Self-Organization in LTE

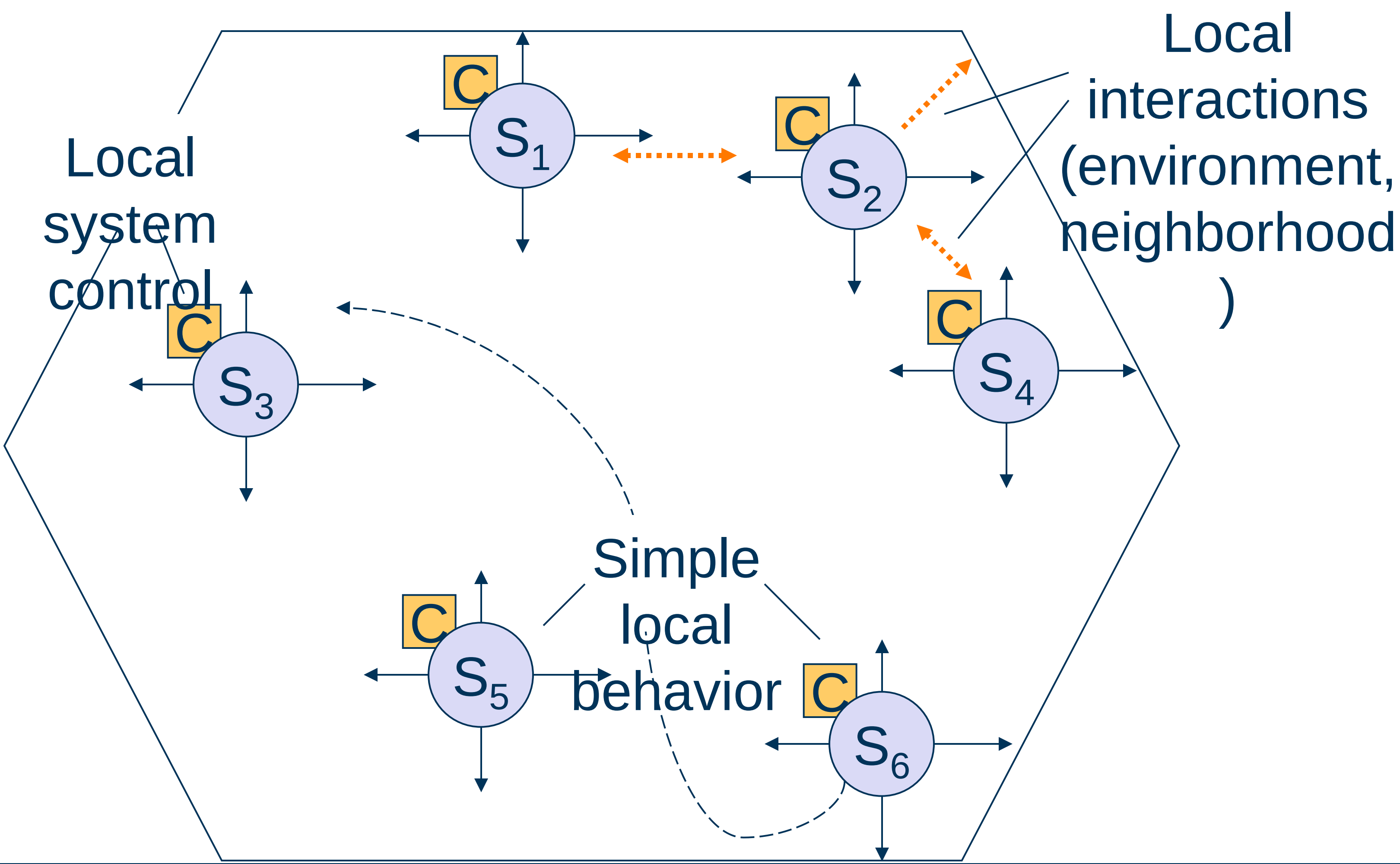
Prof. Dr.-Ing. habil. Andreas Mitschele-Thiel
M.Sc. Nauman Zia
M.Sc. Stephen Mwanje

Outline

- Introduction
- Functionalities of Self-Organizing Networks (SONs)
- Architectures of SONs
- Use Cases
- Coordination
- References

