Interferene Coordination in OFDMA Networks

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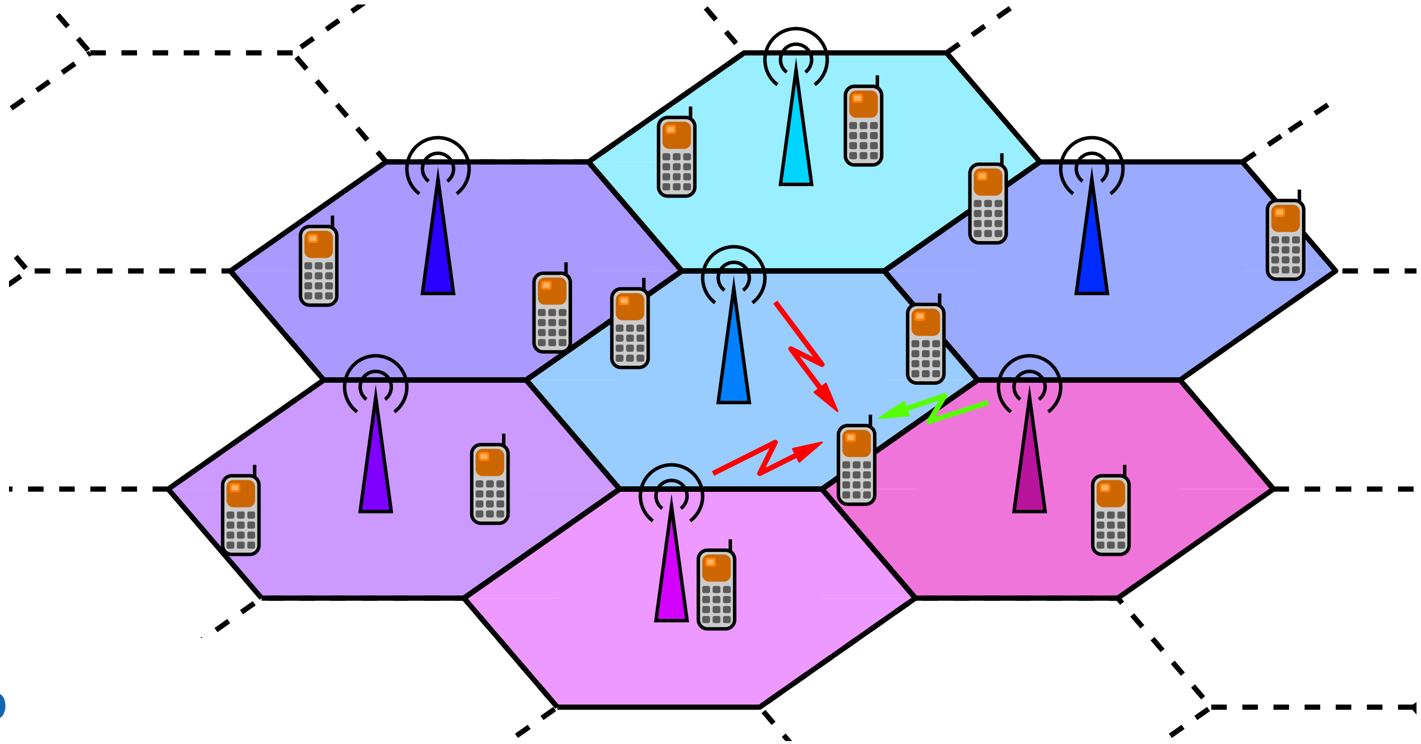
Outline

- **Introduction and motivation**
  - Requirements and challenges in cellular networks
  - Introduction to OFDMA networks
- **Interference mitigation techniques**
  - Fractional Frequency Reuse (FFR)
  - Interference Coordination (IFCO)
- **Coordinated Fractional Frequency Reuse**
  - Concept and architecture
  - Algorithm description
- **Performance Evaluation**
  - Comparison with conventional systems

Motivation



Scenario

- **Cellullar OFDMA network according to 3GPP Long Term Evolution (LTE) or IEEE 802.16e (WiMAX)**

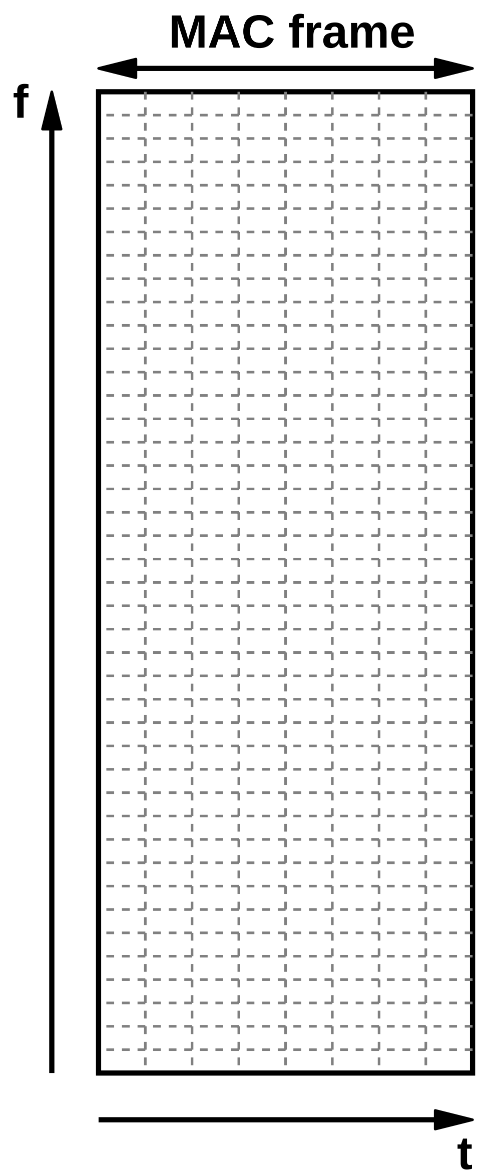
Requirements

- **High aggregate throughput ☞ serve as many users as possible**
- **High cell edge throughput ☞ good performance even with weak signal**

Major problem: Inter-cellular interference

Orthogonal Frequency Division Multiple Access

- **Based on Orthogonal Frequency Division Multiplex (OFDM)**
  - subdivision of frequency spectrum into subcarriers
  - well suitable for multi-path fading environments
- **Basis of several emerging cellular standards e.g., 802.16e/m (WiMAX), 3GPP LTE**



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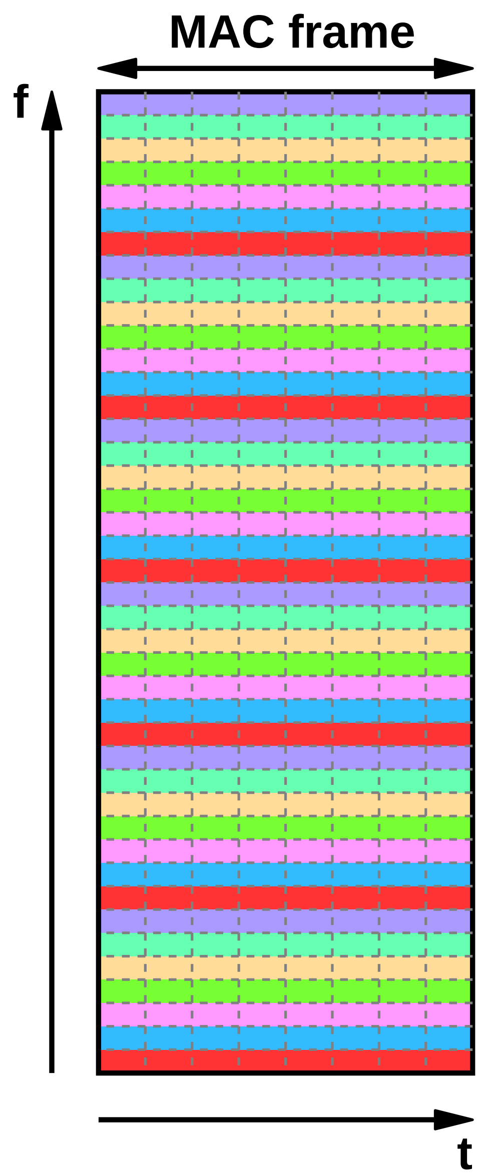

Example: 802.16e MAC Layer ("mobile WiMAX")

- **Frequency-diverse (PUSC zone, FUSC zone) and frequency-selective modes (AMC zone)**

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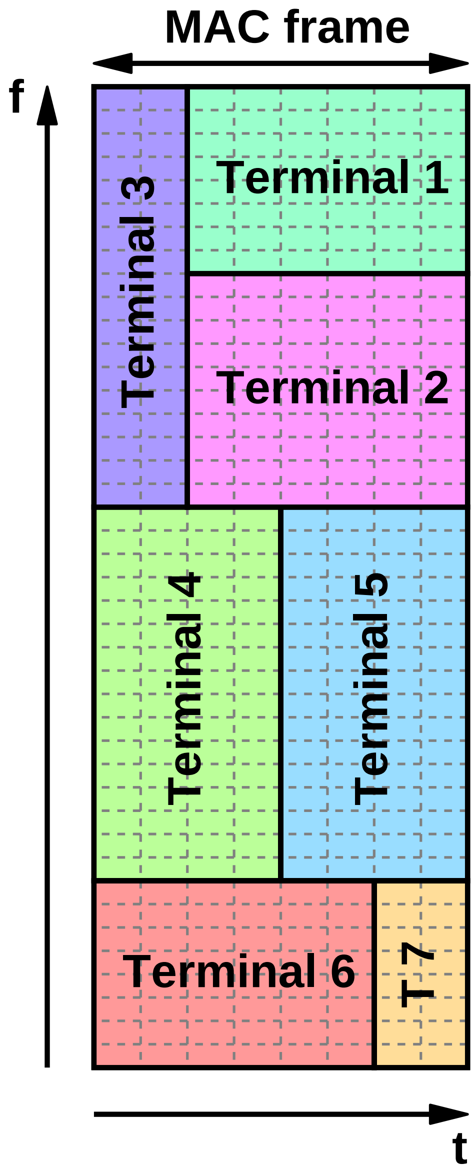
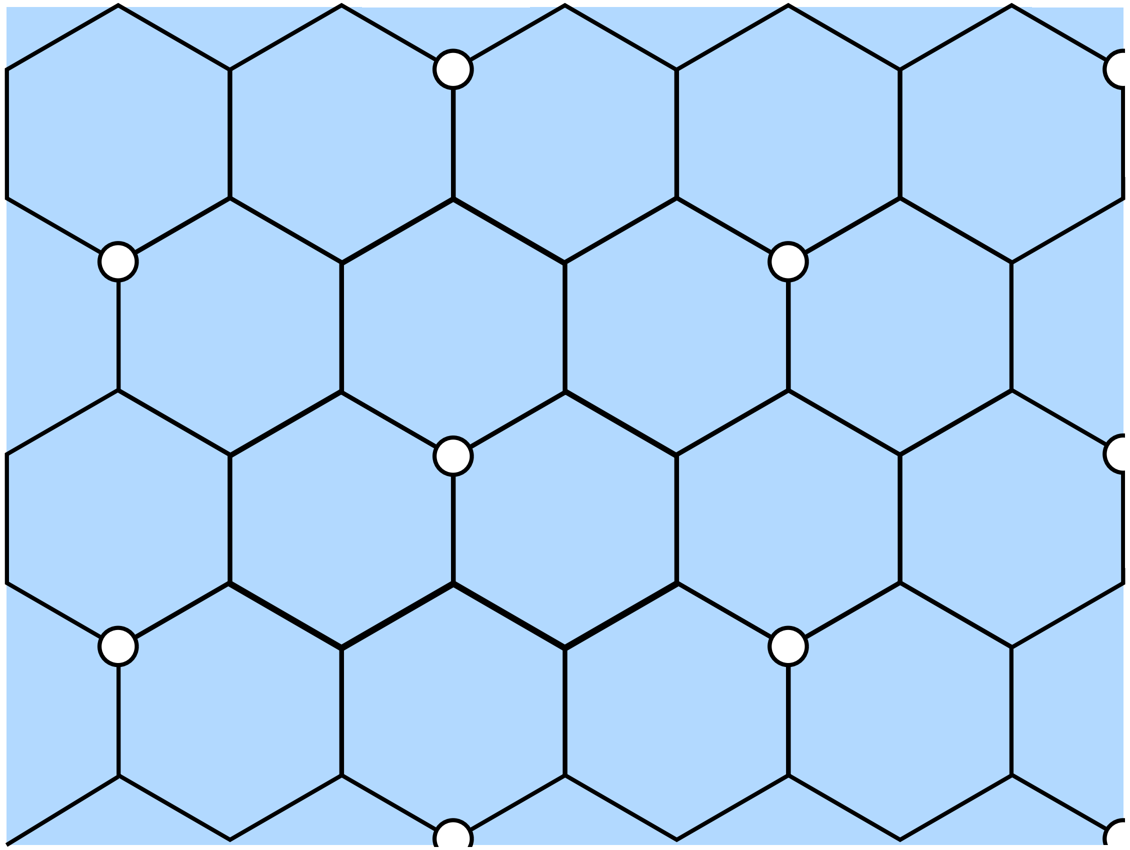


