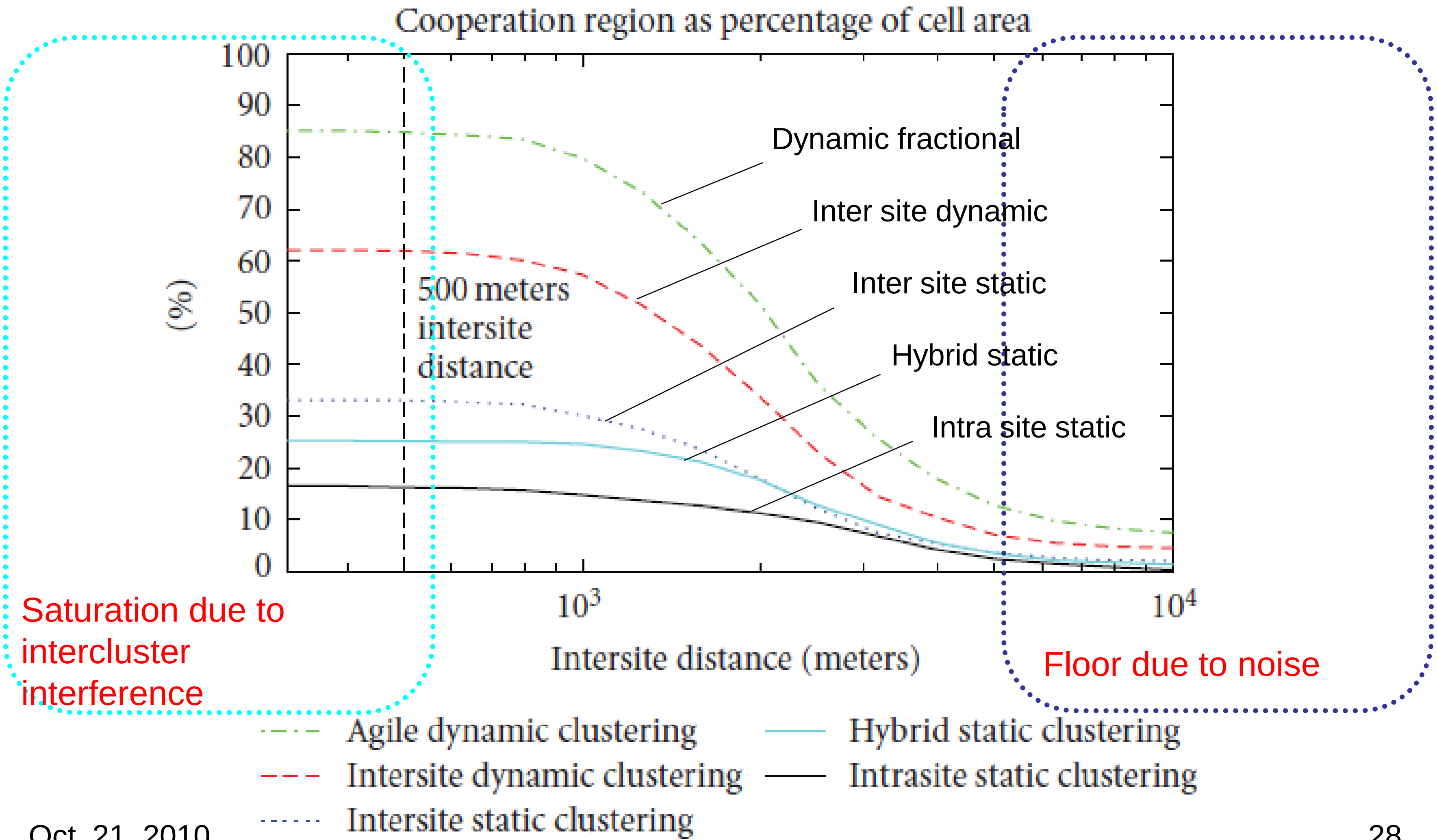
Cooperative Region and Cluster Cells of Dynamic Fractional CoMP



