



Increasing Capacity of Cellular WiMAX Networks by Interference Coordination

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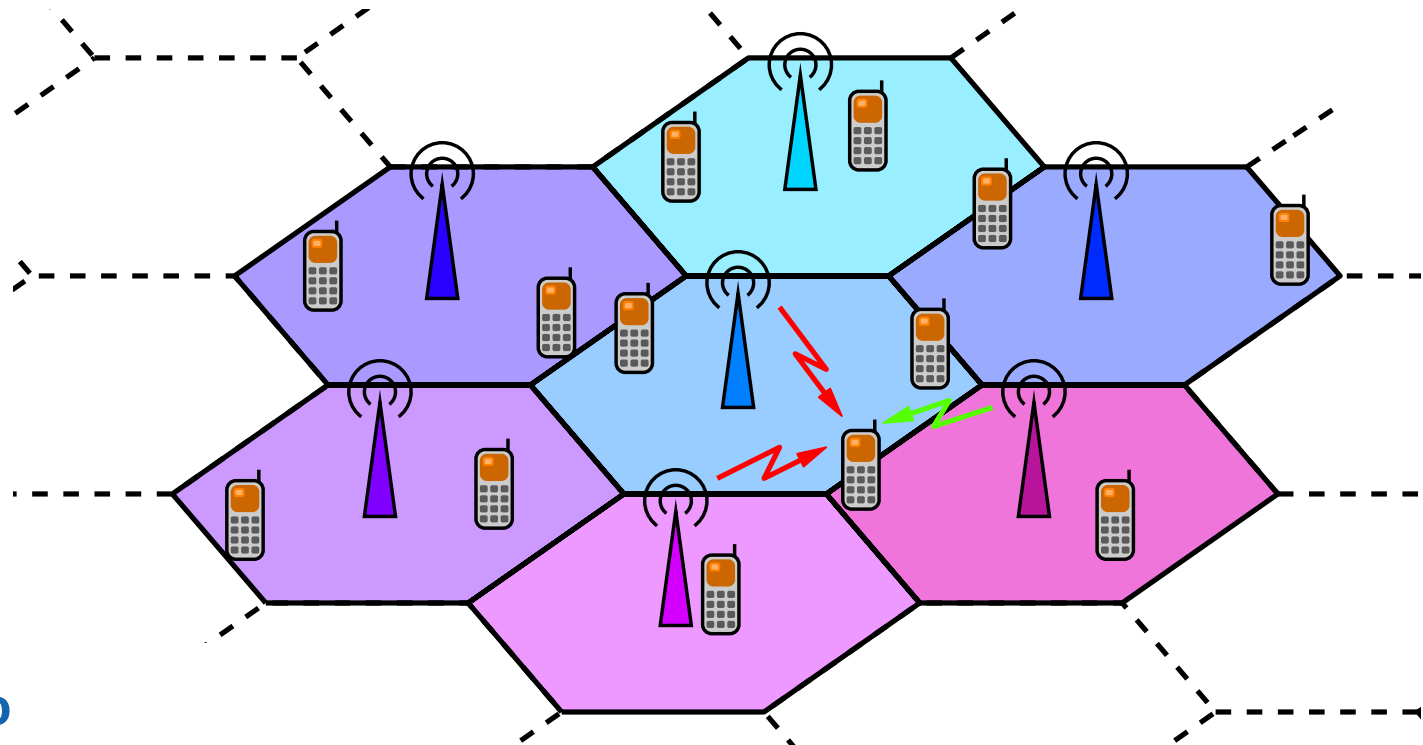
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Outline

- **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

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

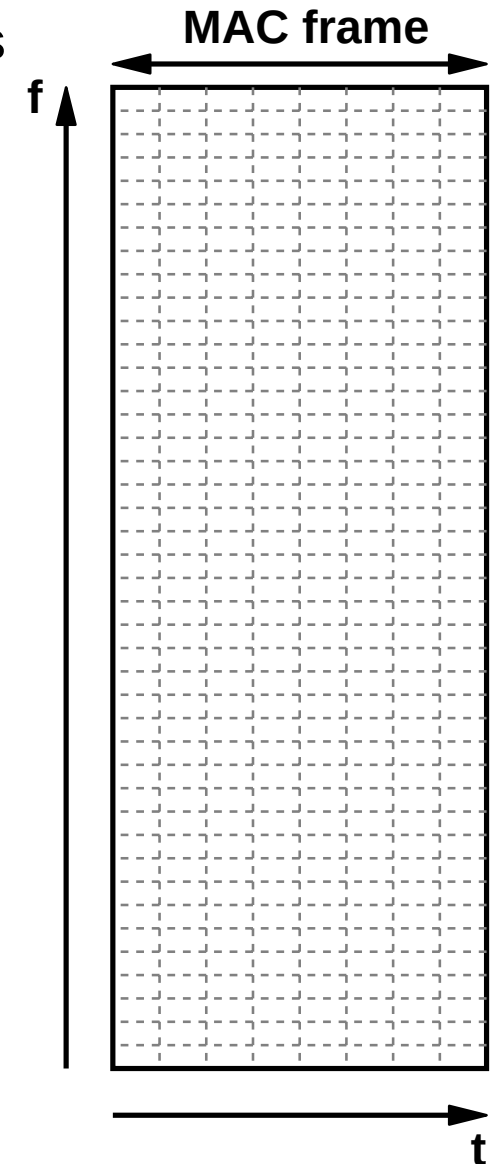
Requirements

- 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

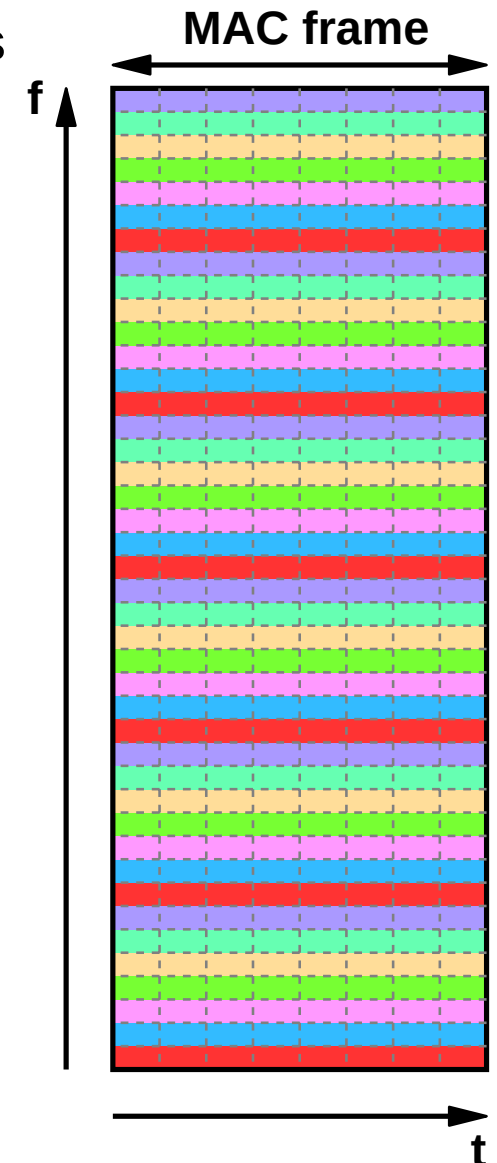


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Example: 802.16e MAC Layer ("mobile WiMAX")