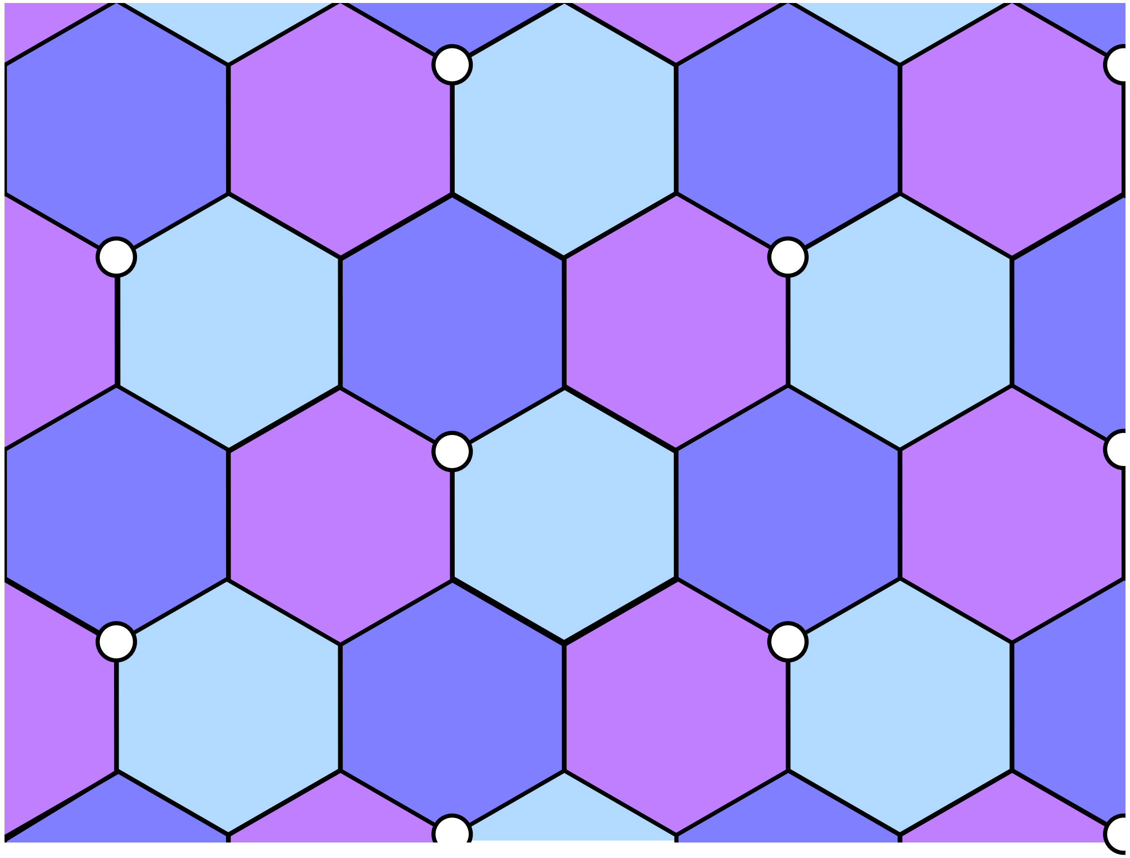
Example: 802.16e MAC Layer ("mobile WiMAX")

- **Frequency-diverse (PUSC zone, FUSC zone) and frequency-selective modes (AMC zone)**
- **AMC zone (Adaptive Modulation and Coding)**
  - allocation of consecutive subchannels for the transmission to one terminal
  - allocations have rectangular shapes
  - ☞ allows frequency-selective scheduling
  - ☞ well suitable for interference coordination

Interference in Cellular Networks



- **Major issue in OFDMA: inter-cellular interference**



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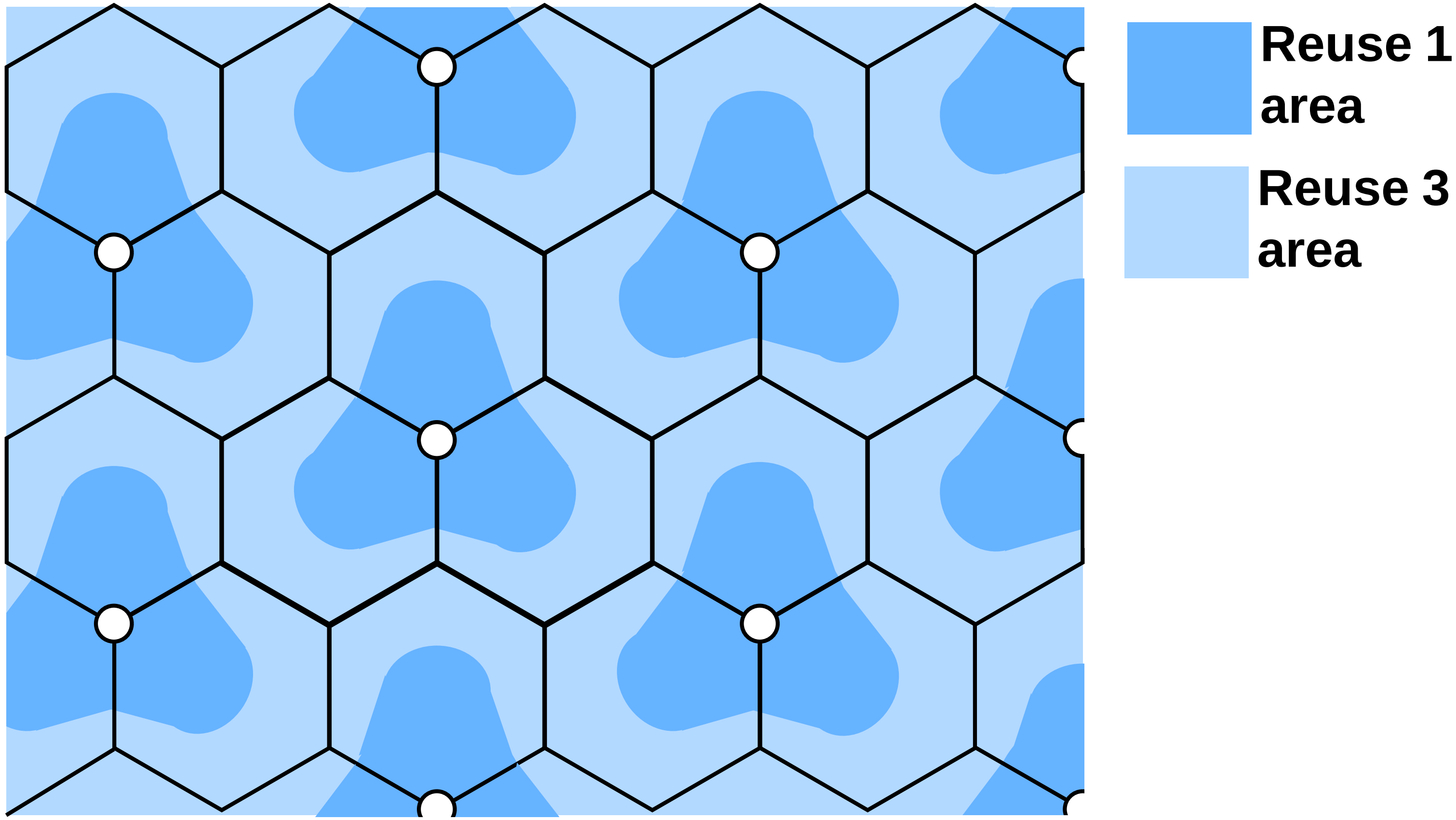
  - standard solution: frequency reuse pattern
    disadvantage: waste of precious frequency resources



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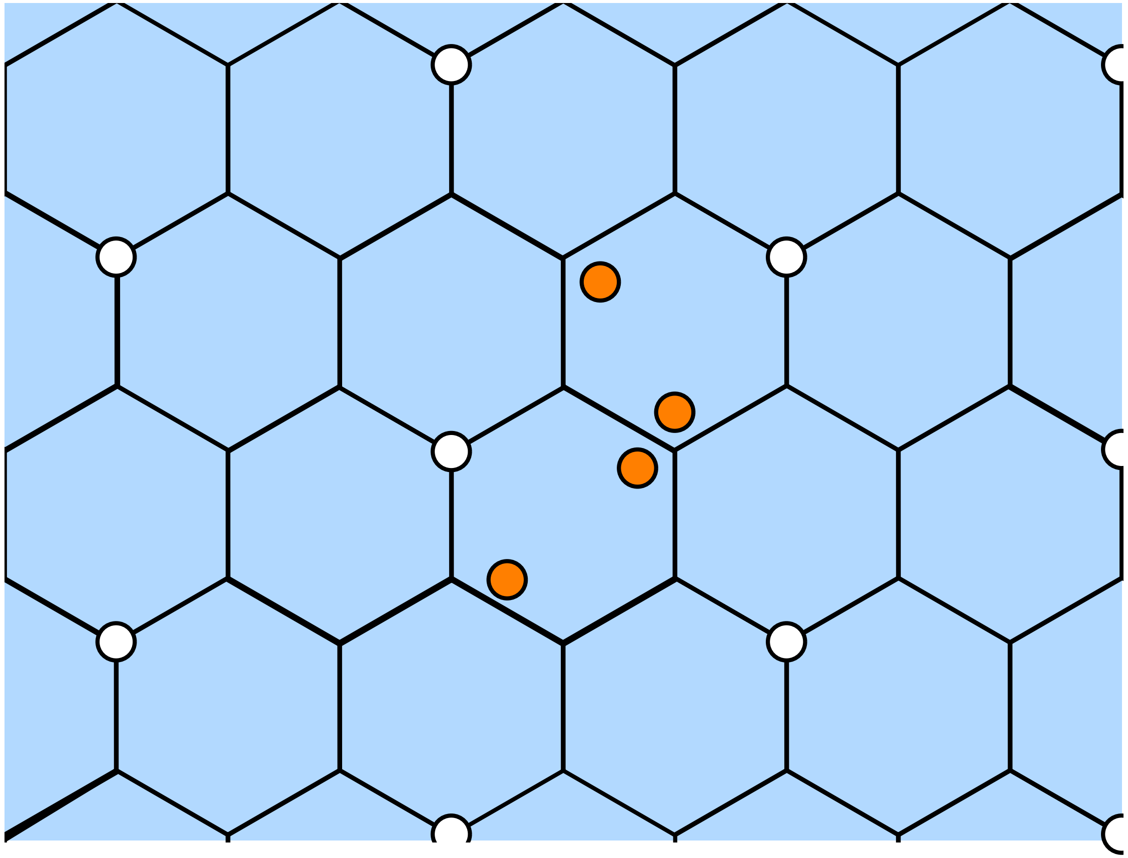
Interference in Cellular Networks



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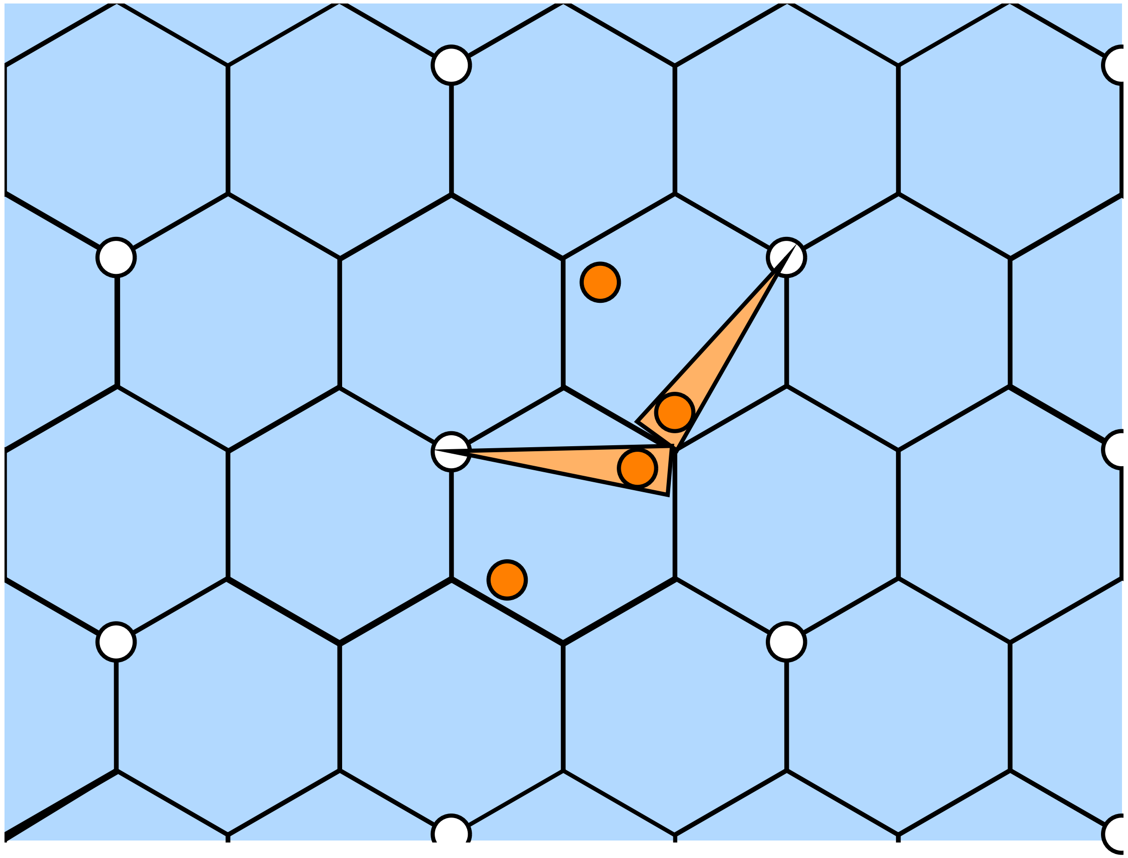

