Inter-Cell Interference Mitigation in Cellular Networks Applying Grids of Beams

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Resource Blocks

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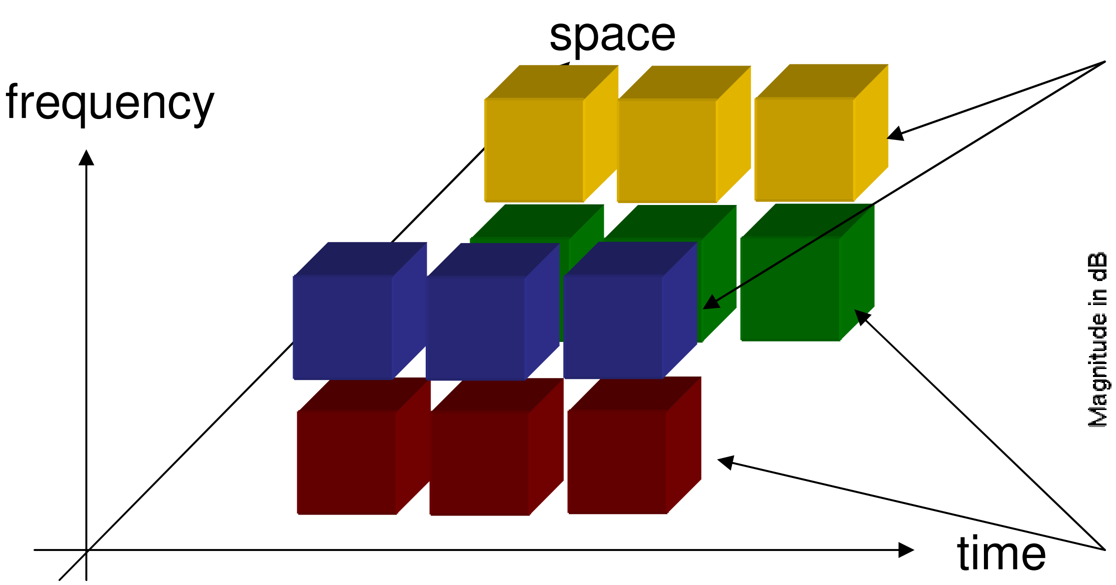
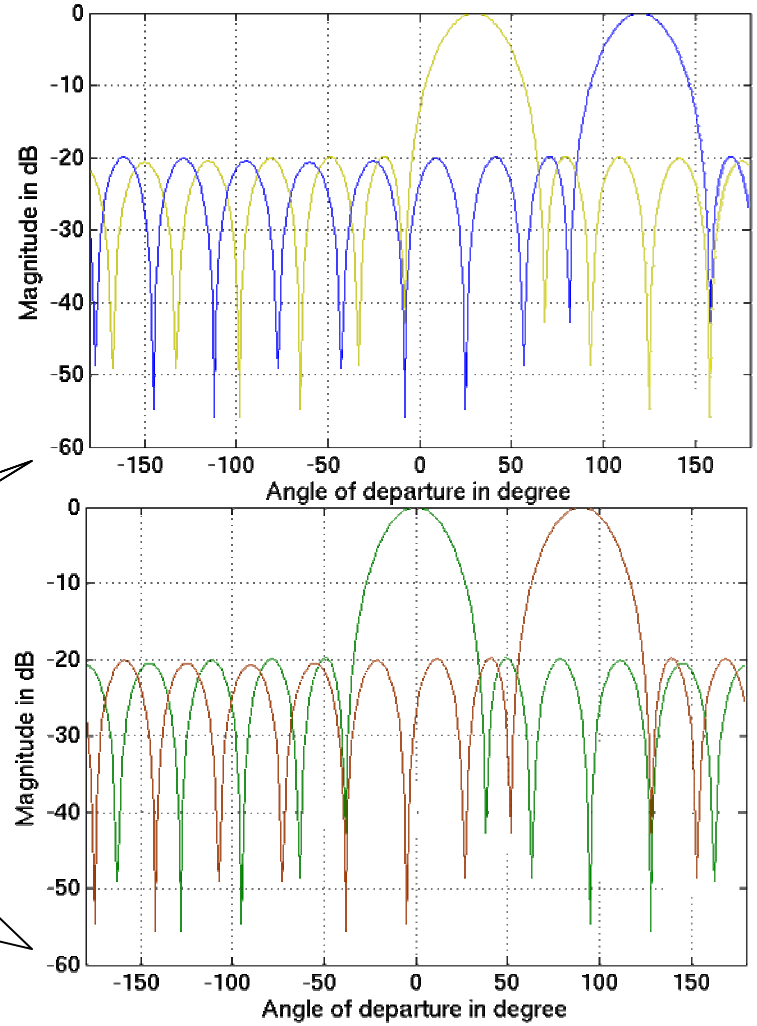
- downlink of OFDMA-based cellular network
- multiple antenna at transmitter
- single antenna at receiver
- beamforming without channel state information → grids of beams