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

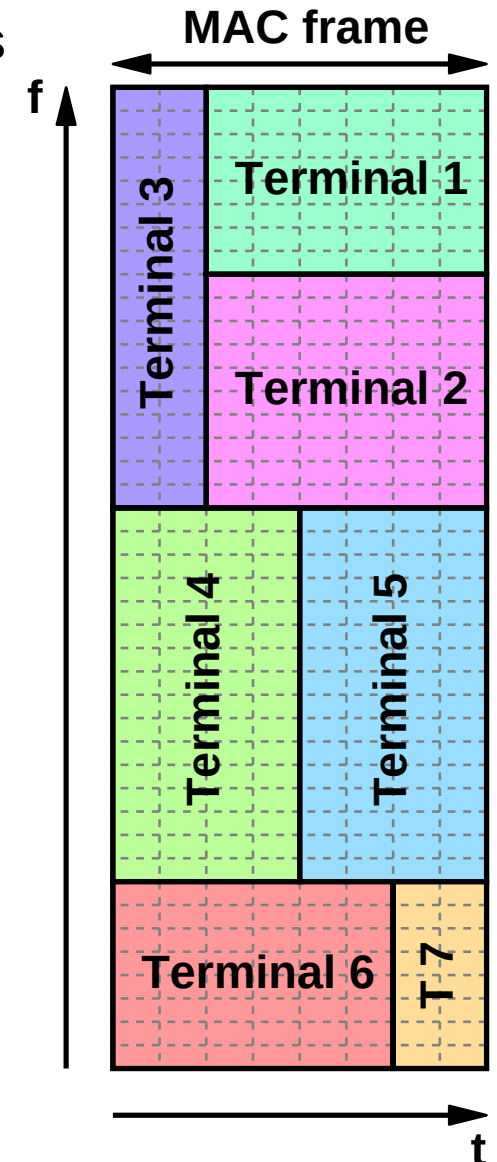


Orthogonal Frequency Division Multiple Access

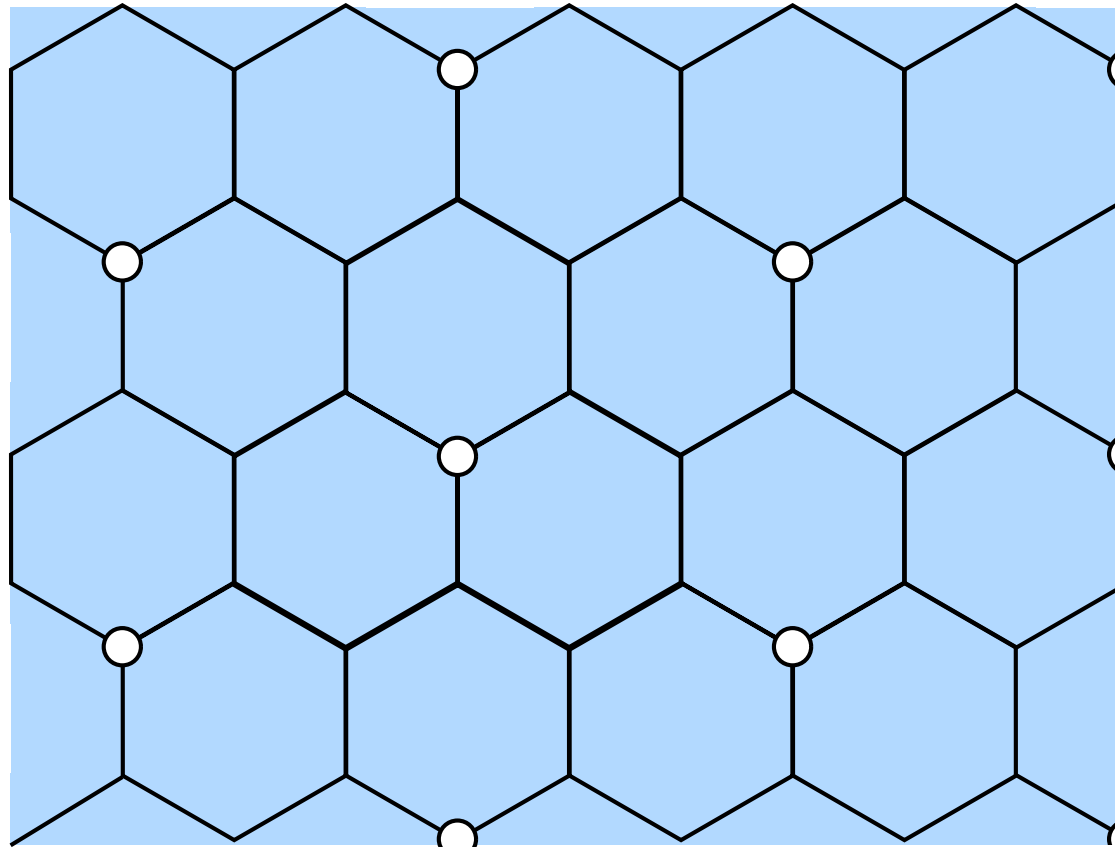
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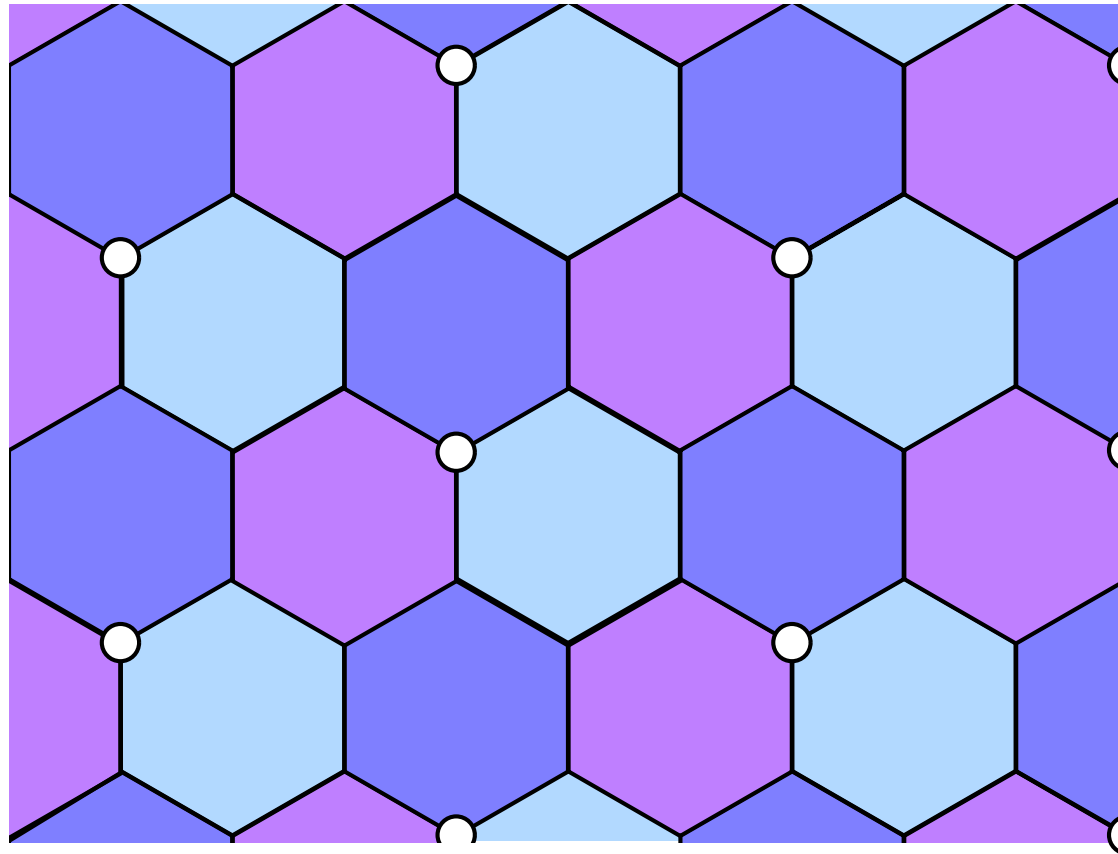
- **Frequency-diverse (PUSC zone, FUSC zone) and frequency-selective modes (AMC zone)**
- **AMC zone (Adaptive Modulation and Coding)**
 - allocation of consecutive subchannels for the transmission to one terminal
 - allocations have rectangular shapes
 - ☞ allows frequency-selective scheduling
 - ☞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



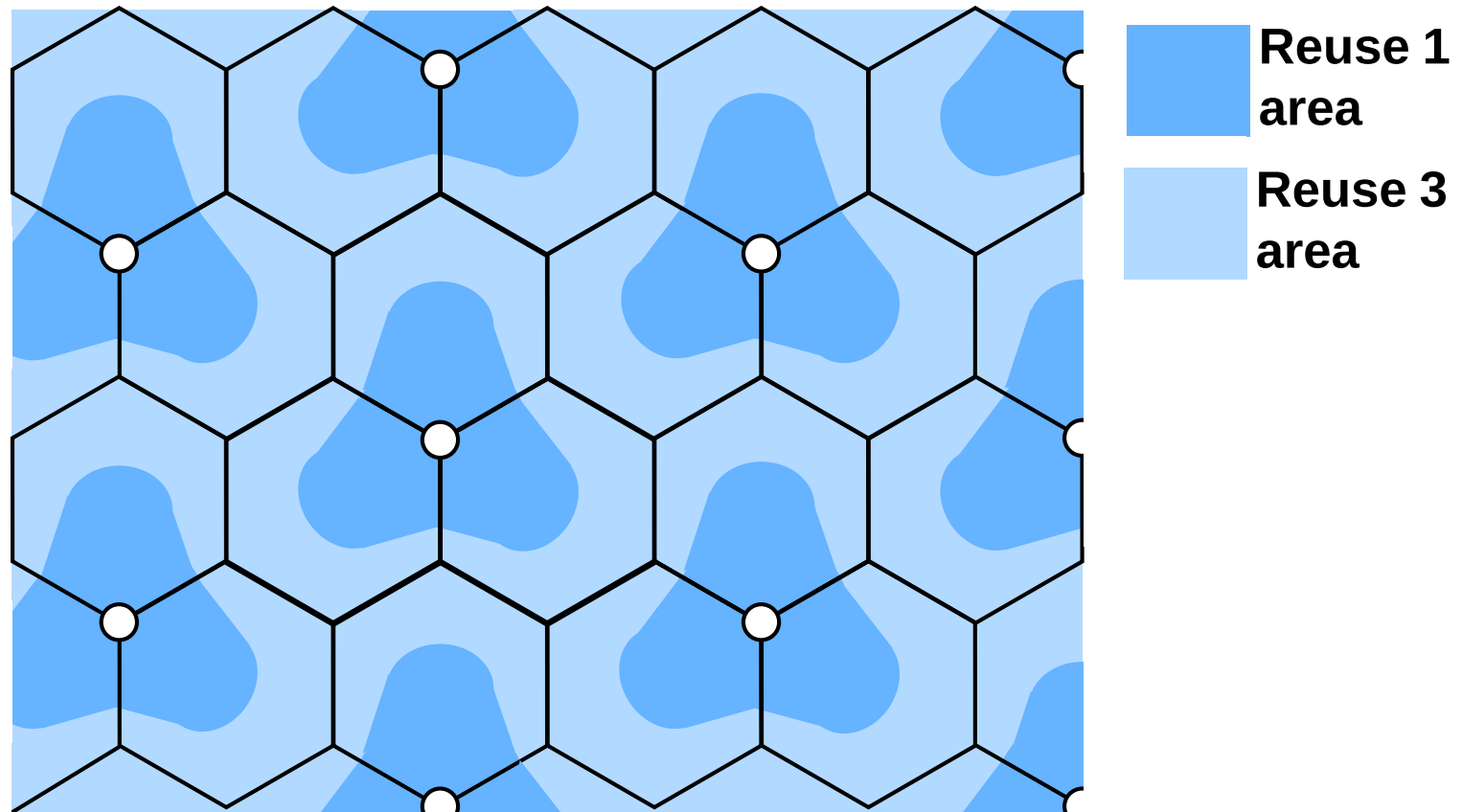
Interference in Cellular Networks



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

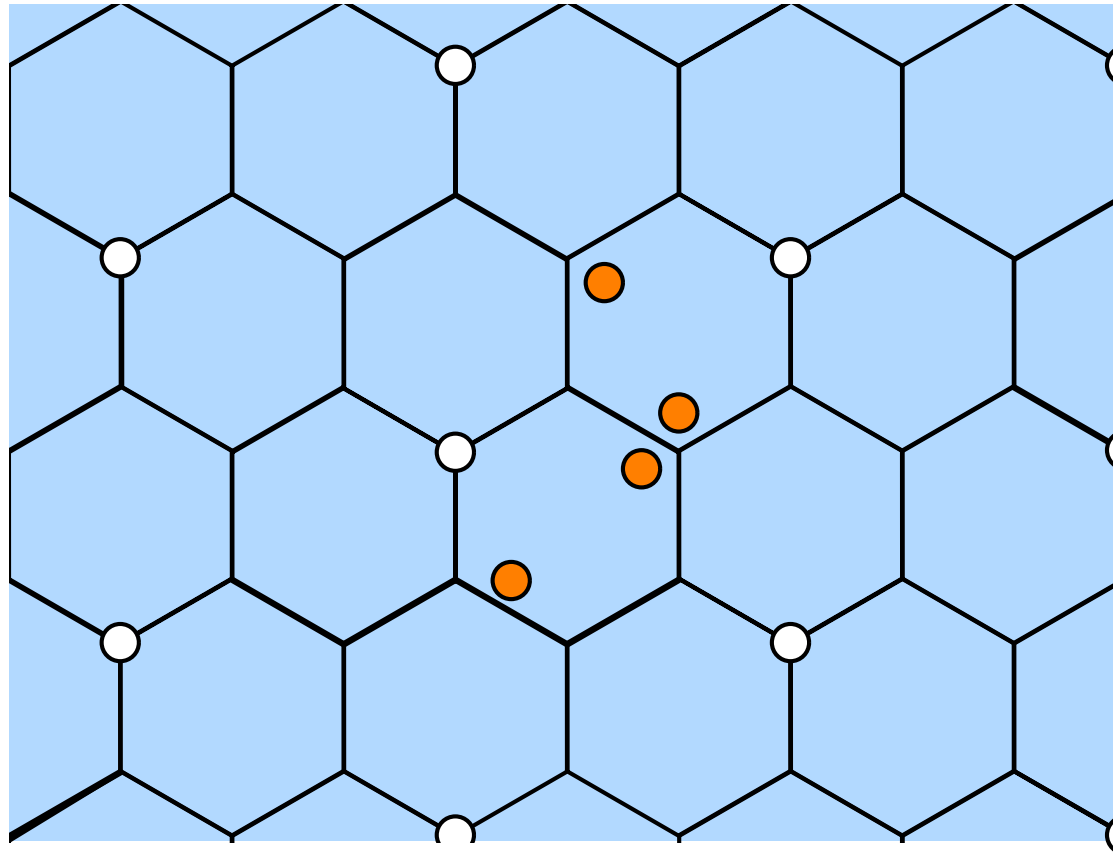


- **Major issue in OFDMA: inter-cellular interference**
 - standard solution: frequency reuse pattern
 - disadvantage: waste of precious frequency resources



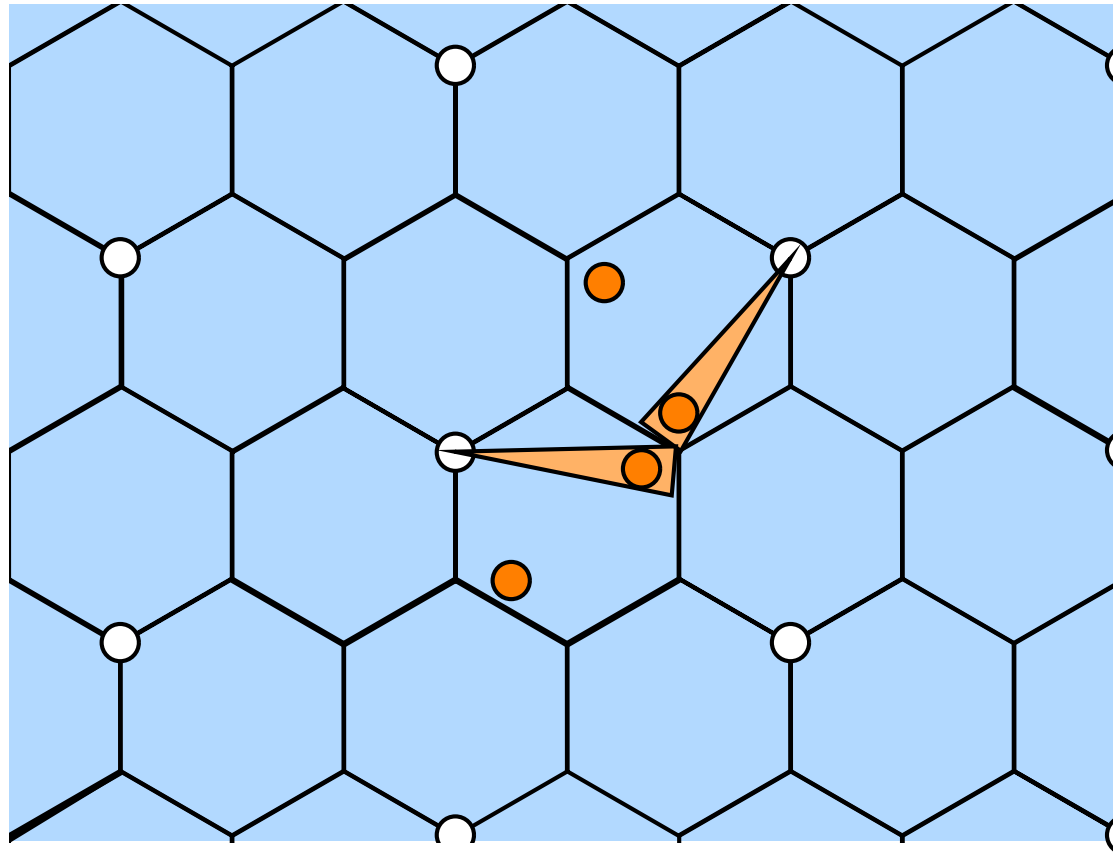
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Interference in Cellular Networks