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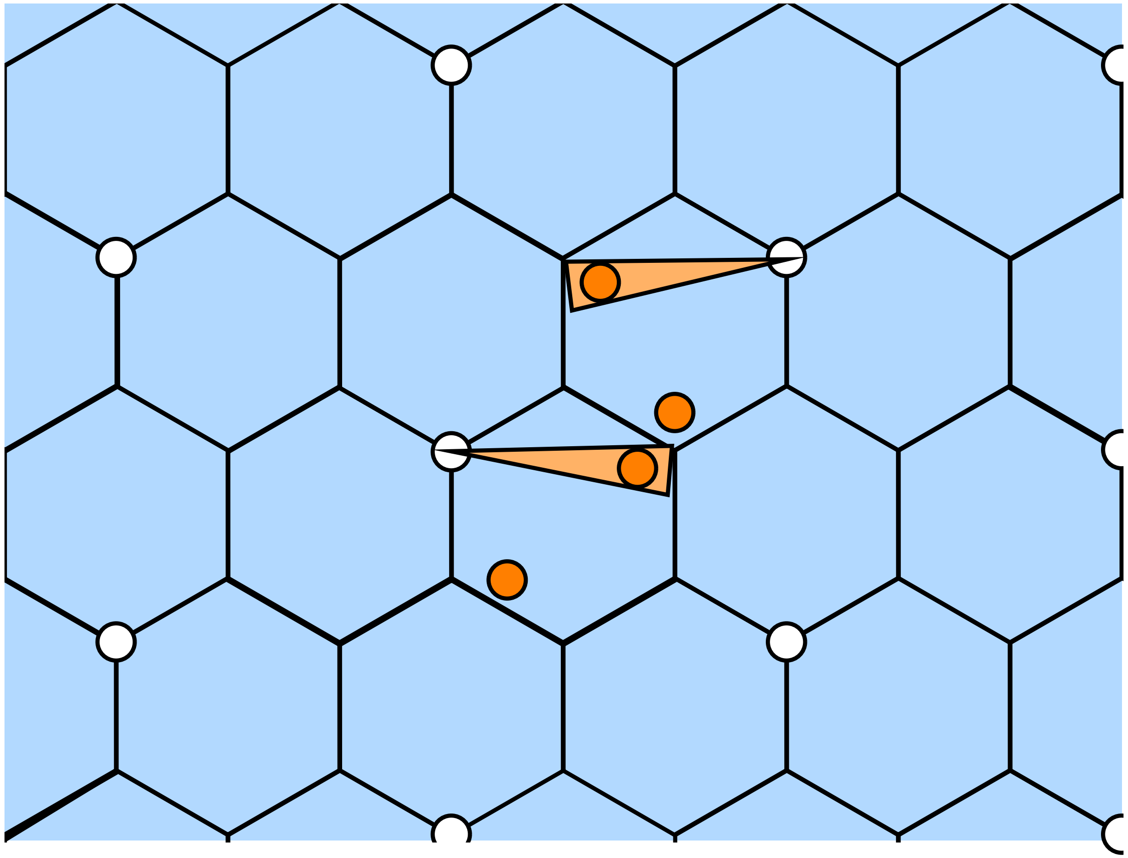


- **Major issue in OFDMA: inter-cellular interference**
  - standard solution: frequency reuse pattern
  - optimization: Reuse Partitioning / Fractional Frequency Reuse (FFR)
  - Usage of directional antennas to lower inter-cellular interference
    ☞ Additional coordination necessary ☞ interference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

Classification wrt. time-scale of operation (3GPP)

- **Static schemes**
  - static planning of interference situation in network
  - does not adapt to present load situtation
  - example: Reuse Partitioning / Fractional Frequency Reuse
- **Semi-static schemes**
  - self-configured coordination (level of days ☞ almost static)
  - cell load adaptive coordination (level of minutes)
  - user load adaptive coordination (level of hundreds of milli seconds)
- **Dynamic schemes**
  - fully synchronized scheduling
  - coordination takes place every frame or every few frames

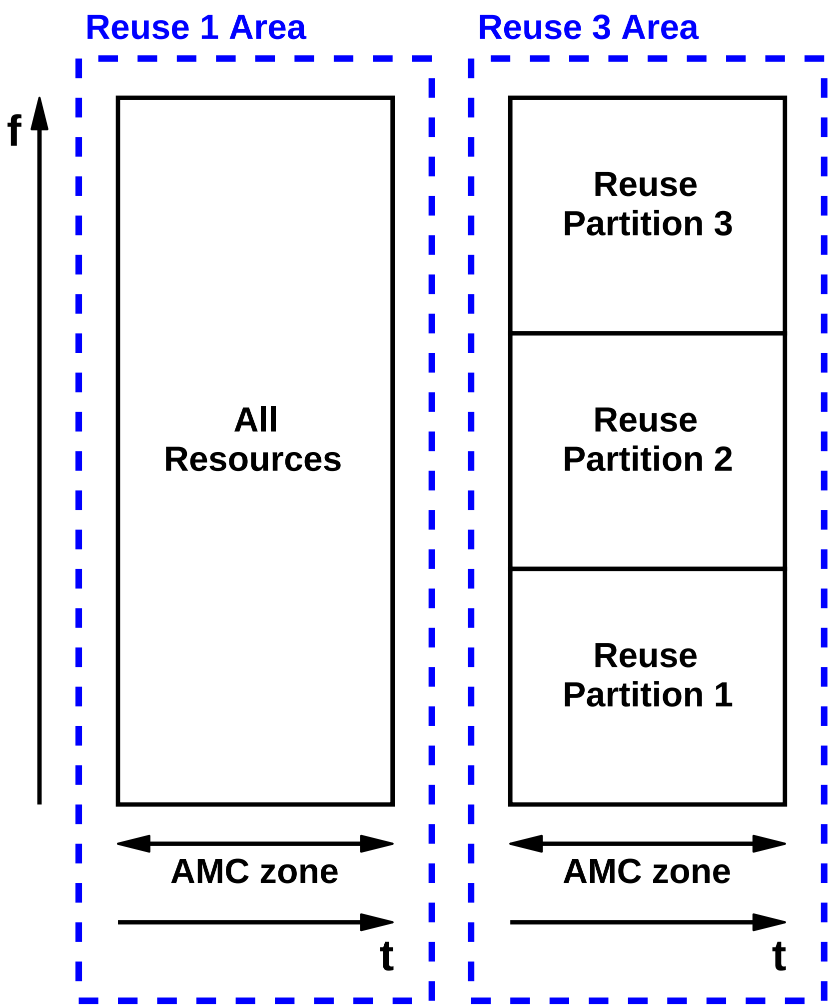
  ☞ well suitable if only sectors of one base station are coordinated

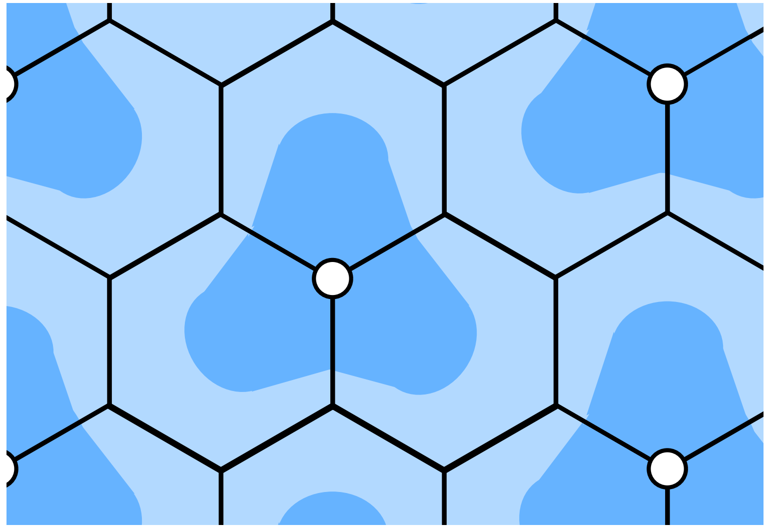
Classification wrt. degree of distribution

- **Global schemes**
  - base stations have no power of decision
  - omniscient entity, which is capable of performing scheduling decisions in all cells on a per-frame basis
- **Distributed schemes with central entity**
  - base stations have (limited) power of decision
  - ideal: central component acquires system state and distributes scheduling decisions every frame
  - realistic: central component acquires system state and distributes scheduling decisions e.g. once per second
- **Decentralized schemes (without central component)**

  information exchange among base stations
  - via signaling network
  - via mobile terminals
- **Decentralized schemes, using only local state information**

Conventional Fractional Frequency Reuse (FFR)

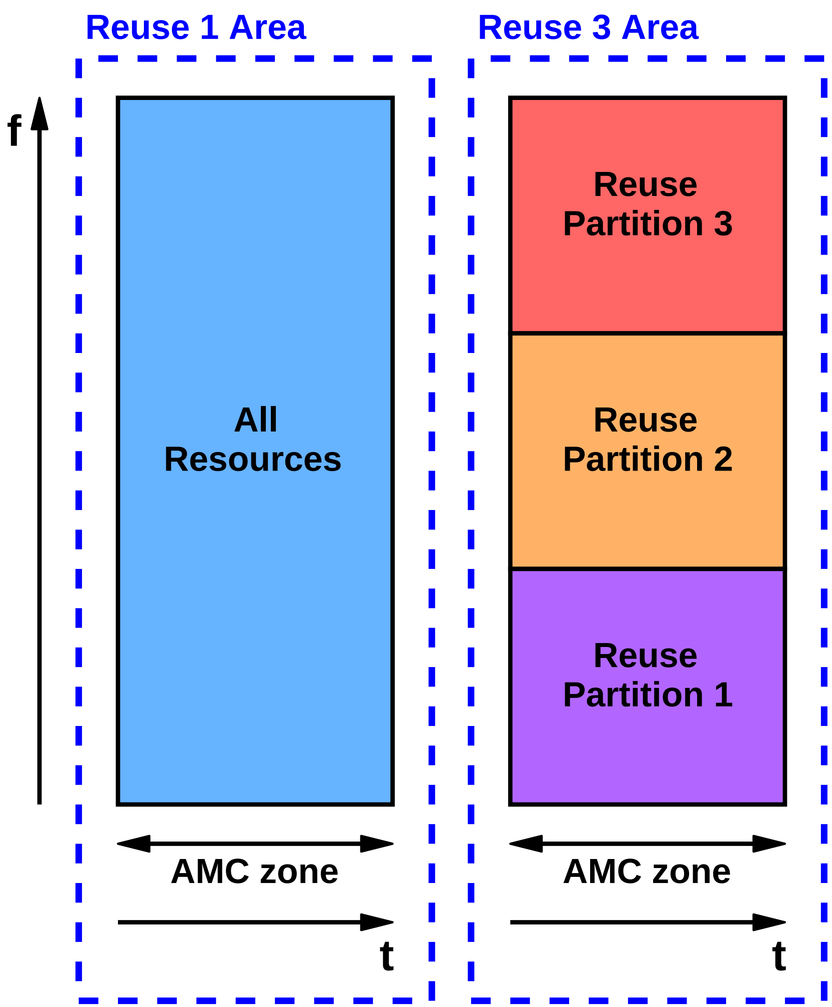


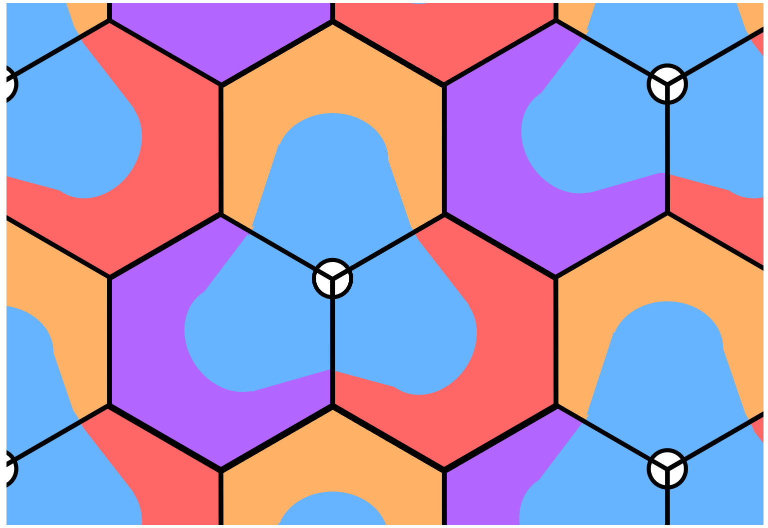


- **Reuse 1 & reuse 3 areas may or may not be on same frequency range**
- **Power levels may or may not be adjusted depending on area**

- **Assignment of mobiles to reuse 1 or 3 based on position or SINR**

Conventional Fractional Frequency Reuse (FFR)