Motivation

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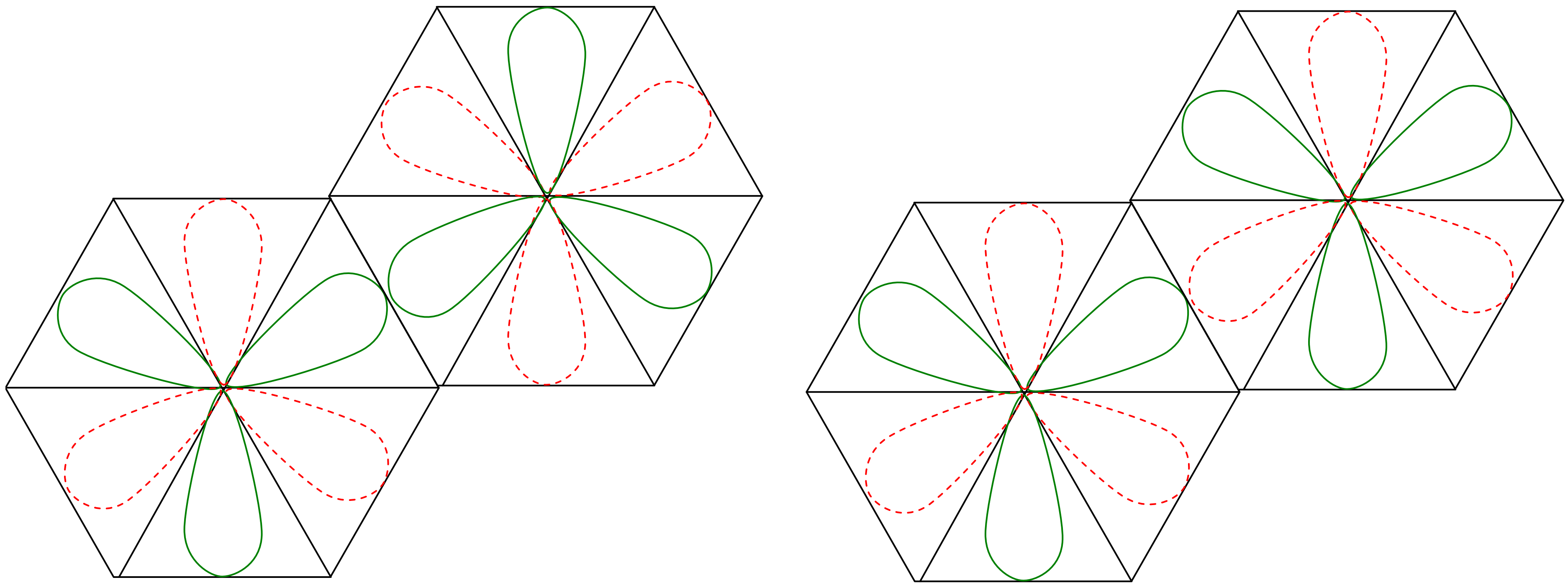

beam of time-frequency unit A

beam of time-frequency unit B

Which beams shall be used on a time-frequency unit?

Overview

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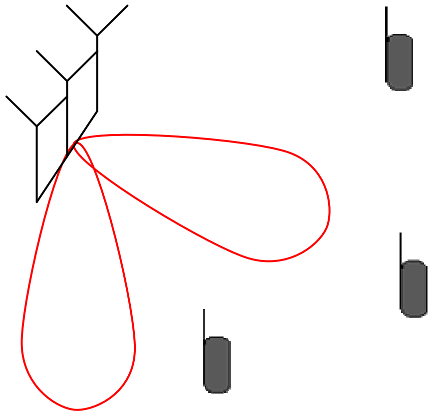
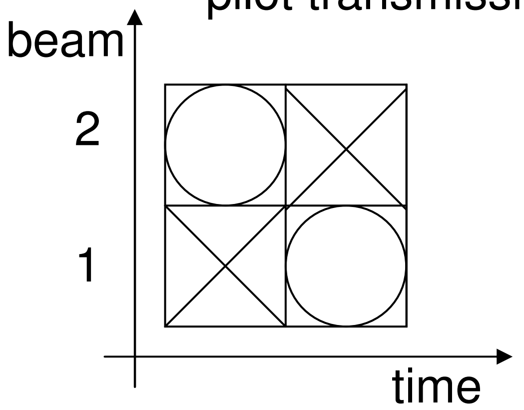
- System concept: grids of beams in cellular network
- Design of grids of beams
  - Problem of interference mitigation: objective function and constraints
  - Low complex algorithm for interference mitigation
- Simulation results
- Conclusion

System Concept

preamble phase



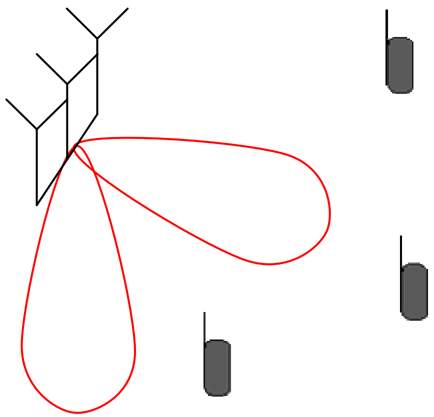
pilot transmission



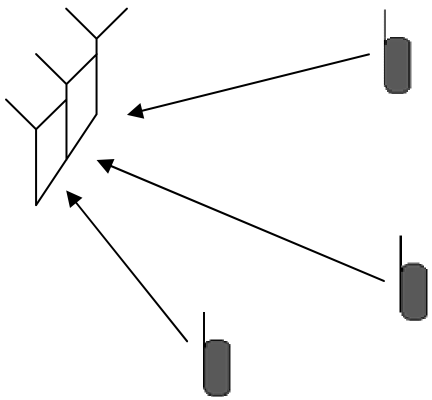
R. Grünheid, H. Rohling, K.Brüninghaus, “Self-Organized Beamforming and Opportunistic Scheduling in an OFDM-based Cellular Network“, Proc. VTC 2006, Melbourne Australia, April 2006.