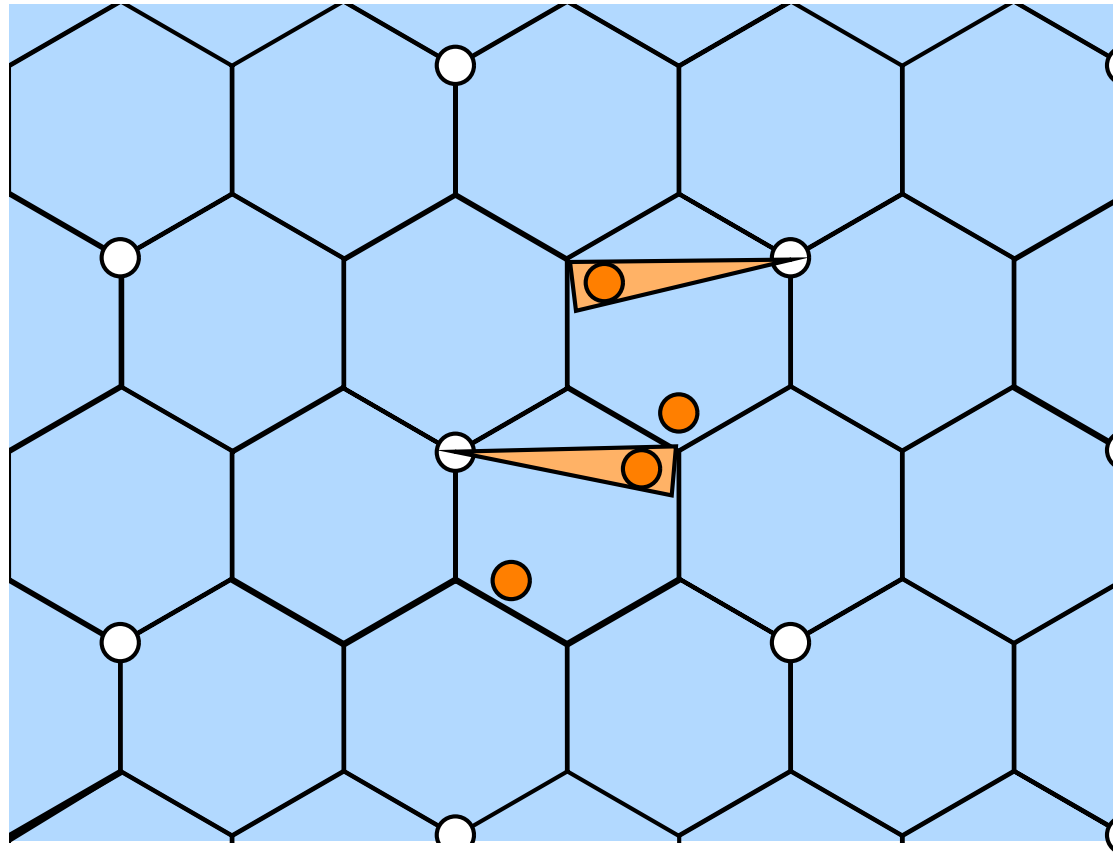
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Interference in Cellular Networks



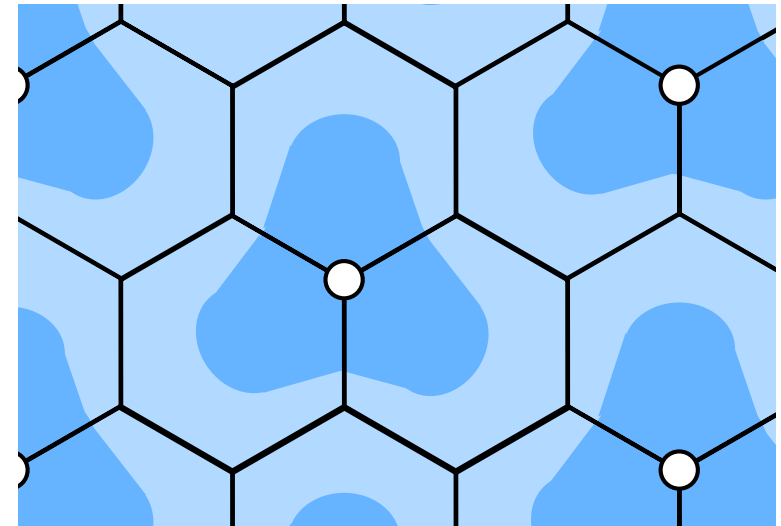
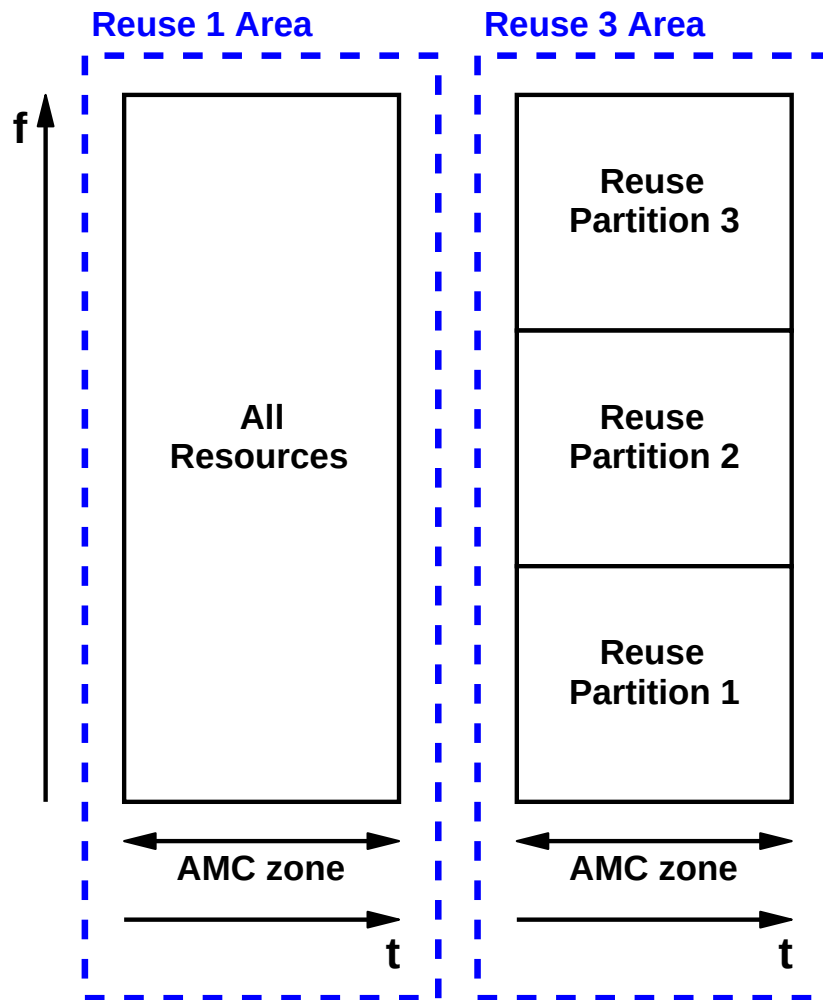
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Interference in Cellular Networks



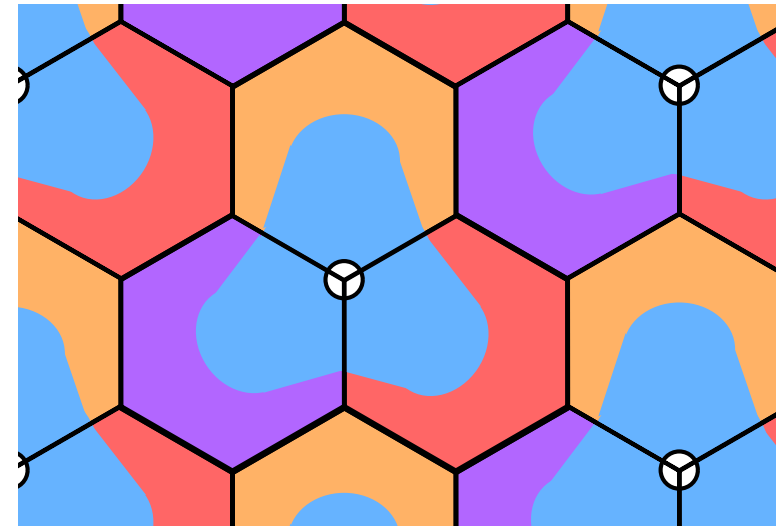
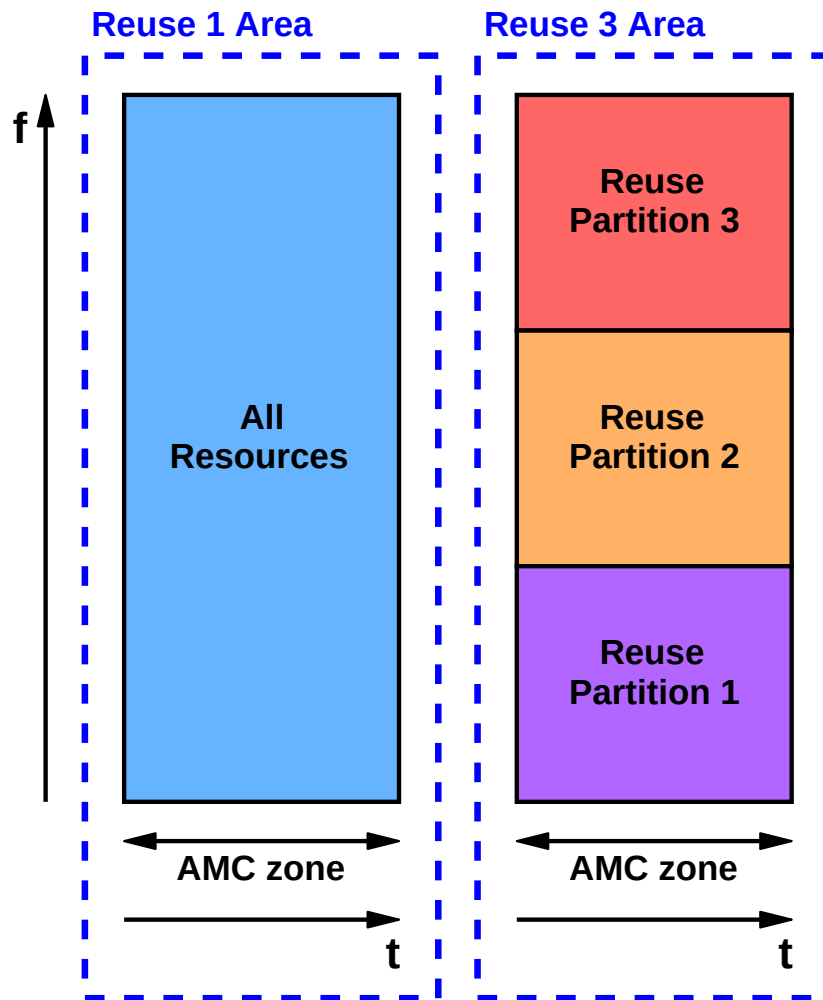
- **Major issue in OFDMA: inter-cellular interference**
 - standard solution: frequency reuse pattern
 - optimization: Fractional Frequency Reuse (FFR)
 - Usage of directional antennas to lower inter-cellular interference
 - ☞ Additional coordination necessary ☞ [interference coordination \(ICFO\)](#)

