Universität Stuttgart

INSTITUT FÜR
KOMMUNIKATIONSNETZE
UND RECHNERSYSTEME
Prof. Dr.-Ing. Dr. h. c. mult. P. J. Kühn

Towards Next Generation Wireless Networks

Marc Necker
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Ursinus College
October 3, 2007

Outline

- **Overview of cellular networks**
  - The cellular concept
  - Multiplexing techniques
- **Interference and reception quality**
  - The wireless channel
  - State-of-the-art interference mitigation techniques
- **Interference Coordination**
  - Basic principle
  - Solution by graph coloring
- **Performance evaluation**

The University of Stuttgart

- **One of the big engineering schools in Germany**
- **Offers undergraduate and graduate level programs in many engineering and science areas**
  - Electrical Engineering
  - Computer Science
  - Mechanical Engineering
  - Aeronautical Engineering
  - Civil Engineering
  - Chemical Engineering
  - Environmental Engineering
  - Cybernetics
  - Mathematics
  - ...
- **Also offers non-technical programs**
  - Finance, Management, History
  - ...

The Faculty of CS and ECE

Faculty of Computer Science, Electrical Engineering, and Information Technology

- **BS, MS, and PhD program**
- **Undergraduate & graduate level courses in various areas**
  - semiconductors, solar cells, analog circuit design, components
  - physical layer communications
  - networking, protocols, distributed systems, network architectures
  - software engineering, services
  - node architectures, digital circuit design, processor design
  - control
  - energy systems
  - massively parallel and high-performance computing
  - intelligent systems
  - computer graphics, databases
  - algorithms, theoretical computer science

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The Institute at a Glance

Location

- **University campus in Vaihingen**

Staff

- **Director: Professor P. J. Kühn**
- **Scientific staff:**
  - 7 university funded
  - 10-15 project funded
- **6 members of administrative and technical staff**

Laboratories

- **Hardware and system development lab**
- **Software development lab**
- **Communication networks lab**

Research

Architectures and Protocols

- **2.5/3/4G mobile networks**
- **Photonic networks**
- **IP-based networks**
- **Quality of service and service architectures**

Teletraffic Theory and Engineering

- **Performance modelling and simulation**
- **System and network optimization and planning**

Security and privacy in networks and services

- **Authentication, confidentiality and pseudonymity**
- **Design of secure systems**

System design

- **Design of digital systems**
- **Software engineering**

Infotech

Master of Science in Information Technologies

- International graduate program of the ECE/CS department in Stuttgart
- 1.5 years master program
- all courses tought in English

Possible focus options

- Information technology
- Embedded systems

Program includes

- classes
- labs
- industrial internship
- master thesis

Further Information

☞ http://www.infotech.uni-stuttgart.de

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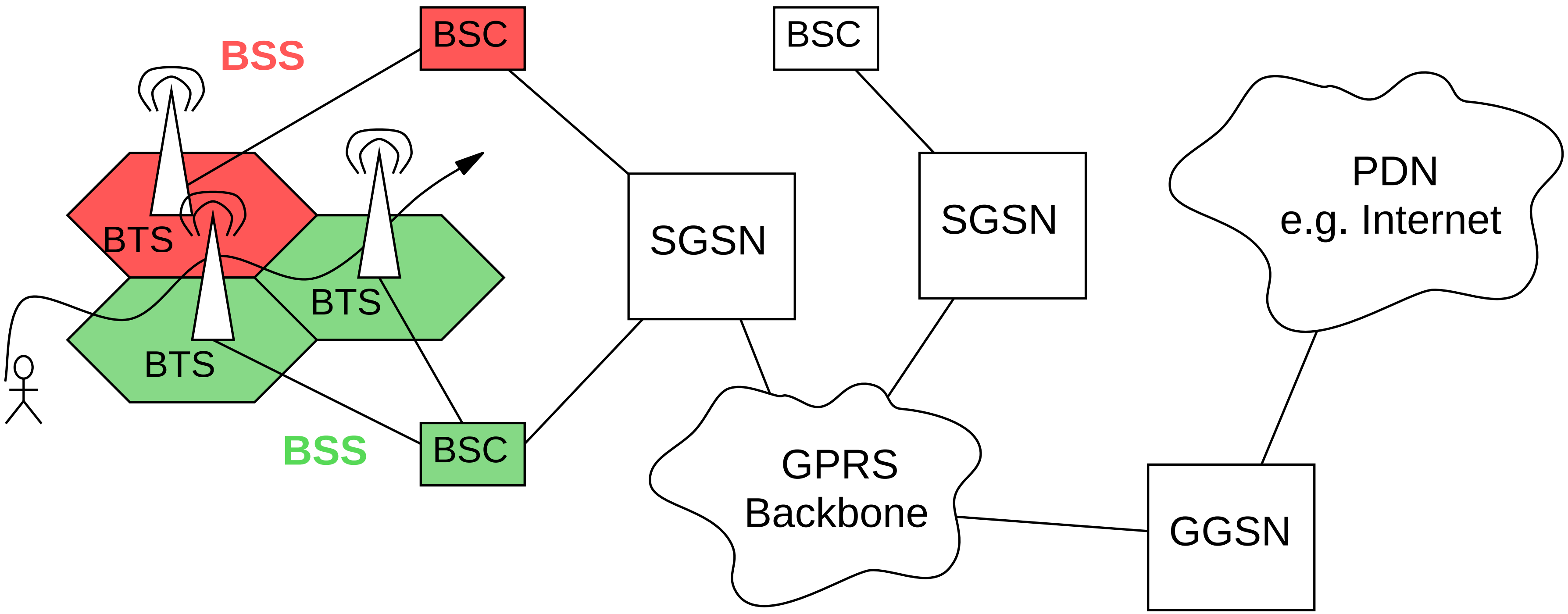
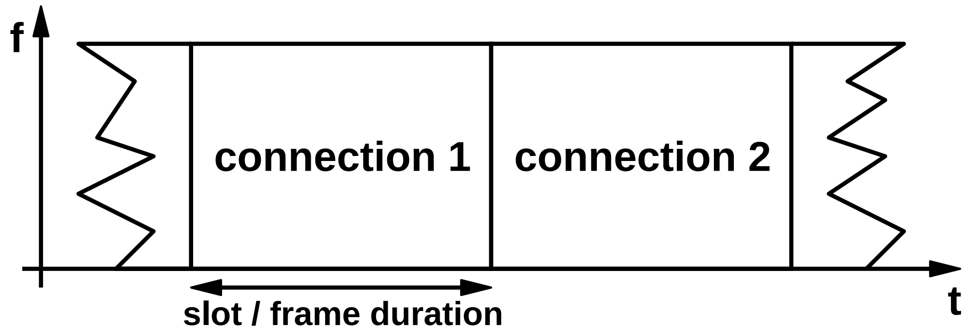
Architecture of a GSM/GPRS Network



BTS: Base Transceiver Station
BSC: Base Station Controller } **BSS**
SGSN: Serving GPRS Support Node
GGSN: Gateway GPRS Support Node

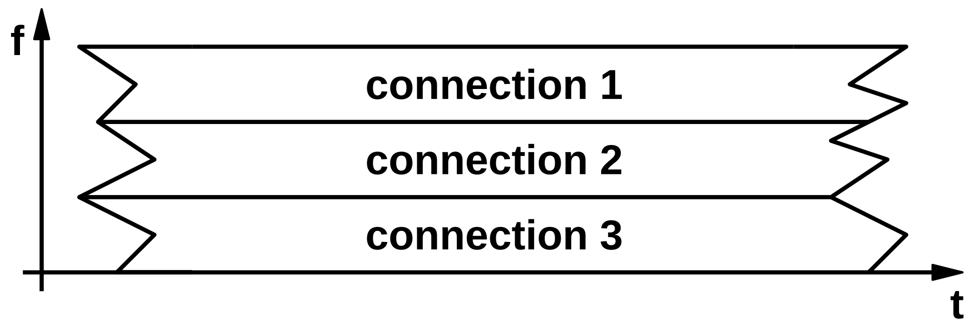
Time Division Multiple Access (TDMA)

- **Divide time axis into time slots**
- **Assign one or more time slots to individual connections**



Frequency Division Multiple Access (FDMA)

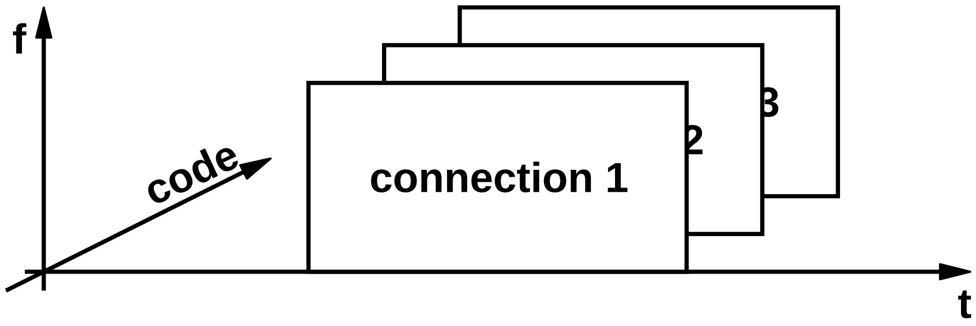
- **Divide frequency axis into several frequency bands**
- **Assign one or more frequency bands to individual connections**



Multiplexing Techniques II

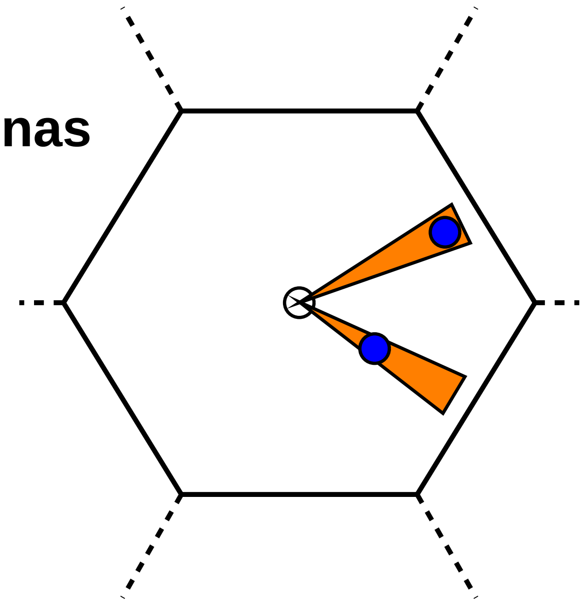
Code Division Multiple Access (CDMA)

- All users transmit at the same time on the same time and frequency resources
- Assign connections different orthogonal codes



Space Division Multiple Access (SDMA)

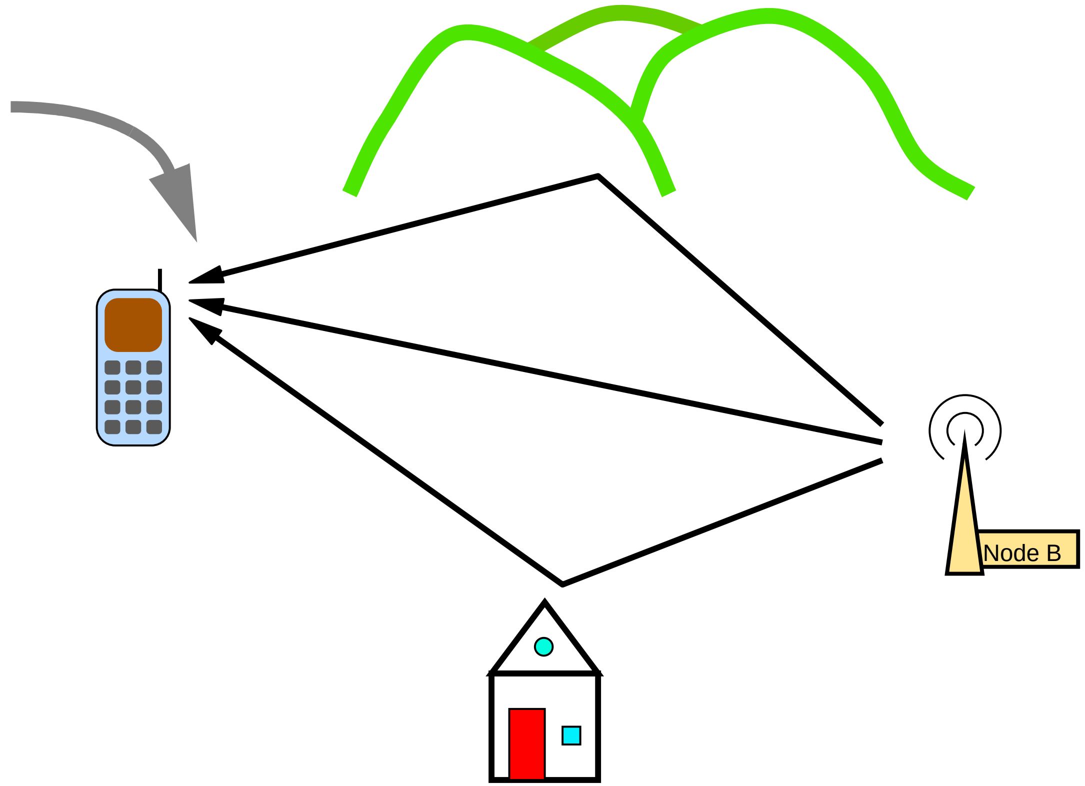
- Separate users in space by directional antennas
- Separated users can transmit on same frequency / time resources