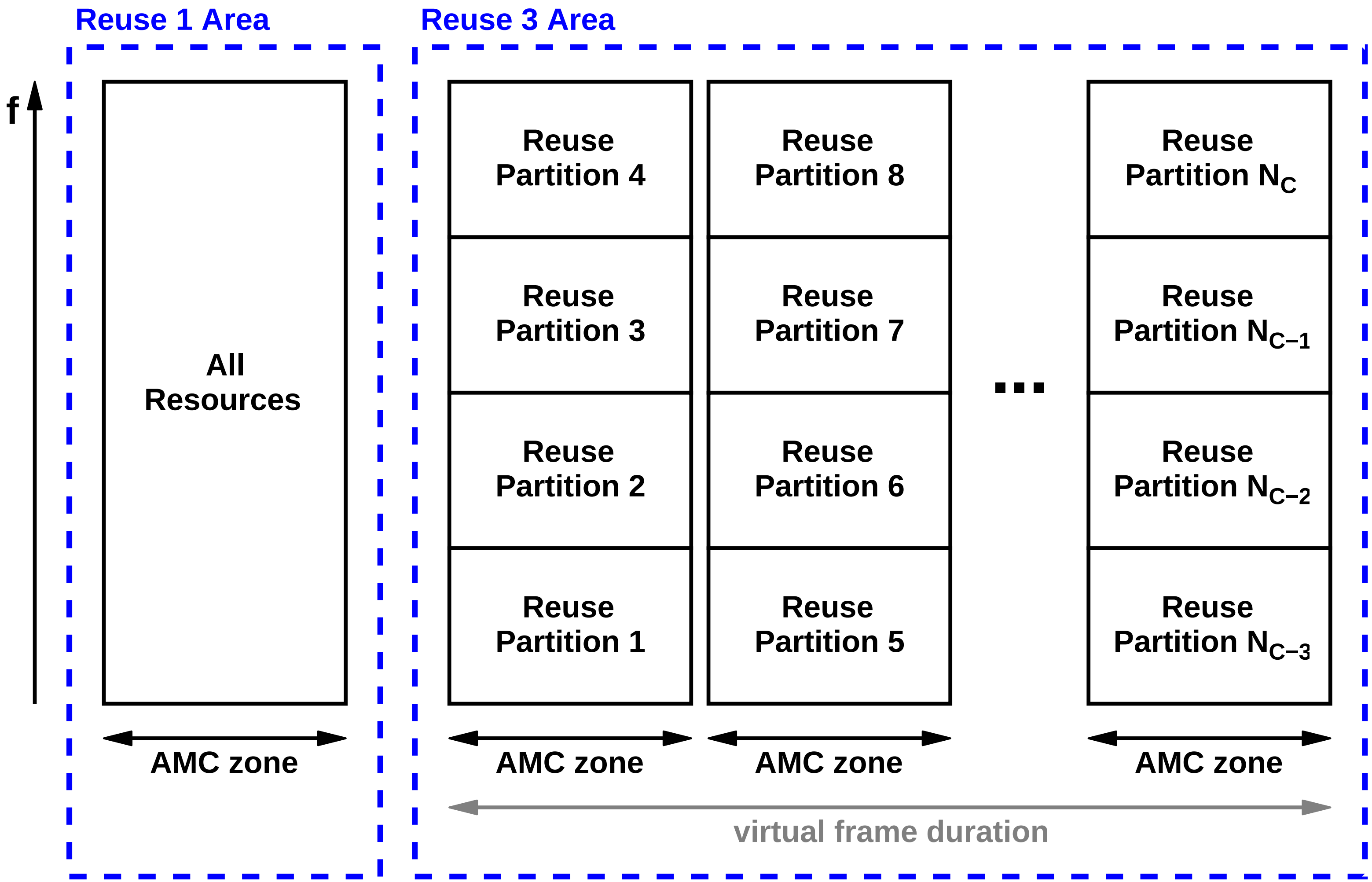




- Reuse 1 & reuse 3 areas may or may not be on same frequency range
- Power levels may or may not be adjusted depending on area

- Assignment of mobiles to reuse 1 or 3 based on position or SINR
- Choice of reuse partition depending on cell sector (static)

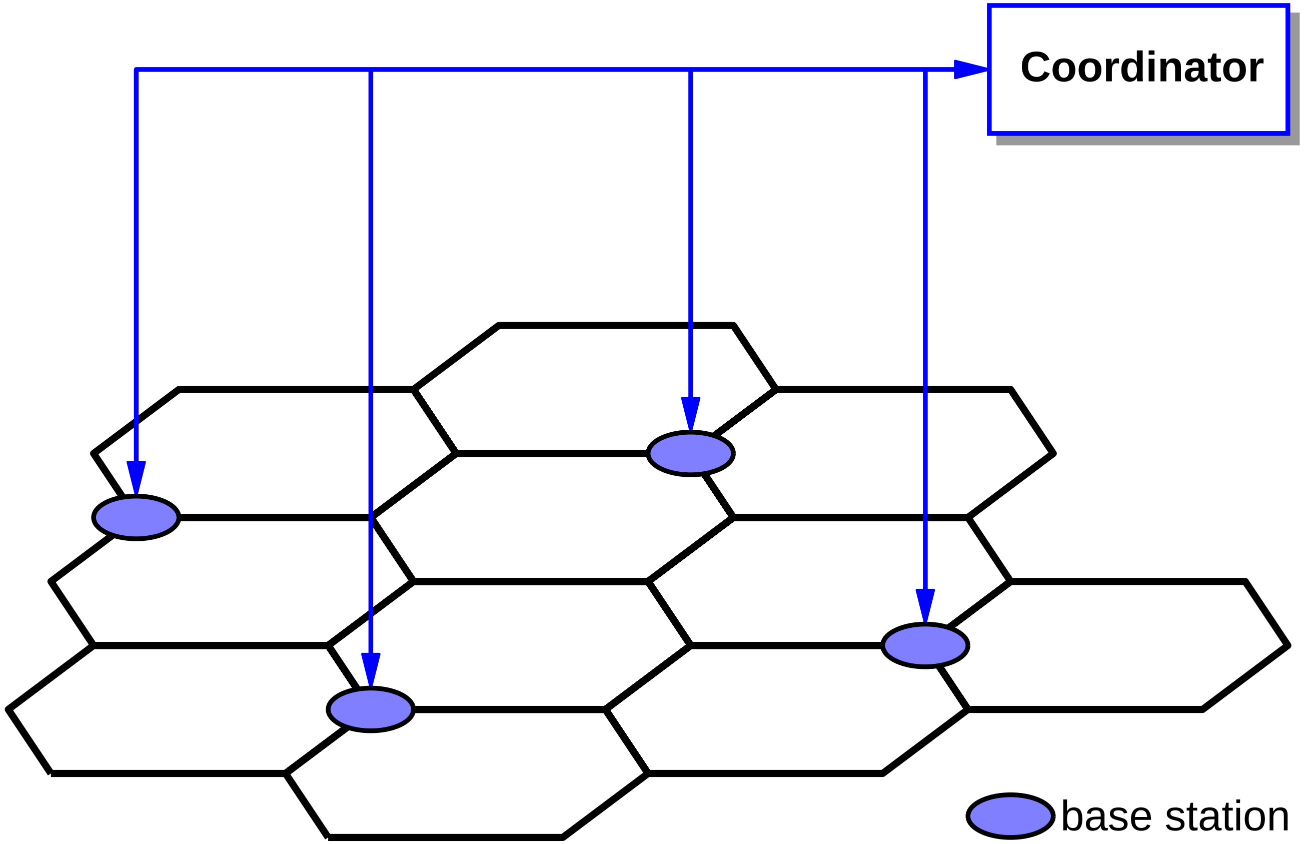
Coordinated Fractional Frequency Reuse



Idea: Reduce interference by optimized and coordinated dynamic choice of reuse partition (semi static or dynamic)

☞ **interference coordination**

System Architecture

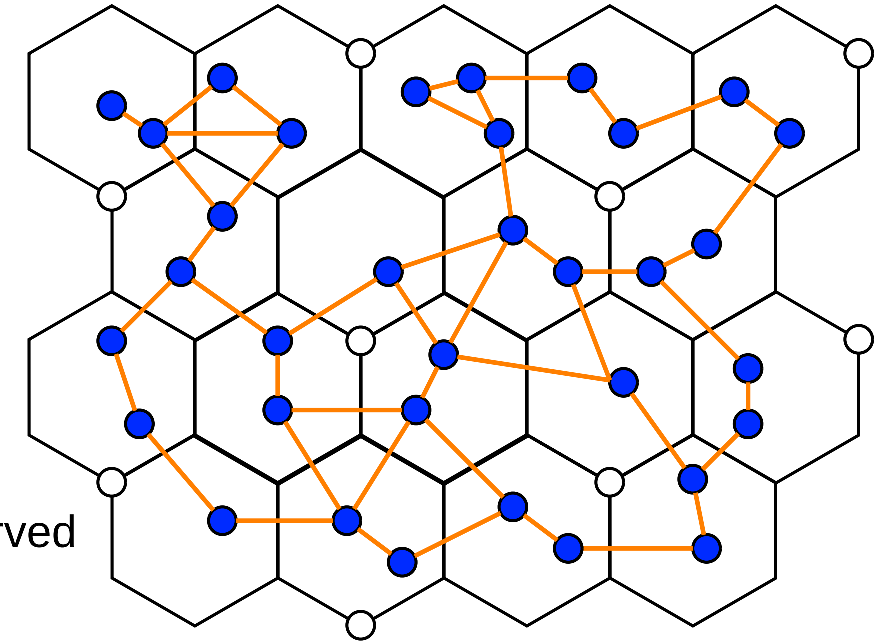


- **Base stations communicate relevant information to central coordinator**
- **Central coordinator assigns mobile terminals to resource partitions in a coordinated fashion**

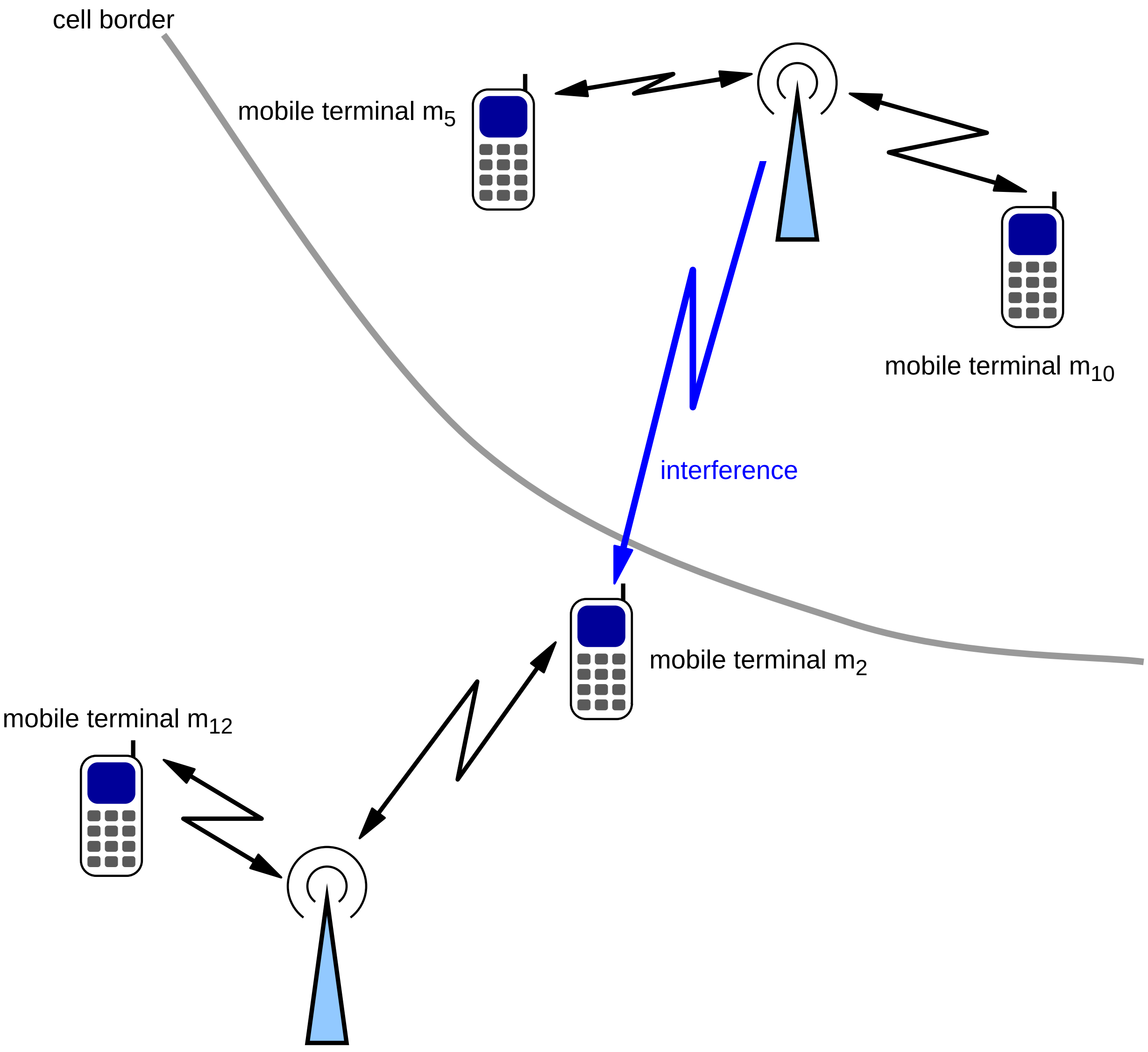
Coordination of Resource 3 Partitions

- **Approach**
  - construction of an interference graph *G* in central coordinator
    - nodes $m_i \in \boldsymbol{M}$
    - edges $e_{ij} \in \boldsymbol{E}$ (non-directional)
  - assignment of resource partitions based on interference graph
  - communication of resource partitions to base stations