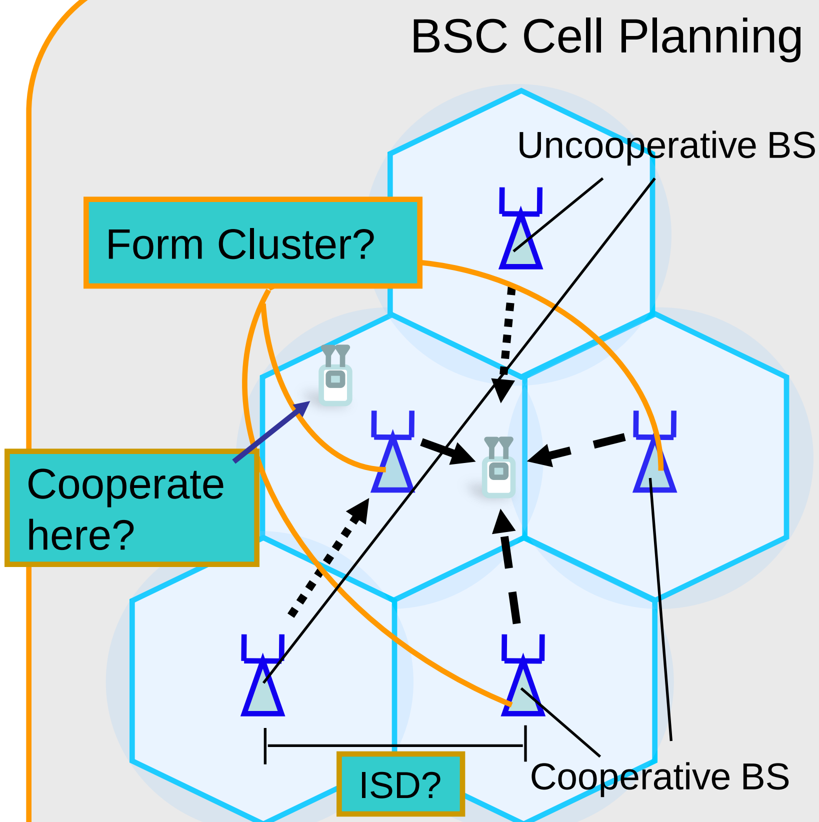
cluster cell is the area at which its associated BSC Cluster performs CoMP to the UEs inside the area

ISD Dependency

- Inter site distance can be optimized via coverage of cooperation region



Cell Planning for CoMP Conclusion



BSC Cell Planning Design
- Typical Cell Planning Design

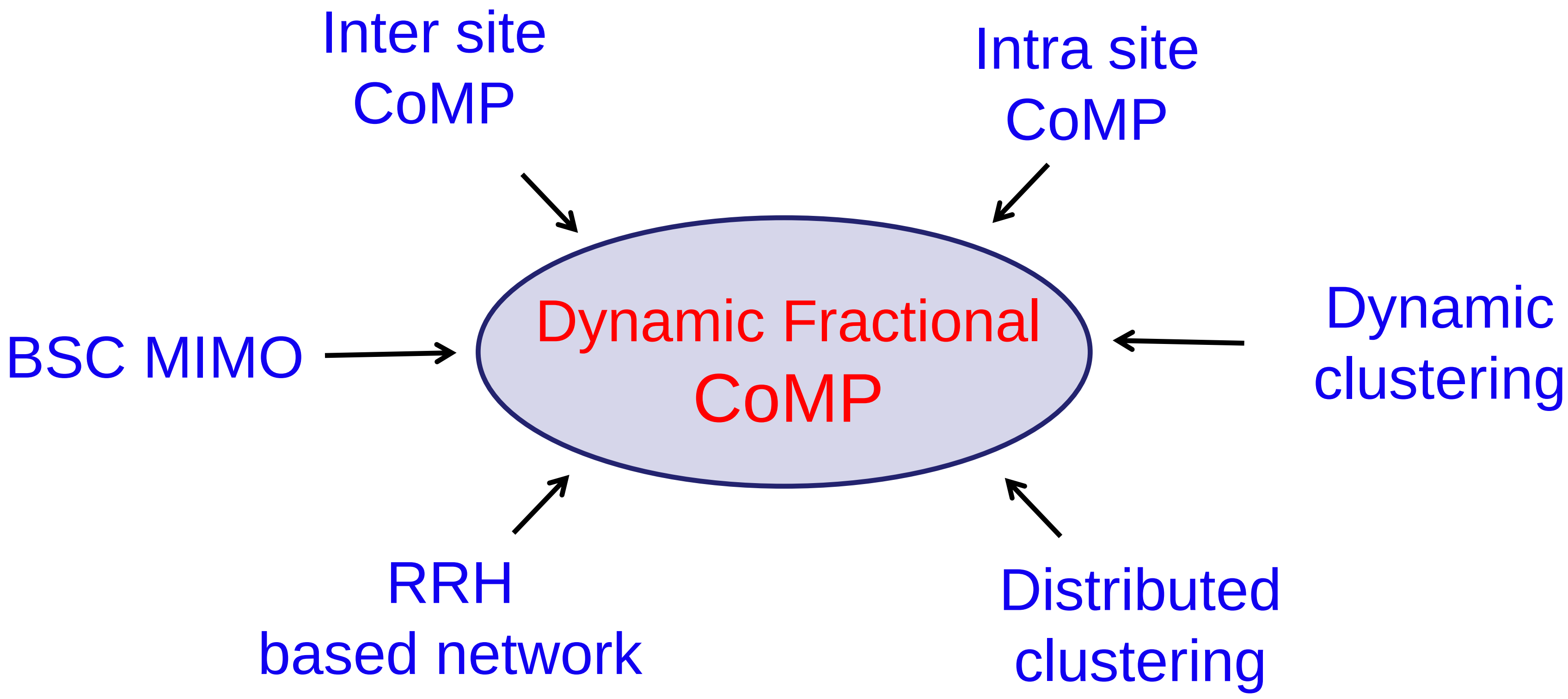
+
- Cell Partitioning? (Cooperation regions)
- BS Cluster Partitioning?