Conventional Fractional Frequency Reuse (FFR)



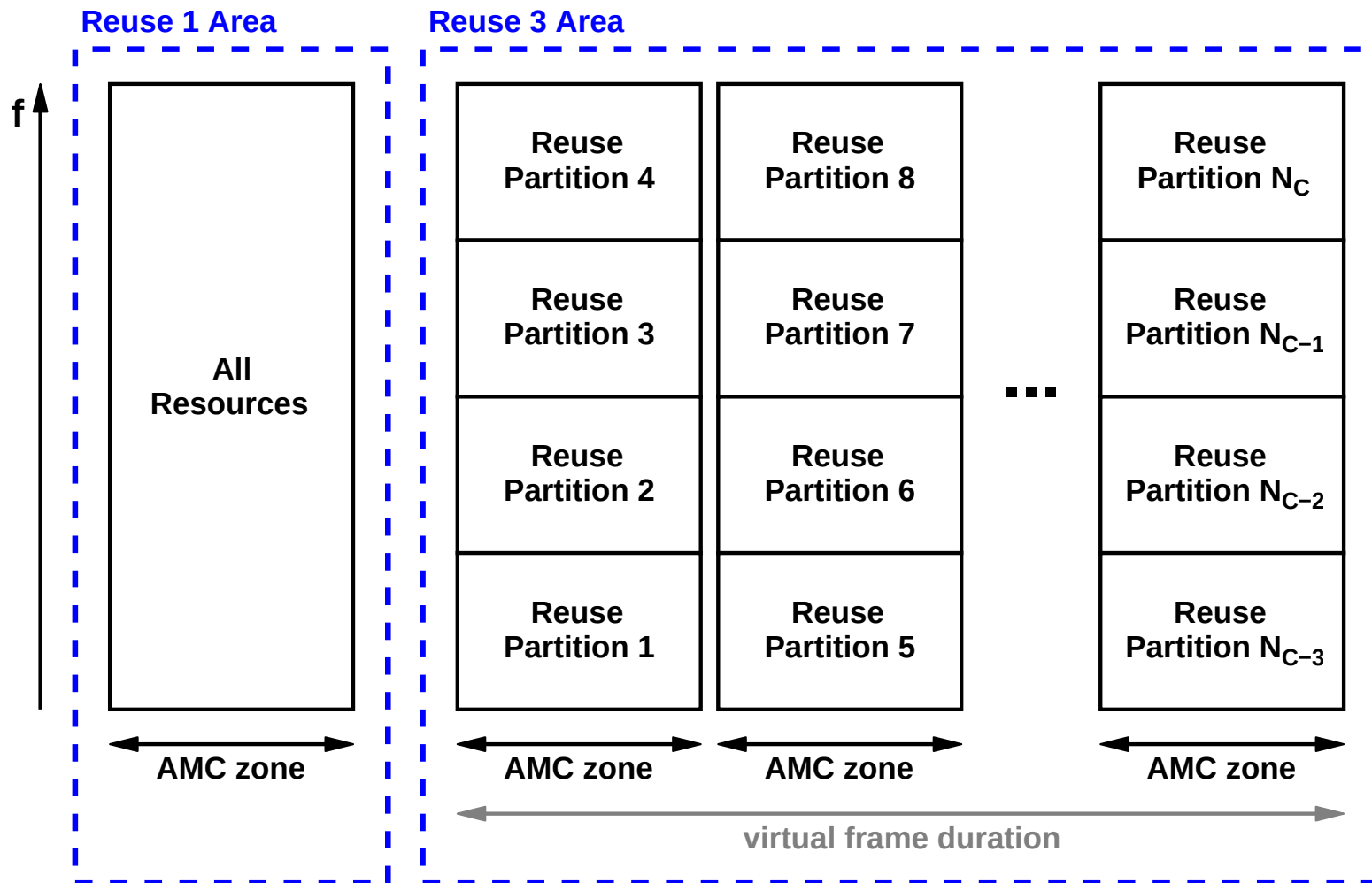
- Reuse 1 & reuse 3 areas may or may not be on same frequency range
 - Power levels may or may not be adjusted depending on area
-
- Assignment of mobiles to reuse 1 or 3 based on position or SINR

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

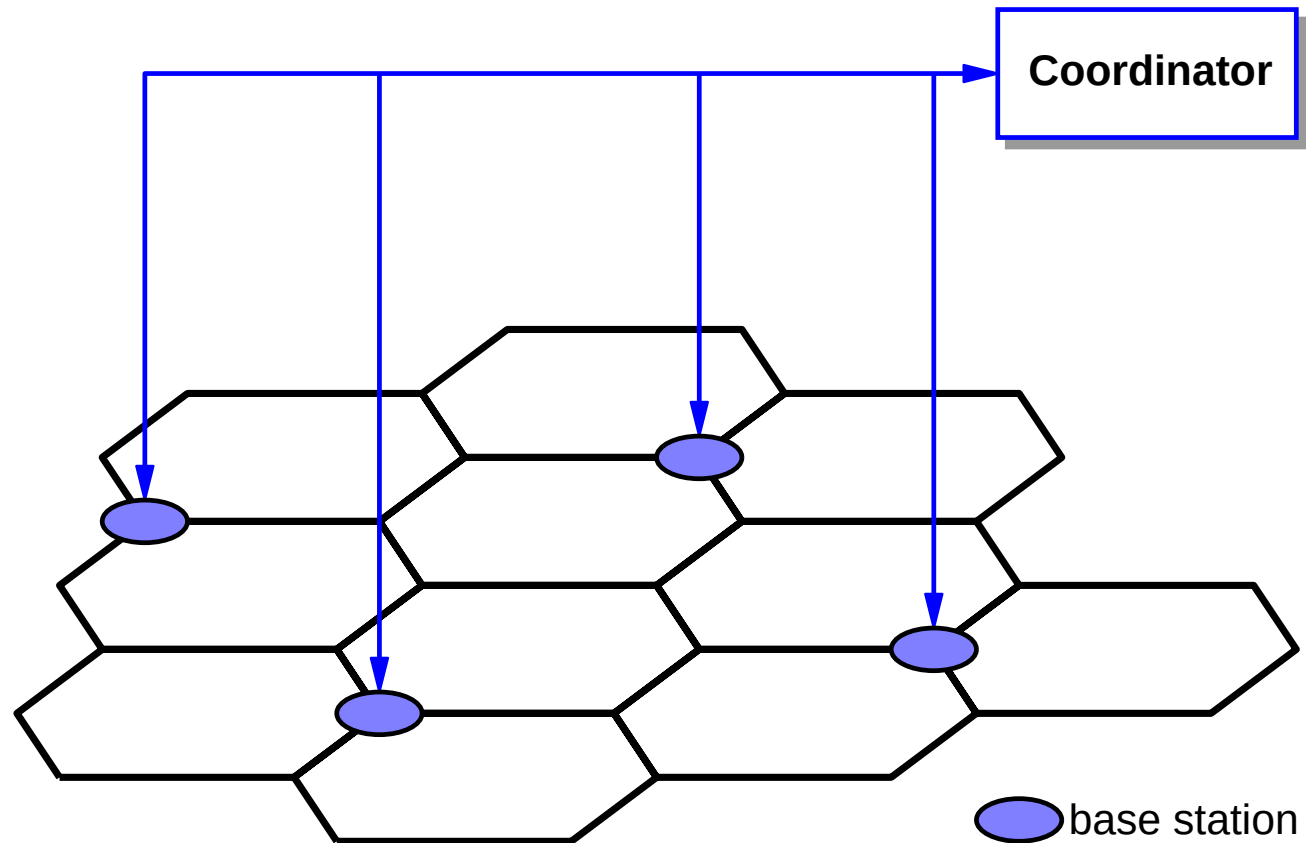
Coordinated Fractional Frequency Reuse



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**

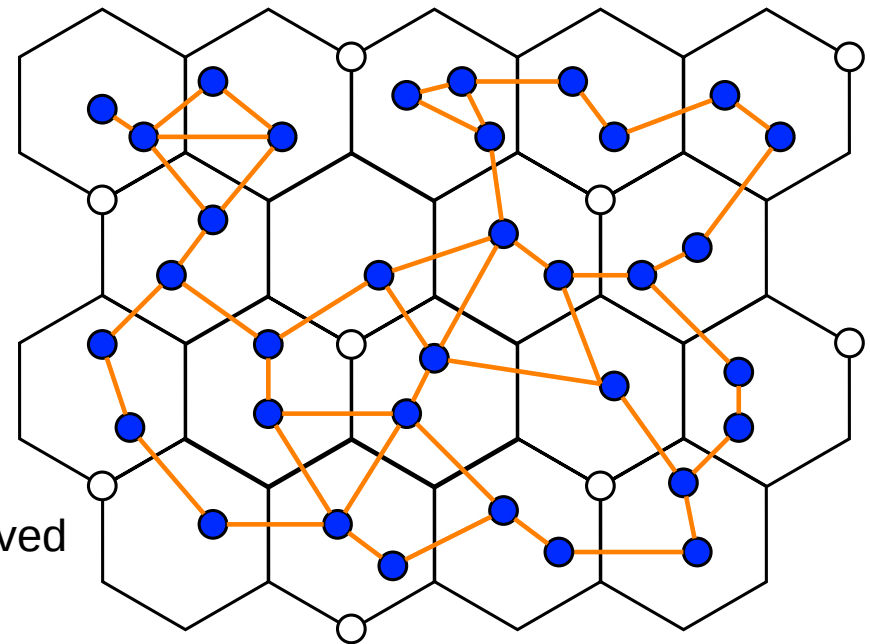
Coordination of Resource 3 Partitions

- **Approach**

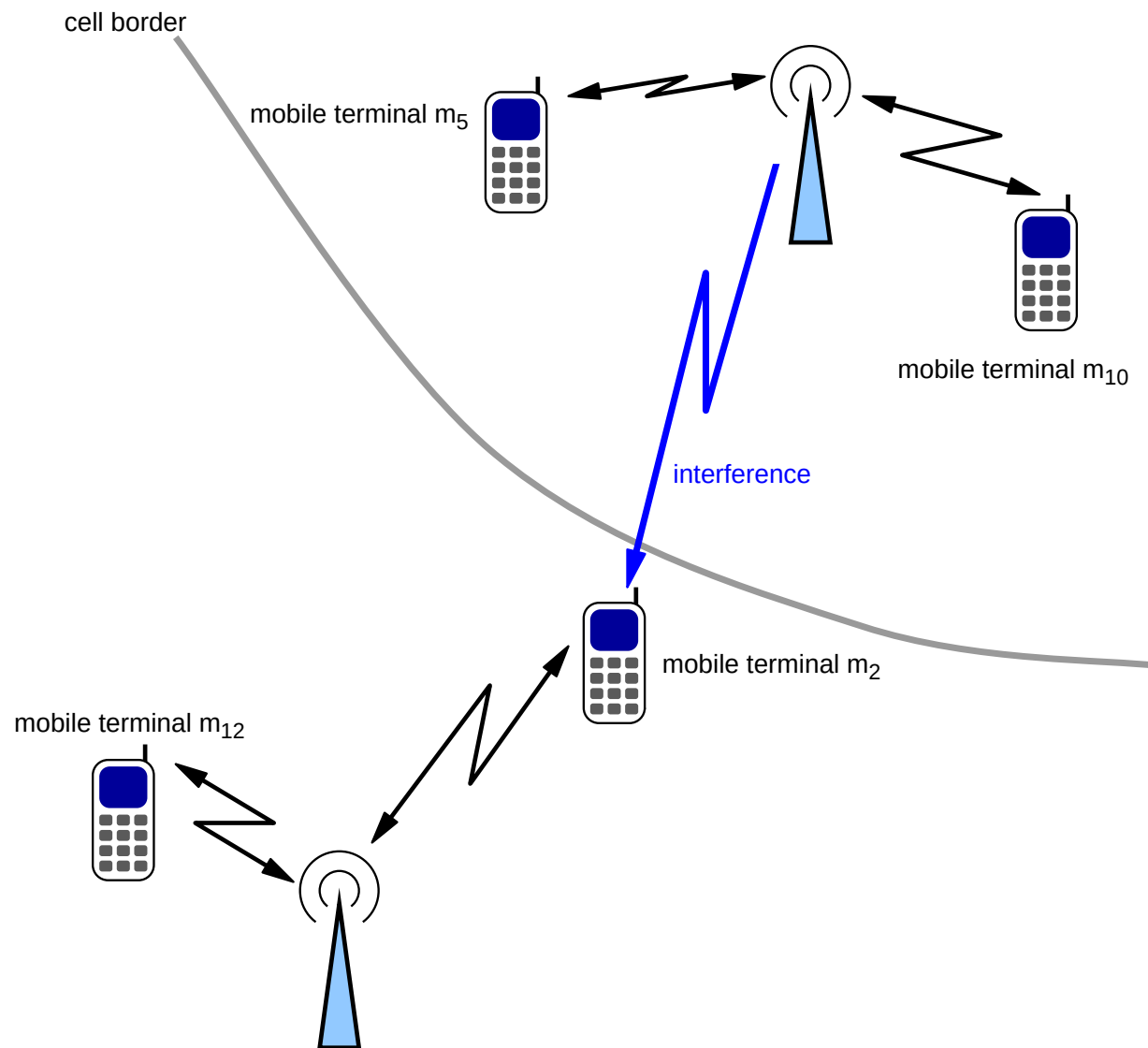
- construction of an interference graph G in central coordinator
 - **nodes** $m_i \in M$
 - **edges** $e_{ij} \in E$ (non-directional)
- assignment of resource partitions based on interference graph
- communication of resource partitions to base stations