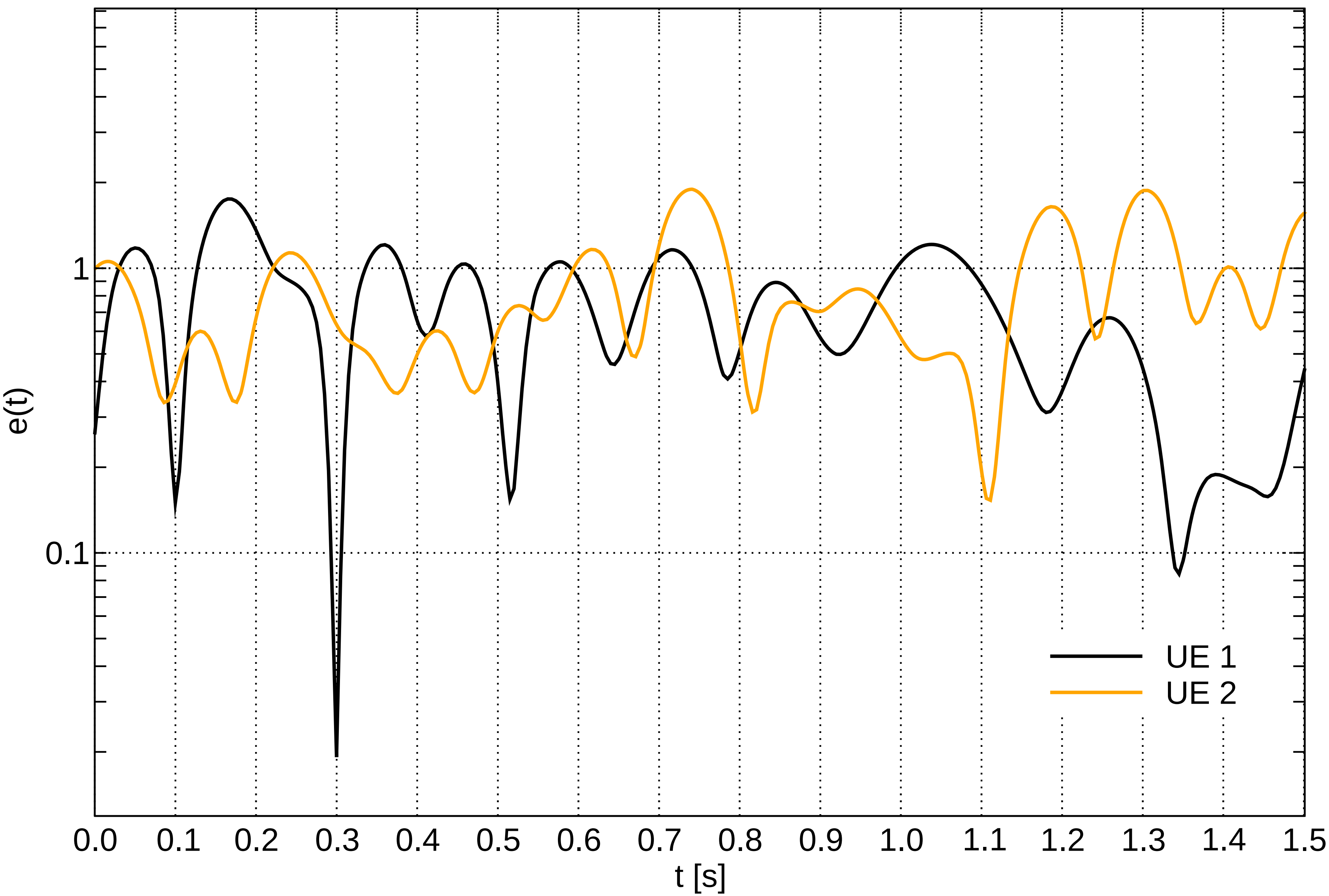


Three different additive signal fading types

- **Propagation loss: Distance dependent signal fading**
- **Slow Fading / Shadowing: Fading due to shadowing of buildings, etc.**
- **Fast Fading: Fading due to constructive and destructive interference in multipath fading environments**

constructive interference
destructive interference





e(t)
1
0.1
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
t [s]
UE 1
UE 2

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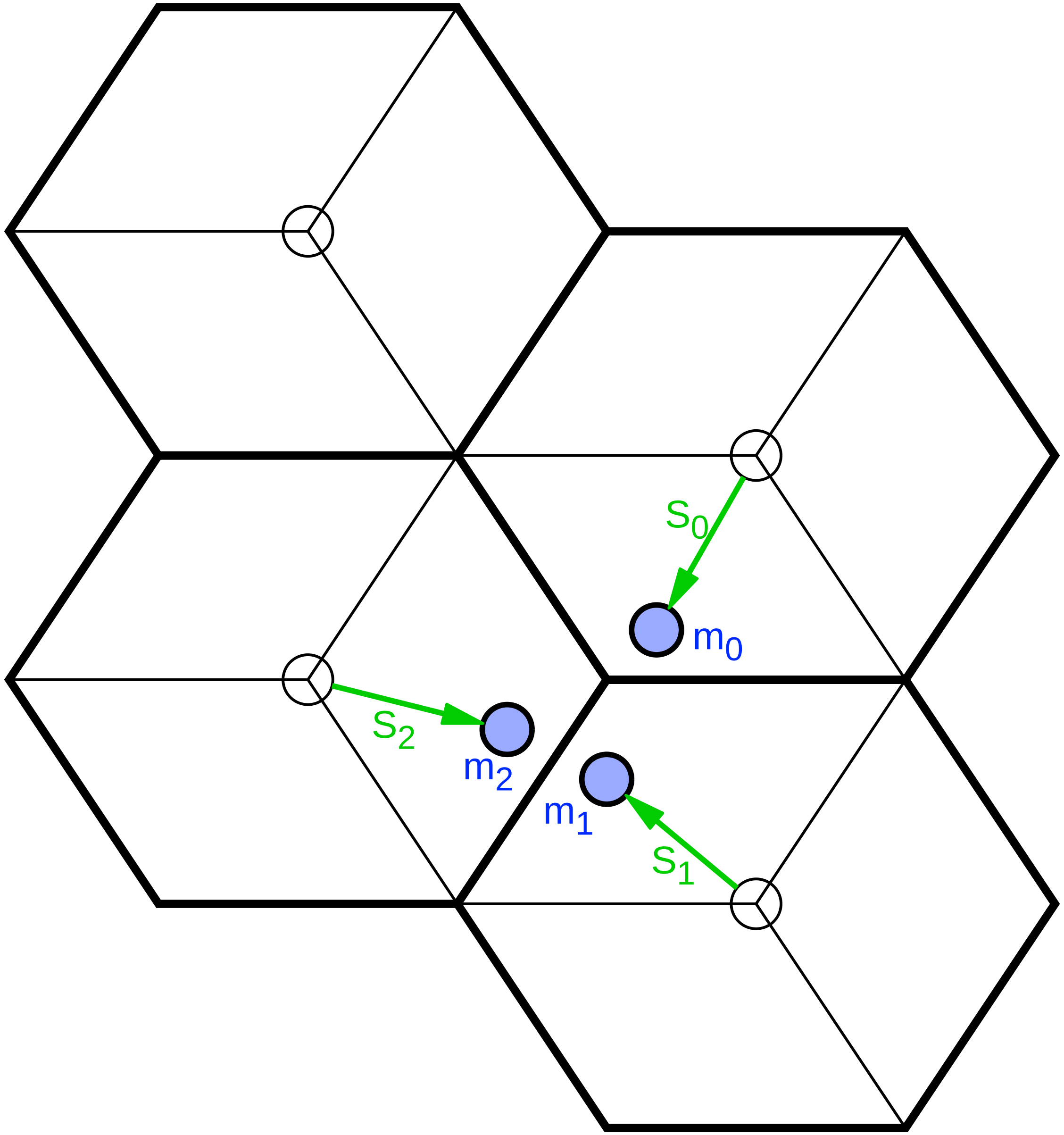
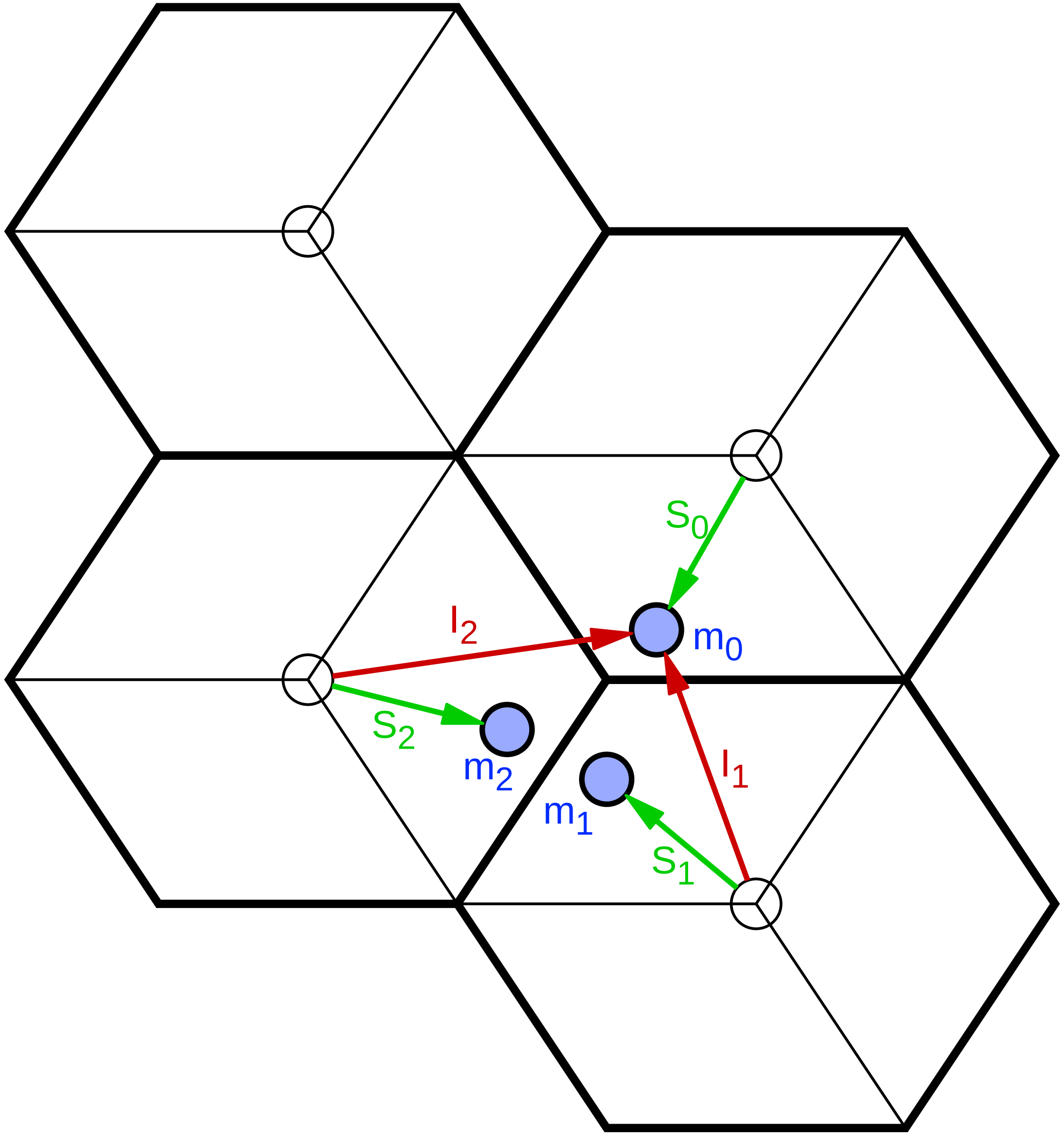
Interference Between Neighboring Cells



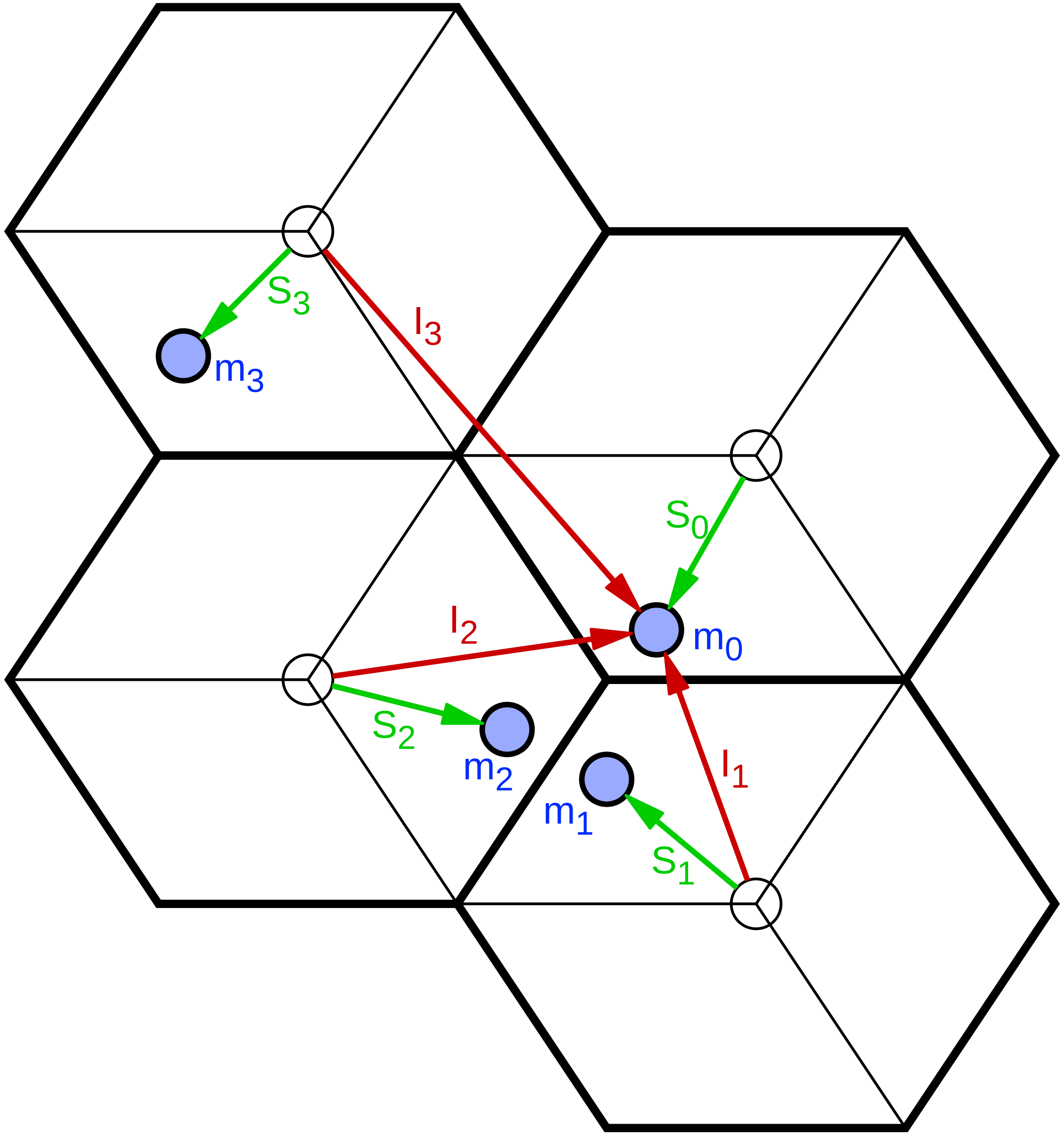
- **Mobiles m_i receive signal with received power S_i**

Interference Between Neighboring Cells



- Mobiles m_i receive signal with received power S_i
- Transmissions to m_1 and m_2 create interference to m_0

Interference Between Neighboring Cells



- Mobiles m_i receive signal with received power S_i
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- Even transmission to m_3 creates interference to m_0

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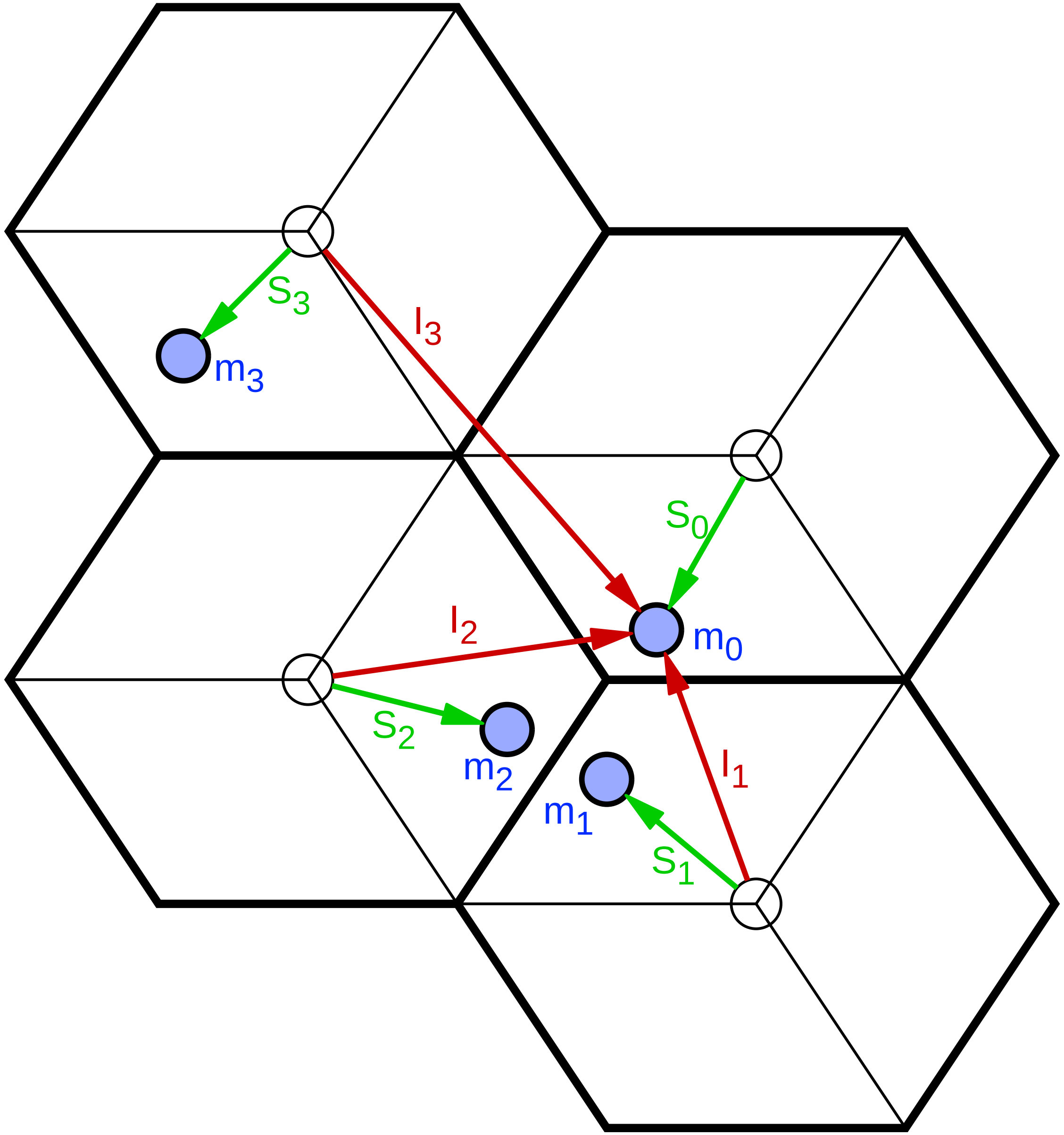