Introduction

Self-Organizing Systems

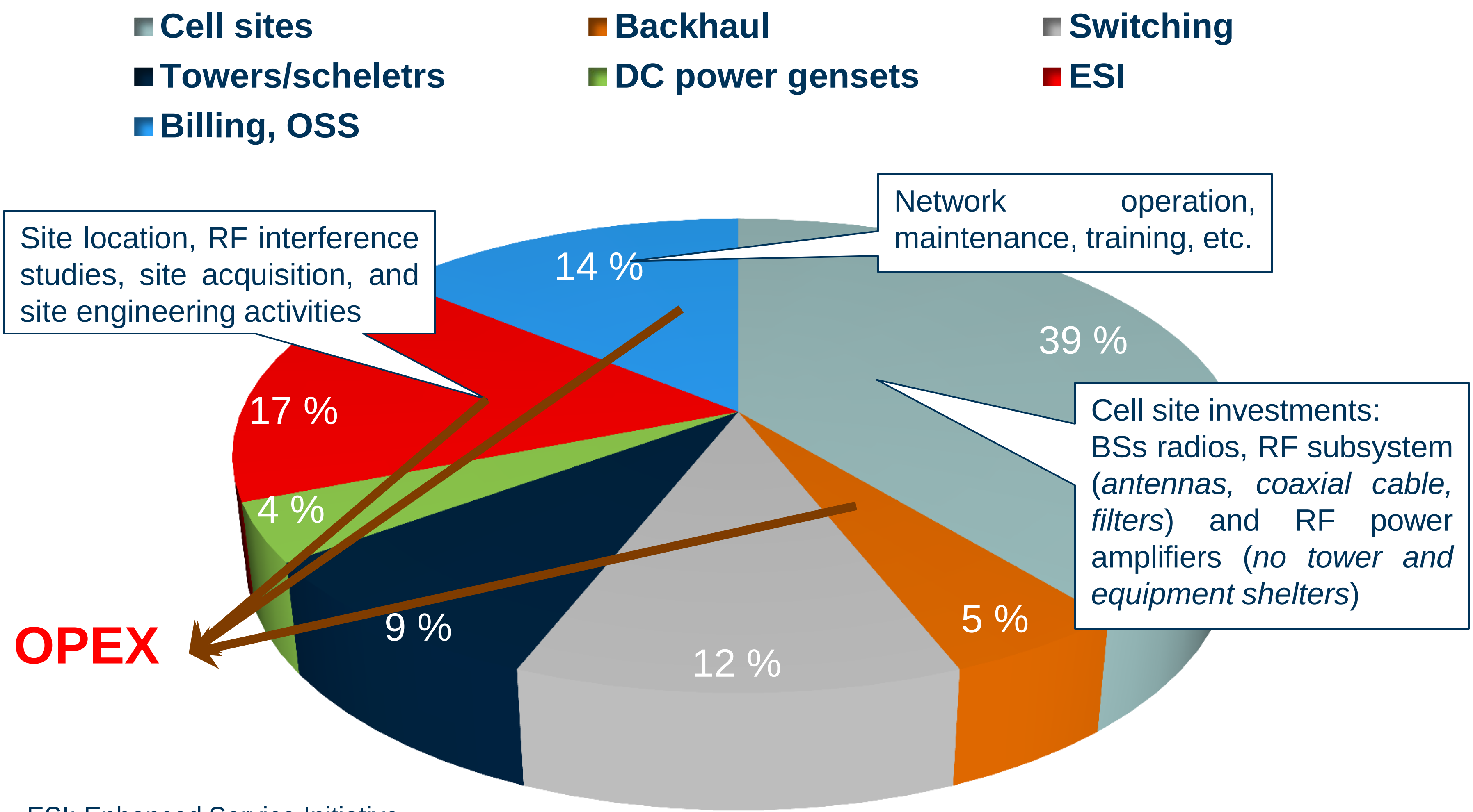


TOTal EXpenditures (TOTEX)

- TOTal EXpenditures (TOTEX)
  - CAPital EXpenditures (CAPEX) determine the direction and level of investment telecommunications carriers make (in network equipment as well as services)
    - CAPEX is based on a combination of two primary factors
      - Number of customers served
      - Volume of services provided
  - OPerational EXpenditures (OPEX): running cost

- **Growing wireless markets imply growing OPEX**

Wireless TOTEX Allocations (2007, USA)



ESI: Enhanced Service Initiative

Drivers For Self-Organization

- High complexity and high number of parameters
- Operation of heterogeneous networks
- Expanding number of Base Stations (BSs)
  - Introducing of home evolved NodeBs (eNBs) leads to a huge number of nodes to be operated in multi-vendor scenarios

→ OPEX is expanding

- **Reduction of OPEX** requires reducing human interactions by
  - Configuring and optimizing the network automatically while **allowing the operator to be the final control instance**
- High quality must be ensured → **SONs** are essential