- **Interference graph**
  - based on global knowledge collected from all base stations
  - edges represent critical interference relations in-between terminals
    - ☞ connected terminals should not be served on the same resource (time/frequency slot)



Creation of Interference Graph



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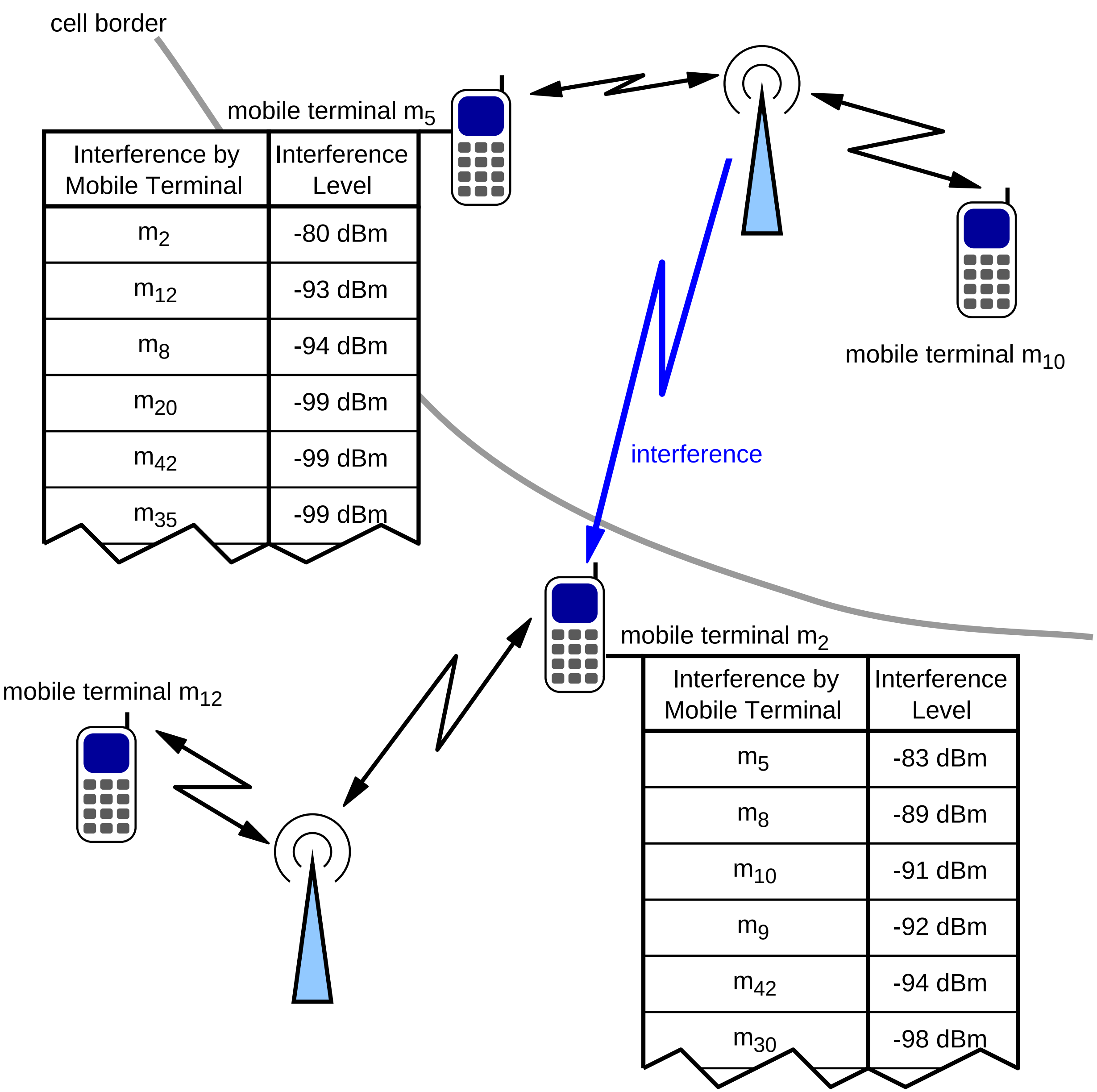

Mobile terminal m_5:

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

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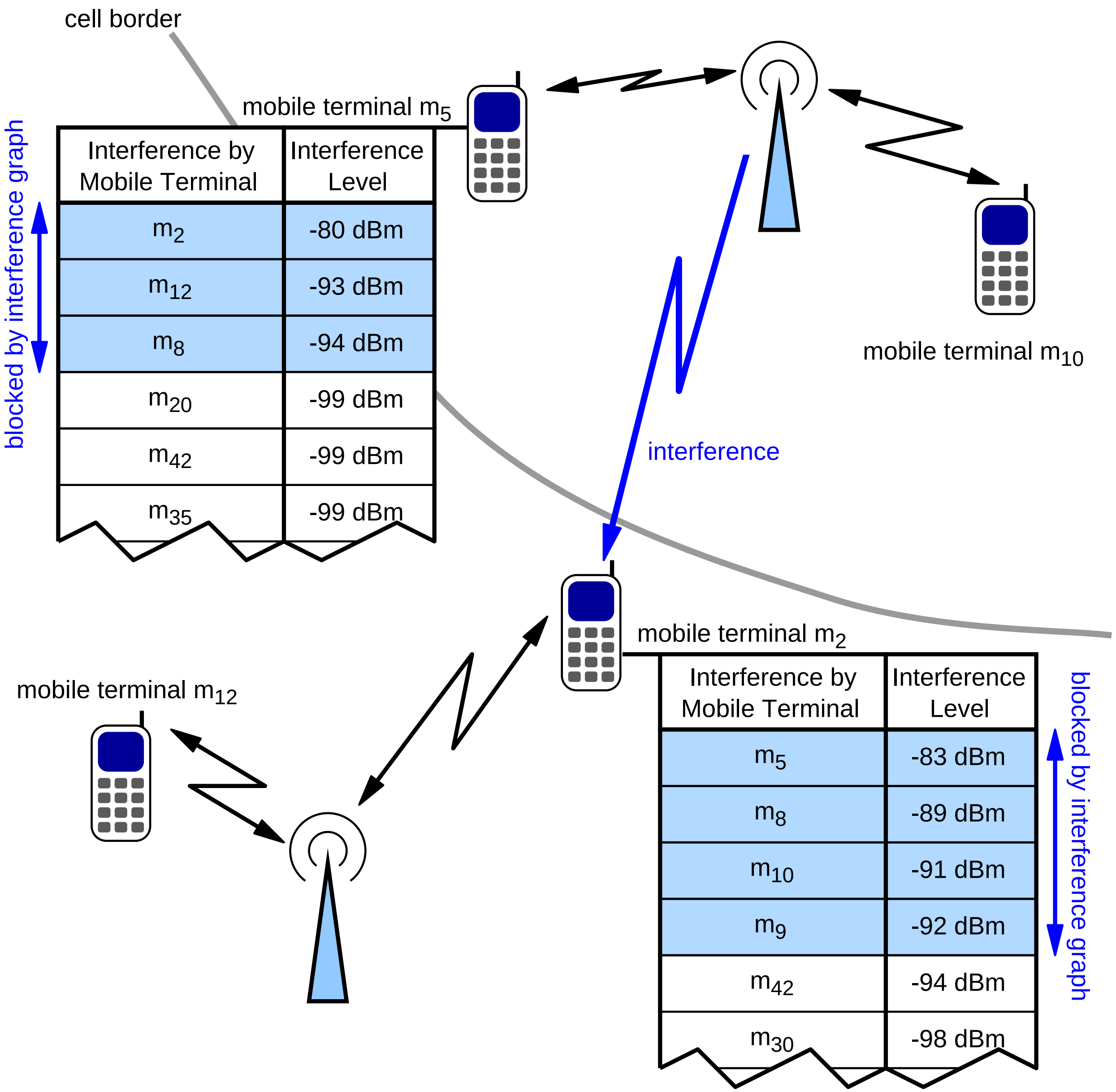

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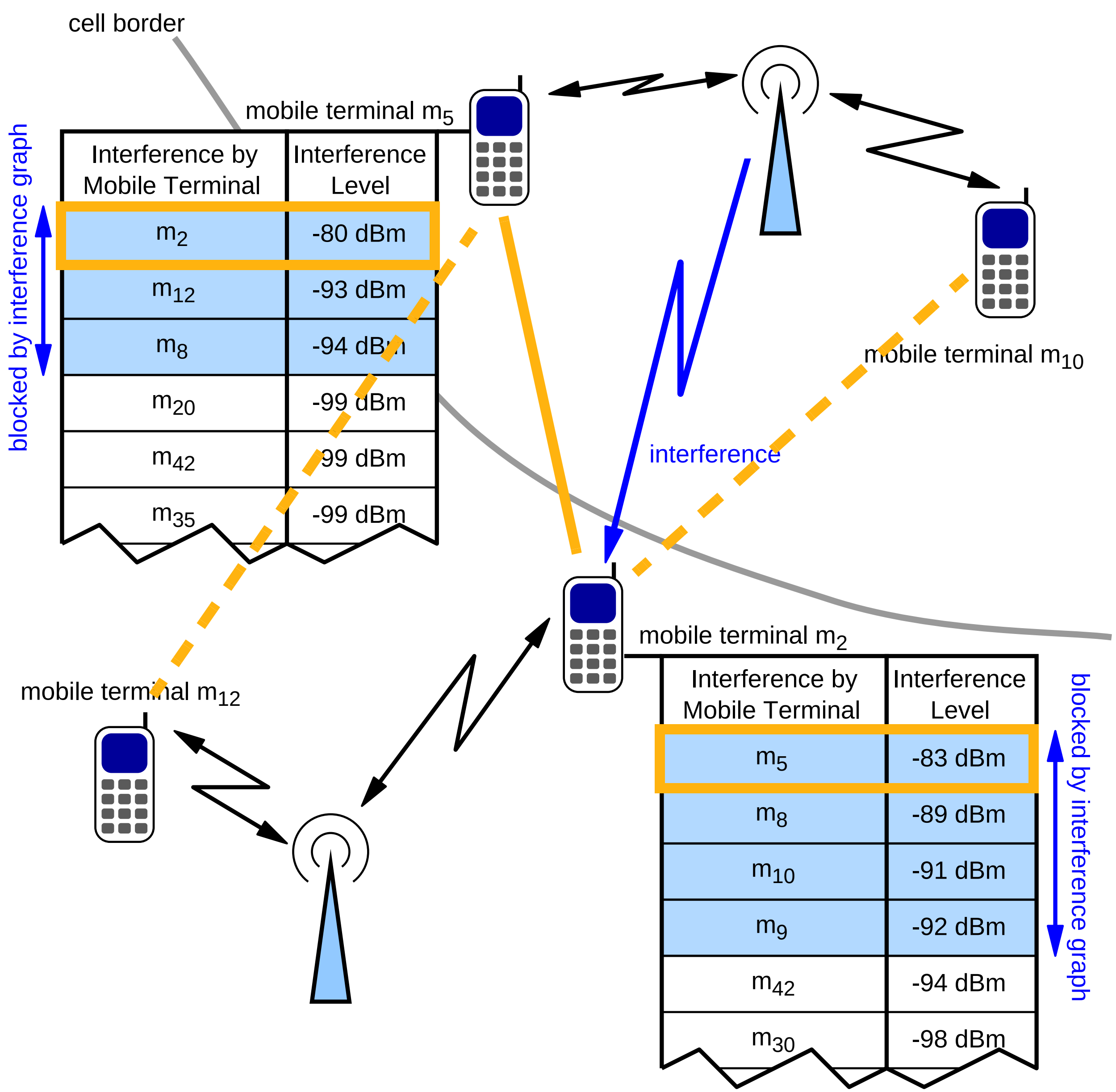
- **Calculation of signal strength of interferers for a particular mobile terminal m_j**
- **Blocking of strongest interferers such that a desired minimum SIR D_S is achieved**