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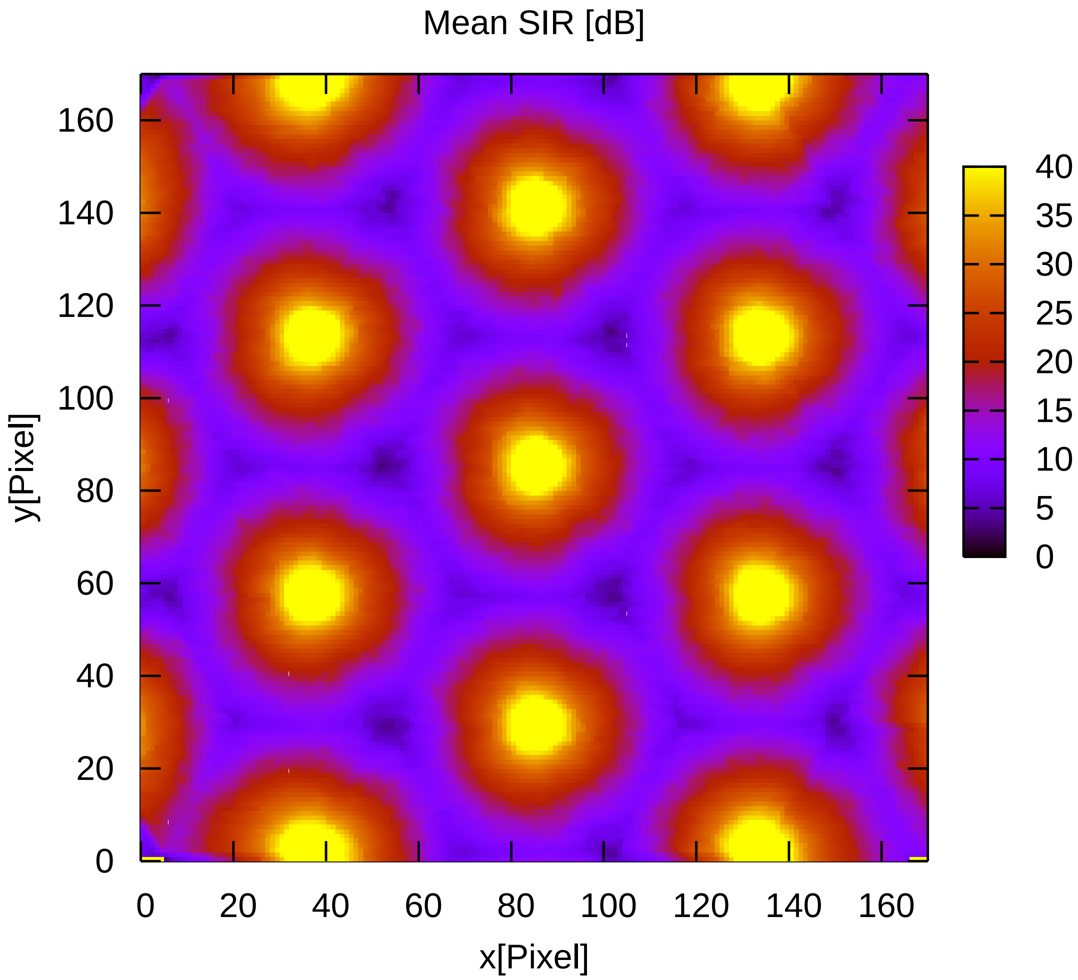
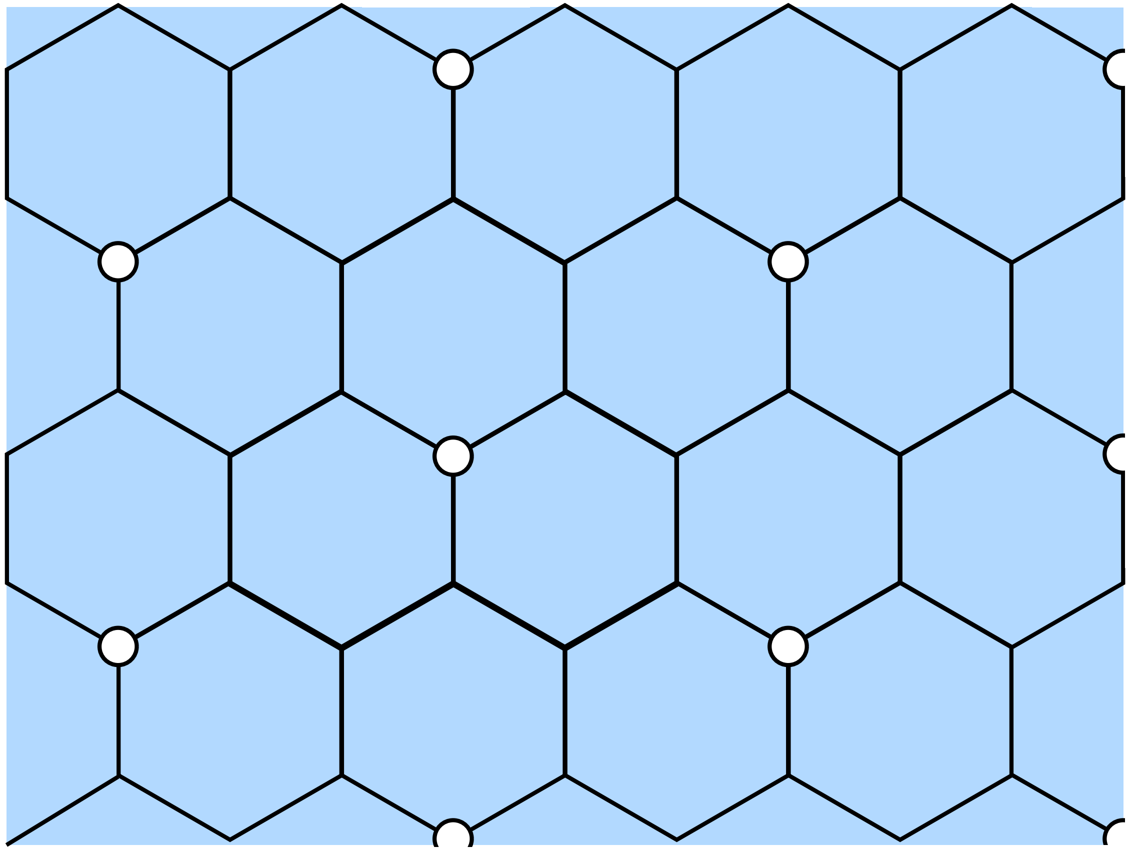
☞ $$SINR = \frac{S_o}{N_0 + \sum_{i \in \Im} I_i}$$

Interference Between Neighboring Cells

Sample Mean SINR over Area



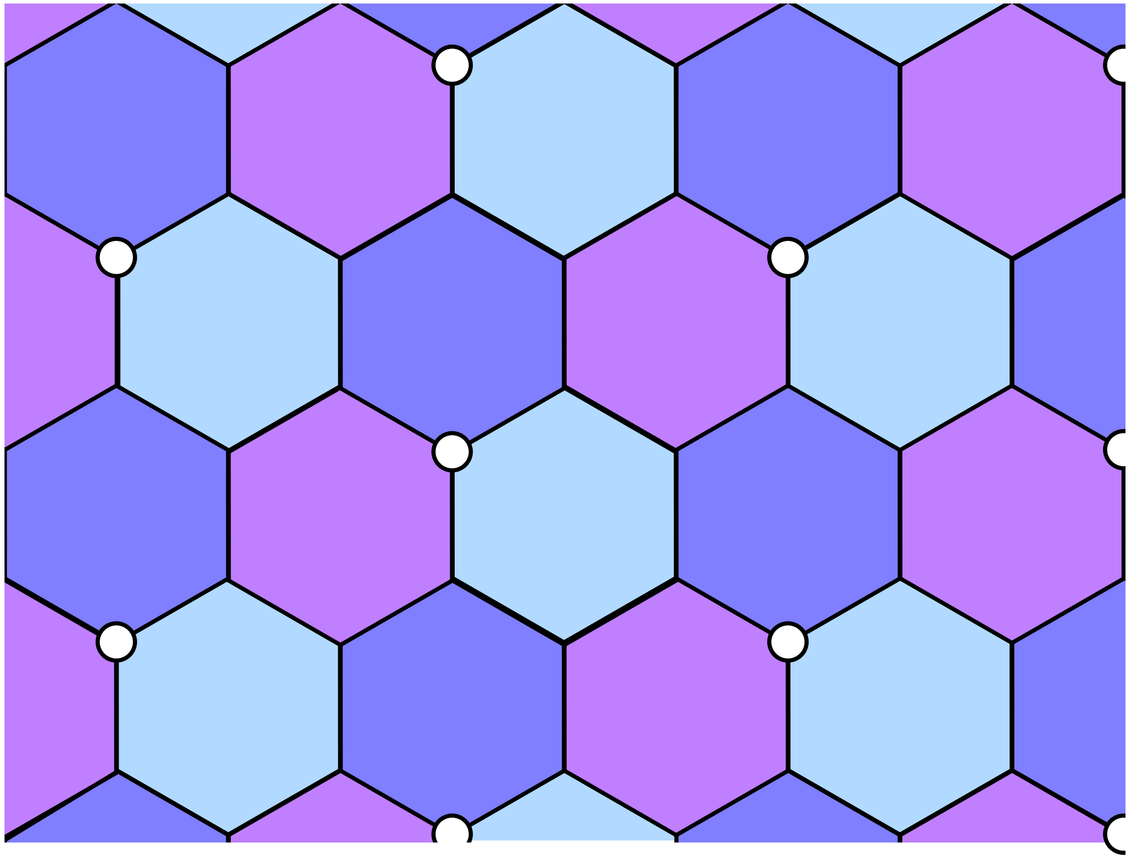
Interference in Cellular Networks



- **Cellular 802.16e WiMAX network based on Orthogonal Frequency Division Multiple Access (OFDMA, combined FDM/TDM)**

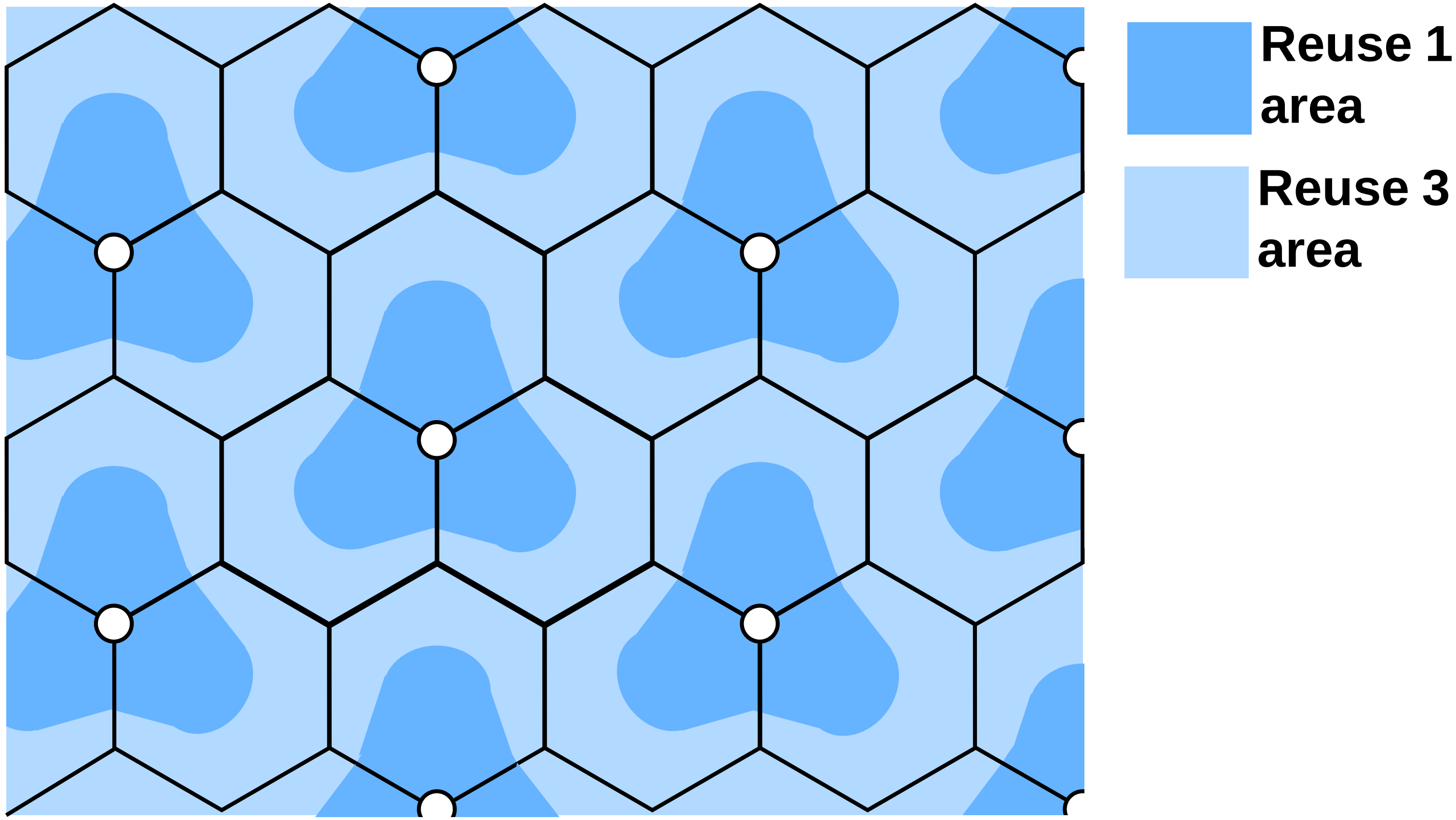
  e.g., 802.16e (WiMax), 3GPP Long Term Evolution (LTE)

- **Major issue in FDM / TDM networks: inter-cellular interference**



- **Major issue in FDM / TDM networks: inter-cellular interference**
  - ☞ standard solution: frequency reuse pattern
    disadvantage: waste of precious frequency resources