- Our Contribution: A framework for cell planning of CoMP networks based on receive signal strength ratios
  - Cluster Types
  - LUNR and LCR
  - Cell regions
  - Cooperation regions
  - Cluster cells
  - Spectral Efficiency of CoMP
  - ISD Dependency
  - Cluster Selection Optimization

I. Garcia, N. Kusashima, K. Sakaguchi, K. Araki, S. Kaneko, Y. Kishi, “Impact of Base Station Cooperation on Cell Planning,” EURASIP J. Wireless Commun. and Networking, Vol. 2010, Article ID 406749, Aug. 2010.

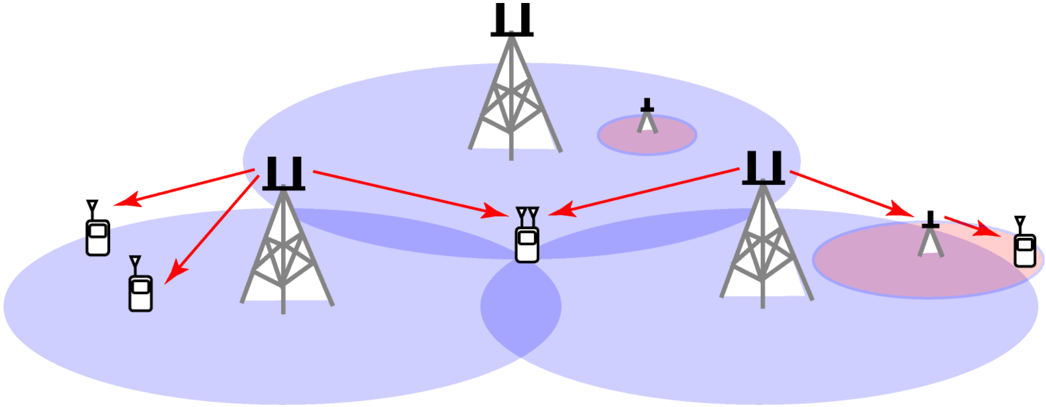
Summary

- Interference management scheme to improve cell-edge throughput for advanced cellular networks



Future Perspective

- CoMP MIMO transmission scheme using non-linear algorithm such as dirty paper coding or convex optimization
- CoMP between BSs with different cell size and backhaul architecture (heterogeneous network)
- Standardization of Dynamic Fractional CoMP for LTE-Advanced (Release 11) and amendment of 16m