Functionalities Of SONs

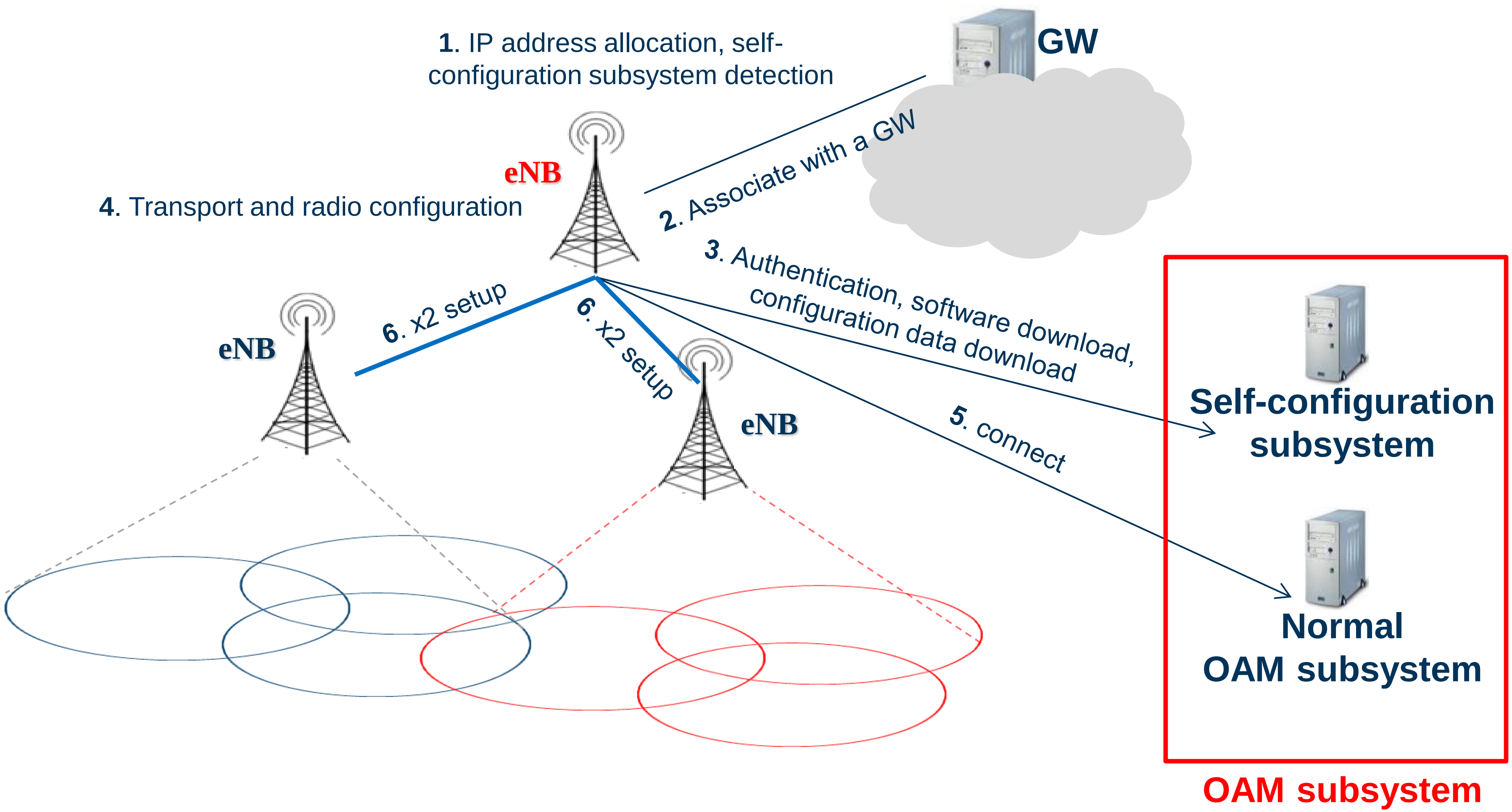
Functionalities Of SONs

Self-Configuration (plug and play)	• Auto-setup • Auto- neighbor detection • ...	**Self-Planning** (dymnic re-computation)
Self-Optimization (auto-tune)	• Coverage & capacity • Mobility robustness • Load balancing • ...	
Self-Healing (auto-repair)	• HW/SW failure detection • Cell outage detection • ...	

Self-Configuration

- Definition
  - “The process where newly deployed eNBs are configured by automatic installation procedures to get the necessary basic configuration for system operation”
- Works in preoperational state
- How
  - Create logical associations with the network
  - Establishment of necessary security contexts (providing a secure control channel between new elements and servers in the network)
  - Download configuration files from a configuration server (using NETCONF protocol)
  - Doing a self-test to ensure that everything is working as intended

Self-Configuration



Self-Optimization

- Definition
  - "The process where User Equipments' (UE) and eNBs' performance measurements are used to auto tune the network"
- Works in operational state
- How
  - Optimizing the configuration while taking into account regional characteristics of radio propagation, traffic and UEs mobility
  - Analysis of statistics and deciding what are optimal parameters
  - Detecting problems with quality, identifies the root cause, and automatically takes remedial actions
- Examples: neighbor list optimization, coverage optimization, etc.