- **Interference graph**

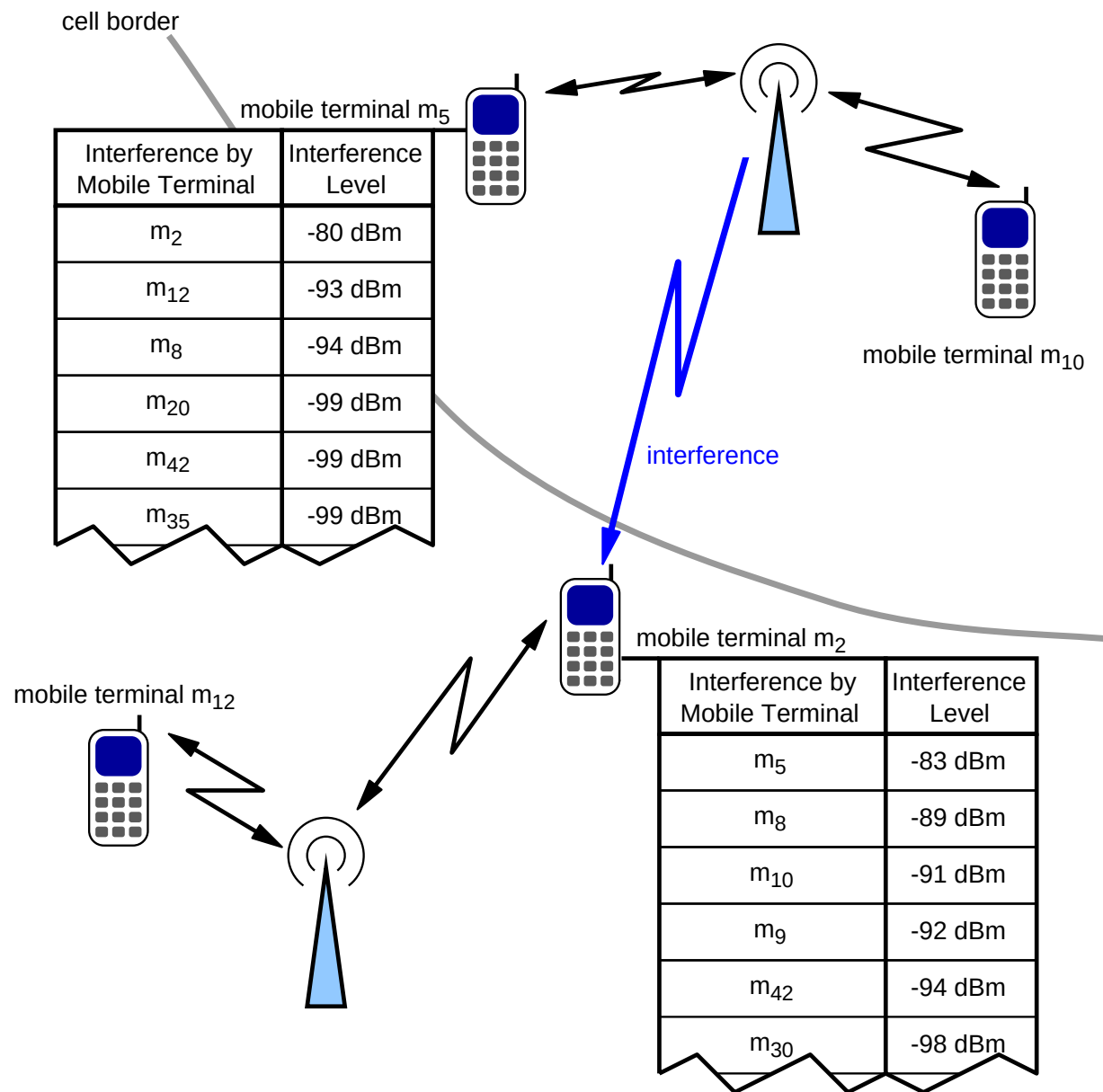
- based on global knowledge collected from all base stations
- edges represent critical interference relations in-between terminals
 - ☞ connected terminals should not be served on the same resource (time/frequency slot)



Creation of Interference Graph

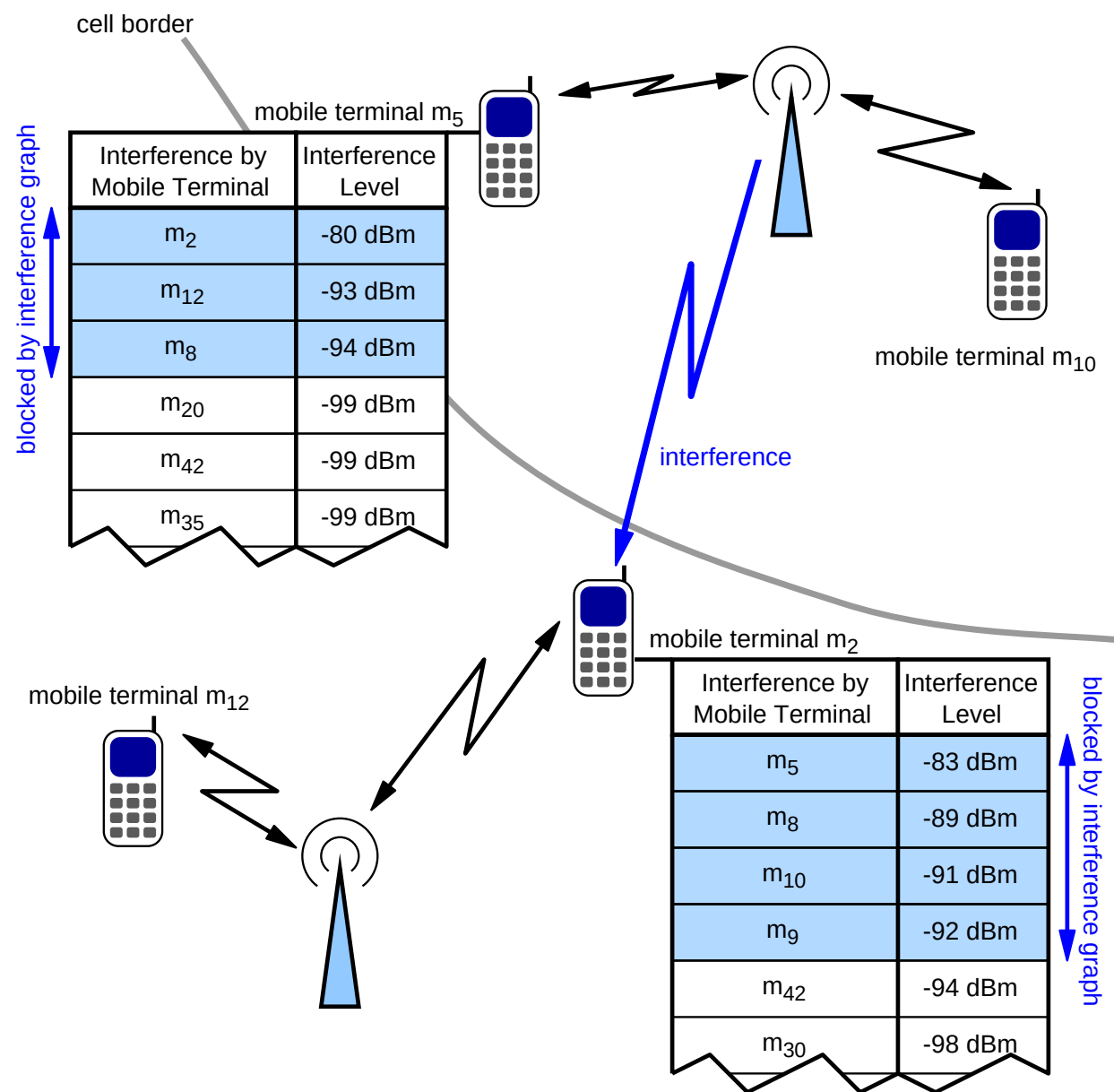


Creation of Interference Graph



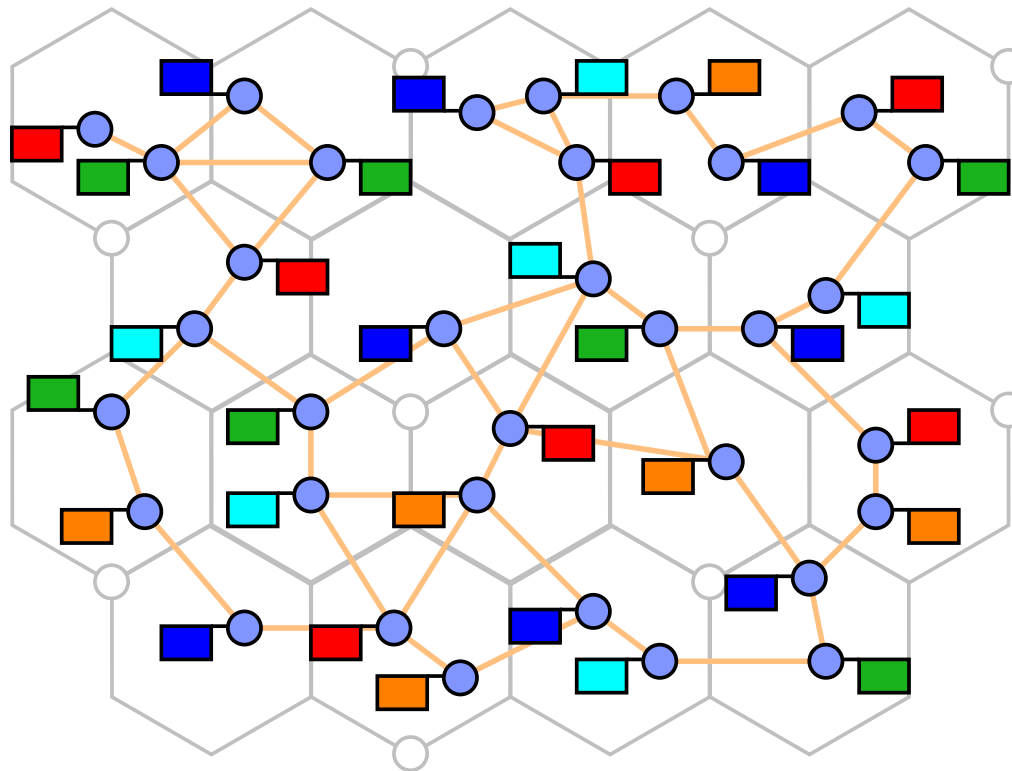
- Calculation of signal strength of interferers for a particular mobile terminal m_j