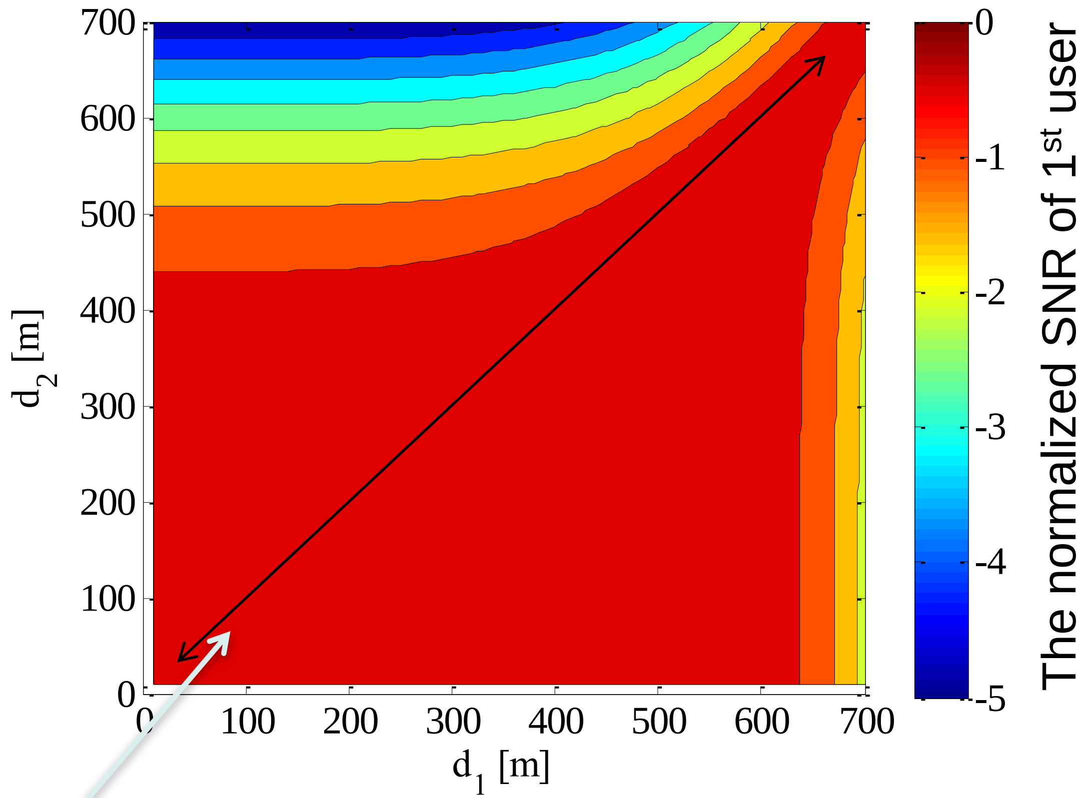


Co-scheduling

- Average receive SNR of 1st user

$$\gamma_1 = \frac{g_{11}g_{22} + g_{12}g_{21}}{g_{21} + g_{22}} \frac{\Omega P}{\sigma^2}$$