Self-Healing

- Definition
  - “The process enabling the system detecting the problems by itself and mitigating them whilst avoiding user impact and reducing maintenance costs”
- Works in operational state
- End-to-end service recovery time should be < 1 sec
- How
  - Automated fault detection
  - Root cause identification
  - Recovery actions application
  - If fault cannot be resolved, do some actions to avoid performance degradation

Architectures Of SONs

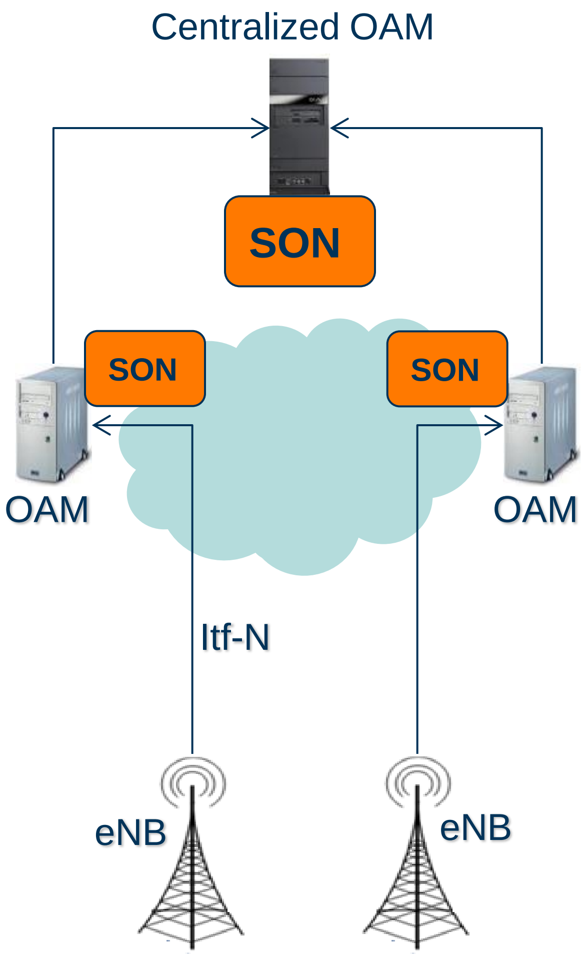
Requirements & Taxonomy

- Support of network sharing between network operators
- Providing an easy transition from operator controlled (open loop) to autonomous (closed loop) operation

- Three architecture
  - Centralized SON
  - Distributed SON
  - Hybrid SON

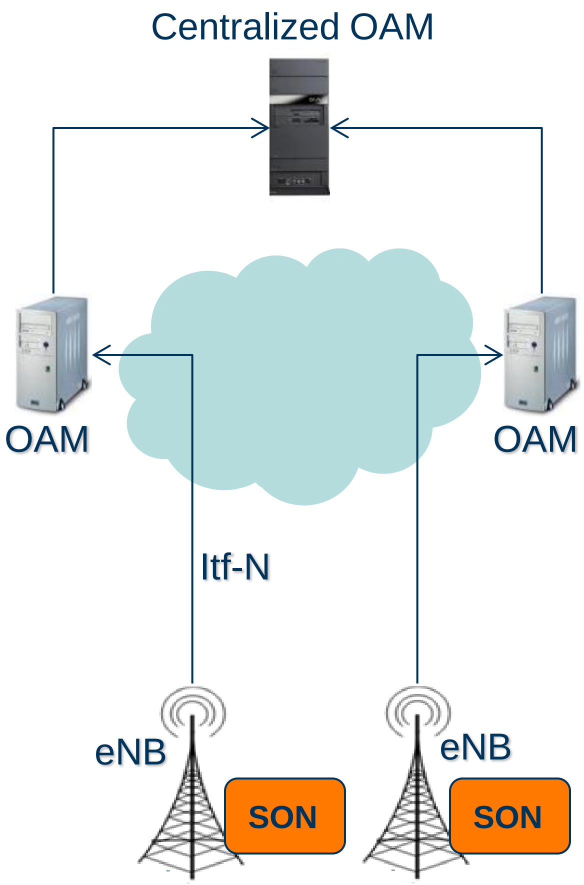
Centralised SON

- SON algorithms are executed in the OAM System
- SON functionalities reside in a small number of locations at a high level in the architecture
- Pros
  - Easy to deploy and to manage
- Cons
  - OAM is vendor specific (multi-vendor optimization is problematic)
  - Not applicable for situations where self-organization tasks should be fast