Creation of Interference Graph

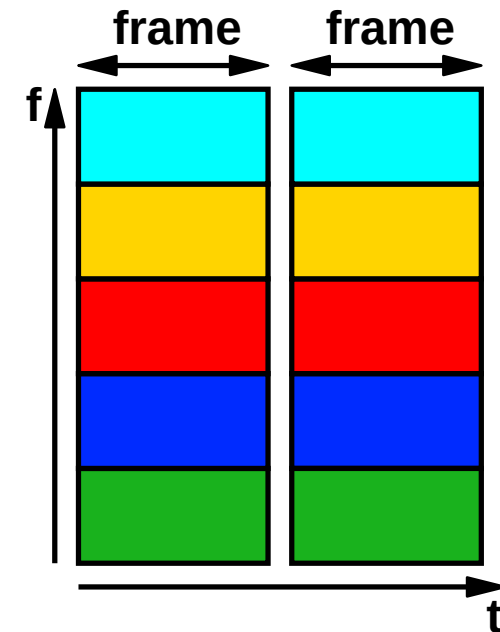


- Calculation of signal strength of interferers for a particular mobile terminal m_j
- Blocking of strongest interferers such that a desired minimum SIR D_S is achieved

Assignment of Resource Partitions

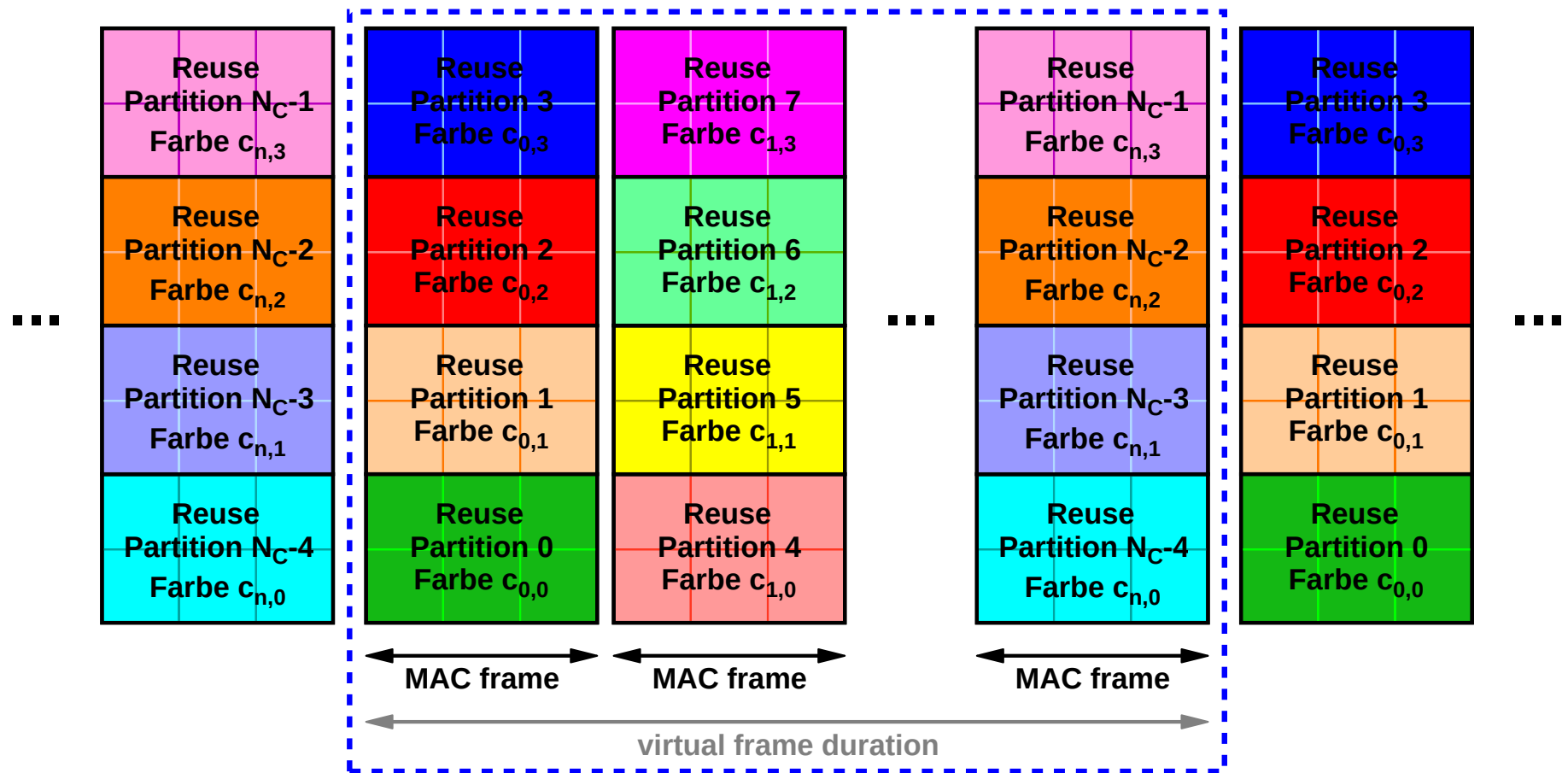


Example of resource mapping



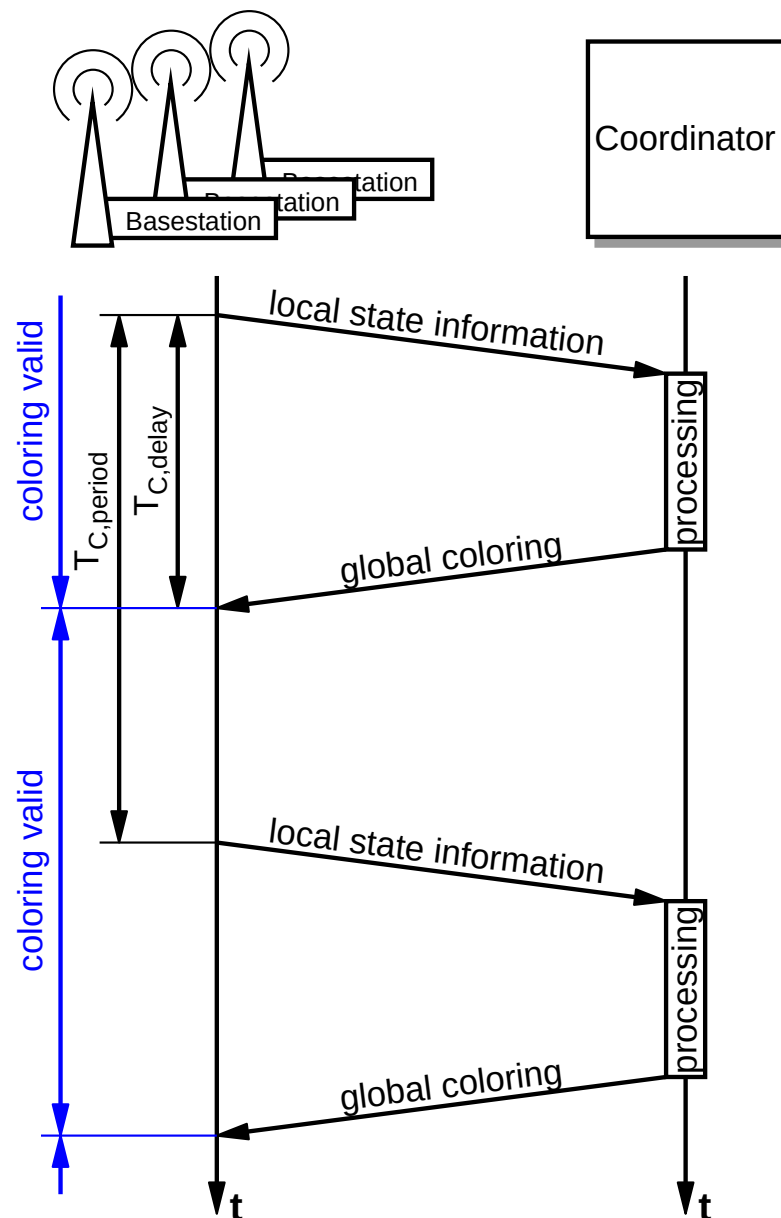
- Treat resource partitions as colors of graph
- Resource partitions can be assigned to mobile terminals by coloring of the interference graph
 - graph coloring is NP hard
 - large number of heuristics: genetic algorithms, simulated annealing, tabu search, other heuristics (e.g., [Dsatur](#))