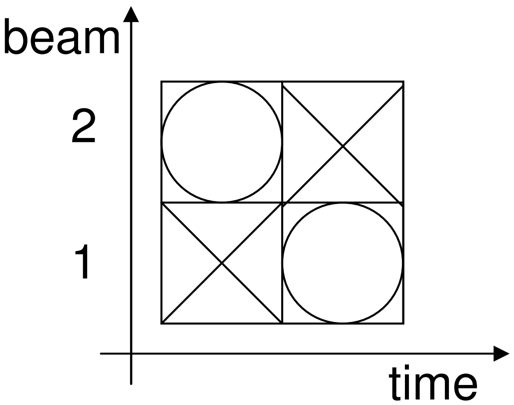
System Concept

preamble phase



feedback phase





SINR values:
- each resource block
- each user

R. Grünheid, H. Rohling, K.Brüninghaus, “Self-Organized Beamforming and Opportunistic Scheduling in an OFDM-based Cellular Network“, Proc. VTC 2006, Melbourne Australia, April 2006.

System Concept

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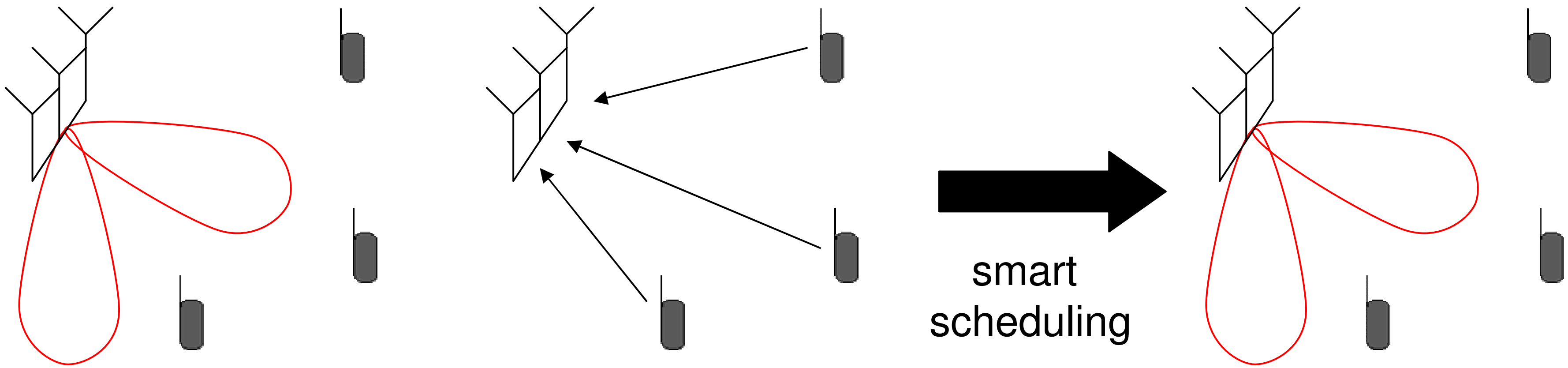
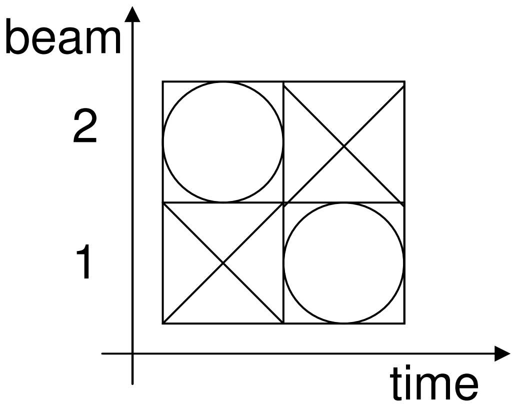
preamble phase | feedback phase | signaling and payload phase





SINR values:
- each resource block
- each user

like in preamble phase:
- same beams
- same power

R. Grünheid, H. Rohling, K.Brüninghaus, “Self-Organized Beamforming and Opportunistic Scheduling in an OFDM-based Cellular Network“, Proc. VTC 2006, Melbourne Australia, April 2006.