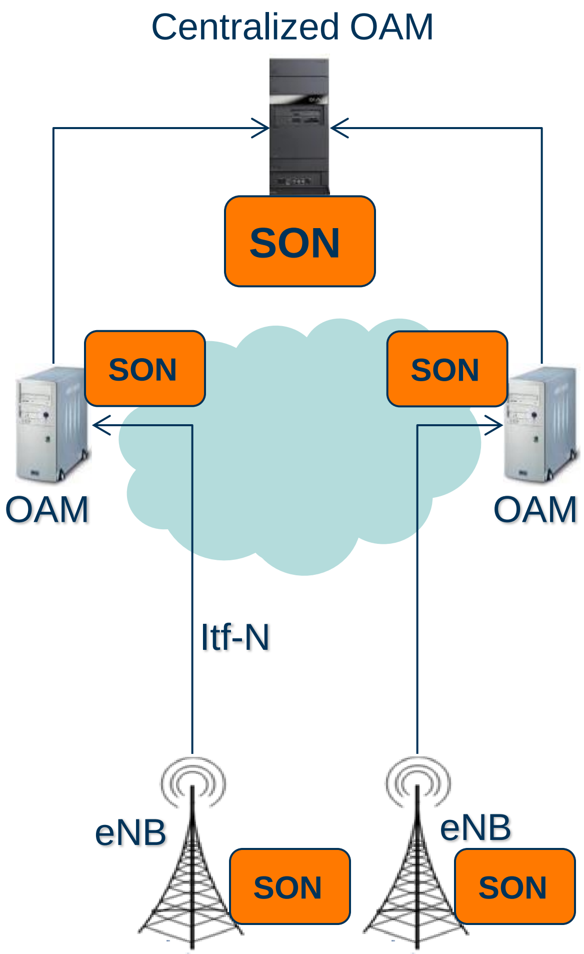
Distributed SON

- SON functionalities reside in the eNB at the lower level of network architecture
- Fully autonomous distributed RAN optimization
- Pros
  - Applicable for situations where self-organization task should be achieved fast
- Cons
  - Hard to deploy and manage
  - X2 interfaces should be extended



Hybrid SON

- Idea is to push some of the SON functionalities on the eNB itself and some on OAMs
- Pros
  - Best exploit of the benefits of SONs
  - Allowance for a high degree of automation guarantee, control and inspection
- Cons
  - Hard to deploy and manage
  - Requiring of multiple interfaces extensions



Use Cases

What Are The Use Cases Defined In 3GPP?

- Physical cell-ID automatic configuration (PCI)
- Automatic Neighbor Relation (ANR)
- Coverage and capacity optimization (CCO)
- Energy saving
- Interference reduction
- Inter-cell interference coordination (ICIC)
- Random Access Channel (RACH) optimization
- Mobility load balancing optimization (MLB)
- Mobility robust optimization (MRO)

Physical Cell-ID Automatic Configuration

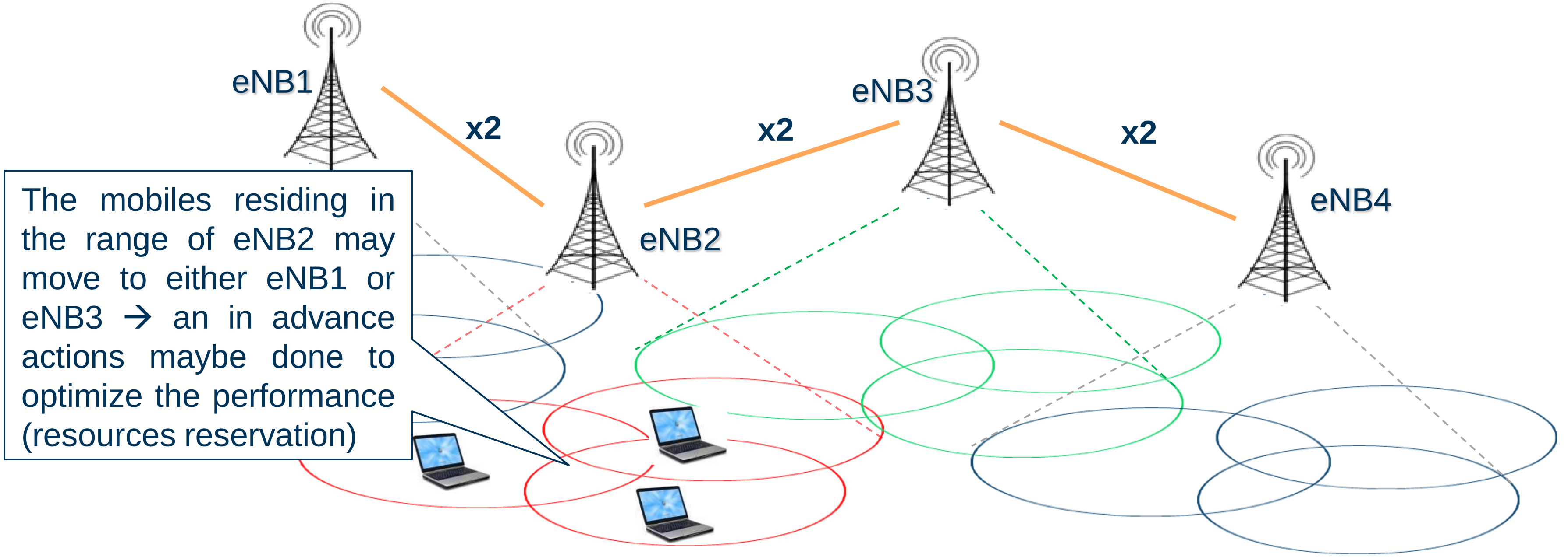
- Goal
  - Automatically configure the physical Cell-ID (collision and confusion free assignment of physical Cell-ID)
- Works in preoperational state
  - A part of self-configuration procedure
- Main limitation is that there are only 504 physical Cell-IDs available
- Solution
  - eNB-based solution (distributed solution)
  - OAM-based solution (centralized solution)