Interference in Cellular Networks FFR



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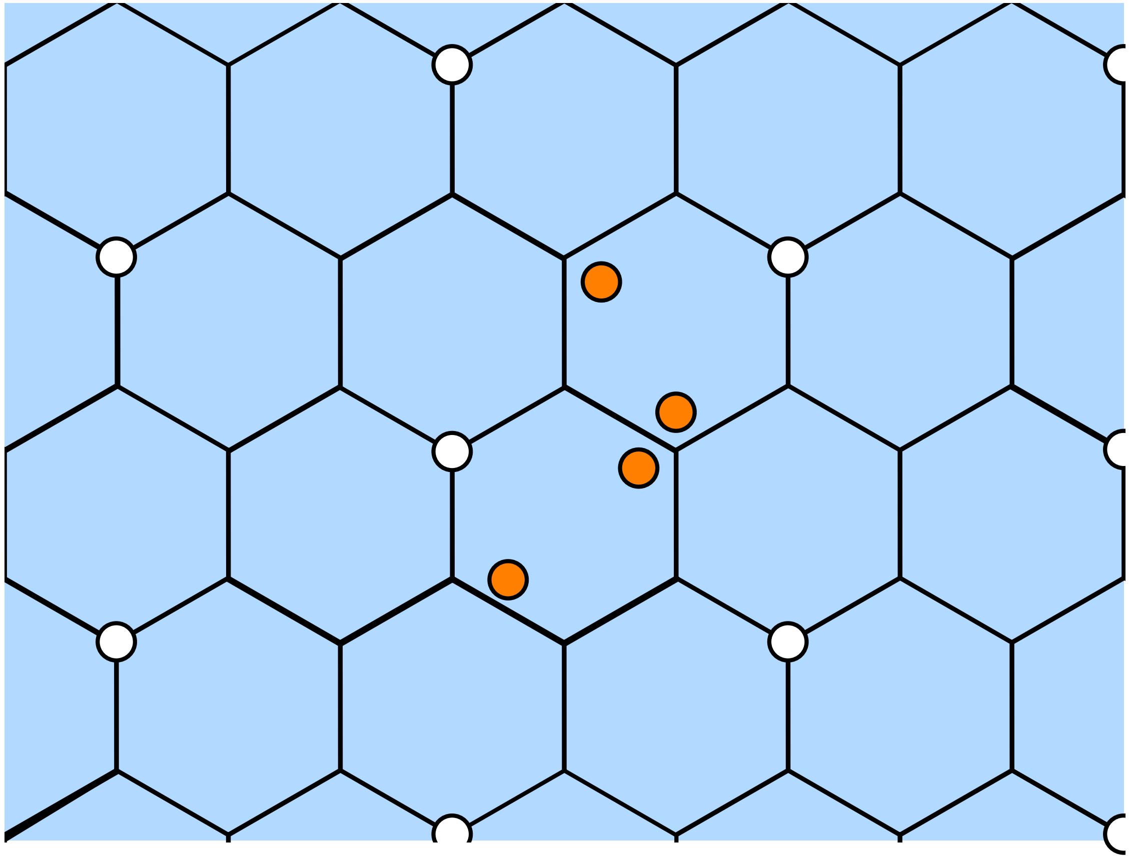
  - ☞ optimization: Fractional Frequency Reuse (FFR)

Interference in Cellular Networks



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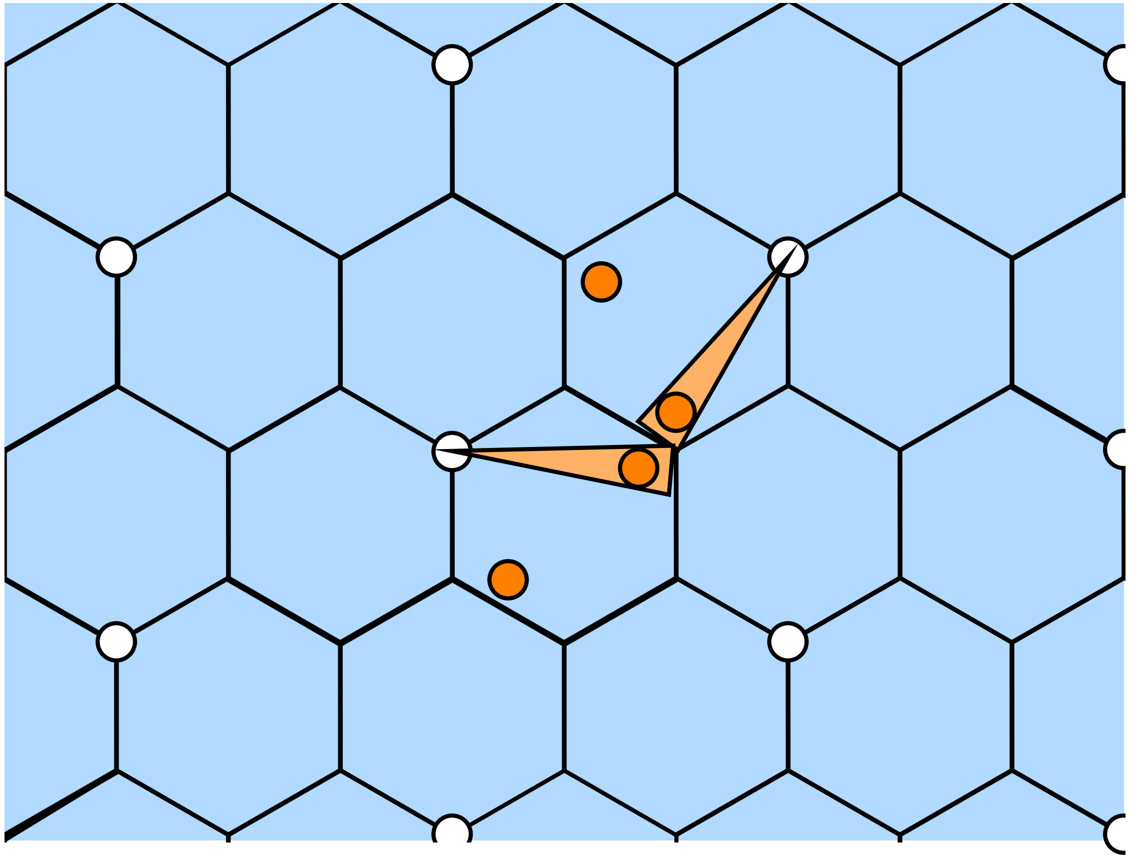
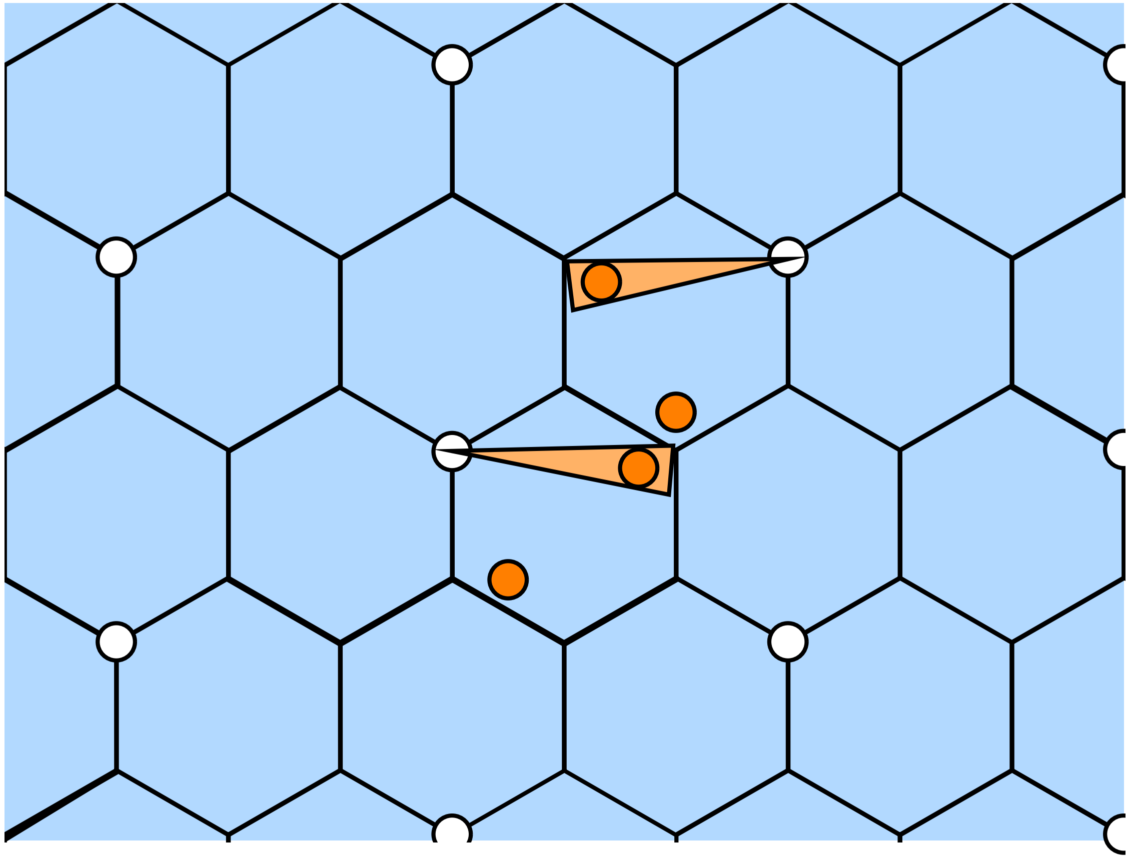
Interference in Cellular Networks



- **Major issue in FDM / TDM networks: inter-cellular interference**
  - ☞ standard solution: frequency reuse pattern
  - ☞ optimization: Fractional Frequency Reuse (FFR)
  - ☞ Usage of directional antennas to lower inter-cellular interference

Interference in Cellular Networks



- **Major issue in FDM / TDM networks: inter-cellular interference**
  - standard solution: frequency reuse pattern
  - optimization: Fractional Frequency Reuse (FFR)
  - Usage of directional antennas to lower inter-cellular interference
    ☞ Additional coordination necessary ☞ interference coordination (IFCO)

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Intercellular Coordination

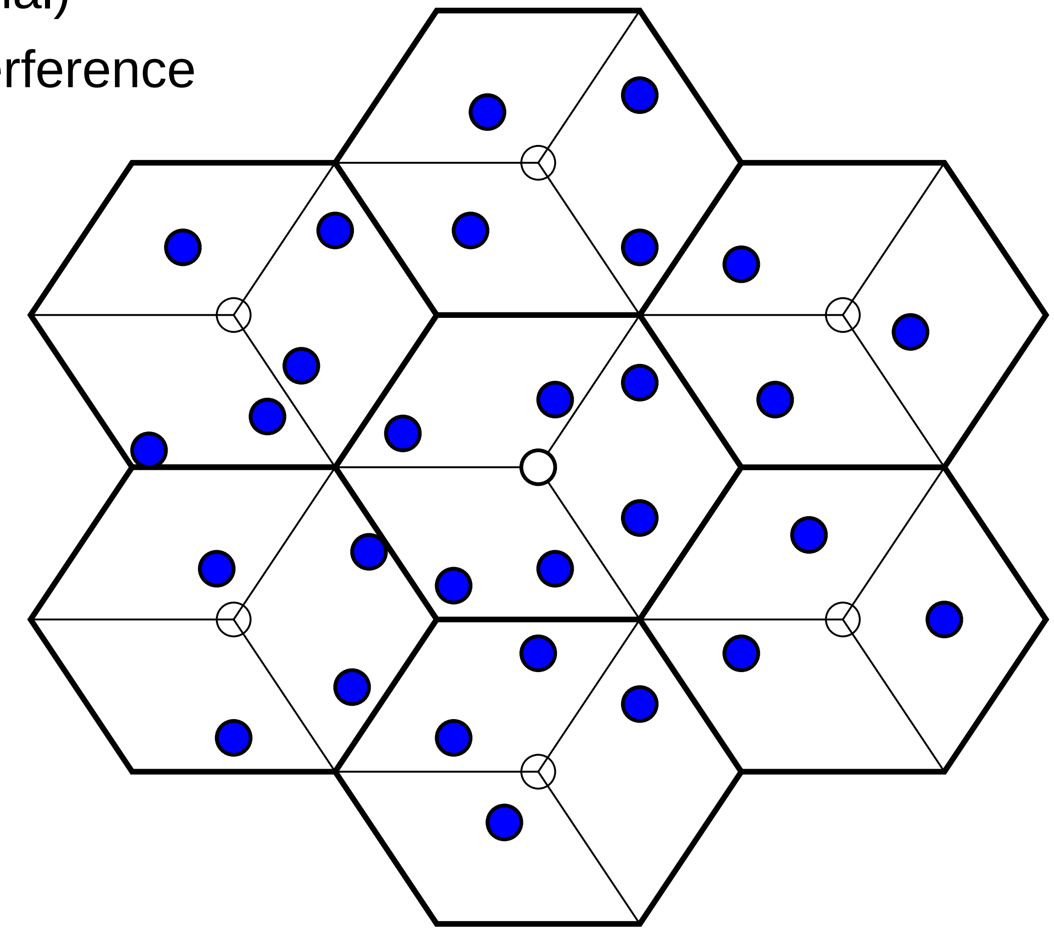
Two-step Approach

1. **Construction of interference graph *G***
   - Vertices $m_i \in \boldsymbol{M}$
   - Edges $e_{ij} \in \boldsymbol{E}$ (non-directional)