Multi-Cell Environment

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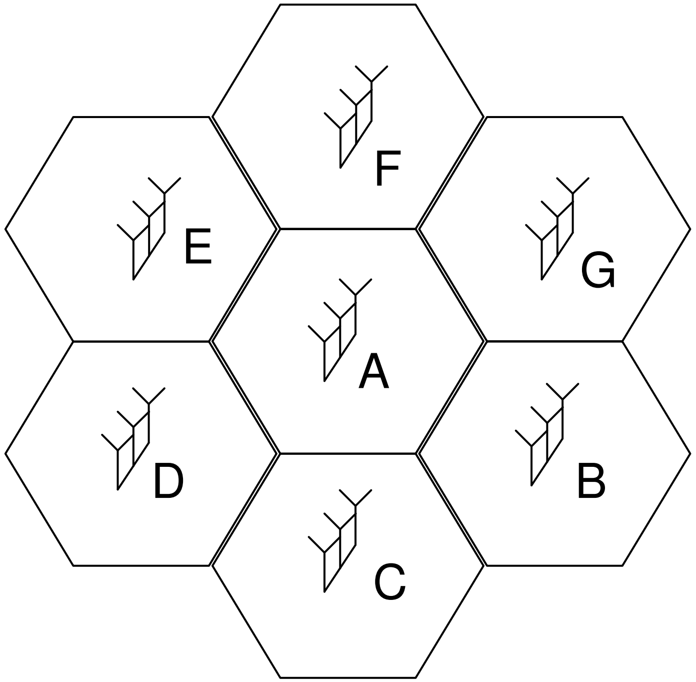

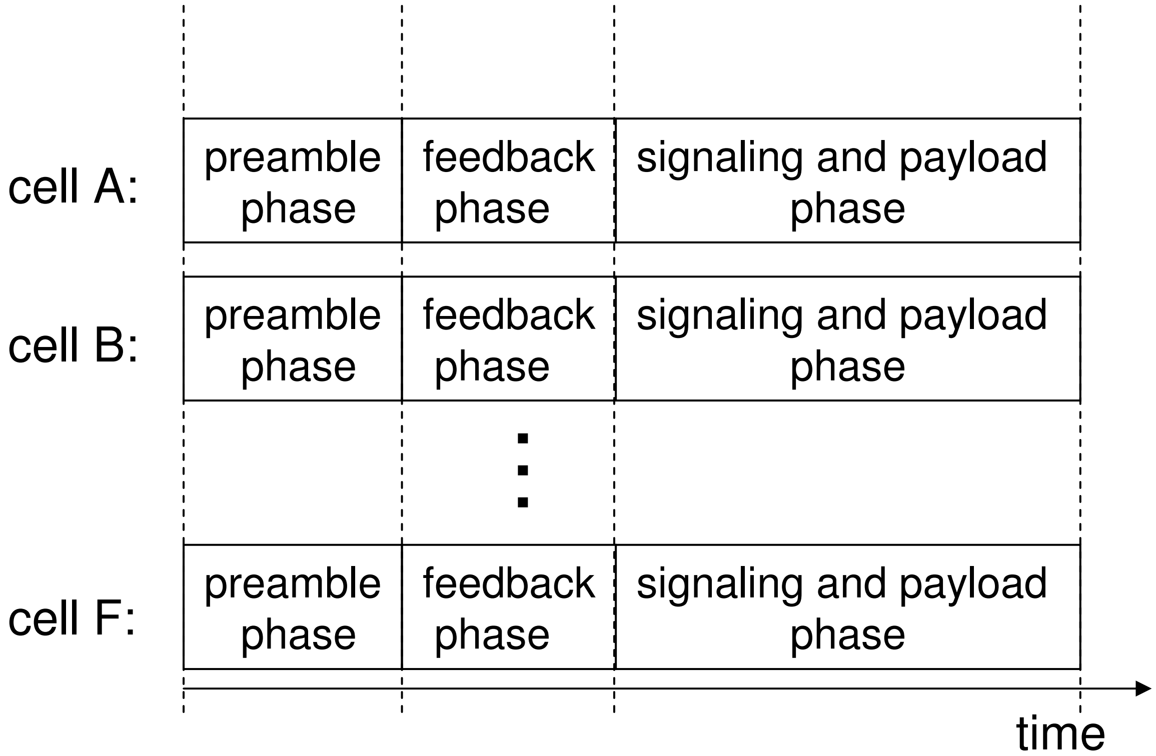

synchronous in time → precise SINR values

Design of Grids of Beams

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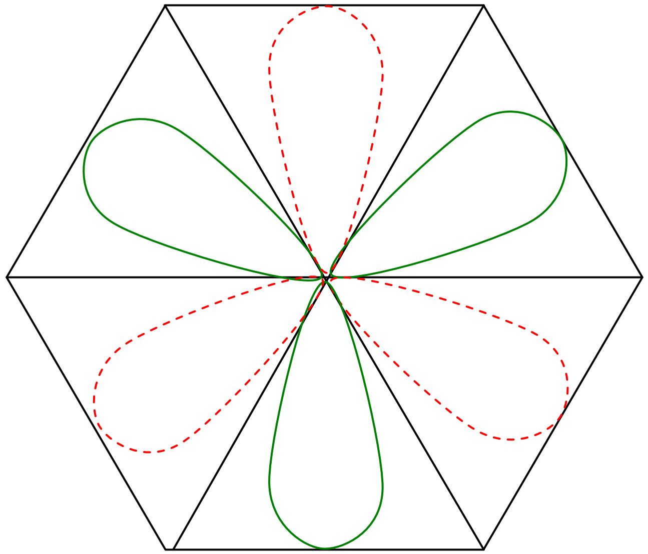
approach in literature:

- filter design
- group beams such that inter-beam interference is avoided → comb-like manner
- use grid of beams serving more users more often



idea:

- design grid of beams for each time-frequency resource such that
  - inter-cell interference is avoided
  - beams serving more users are applied more often

Problem Formulation

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assumptions:
- set of time-frequency units
- set of beams