Physical Cell-ID Automatic Configuration

- eNB-based solution (distributed solution)
  - eNB chooses an arbitrary Cell-ID
  - eNB instructs UEs to do measurements, collects and analyses measurements results
  - eNB starts communicating with neighbors using X2 interfaces
  - In case the eNB has detected a conflict, a new Cell-ID is assigned and the procedure is repeated again
- OAM-based solution (centralized solution)
  - eNB instructs UEs to do measurements, collects and sends the results to the OAM
  - The OAM assigns a Cell-ID to the eNB
  - Cell-ID assigning procedure may require doing updates to other eNBs in the network

Automatic Neighbor Relation (ANR)

- Relations between neighbor eNBs should be carefully determined since they affect the network performance
  - Handoff performance, call dropping probability, etc.

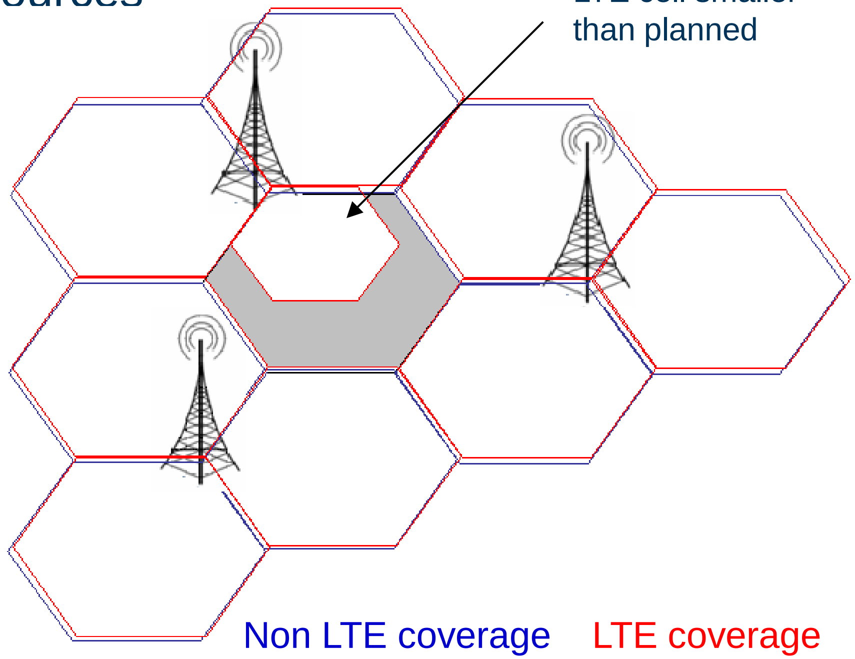


Automatic Neighbor Relation (ANR)

- ANRs covers following steps
  - Neighbor cell discovery
    - eNB instructs UEs to do measurements
    - New joined eNBs are detected based on the analysis of measurment results
  - Configuration of X2 interfaces between eNBs
  - Connection setup with neighbor eNBs
  - ANR optimization
    - Update as new eNBs join/disjoin the network
    - How to accurately optimize the neighbor relation is still an open issue till now
- Some steps work in preoperational state, while some others work in operational state