   ☞ graph represents critical interference relations

2. **Assignment of resources based on interference graph**

   ☞ connected terminals must not be served on the same resources



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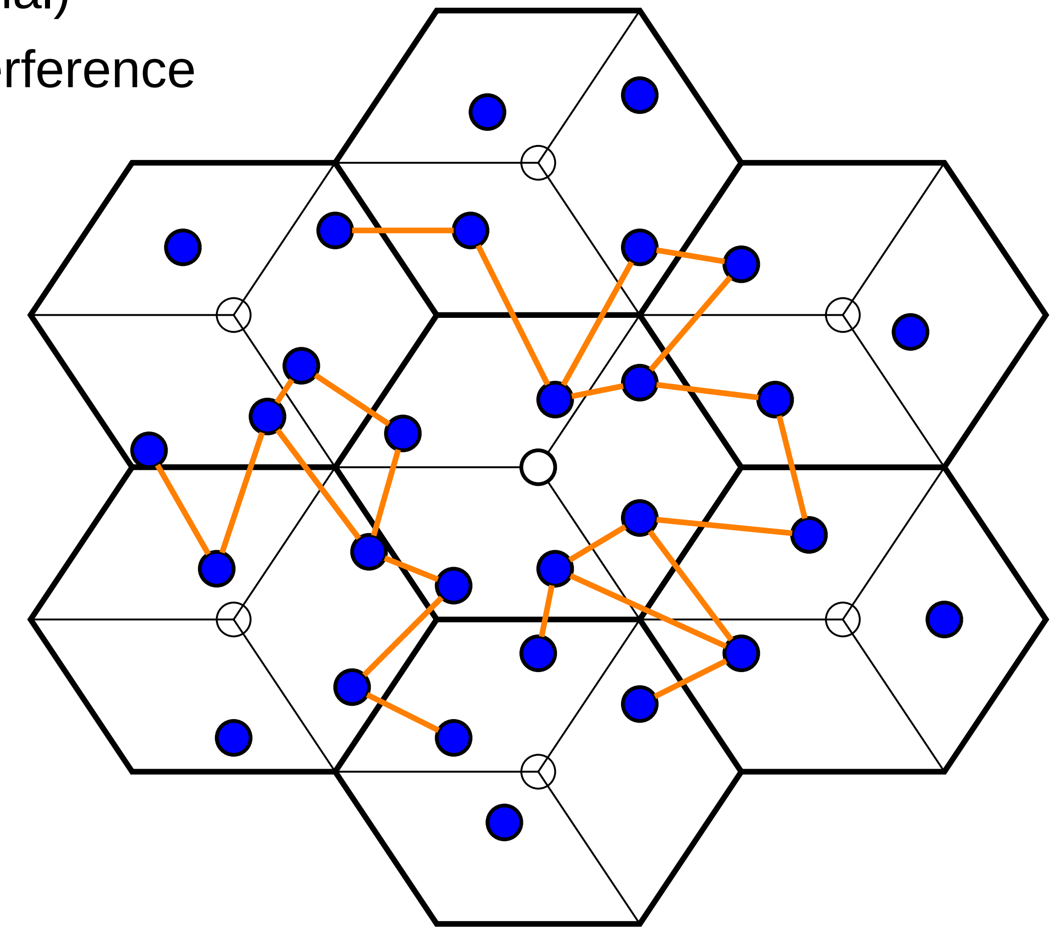
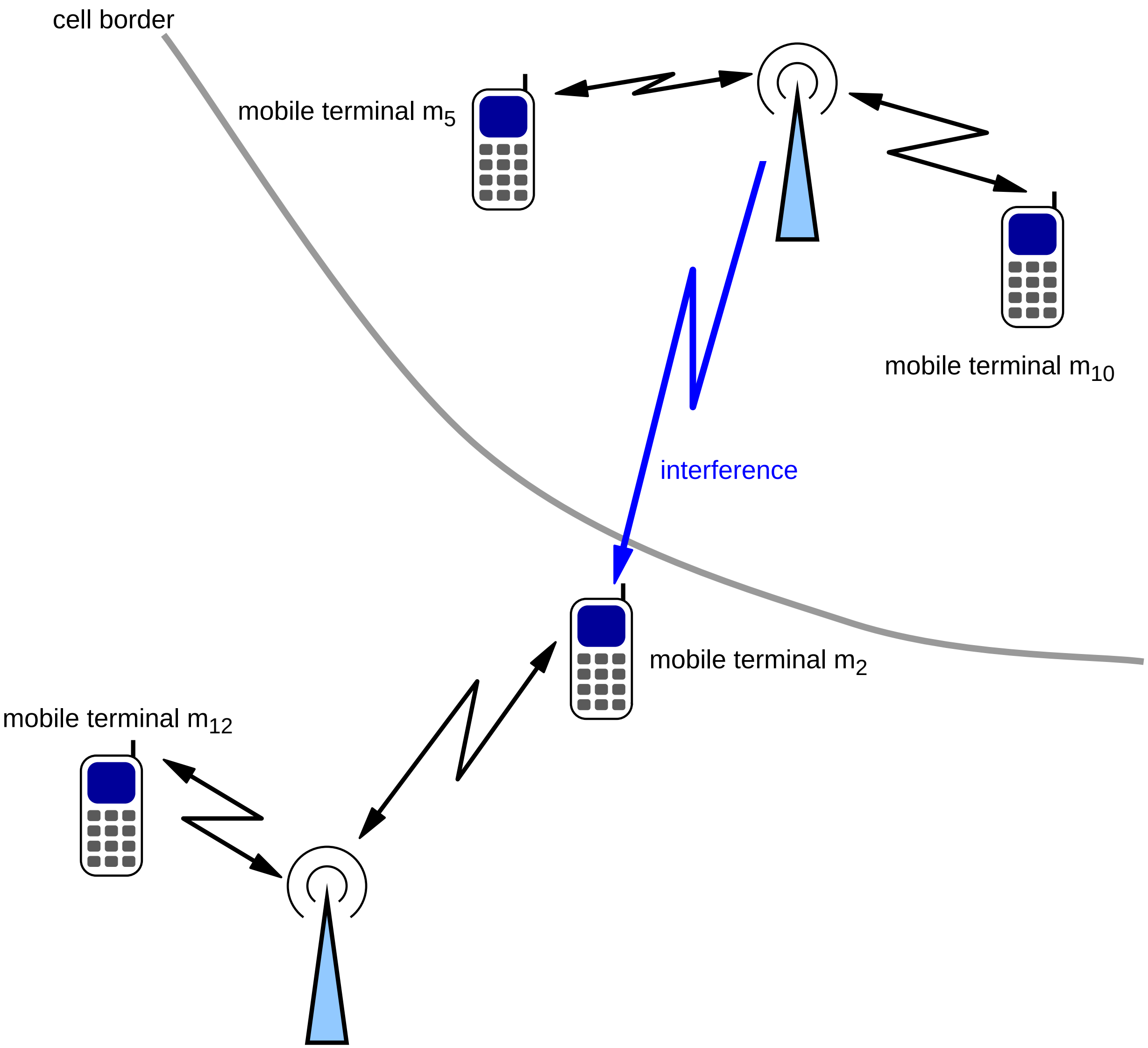


Global Scheme with Central Entity



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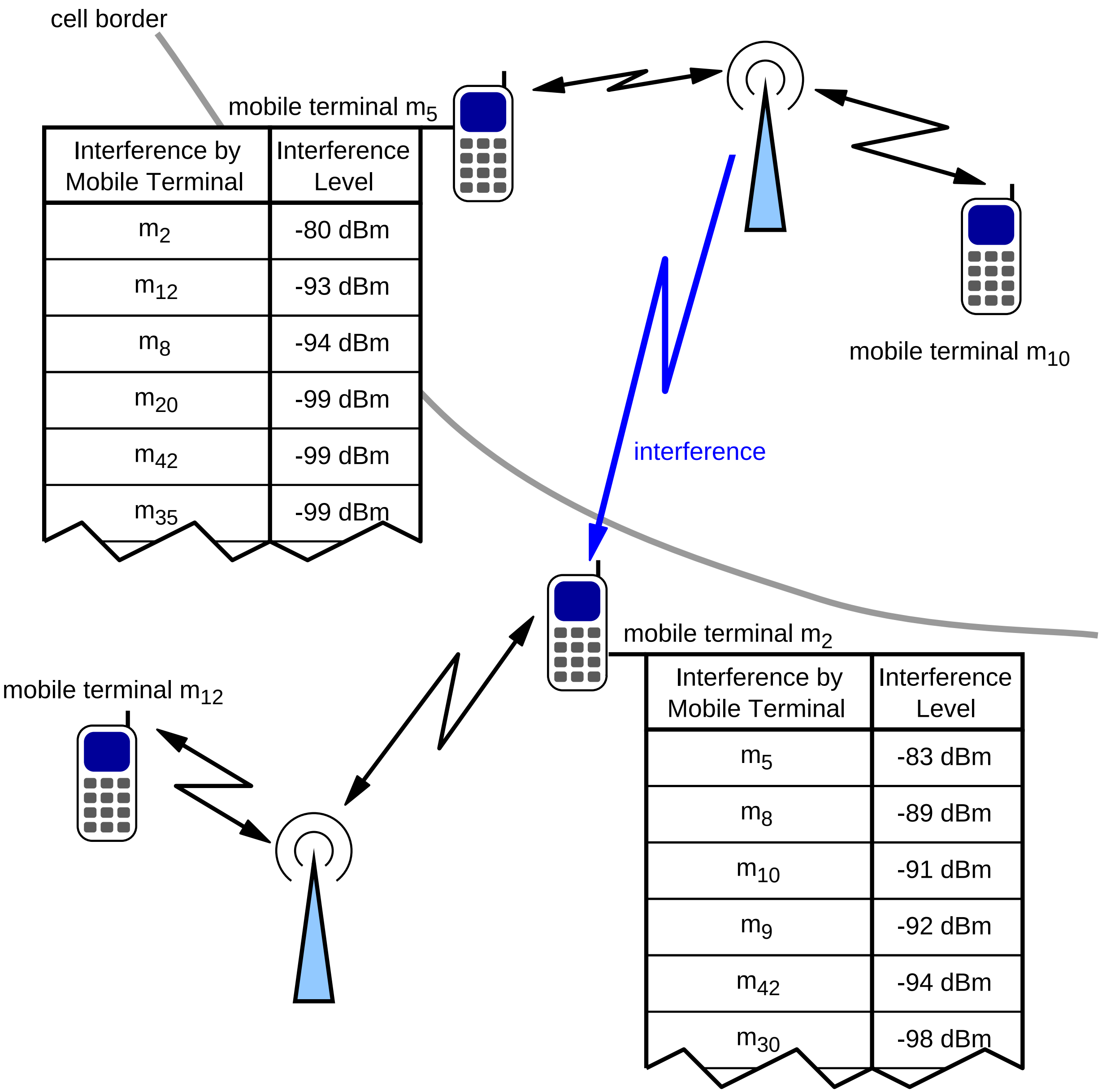


Mobile terminal m_5:

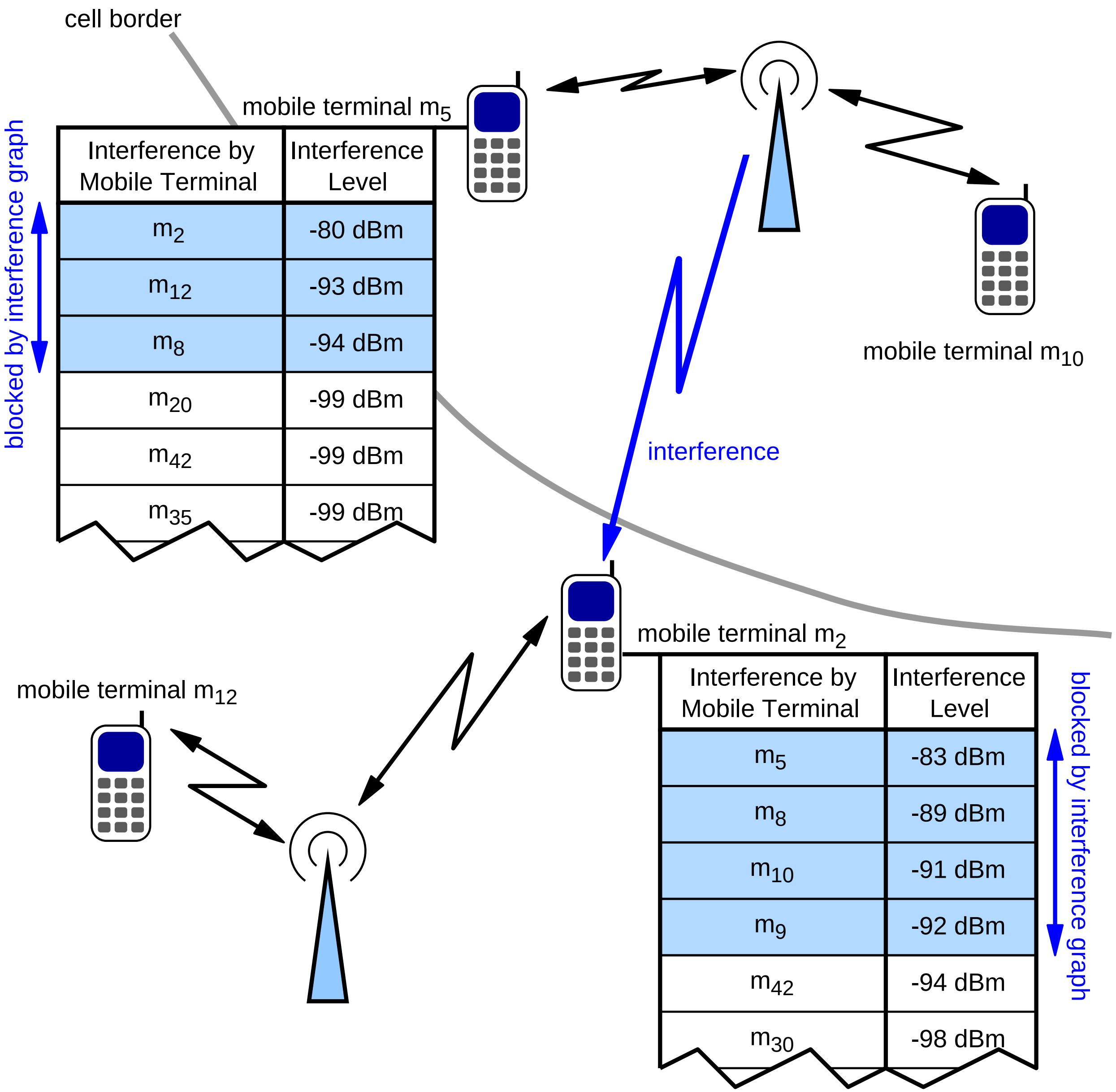
Interference by Mobile Terminal	Interference Level
m_2	-80 dBm
m_{12}	-93 dBm
m_8	-94 dBm
m_{20}	-99 dBm
m_{42}	-99 dBm
m_{35}	-99 dBm

Mobile terminal m_2:

Interference by Mobile Terminal	Interference Level
m_5	-83 dBm
m_8	-89 dBm
m_{10}	-91 dBm
m_9	-92 dBm
m_{42}	-94 dBm
m_{30}	-98 dBm

- **Calculation of signal strength of interferers for a particular mobile terminal *m_j***