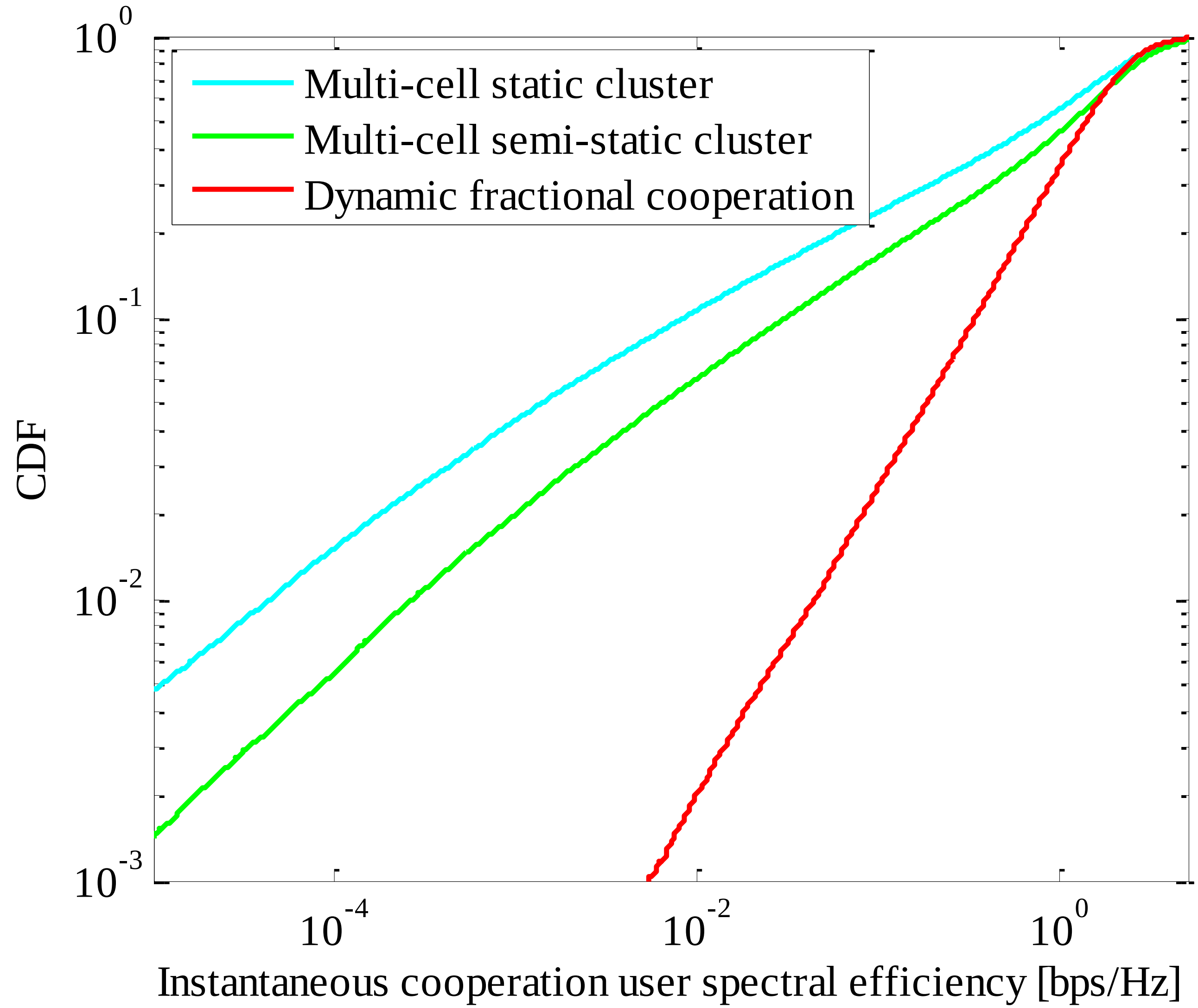
- $d_1 = d_2$
  - SNR is maximized



Co-scheduling

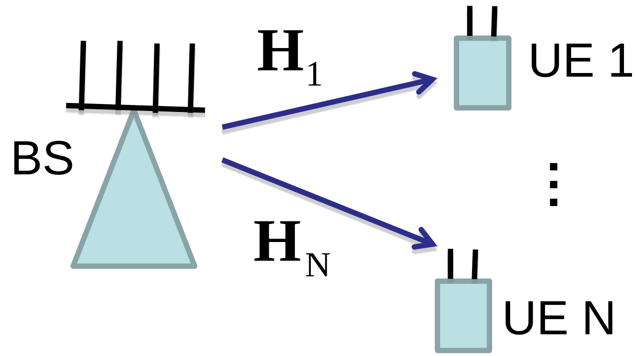
The BSs select users with the same SINR

Co-scheduling



MU Precoding based on V Feedback

- Channel estimation



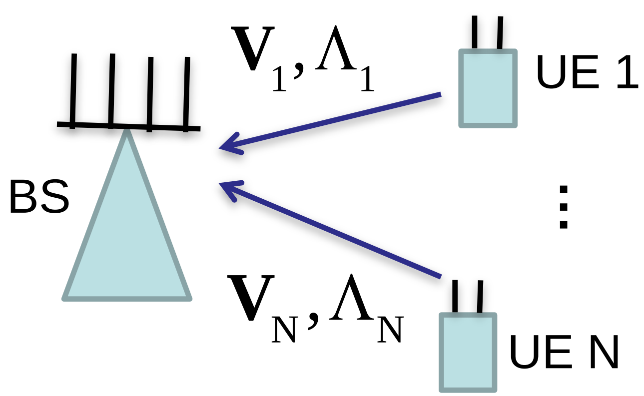
Denote channel between BS and k-th user

$$\mathbf{H}_k = \mathbf{U}_k \Sigma_k \mathbf{V}_k^{\mathrm{H}}$$

Correlation matrix of $\mathbf{H}_k$ is given by

$$\mathbf{H}_k^{\mathrm{H}} \mathbf{H}_k = \mathbf{V}_k \Lambda_k \mathbf{V}_k^{\mathrm{H}}$$

- Channel State Information (CSI) feedback



The k-th UE feeds back $\mathbf{V}_k, \Lambda_k$ to BS

MU Precoding based on V Feedback

- Precoding calculation

Denote $\tilde{\mathbf{H}}_k$ (Block diagonalized channel)

$$\tilde{\mathbf{H}}_k = \mathbf{H}_k \mathbf{V}_{\backslash k}^{\perp} = \tilde{\mathbf{U}}_k \tilde{\Sigma}_k \tilde{\mathbf{V}}_k^H$$

$$\left(\begin{array}{l} \mathbf{V}_{\backslash k}^{\mathrm{H}} = \begin{bmatrix} \mathbf{V}_1 & \cdots & \mathbf{V}_{k-1} & \mathbf{V}_{k+1} & \cdots & \mathbf{V}_K \end{bmatrix} \\ \mathbf{V}_{\backslash k}^{\mathrm{H}} \mathbf{V}_{\backslash k}^{\perp} = \mathbf{O} \end{array} \right)$$