⇓

input:
- **demand** for a beam
- **interference** generated by a beam

⇓

optimization problem:
minimize interference in network

⇓

result:
beams used on time-frequency units

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Demand of Beams

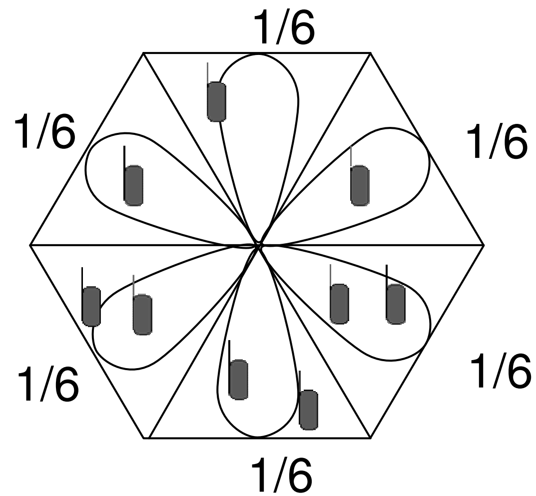
- preference:
  - from estimation of angle of arrival or
  - from tracking SINR values
- aims at
  - good coverage
  - high signal power at receiver
- sum of demands is given by number of time-frequency units and beams in a grid of beams
- no preference known

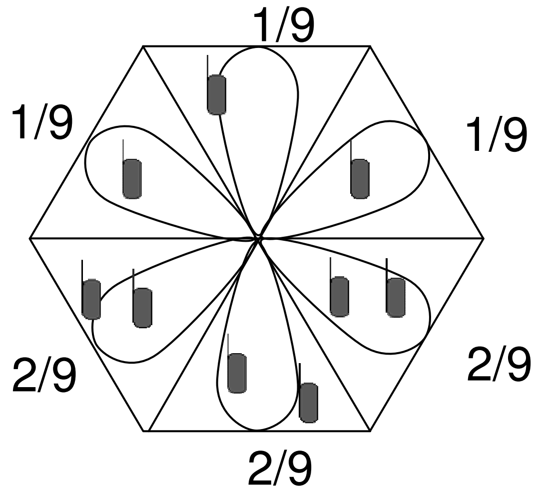
→ use each beam same often

- preference known

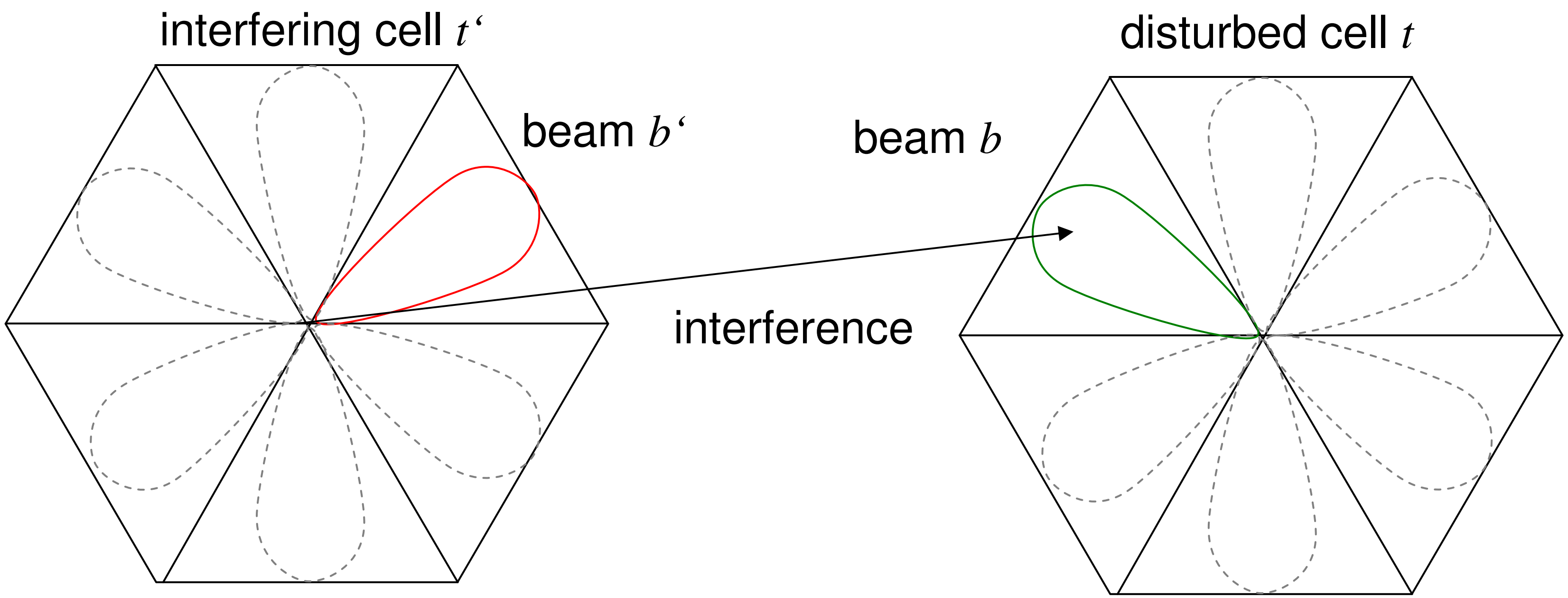
→ use beam proportional to traffic in its direction

- demand of a beam is time-variant





Interference of a Beam



for each pair of beams:

average interference $I_{(t',b')}^{(t,b)}$ in sector depending on

- path loss
- antenna pattern
- user distribution (probability density function)

Note: Average interference is quasi time-invariant.