Global Scheme with Central Entity



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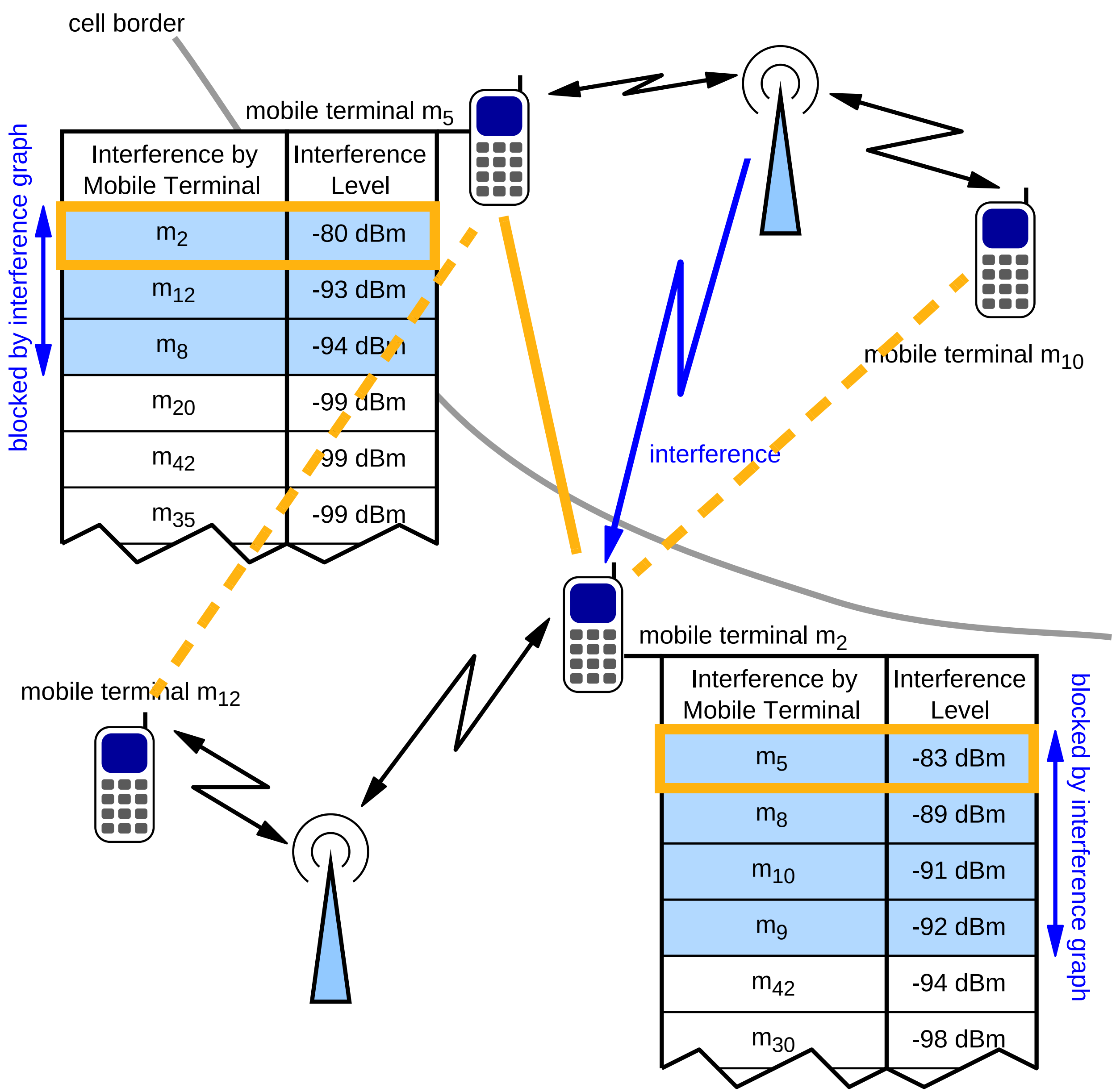
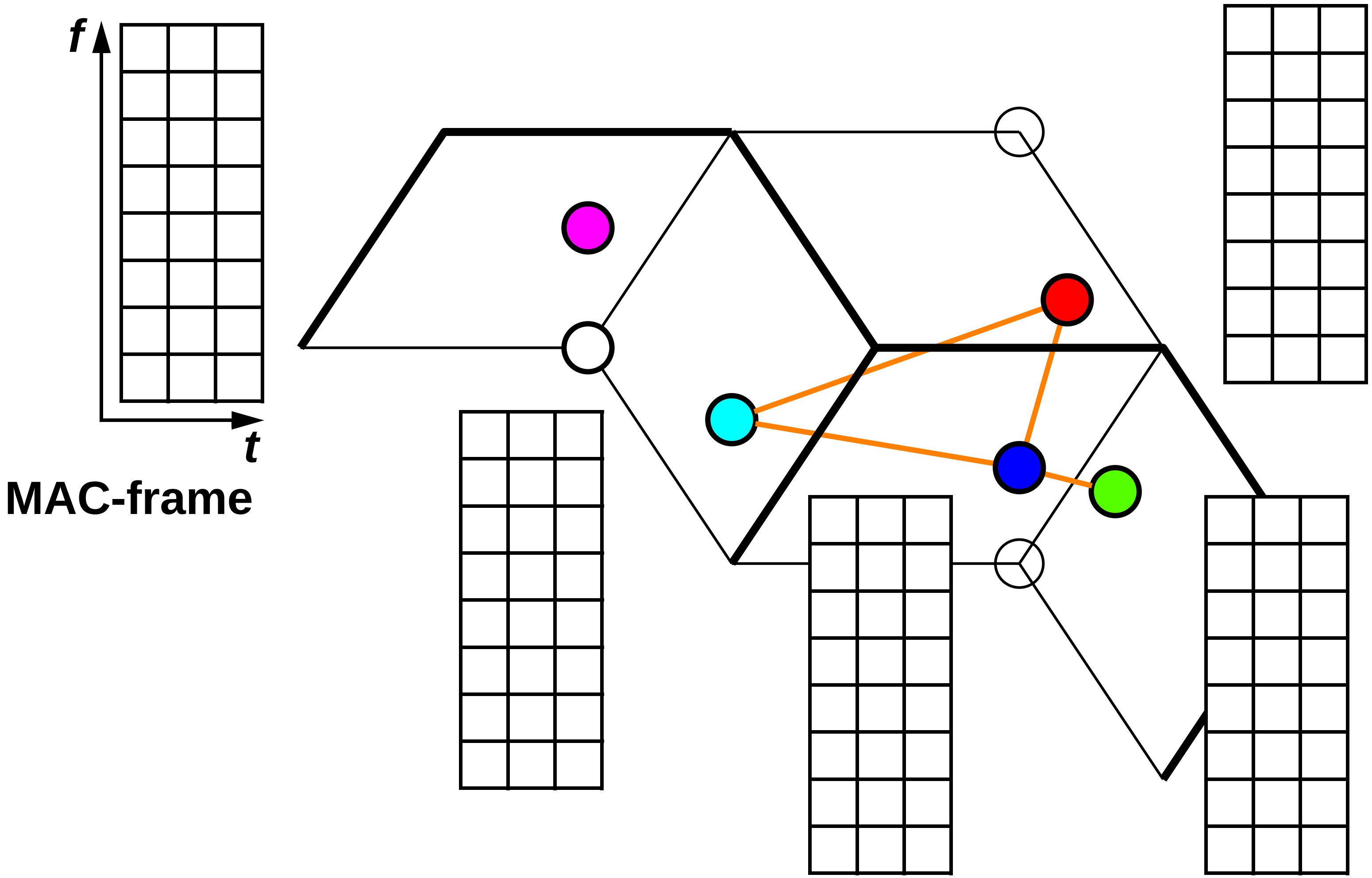
- **Calculation of signal strength of interferers for a particular mobile terminal m_j**
- **Blocking of strongest interferers such that a desired minimum SIR D_S is achieved**

Global Scheme with Central Entity

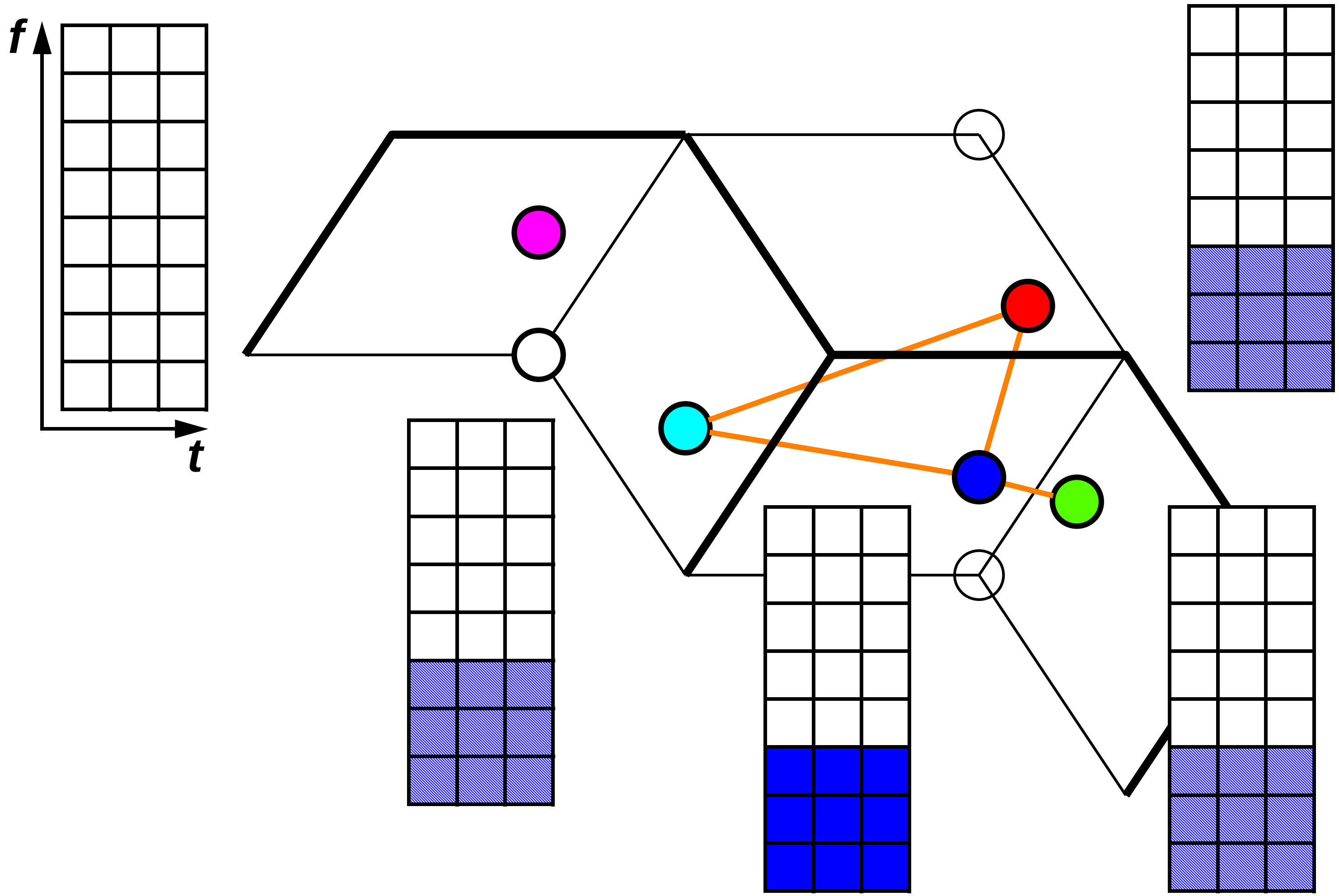


- **Calculation of signal strength of interferers for a particular mobile terminal m_j**
- **Blocking of strongest interferers such that a desired minimum SIR D_S is achieved**
- **Blocked terminals are connected by edge in interference graph**