Creation of Interference Graph



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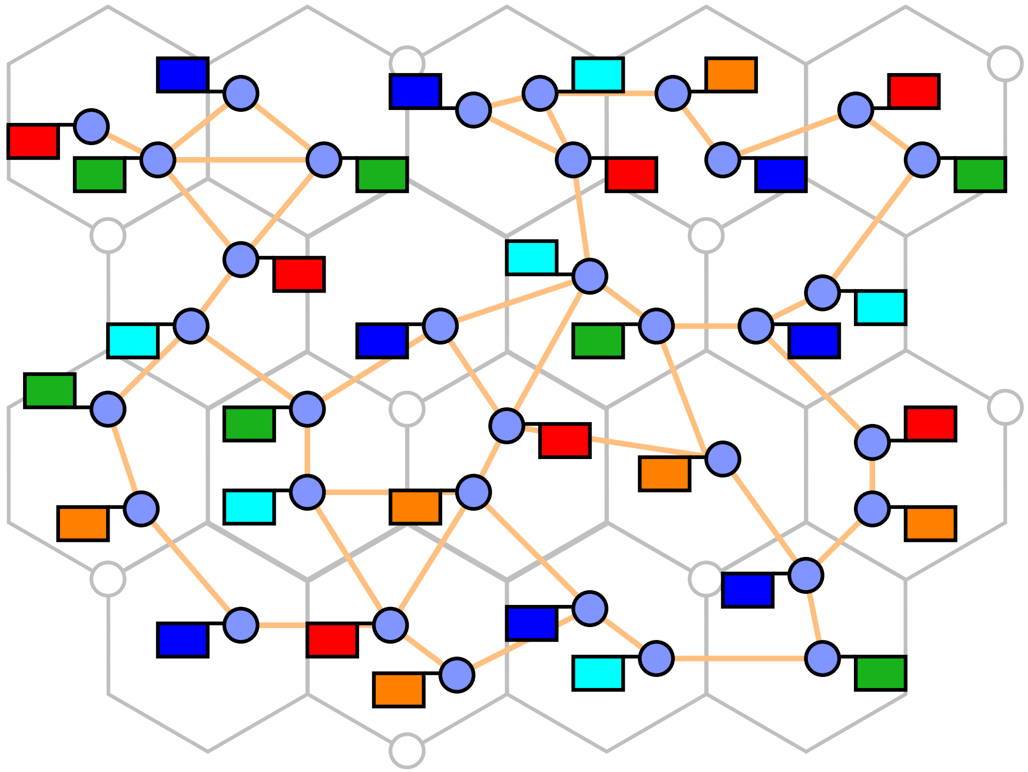
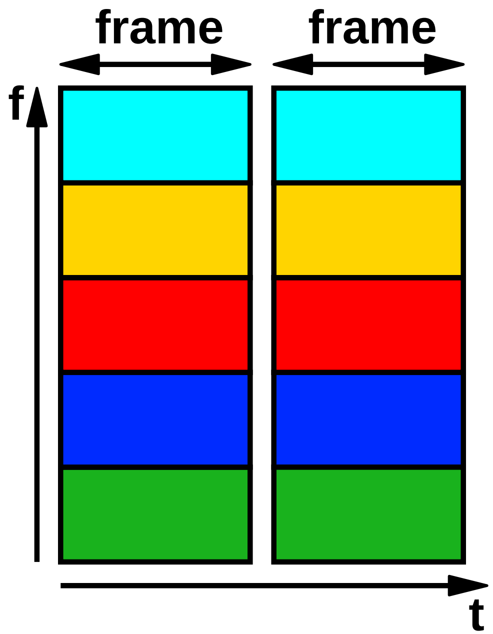
- **Calculation of signal strength of interferers for a particular mobile terminal m_j**
- **Blocking of strongest interferers such that a desired minimum SIR D_S is achieved**
- **Blocked terminals are connected by edge in interference graph**

Assignment of Resource Partitions

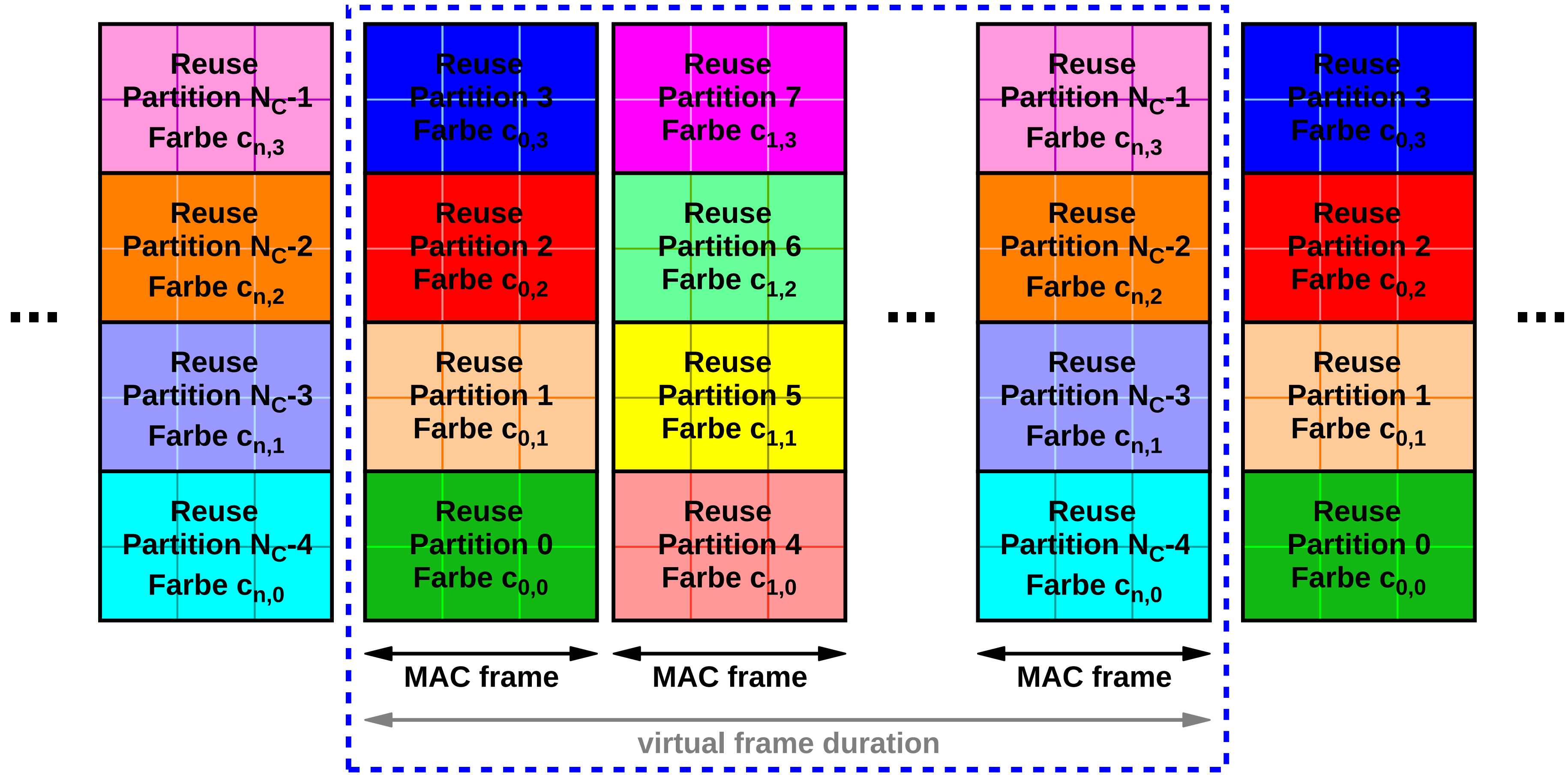


Example of resource mapping



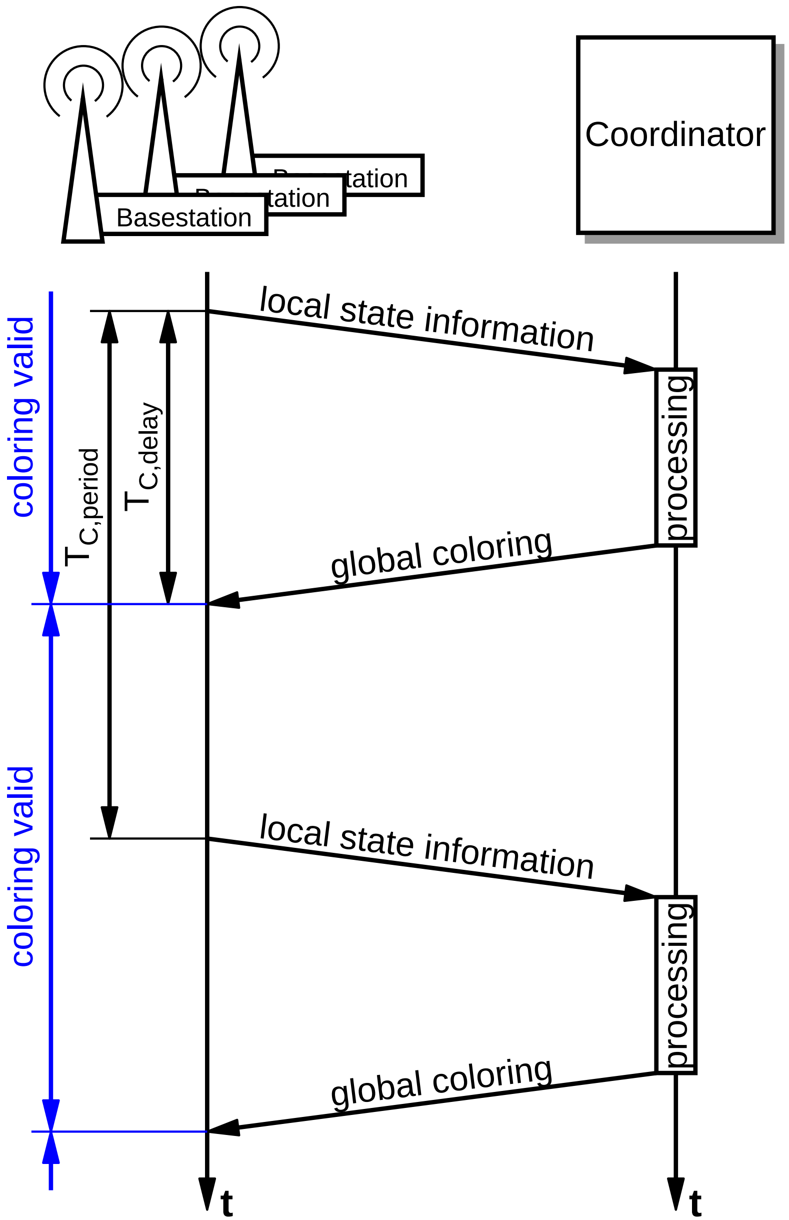
- **Treat resource partitions as colors of graph**
- **Resource partitions can be assigned to mobile terminals by coloring of the interference graph**
  - graph coloring is NP hard
  - large number of heuristics: genetic algorithms, simulated annealing, tabu search, other heuristics (e.g., Dsatur)

Mapping of colors to Resource Partitions



☞ **Virtual frame duration must be adapted to number of colors**

Signaling-Time-Diagram



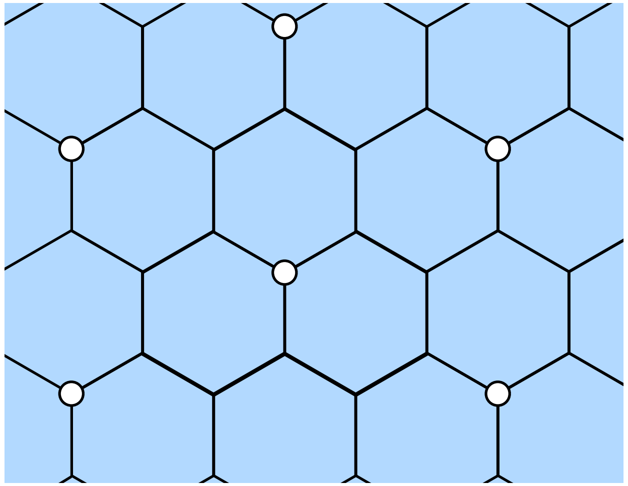
Procedure

- **Communication of all required information to central coordinator**
- **Calculation of interference graph**
- **Graph Coloring**
- **Communication of colors to base stations**
- **Mapping of colors to resource partitions**

Important Parameters

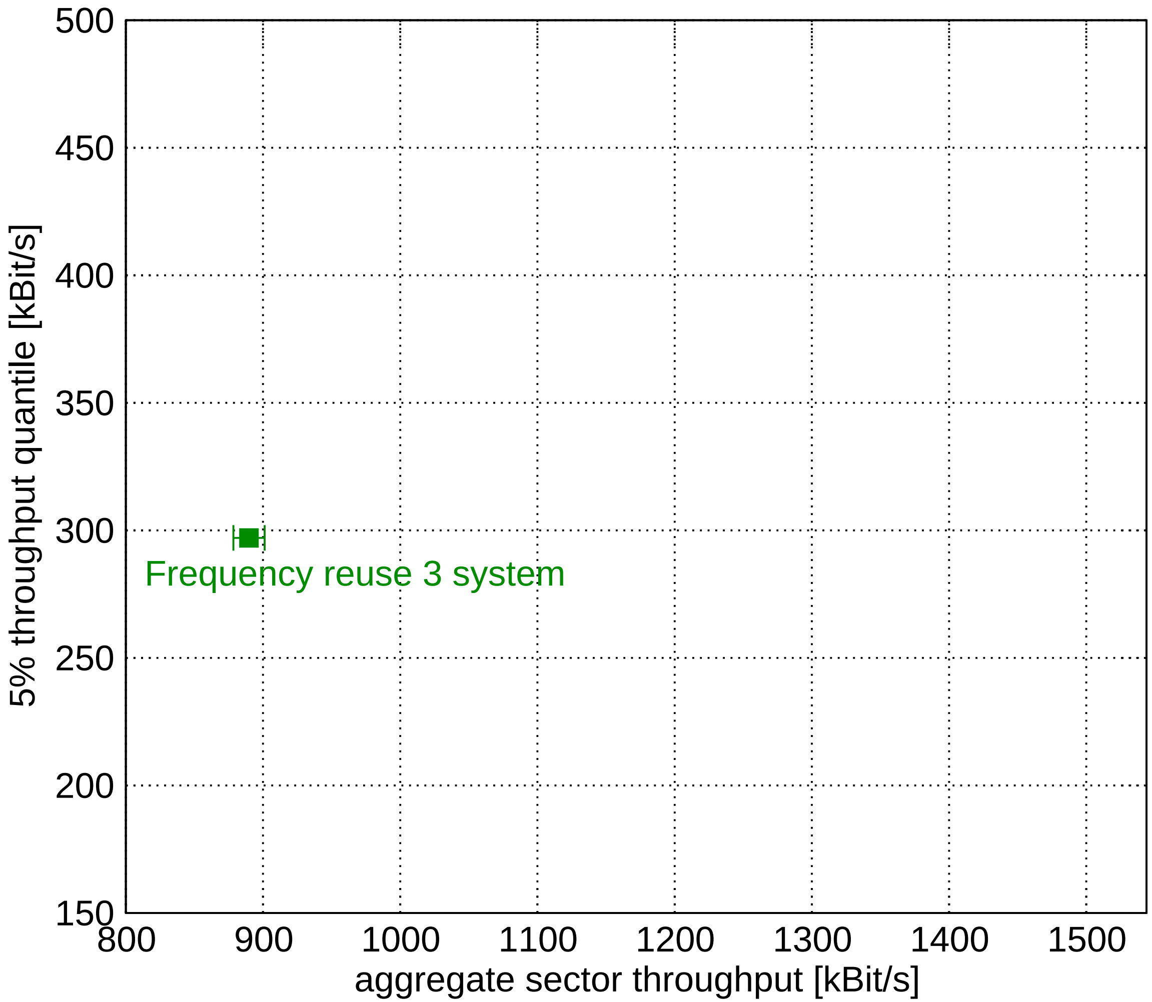
- **update period: $T_{C,period}$**
- **delay: $T_{C,delay}$**