Interference Matrix

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inter-beam interference in sector of first beam and first cell

inter-cell interference in sector of first beam and first cell

interference generated by first beam in first cell

$$
\mathbf{A} = \begin{pmatrix}
I^{(1,1)}_{(1,1)} & I^{(1,1)}_{(1,2)} & \cdots & I^{(1,1)}_{(1,6)} & I^{(1,1)}_{(2,1)} & I^{(1,1)}_{(2,2)} & \cdots & I^{(1,1)}_{(2,6)} \\
I^{(1,2)}_{(1,1)} & I^{(1,2)}_{(1,2)} & \cdots & & & & & I^{(1,2)}_{(2,6)} \\
\vdots & & & & & & & \\
I^{(1,6)}_{(1,1)} & I^{(1,6)}_{(1,2)} & \cdots & & & & & I^{(1,6)}_{(2,6)} \\
I^{(2,1)}_{(1,1)} & I^{(2,1)}_{(1,2)} & \cdots & & & & & I^{(2,1)}_{(2,6)} \\
I^{(2,2)}_{(1,1)} & I^{(2,2)}_{(1,2)} & \cdots & & & & & I^{(2,2)}_{(2,6)} \\
\vdots & & & & & & & \\
I^{(2,6)}_{(1,1)} & I^{(2,6)}_{(1,2)} & \cdots & & & & & I^{(2,6)}_{(2,6)}
\end{pmatrix}
$$

Optimization Problem

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objective:

$$\min_{\mathbf{u}} \ \mathbf{u}^T \begin{pmatrix} \mathbf{A} & \mathbf{0} & \mathbf{0} & \cdots & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{A} & \mathbf{0} & \cdots & \mathbf{0} & \mathbf{0} \\ & & & \ddots & & \\ \mathbf{0} & \mathbf{0} & & \cdots & \mathbf{A} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & & \cdots & \mathbf{0} & \mathbf{A} \end{pmatrix} \mathbf{u}$$

extension of $\mathbf{A}$: consider each time-frequency unit

assignment variable
- for each time-frequency unit
- for each cell
- for each beam

constraints:
- each grid of beams consists of same number of beams
- each beam is used as often as demanded
- elements of $\mathbf{u}$ are equal to 0 or 1

→ integer program which is NP-hard

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Dynamic Design of Grids of Beams

find initial grids of beams

for each time-frequency unit
- find grid of beams by a ***greedy*** algorithm:
- for each beam in grid of beams
  - for each cell
    - sum up affected elements of interference matrix $\mathbf{A}$
    - choose the one leading to lowest interference
    - consider only beams which are still demanded

improve results

for each cell
- for each time-frequency unit
  - for each beam
    - find beam in a grid of beams on different time-frequency unit reducing sum of interference
    - if found, ***swap***

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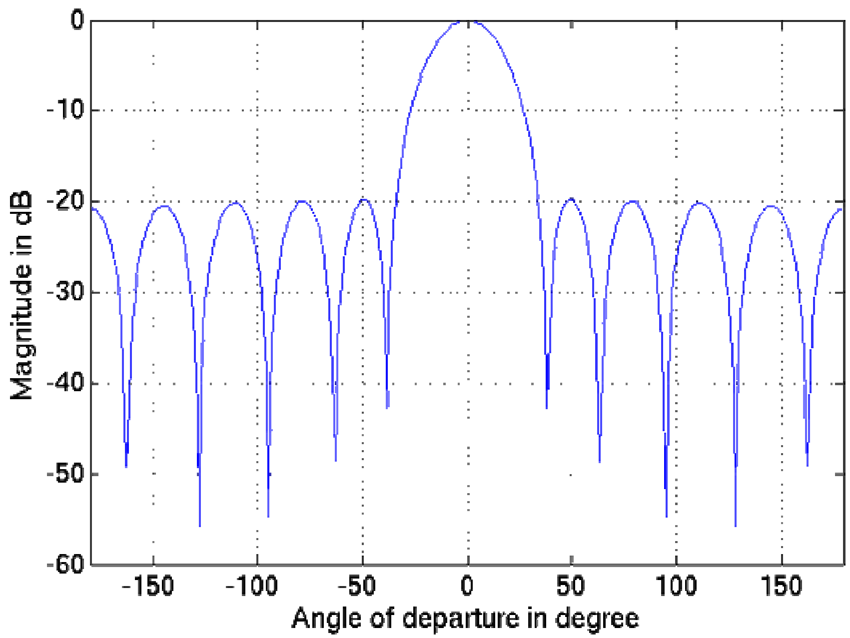
Evaluation Parameters