Correlation matrix of block diagonalized channel matrix $\tilde{\mathbf{H}}_k$ is represented as

$$\begin{aligned} \tilde{\mathbf{H}}_k^{\mathrm{H}} \tilde{\mathbf{H}}_k &= \left(\mathbf{V}_{\backslash k}^{\perp}\right)^{\mathrm{H}} \mathbf{H}_k^{\mathrm{H}} \mathbf{H}_k \mathbf{V}_{\backslash k}^{\perp} \\ &= \mathbf{V}_{\backslash k}^{\perp} \mathbf{V}_k \Sigma_k^{\mathrm{H}} \mathbf{U}_k^{\mathrm{H}} \mathbf{U}_k \Sigma_k \mathbf{V}_k^{\mathrm{H}} \mathbf{V}_{\backslash k}^{\perp} \\ &= \left(\mathbf{V}_{\backslash k}^{\perp}\right)^{\mathrm{H}} \mathbf{V}_k \Lambda_k \mathbf{V}_k^{\mathrm{H}} \mathbf{V}_{\backslash k}^{\perp} \end{aligned}$$

$\Lambda_k, \mathbf{V}_k$ is given by k-th user's feedback

$\mathbf{V}_{\backslash k}^{\perp}$ can be calculated by other user's feedback

Finally $\tilde{\mathbf{H}}_k^{\mathrm{H}} \tilde{\mathbf{H}}_k$ can be reconstructed

This equation can be expressed in another way using ED of $\tilde{\mathbf{H}}_k^{\mathrm{H}} \tilde{\mathbf{H}}_k$ as

$$\begin{aligned} \tilde{\mathbf{H}}_k^H \tilde{\mathbf{H}}_k &= \tilde{\mathbf{V}}_k \tilde{\boldsymbol{\Sigma}}_k^H \tilde{\mathbf{U}}_k^H \tilde{\mathbf{U}}_k \tilde{\boldsymbol{\Sigma}}_k \tilde{\mathbf{V}}_k^H \\ &= \tilde{\mathbf{V}}_k \tilde{\boldsymbol{\Sigma}}_k^H \tilde{\boldsymbol{\Sigma}}_k \tilde{\mathbf{V}}_k^H \\ &= \tilde{\mathbf{V}}_k \tilde{\boldsymbol{\Lambda}}_k \tilde{\mathbf{V}}_k^H \end{aligned}$$

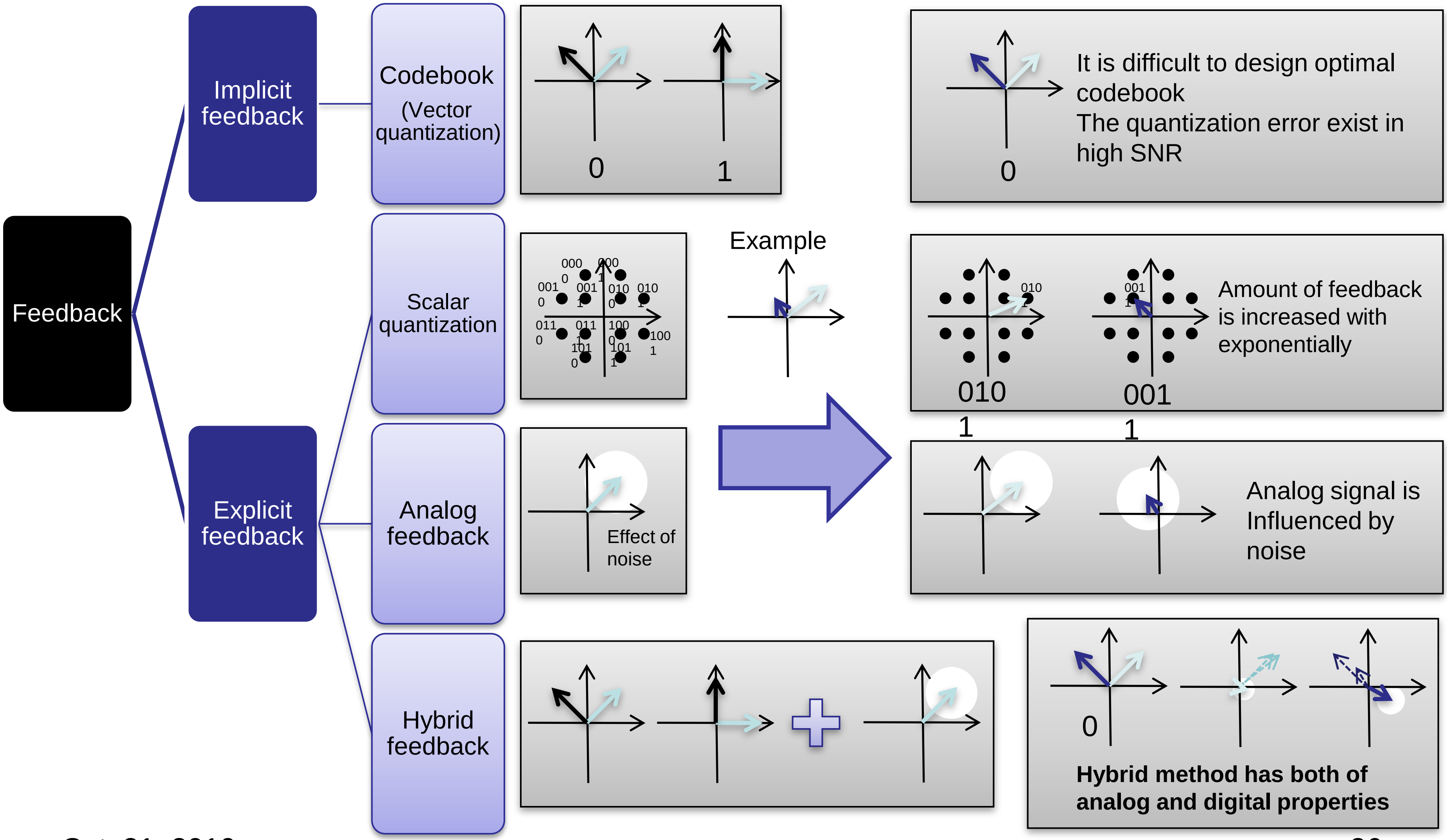
It can be calculated by using reconstructed $\tilde{\mathbf{H}}_k^{\mathrm{H}} \tilde{\mathbf{H}}_k$