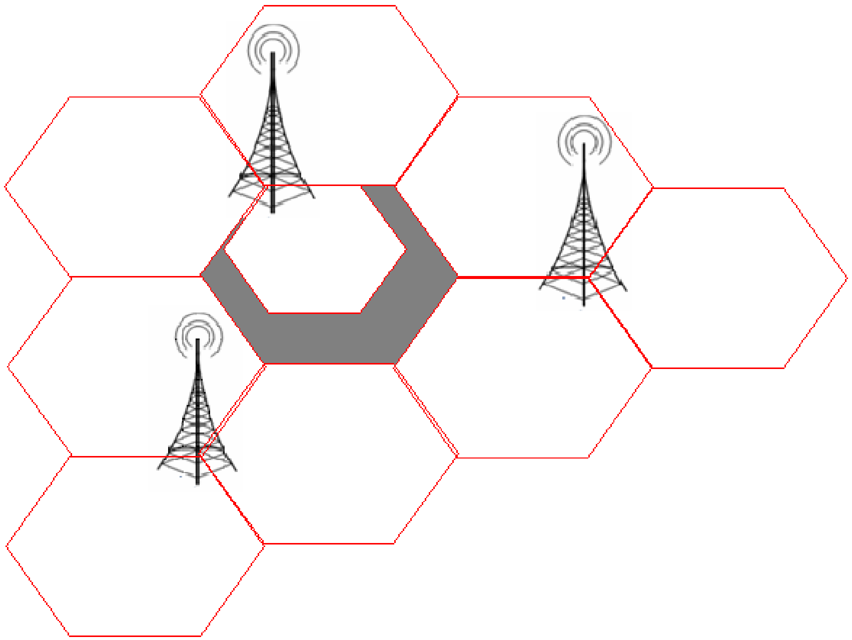
Coverage & Capacity Optimization

- Goal
  - Maximizing the capacity while ensuring coverage requirements
    - Holes free coverage
    - Improved capacity with given resources
- Works in operational state
- 3 Cases
  - LTE coverage holes within other Radio Access Technologies (RATs)
    - QoS degradation due to frequent inter RAT handoffs



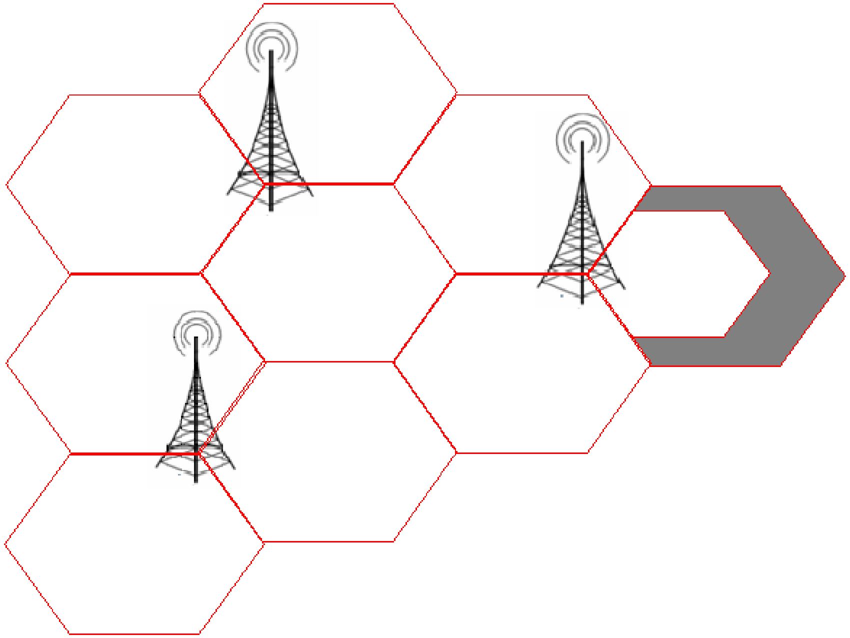
Coverage & Capacity Optimization

– LTE coverage holes and no alternative RAT
  - Significant call drops due to coverage holes