Parameter	Value
bandwidth	5 MHz
number of subcarriers	128
power BS	35dBm
noise power	-102 dBm
antennas BS	uniform circular array, 12 elements
main lobe direction	0°, 30°, 60°, …, 330°
beam type	Chebyshev, 20 dB side lobe attenuation
size of grid of beams	2
channel model	Winner Channel Model C2 NLOS
number of cells	7
cell radius	200m
scheduler	Max-Min

beam with main lobe at 0°



Benchmark Method

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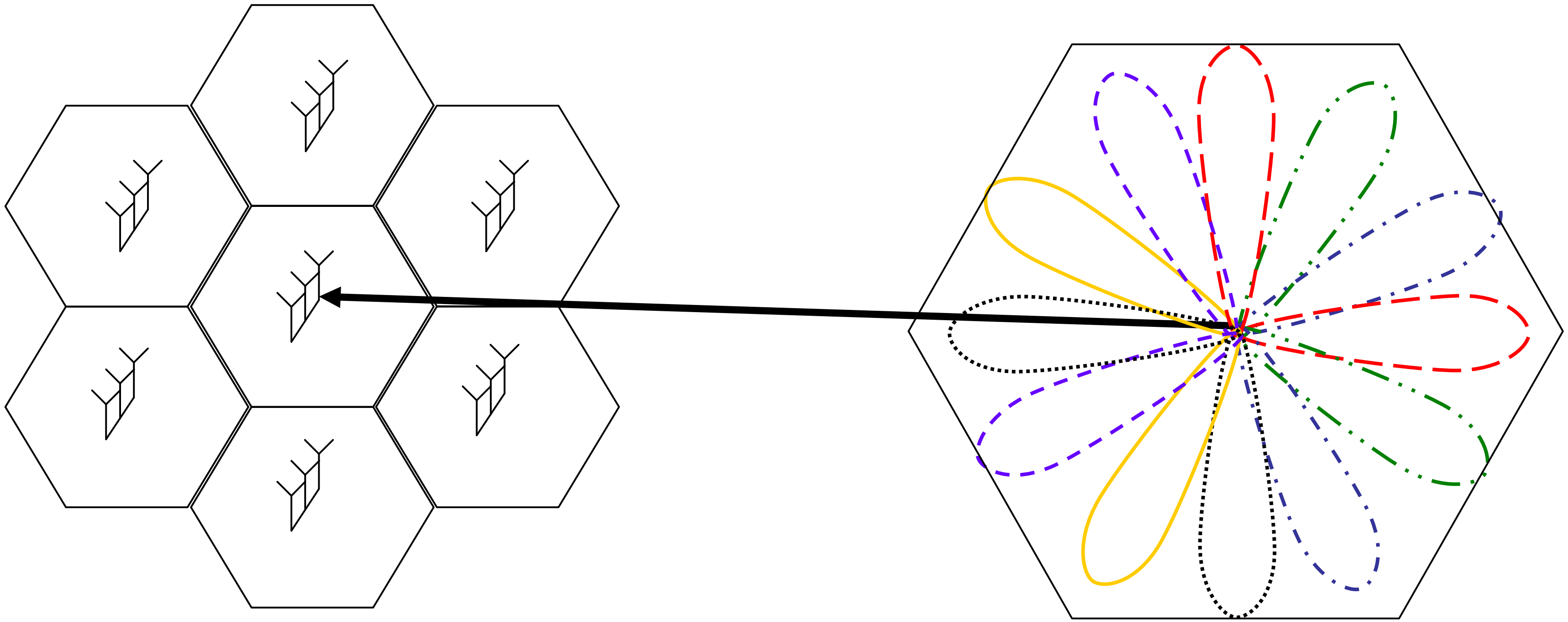
comb-like manner of grid of beams:

subcarrier	1	2	3	4	5	6	7	...
1st beam	0°	30°	60°	120°	150°	180°	0°	...
2nd beam	90°	300°	330°	210°	270°	300°	90°	...