Finally $\tilde{\mathbf{V}}_k^H$ can be obtained

The k-th user's precoding matrix is obtained by

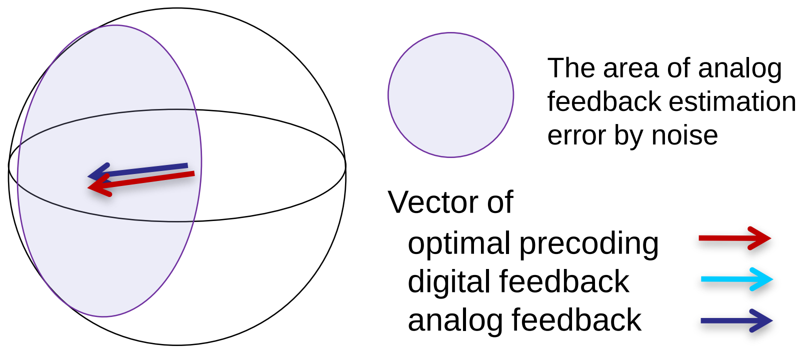
$$\mathbf{W}_k = \mathbf{V}_{\backslash k}^{\perp} \tilde{\mathbf{V}}_k$$

Digital and Analog Feedback



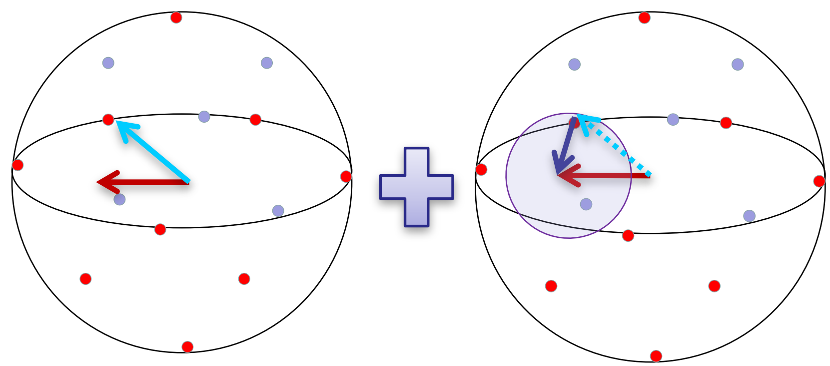
Hybrid Feedback

Normal analog feedback



Analog feedback

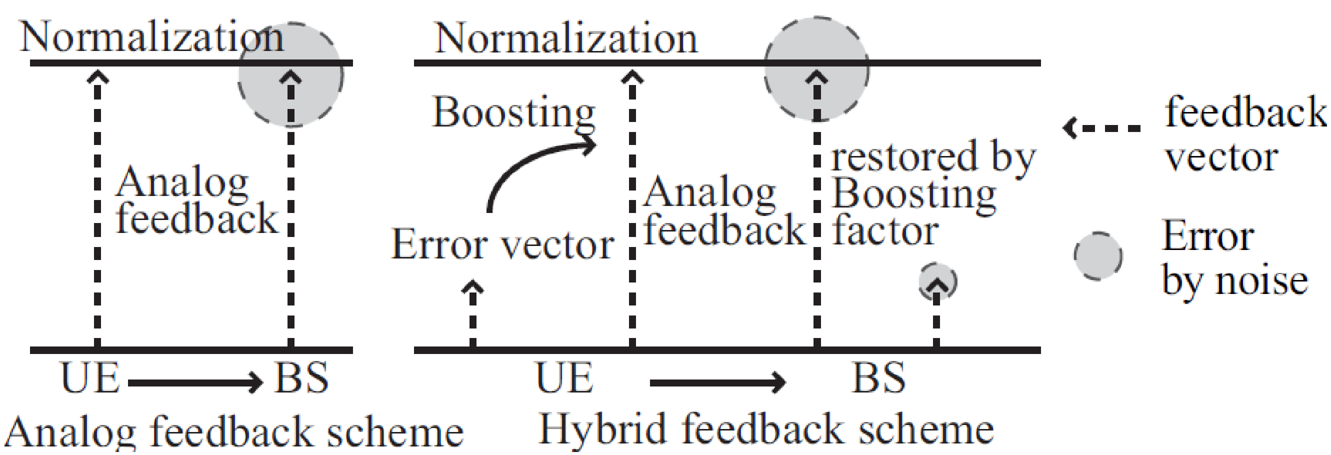
Hybrid feedback



Codebook

Analog feedback
(Error vector between optimal vector and vector given by codebook)

Analog signal boosting

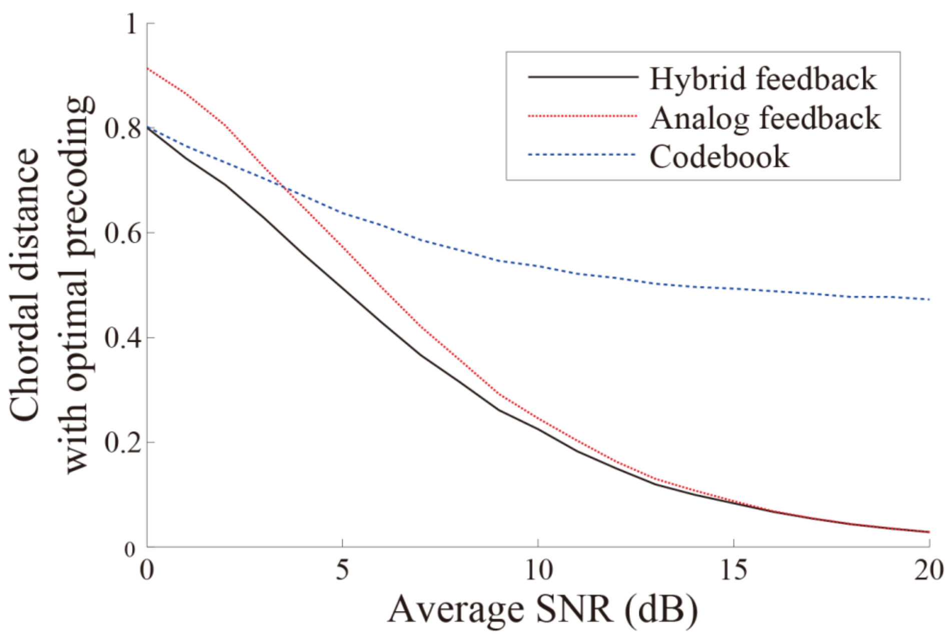


In case of hybrid feedback, the influence of noise is lower than normal analog by boosting

Numerical Examples

parameter	Value
Channel model	AWGN
Channel estimation error	LTE
Codebook	LTE Rel.8
DL/UL SNR	Same
MIMO system	4X1 SU-MISO

Feedback method	Digital Feedback (fixed)	Additional feedback
Codebook	4 bits	Nothing
Analog	4 bits	4 symbols
Hybrid	4 bits	4 symbols



Chordal distance

$$d(\mathbf{V}_1, \mathbf{V}_2) = \frac{1}{\sqrt{2}} \left\| \mathbf{V}_1 \mathbf{V}_1^{\mathrm{H}} - \mathbf{V}_2 \mathbf{V}_2^{\mathrm{H}} \right\|_{\mathrm{F}}$$

Metric of distance between two matrices

The hybrid feedback method gives accurate channel state information

Numerical Examples

- Comparison transmission
  - Single-cell SISO
  - Single-cell MIMO
  - Multi-cell static cluster
  - Dynamic fractional cooperation