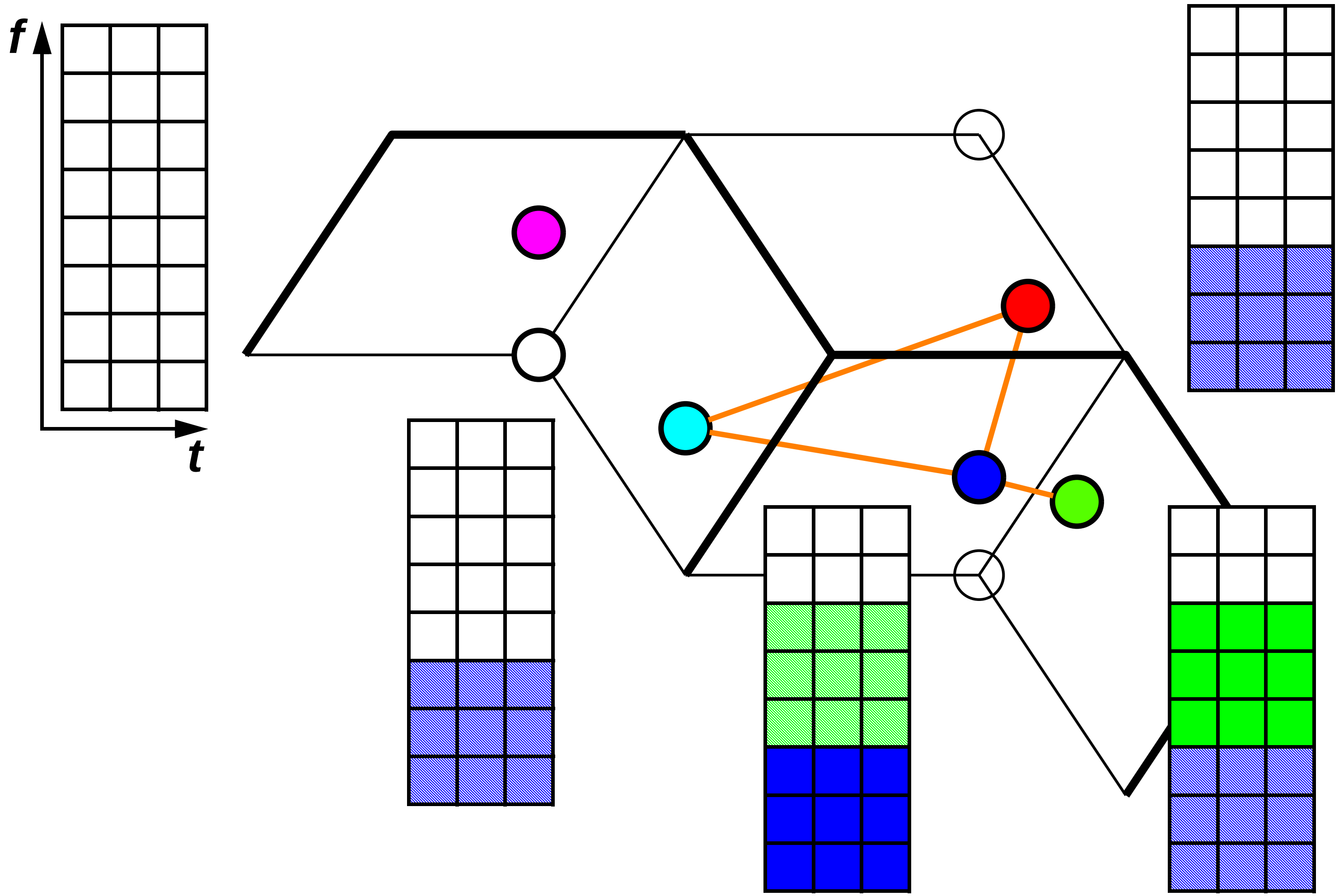
Resource Assignment



Resource Assignment



Resource Assignment



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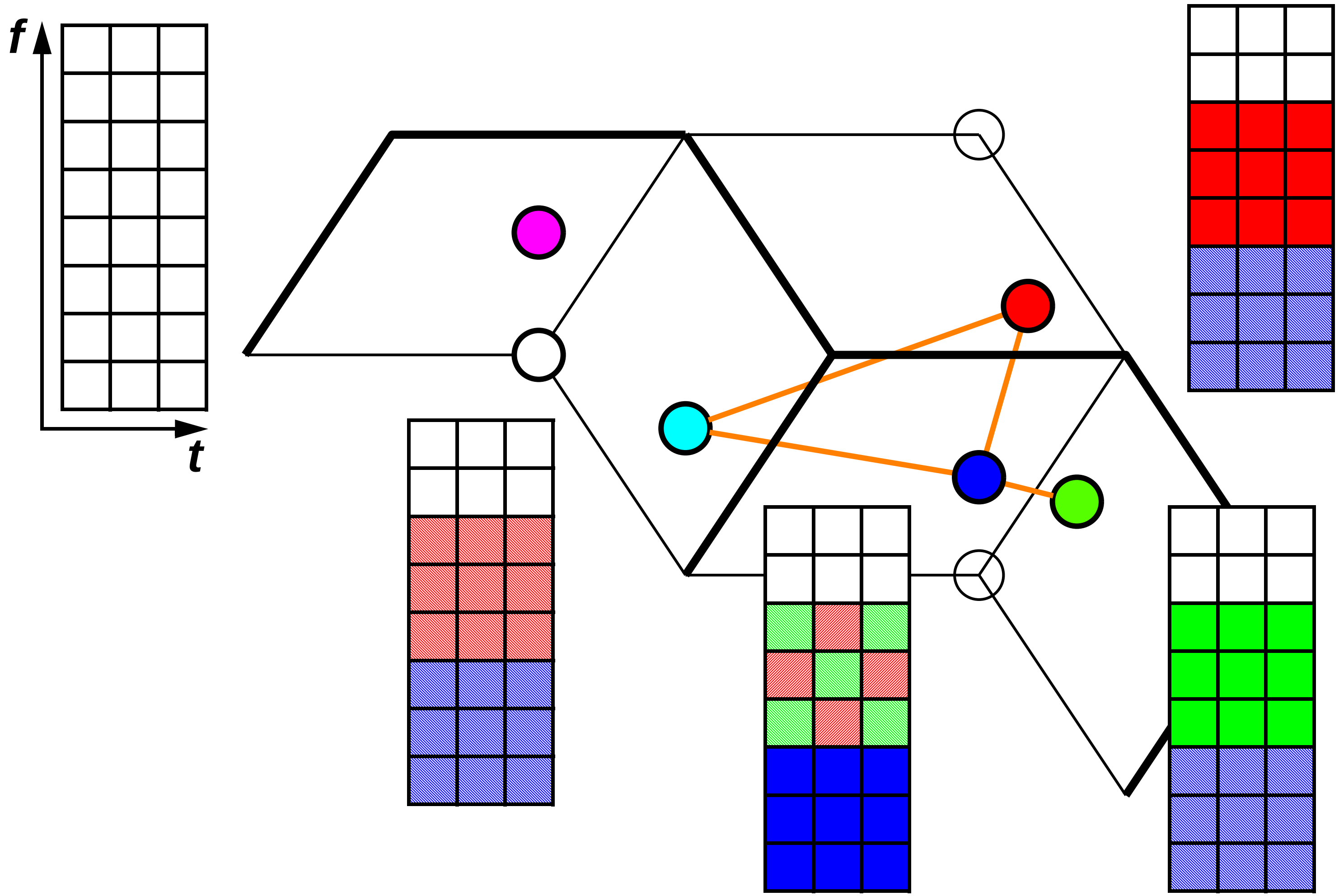
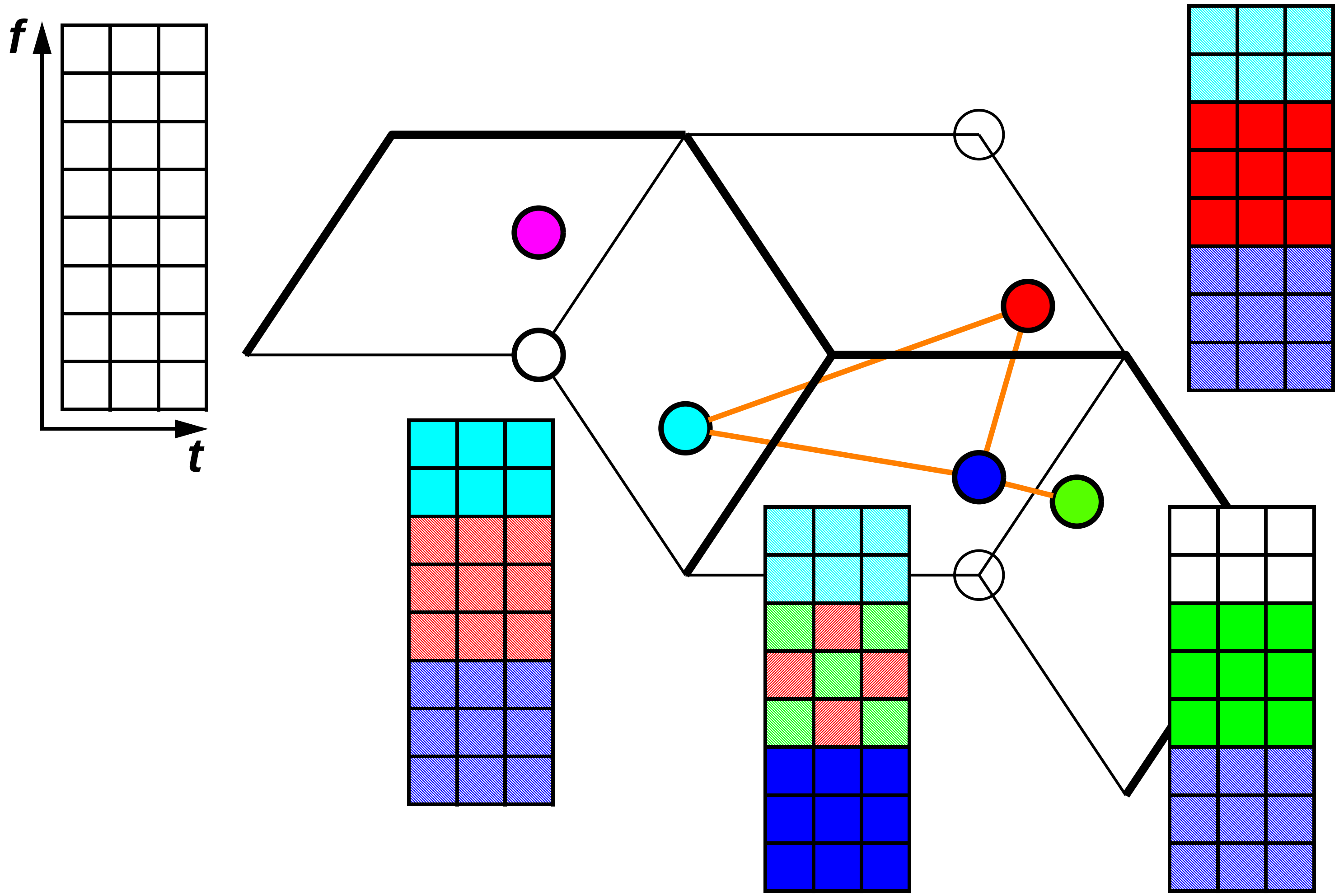


Resource Assignment



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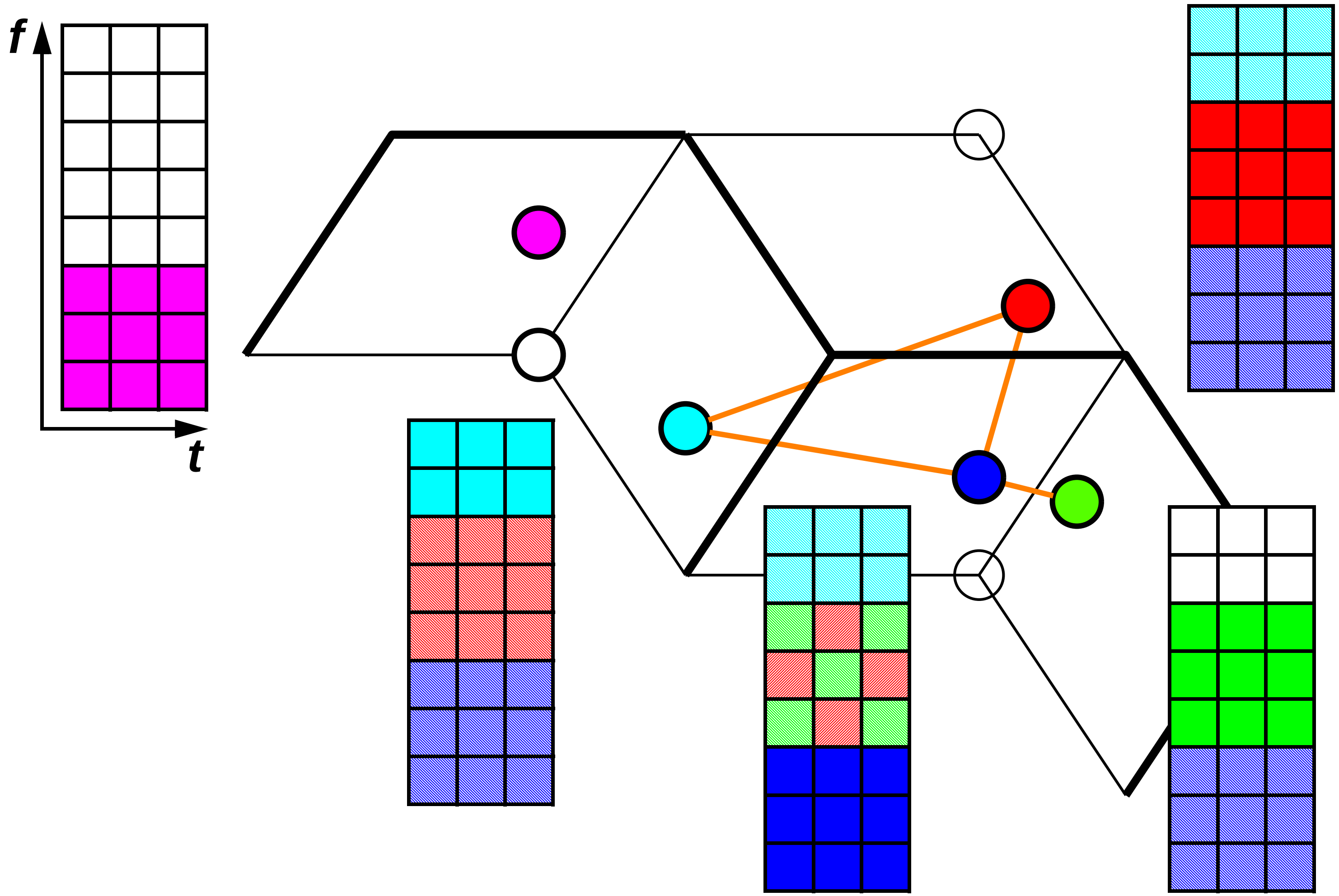

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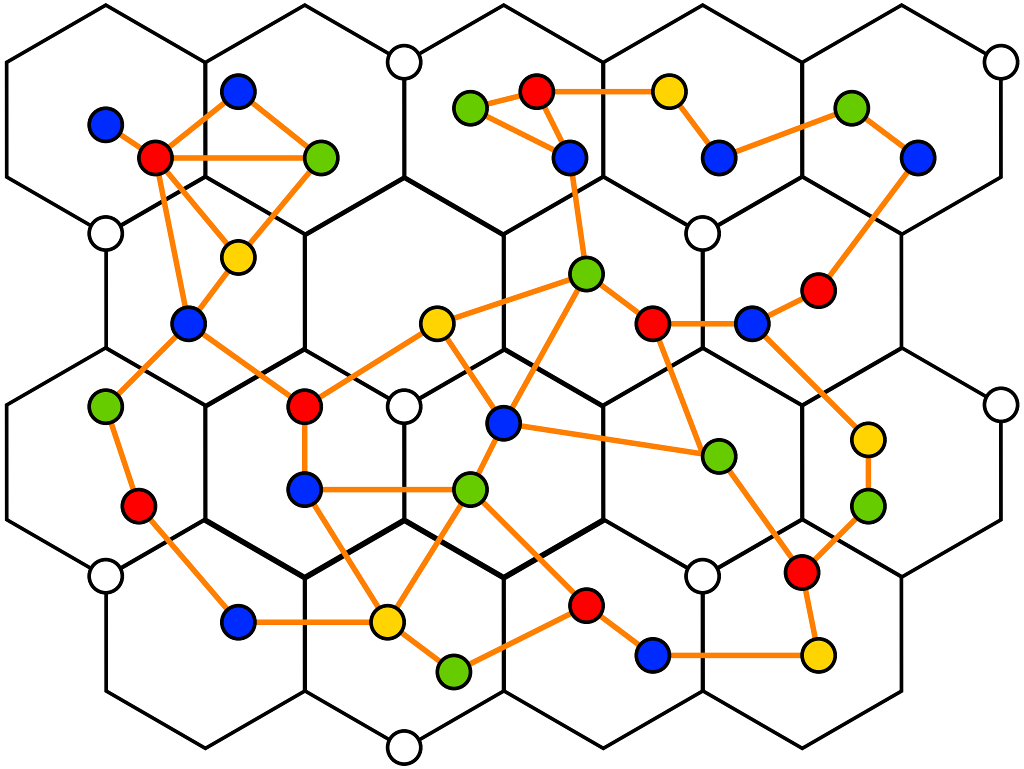
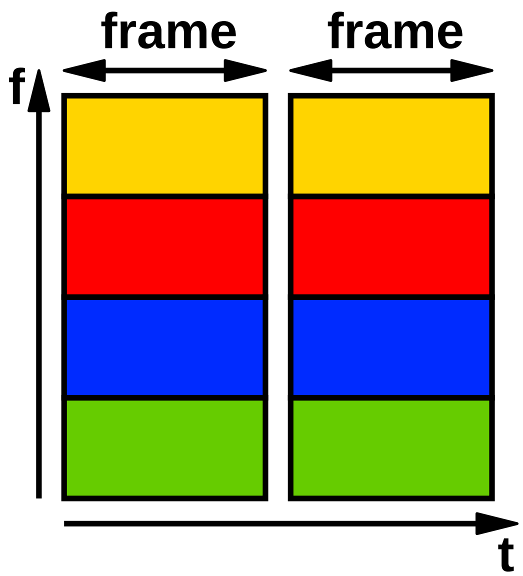
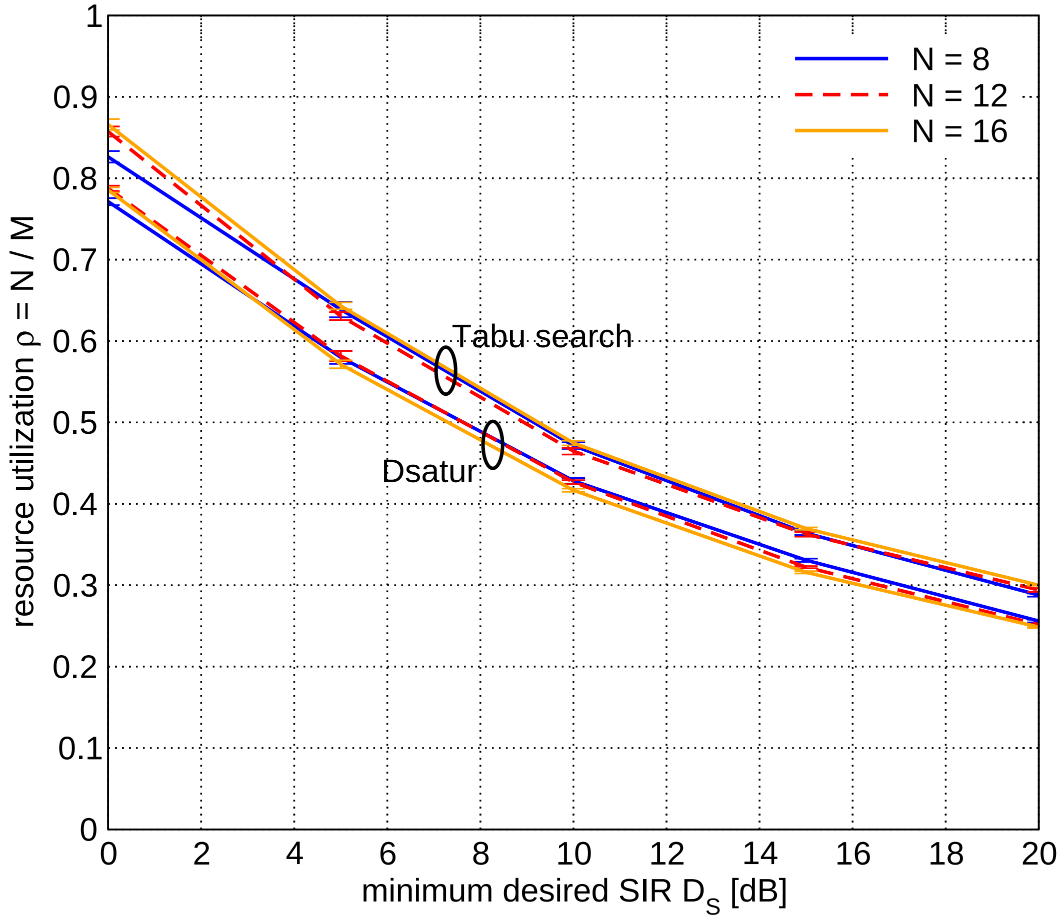


Example of resource mapping



- **Treat air interface resources (time / frequency slots) as colors of graph**
- **Resources can be assigned to mobile terminals by coloring of the interference graph**
  - graph coloring is NP hard
  - large number of heuristics: genetic algorithms, simulated annealing, tabu search, other heuristics (e.g., Dsatur)

Resource Assignment by Graph Coloring



N = number of mobiles
M = number of colors

- **Resource utilization decreases as desired minimum SIR D_S is increased**
- **Resource utilization is independent of number of mobile terminals**
- **10% improvement with Tabu search compared to simple heuristic Dsatur**