- **Event-driven simulation model implemented using IKR SimLib**
- **Hexagonal scenario described before with wrap-around**
- **mobility model**
  - 9 mobile terminals per cell sector
  - 30 km/h, random direction mobility model
- **Traffic model**
  - greedy traffic sources in downlink direction
  - throughput measured at IP level



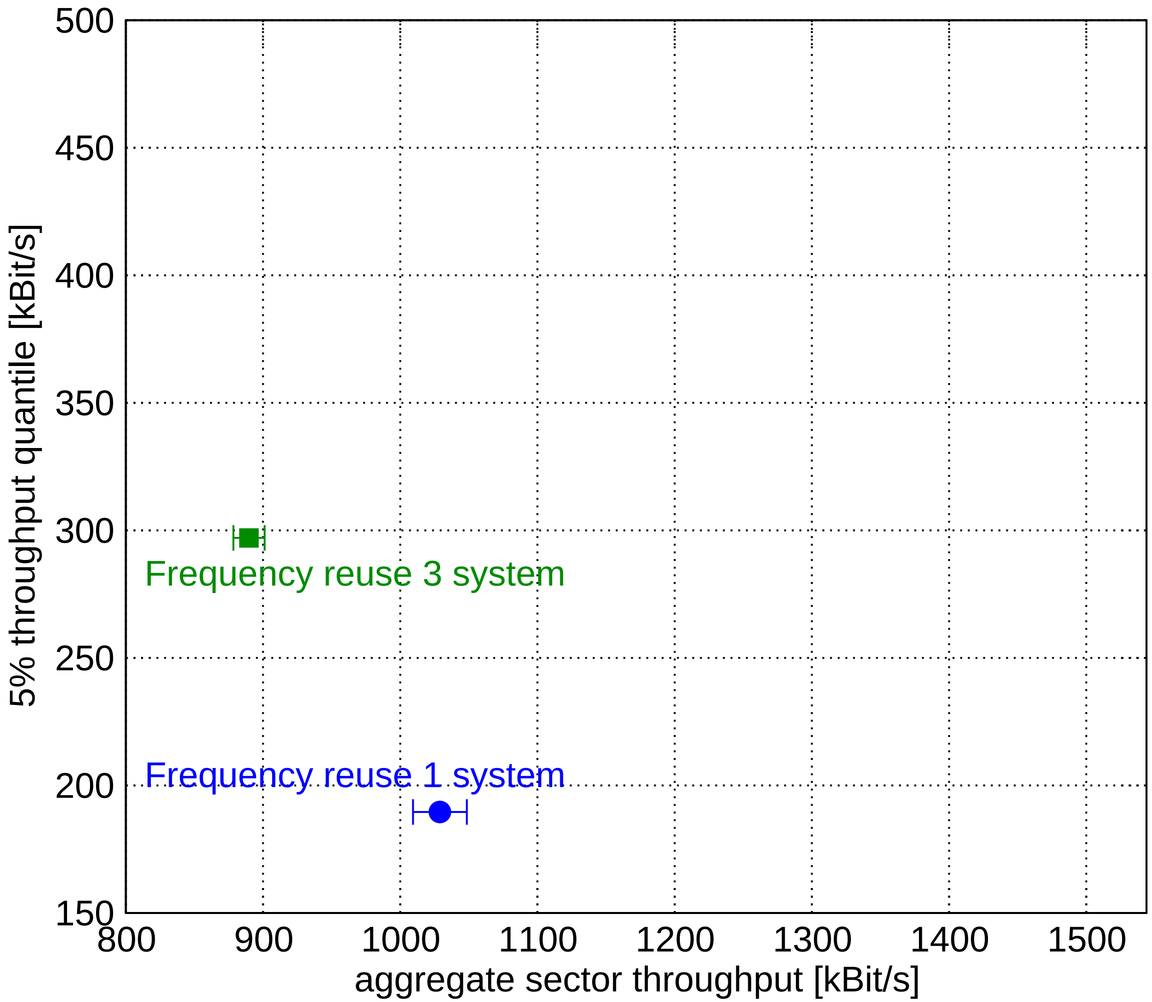
- **Detailed MAC and Physical layer model with path loss and shadowing**
- **Metrics:**
  - **Aggregate sector throughput**
    does not take into account fairness towards cell edge users
  - **5 % quantile of the individual throughputs of all mobiles**
    - terminals close to cell center have high throughput
    - terminals close to cell edge have low throughput
    - ☞ corresponds to throughput of terminals close to cell edge

Throughput Performance



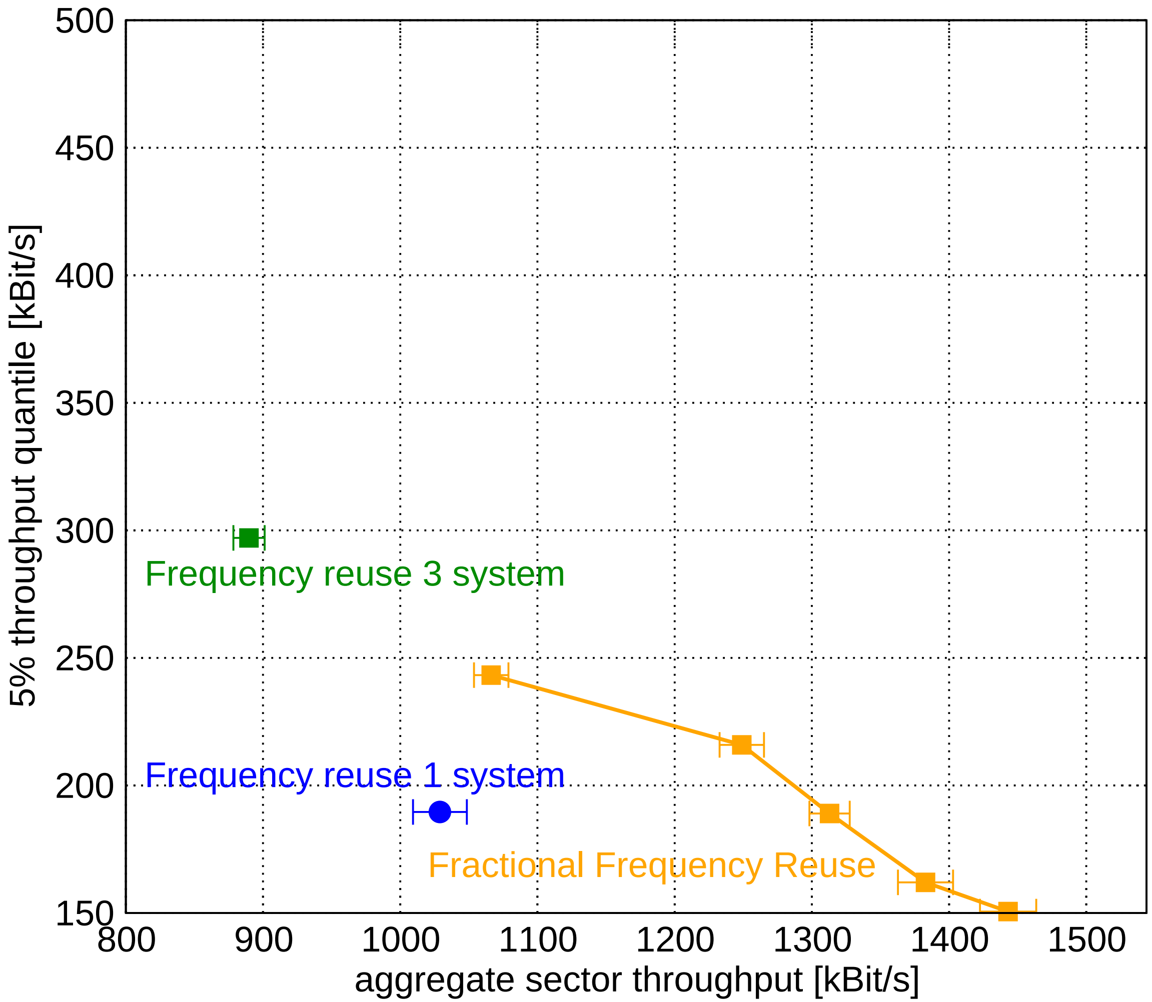
- **Reuse 3 system achieves good aggregate performance and good cell edge performance**

Throughput Performance



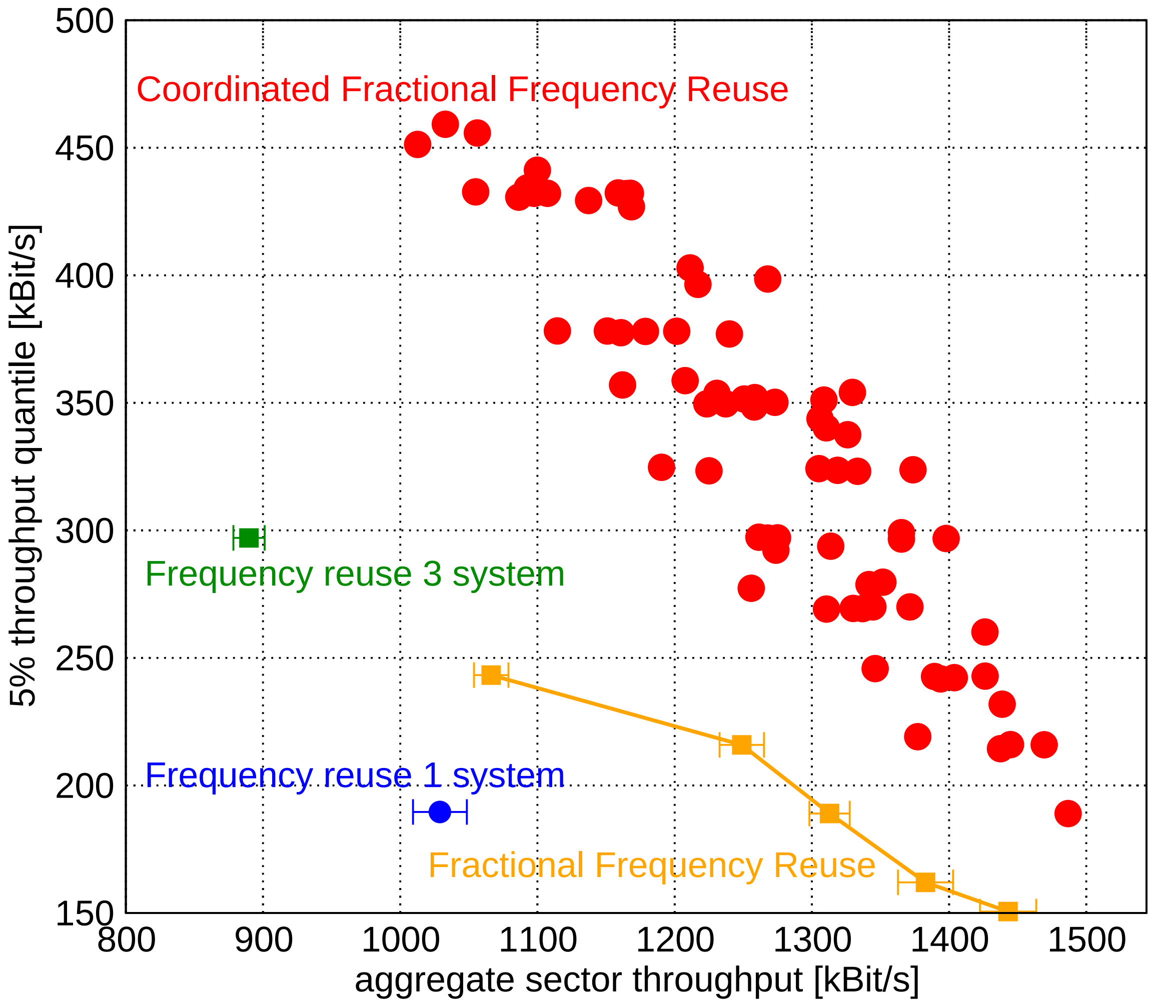
- **Reuse 1 system achieves better aggregate performance but falls short with respect to cell edge performance**