Data Rate of User for 8 Users in Cell

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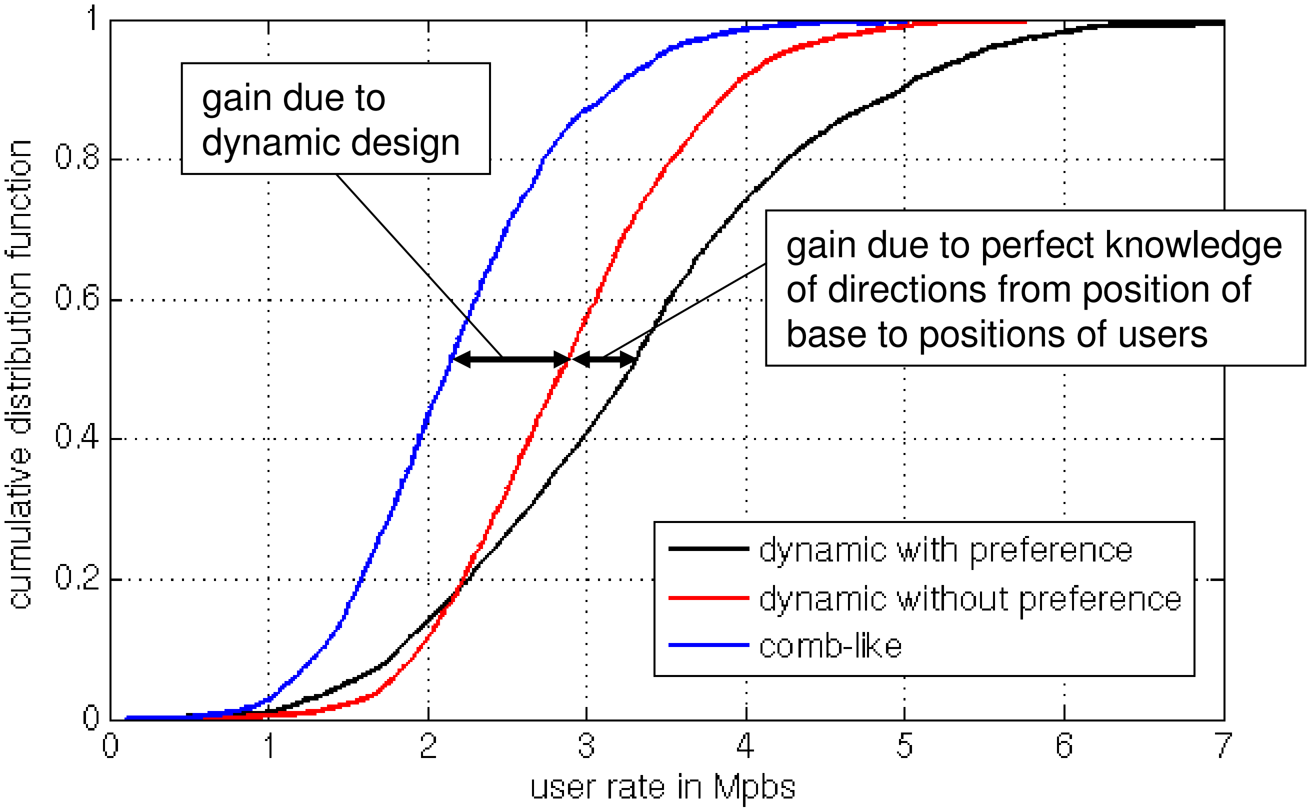
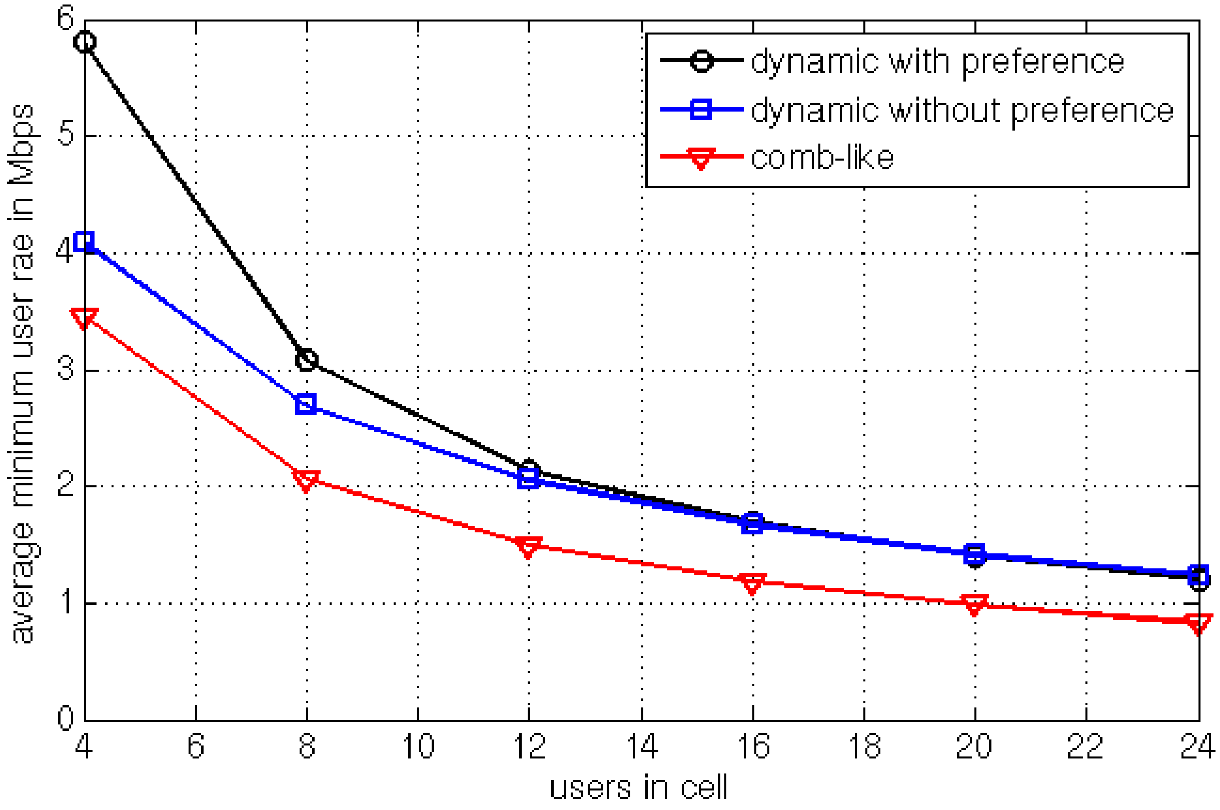


Minimum Data Rate of User in Cell



Conclusion

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- grid of beams as a robust alternative to beamforming requiring full channel state information
- dynamic design of grids of beams considering
  - demand of a beam
  - inter-cell interference
- formulation of optimization problem including definition of an objective function
- presentation of an algorithm improving performance of a network by dynamic design of grids of beams