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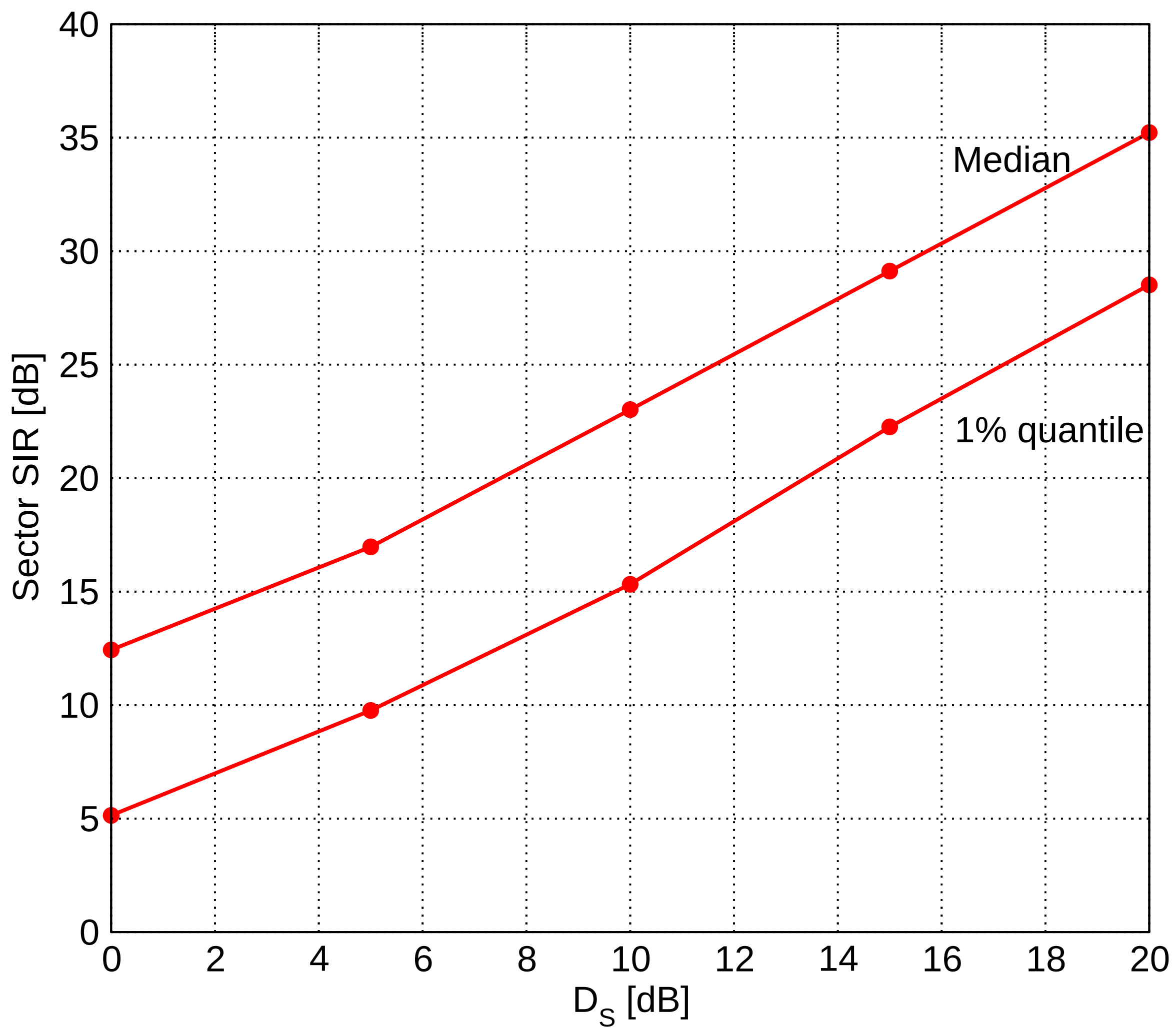
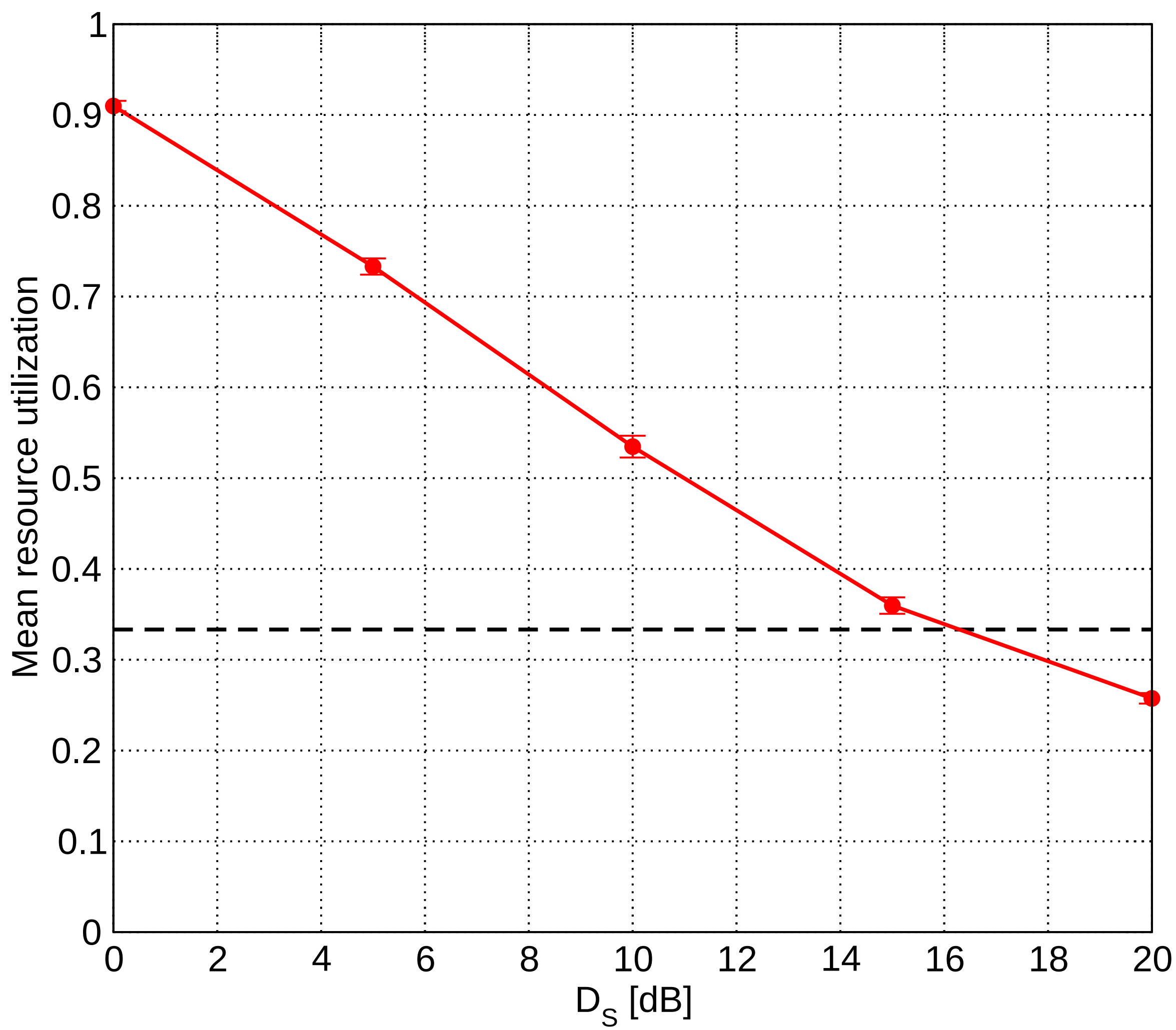
Dependence of SIR on desired SINR D_S



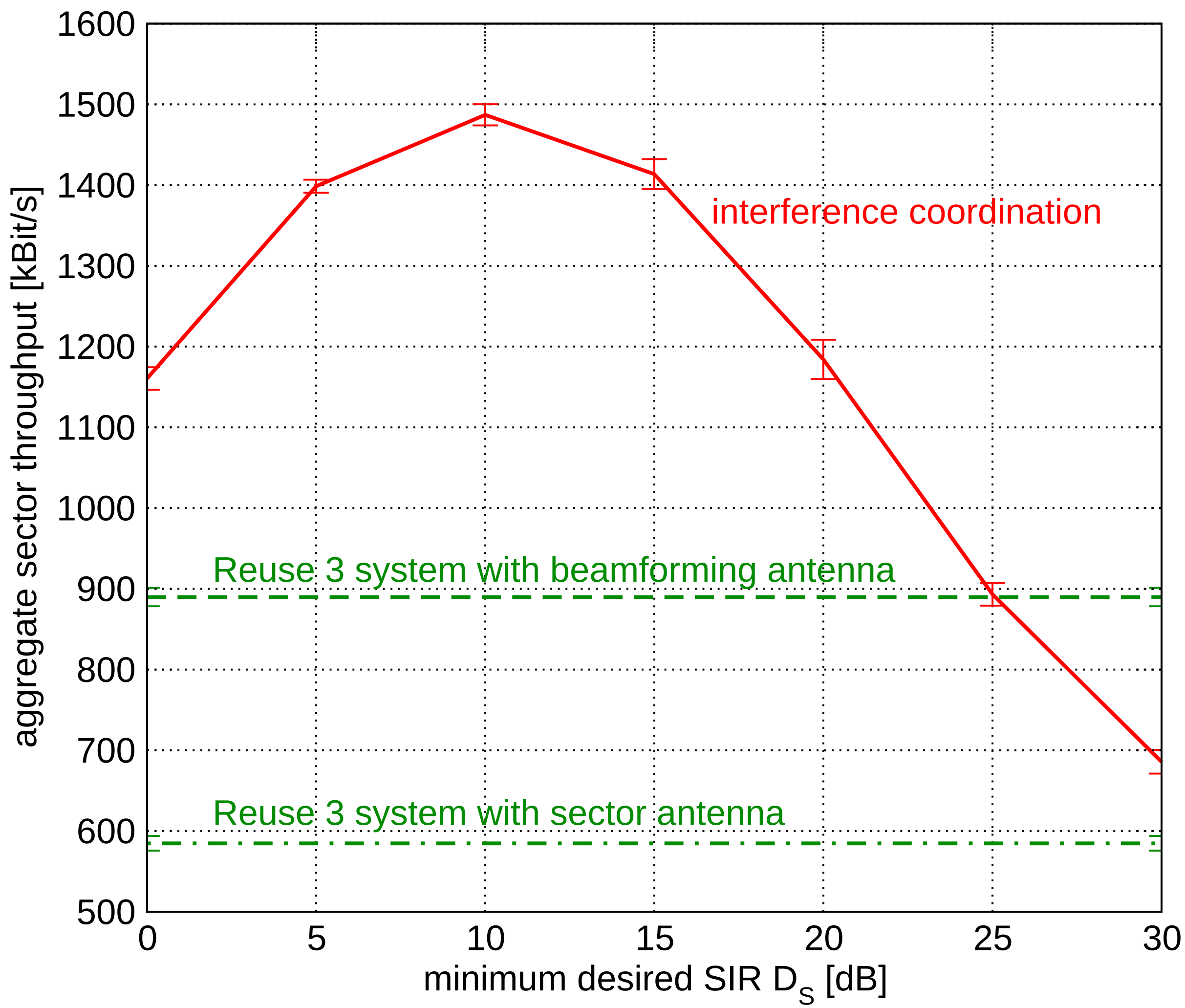
- **Linear increase of median & quantile in considered range of D_S**
- **Significantly better average SIR than desired minimum SIR D_S**

Mean Resource Utilization



- **Linear Decrease of resource utilization in considered range of D_S**
- **Significantly better resource utilization than frequency reuse 3 system**

Mean Throughput per Cell Sector

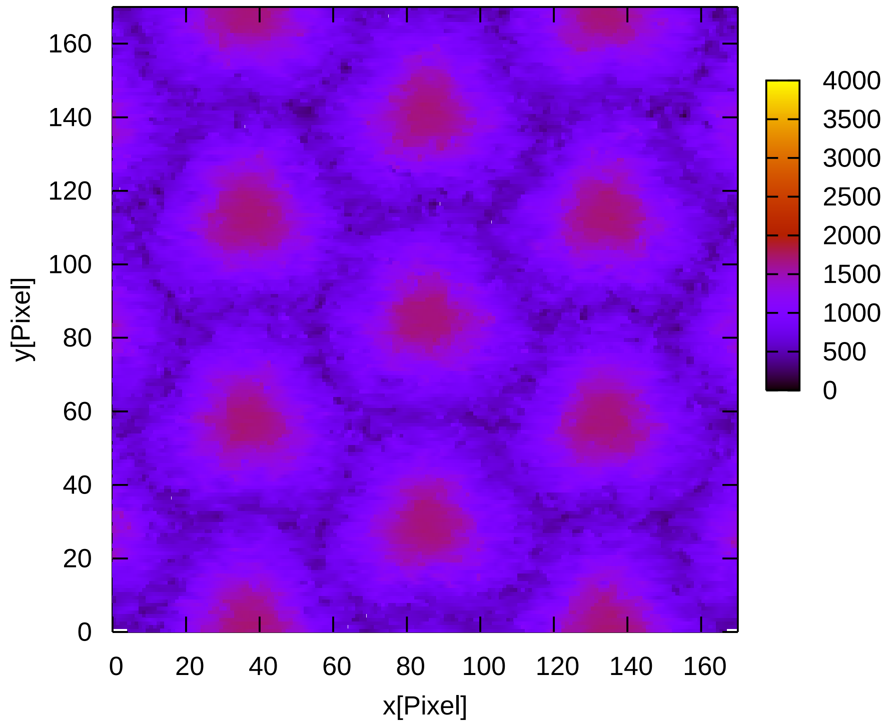


- **Tradeoff between resource utilization and SIR**

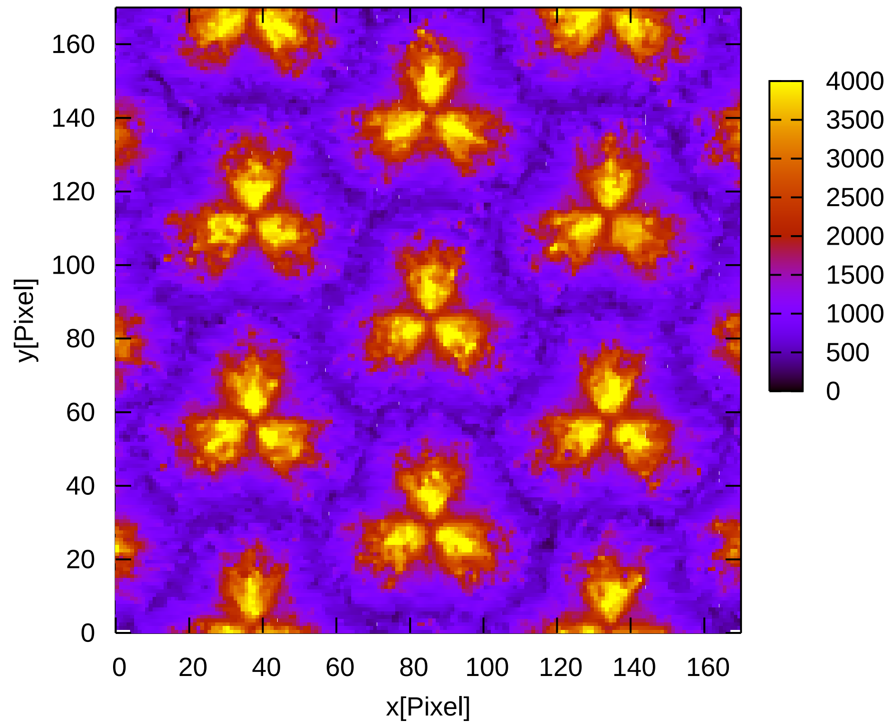
☞ **Maximum of sector throughput for particular D_S**

Throughput at the IP-Layer

Frequency Reuse 3 System



Interference Coordinated System



- **Better overall performance of interference coordinated system**
- **Better cell edge coverage of interference coordinated system**

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