Throughput Performance



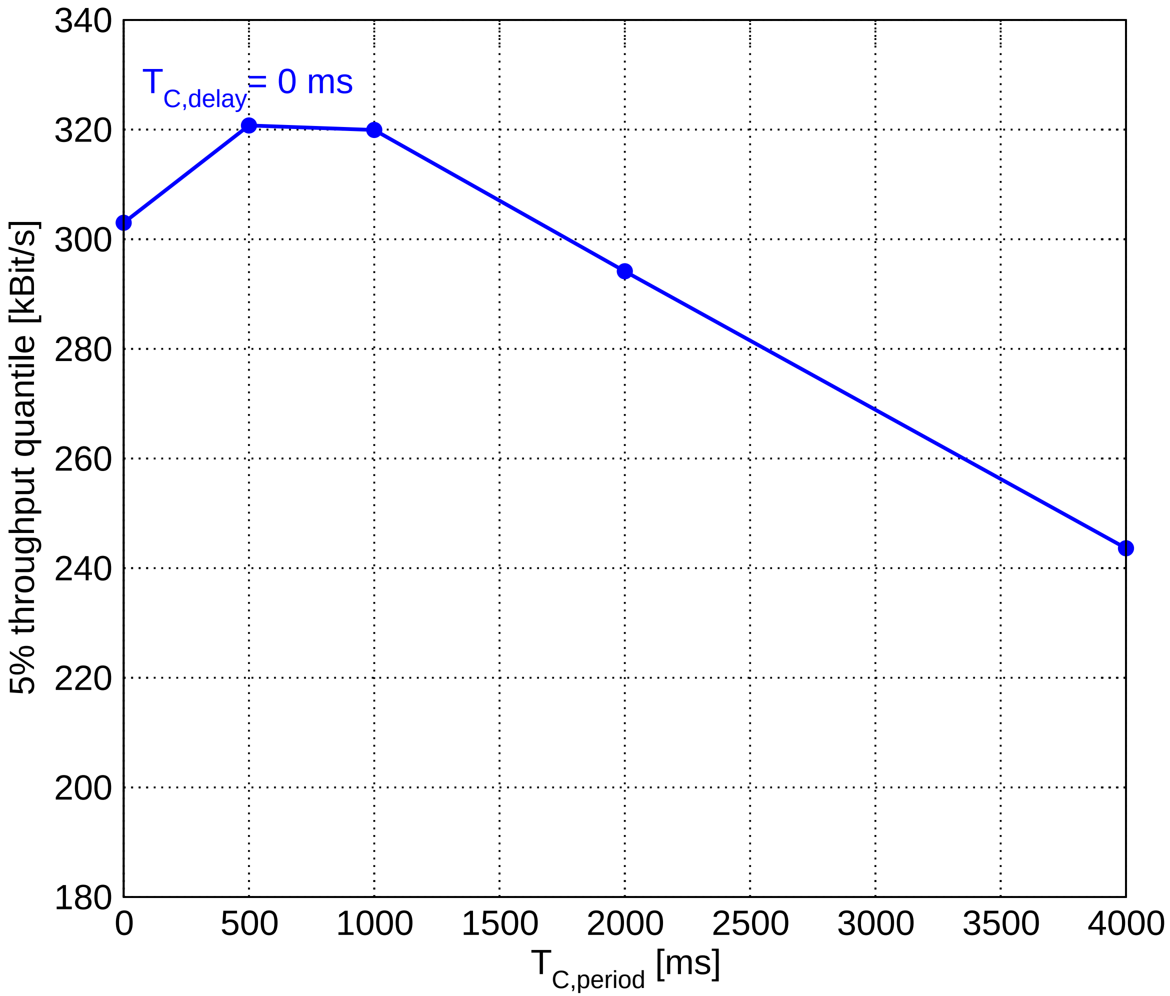
- **Conventional Fractional Frequency Reuse, locally coordinated**
  - achieves great increase in aggregate performance
  - falls short with respect to cell edge performance

Throughput Performance



- **Coordinated Fractional Frequency Reuse**
  - achieves good increase in aggregate and cell edge performance
  - allows to trade off cell edge and aggregate performance on a high level

Impact of Signaling Delays



- **Increased signaling delay $T_{C,period}$**
  - leads to graceful degradation of cell edge performance
  - has much less impact on aggregate performance (not shown here)

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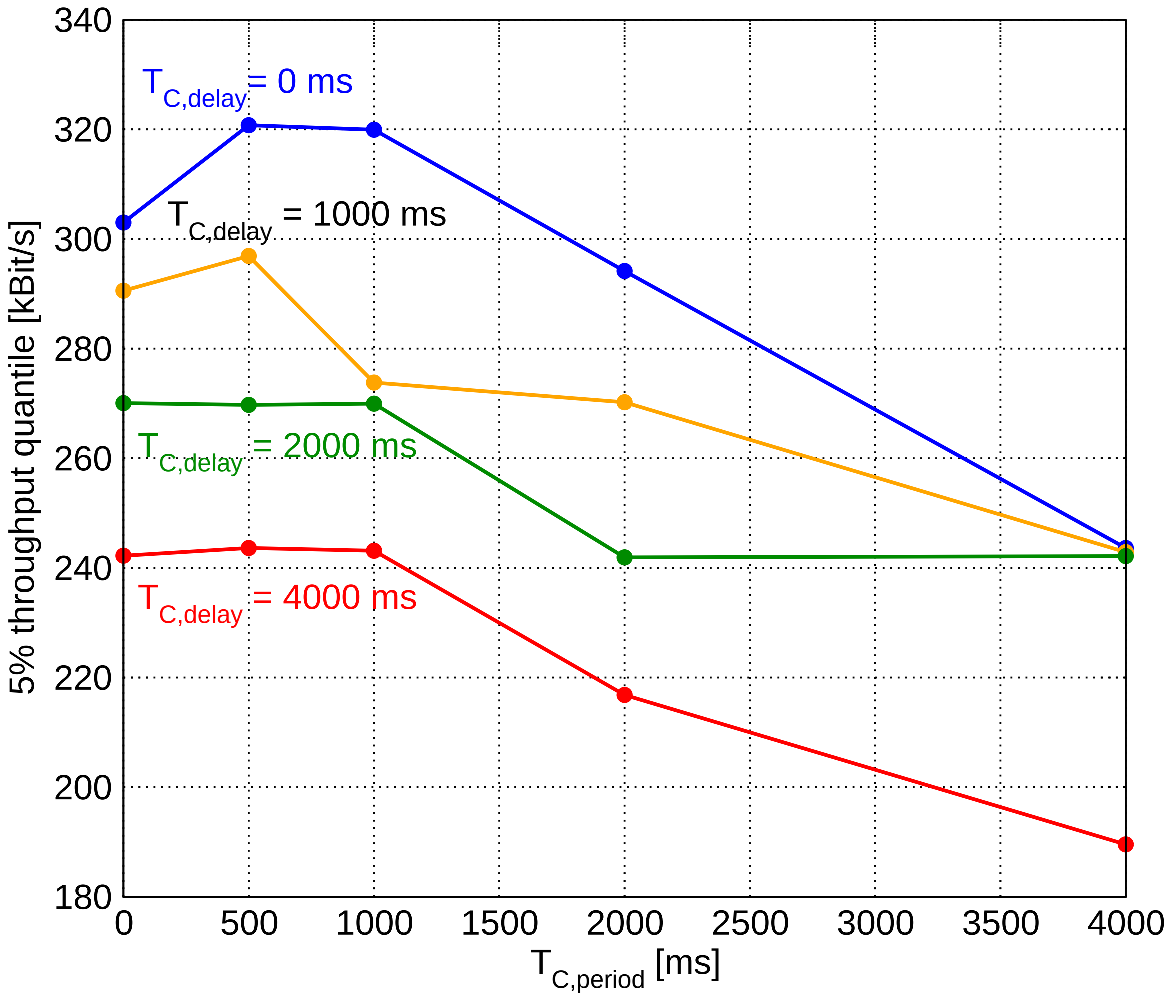

- **Increased signaling delays $T_{C,period}$ and $T_{C,delay}$**
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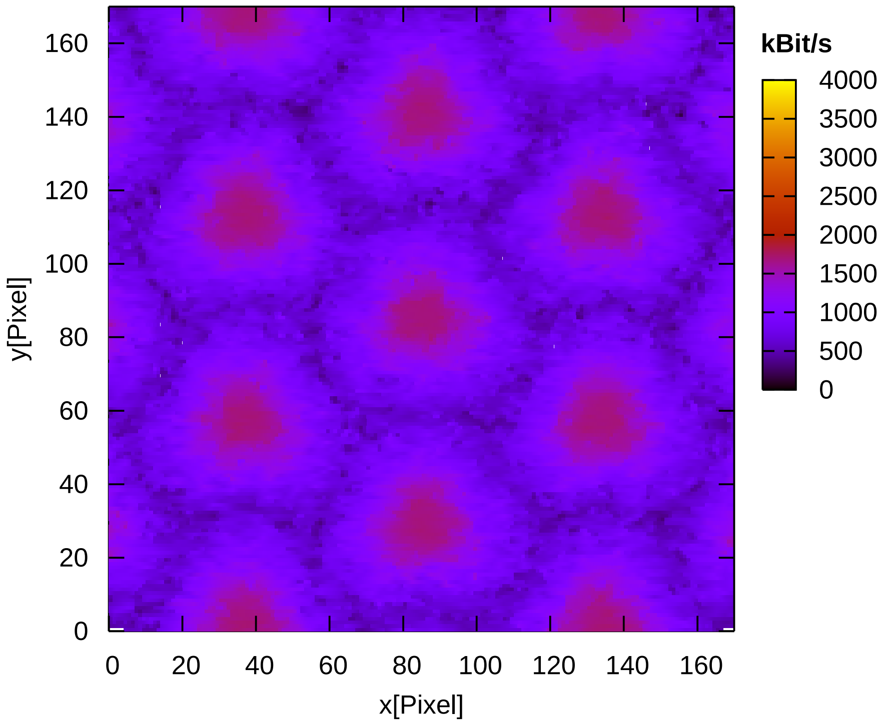
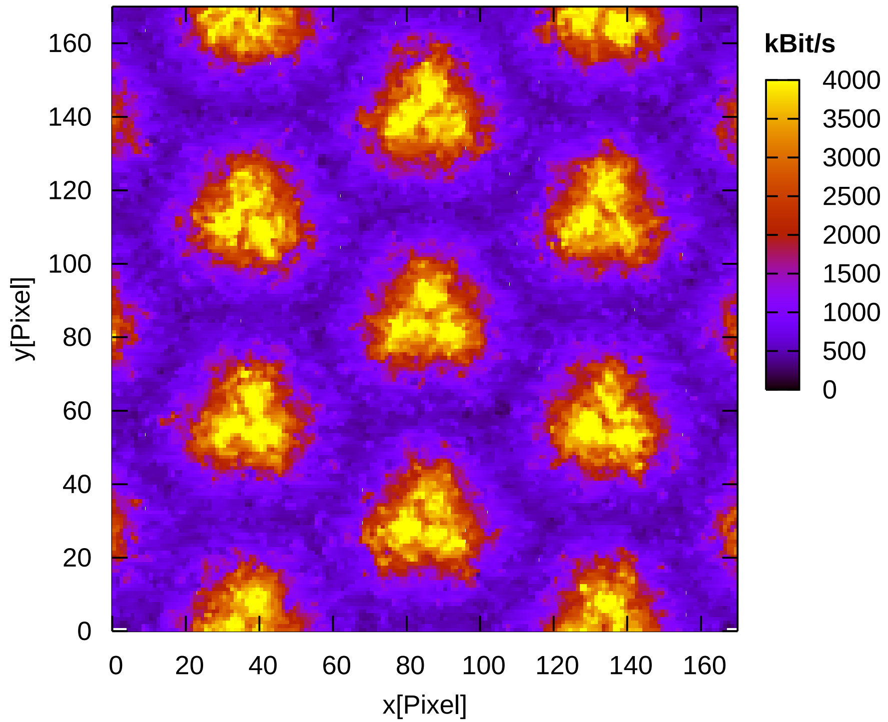
Area Throughput

Reuse 3



Coordinated FFR



$T_{C,period}$ = 2s, $T_{C,delay}$ = 1s
$D_{S,o}$ = 0dB, $D_{S,i}$ = 20dB

- **Big increase close to base stations**
- **Good coverage at cell edge with coordinated FFR**

Conclusion

- **Frequency spectrum is one of the most precious resources**
  ☞ operators strive to get maximum performance out of limited spectrum
- **Possible solutions**
  - denser planning of base station grid
    ☞ high additional cost
  - deployment of advanced algorithms, such as interference coordination
    ☞ capacity improvements achievable by much lower cost
- **Coordinated Fractional Frequency Reuse**
  - algorithm for distributed and dynamic interference coordination
  - low complexity scheme based on central coordinator
    communication with central coordinator in intervals in the order of $\geq$ 500 ms
  - performance improvements of about 50% (compared to Reuse 3)
    - with respect to aggregate throughput (maintaining cell edge throughput)
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