Mapping of colors to Resource Partitions



👉 Virtual frame duration must be adapted to number of colors

Signaling-Time-Diagram



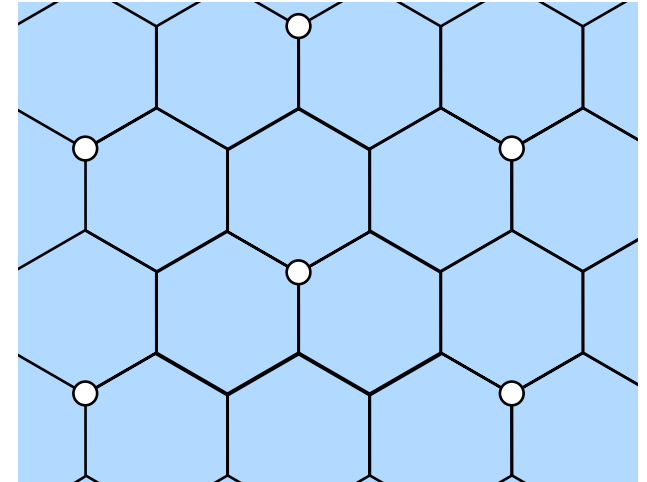
Procedure

- 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

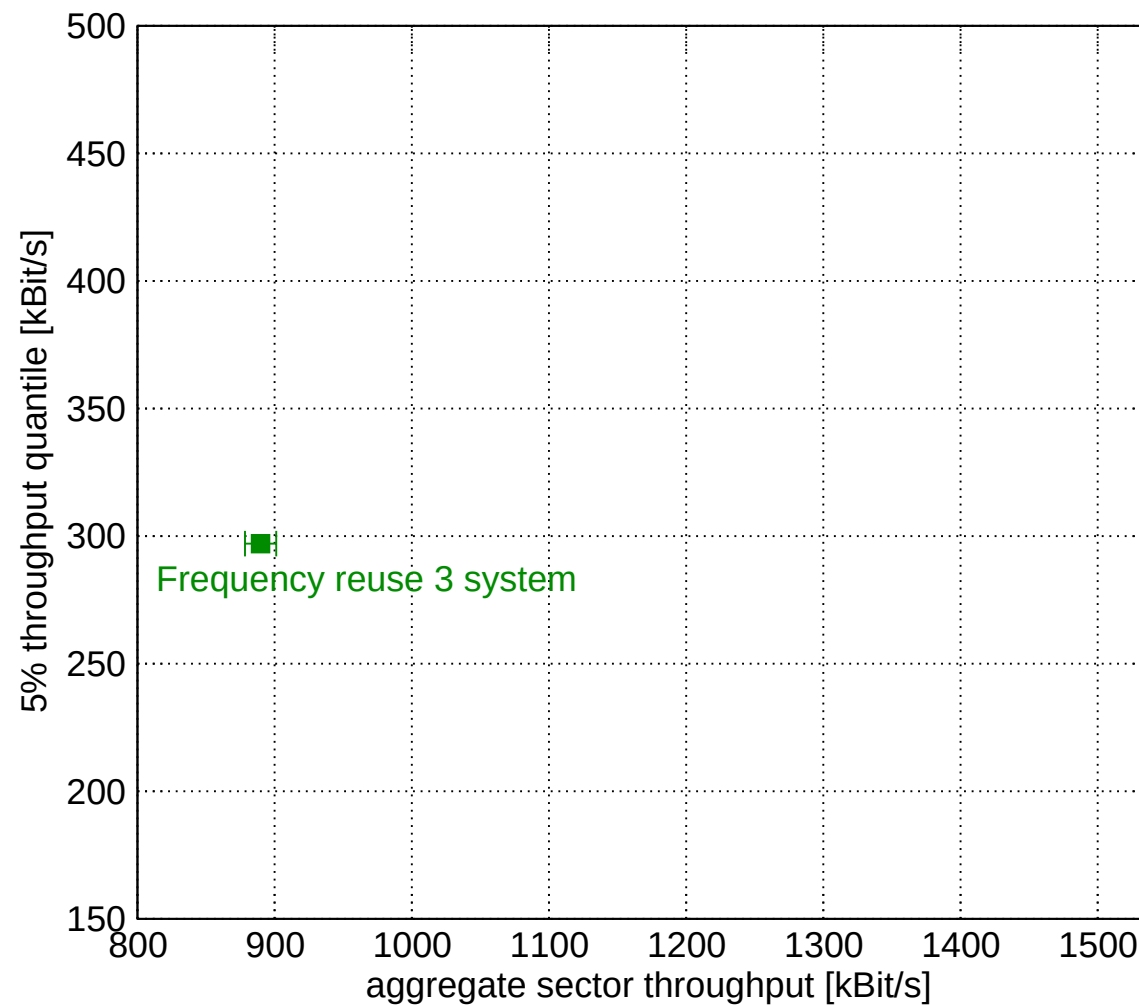
Important Parameters

- 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

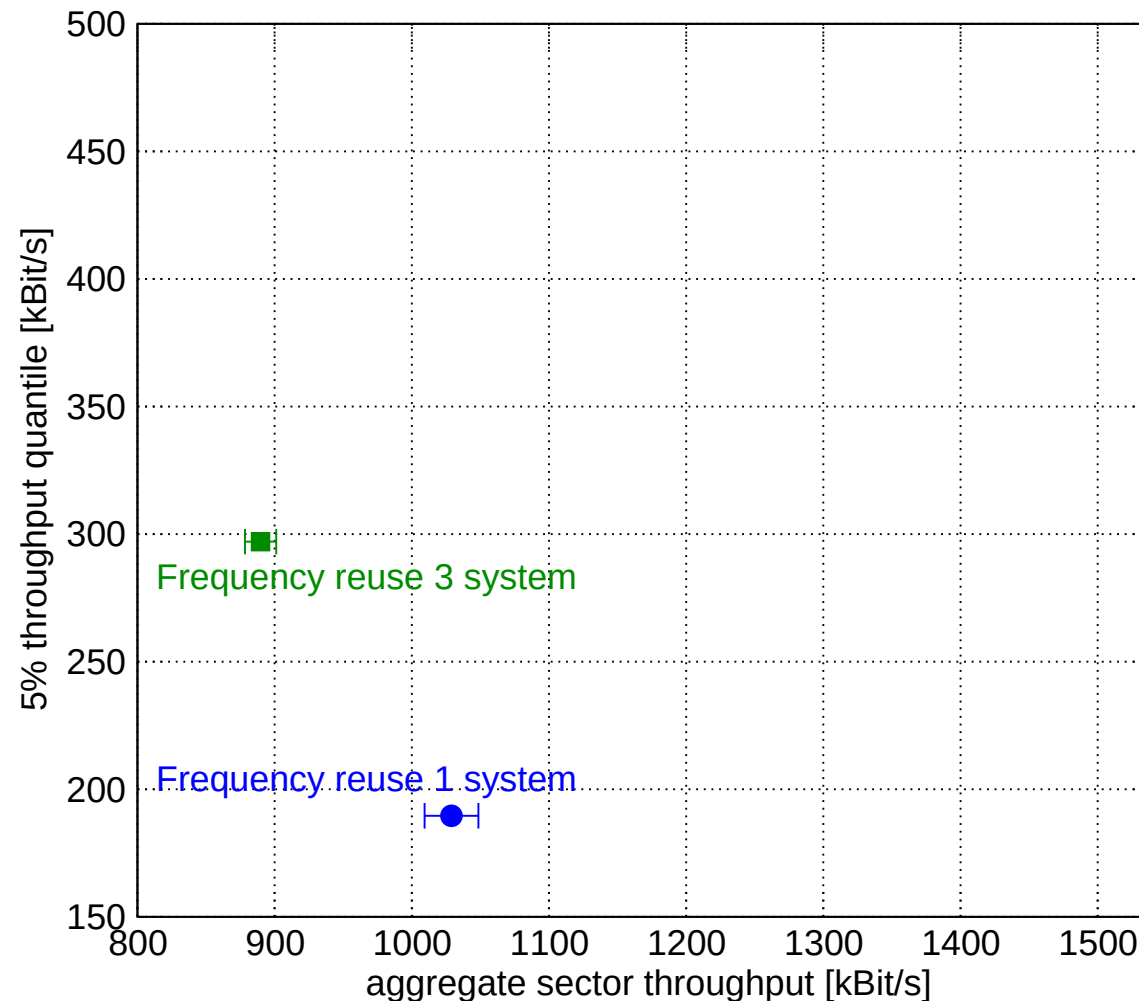


Throughput Performance



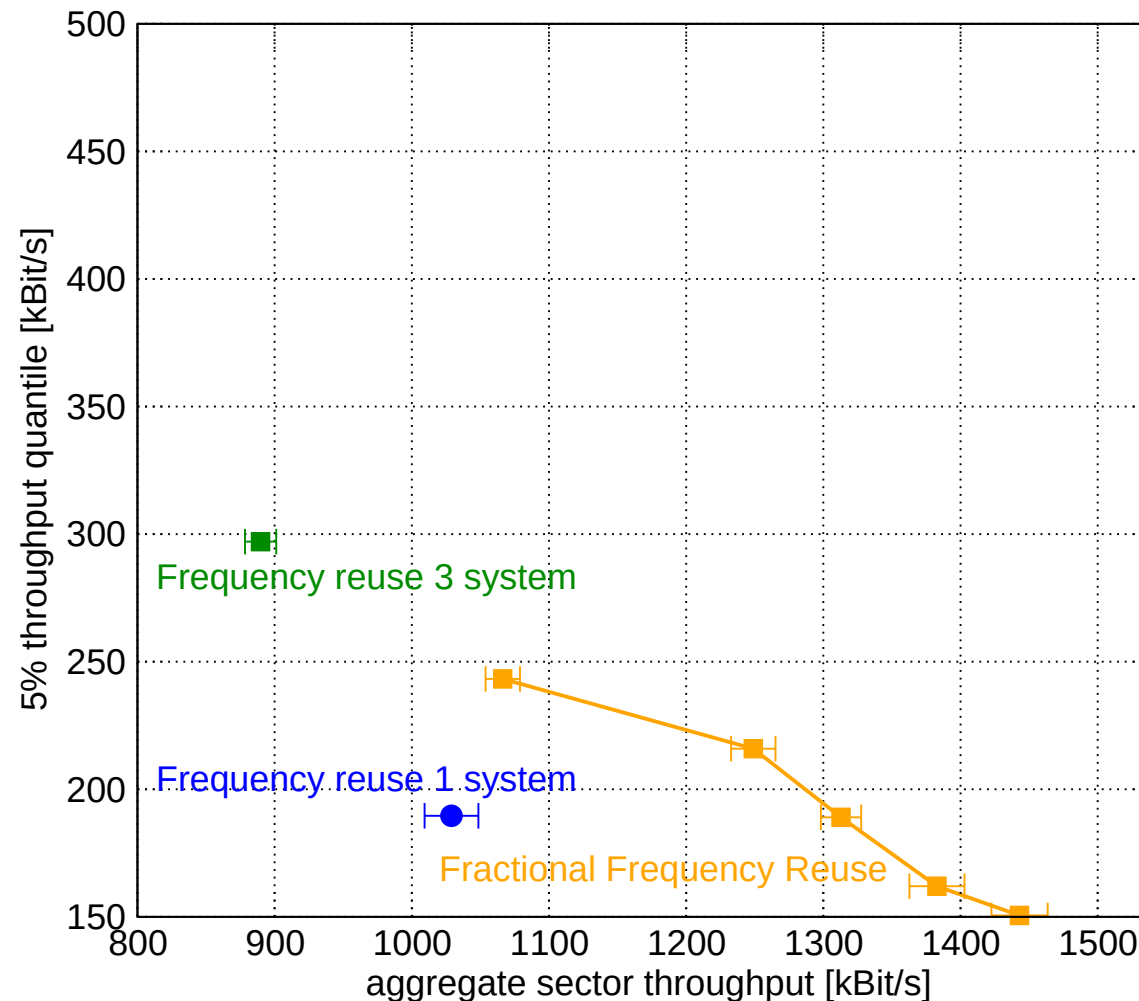
- Reuse 3 system achieves good **aggregate** performance and good **cell edge** performance

Throughput Performance



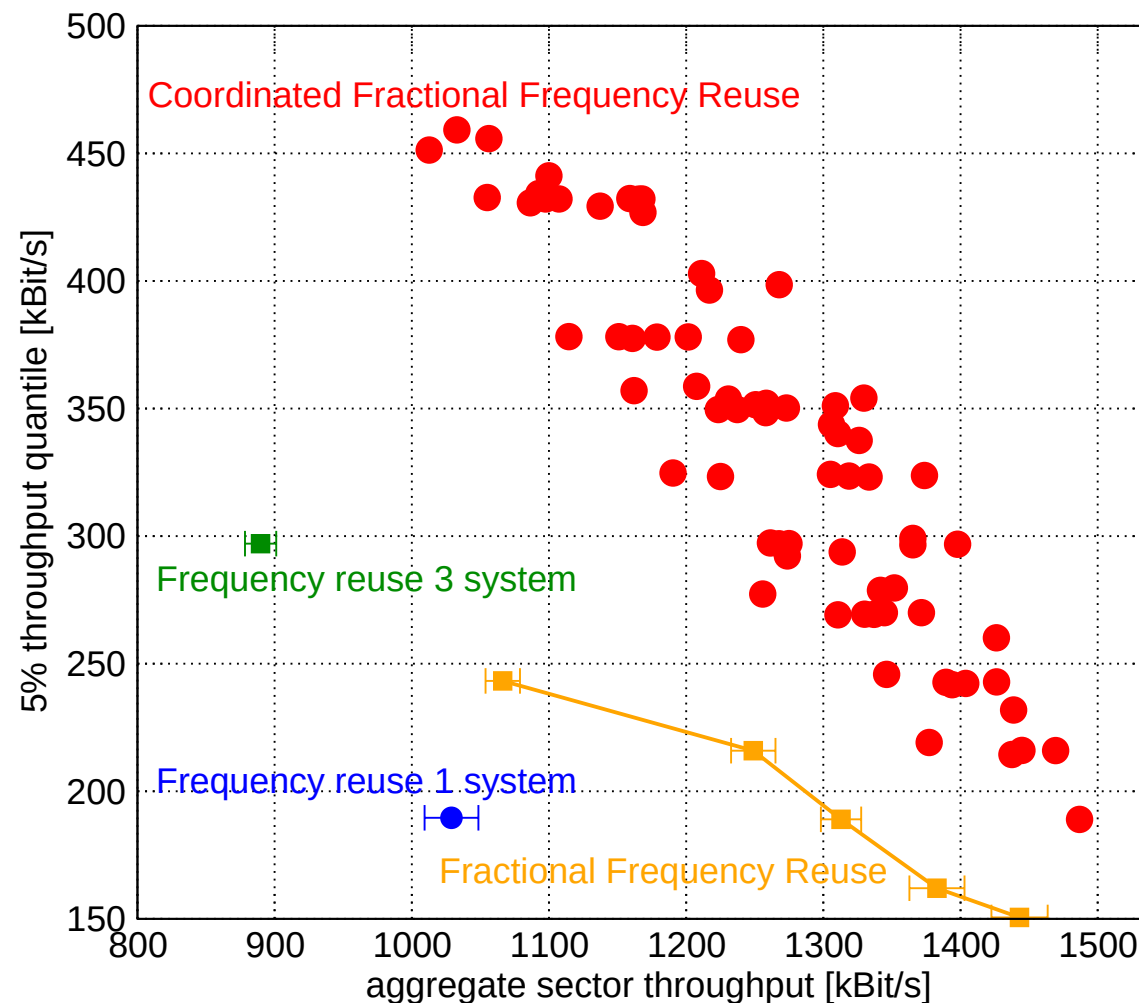
- Reuse 1 system achieves better **aggregate** performance but falls short with respect to **cell edge** performance

Throughput Performance



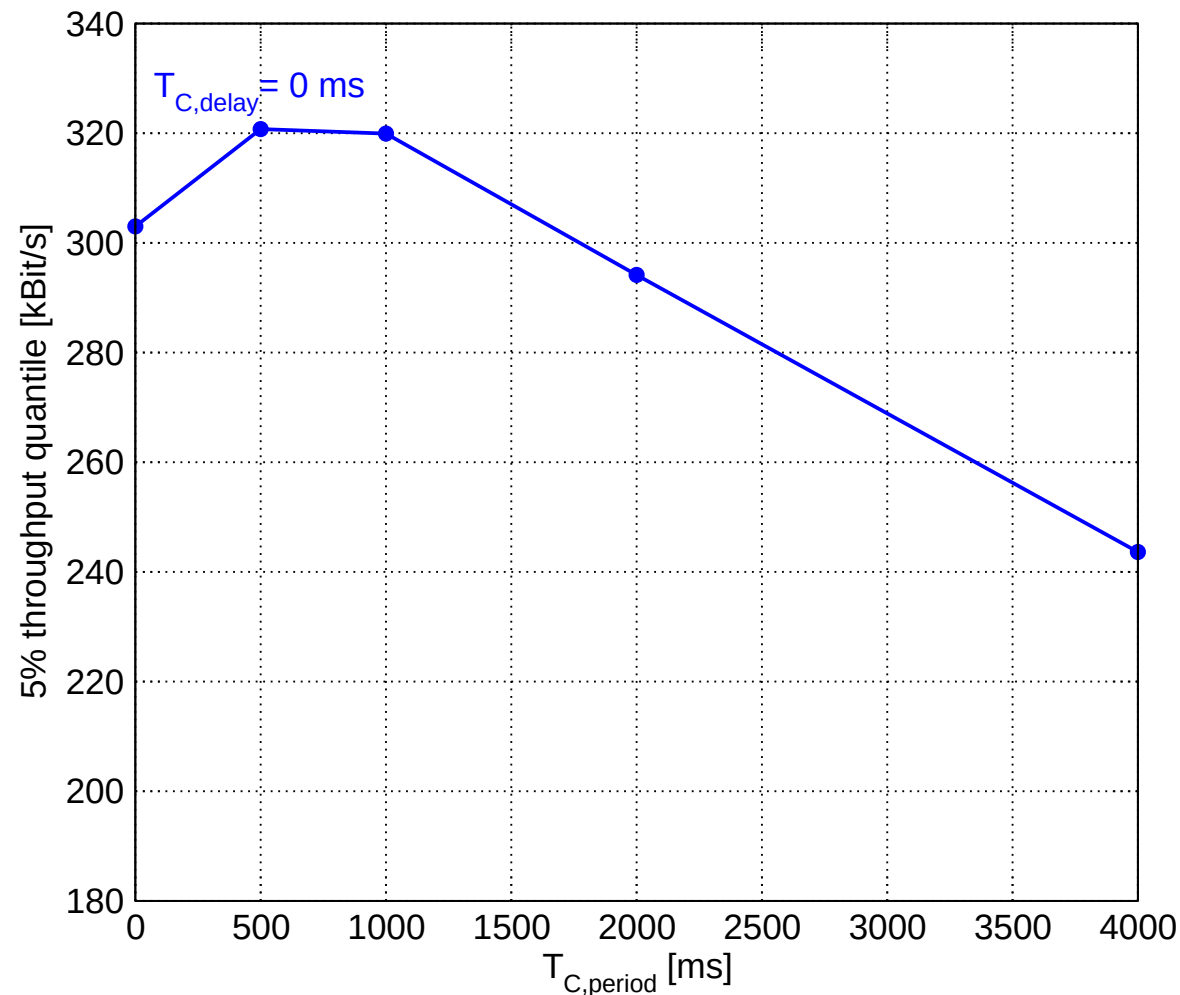
- **Conventional Fractional Frequency Reuse, locally coordinated**
 - achieves great increase in **aggregate** performance
 - falls short with respect to **cell edge** performance

Throughput Performance



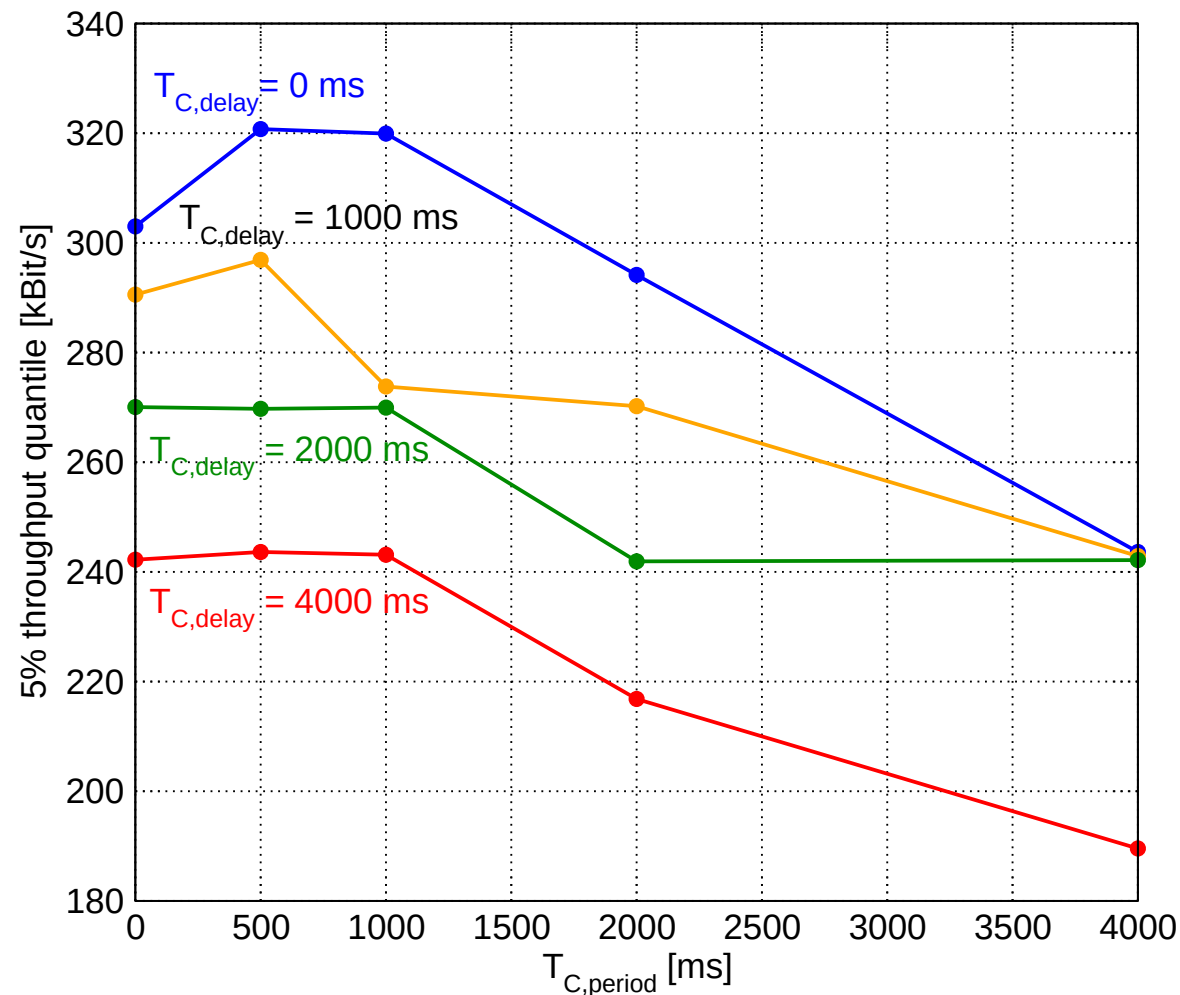
- **Coordinated Fractional Frequency Reuse**
 - achieves good increase in **aggregate** and **cell edge** performance
 - allows to trade off cell edge and aggregate performance **on a high level**

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)

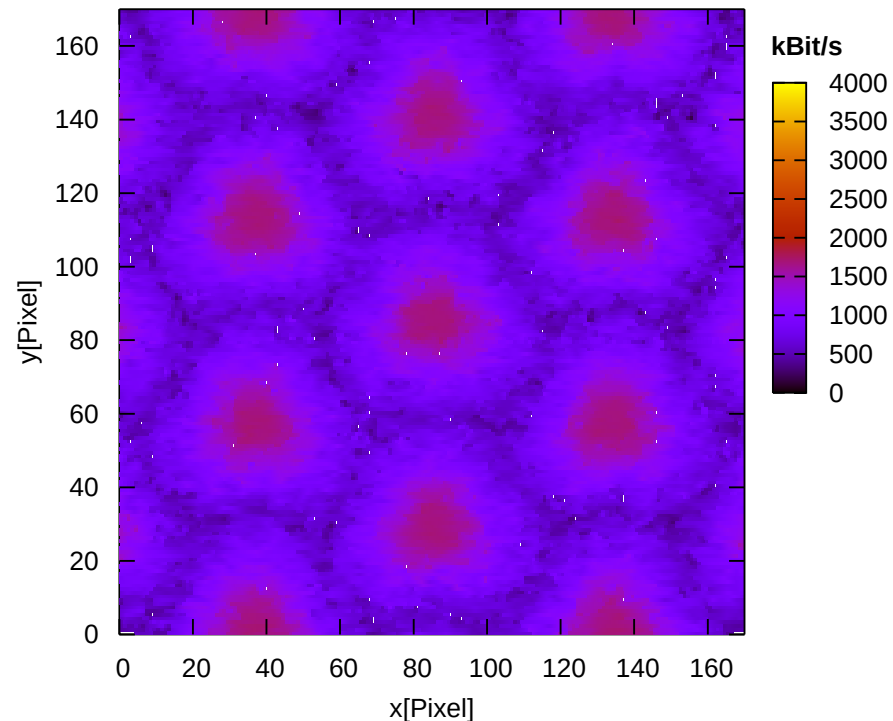
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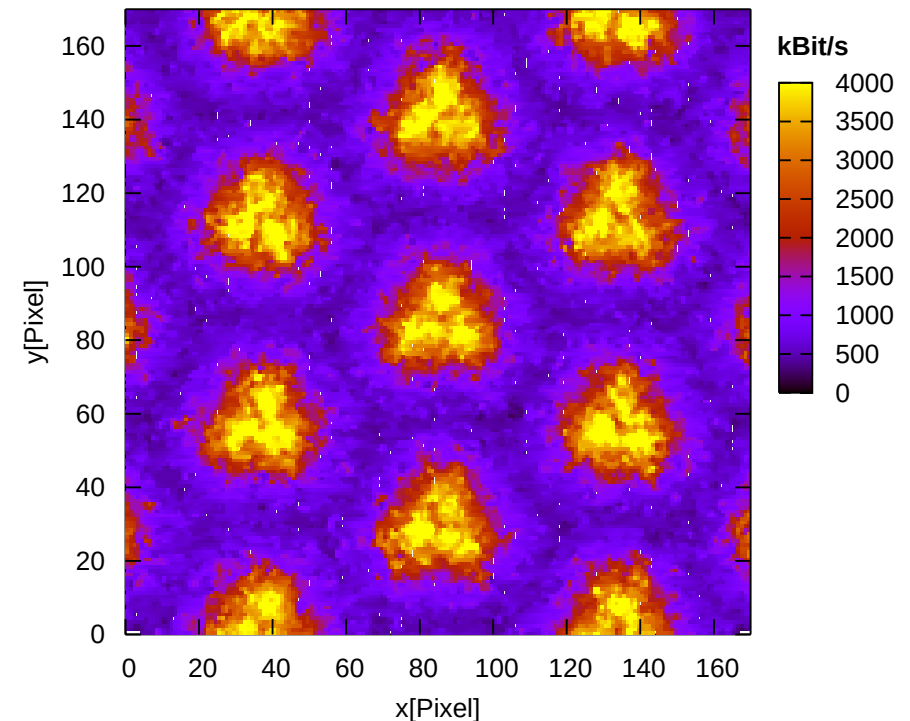
- Increased signaling delays $T_{C,period}$ and $T_{C,delay}$
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Area Throughput

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 ≥ 500 ms
 - performance improvements of about 50% (compared to Reuse 3)
 - with respect to aggregate throughput (maintaining cell edge throughput)
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