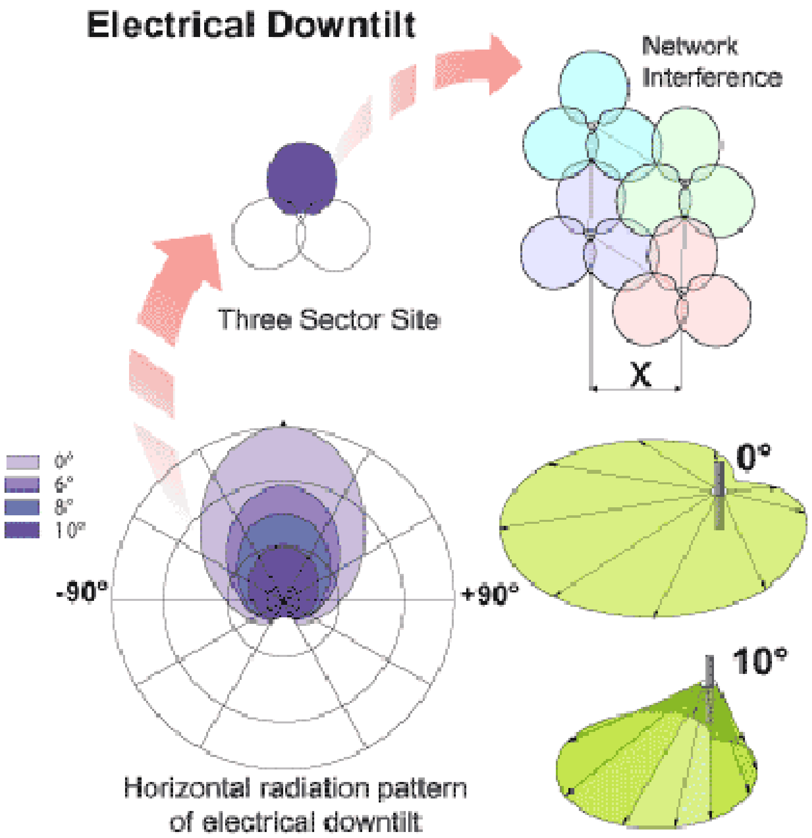
Coverage & Capacity Optimization

- Isolated LTE cells
  - Coverage blackouts in network's border areas



Coverage & Capacity Optimization

- Solution
  - Update the BS parameters such as height, azimuth, tilt and Tx power



Energy Saving

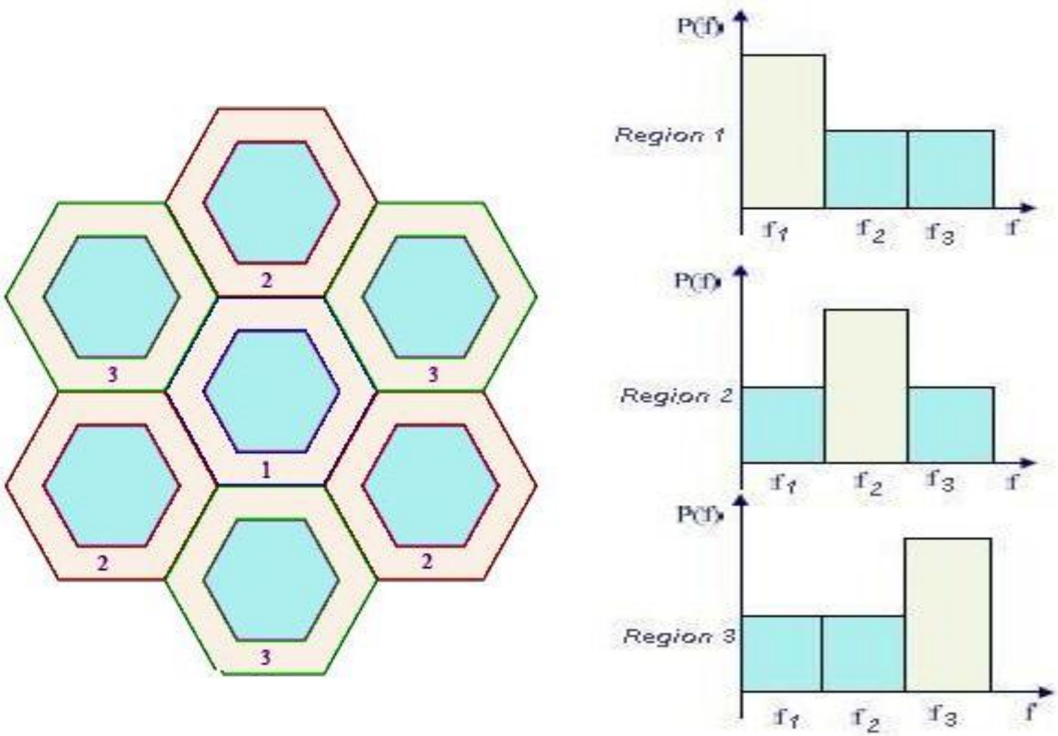
- Goal
  - Reduction of OPEX by saving energy resources
- Works in operational state
- How can energy be saved
  - Tx power optimization
    - Minimal saving but possible throughout the day
  - Switching off some of the Tx of a cell
    - Possible where antenna diversity is not required
  - Complete eNB switch off
    - Maximum saving but possible only during low load times
    - Also if users are away from home eNB and closed subscriber group cells

Interference Reduction

- Goal
  - Improving the network performance by means of reducing the interference between its equipments
- Works in operational state
- Many limitations due to the applied frequency band
  - Interference depends on frequency band characteristics
- Solutions
  - Decrease eNBs density
    - Hard to apply due to the capacity decrease and the existence of home eNBs that are not under the control of the network operator
  - Power control and/or reconfigure the wireless setup
  - Interference cancellation, coordination and randomization

Inter-Cell Interference Coordination

- Soft frequency reuse



RACH Optimization

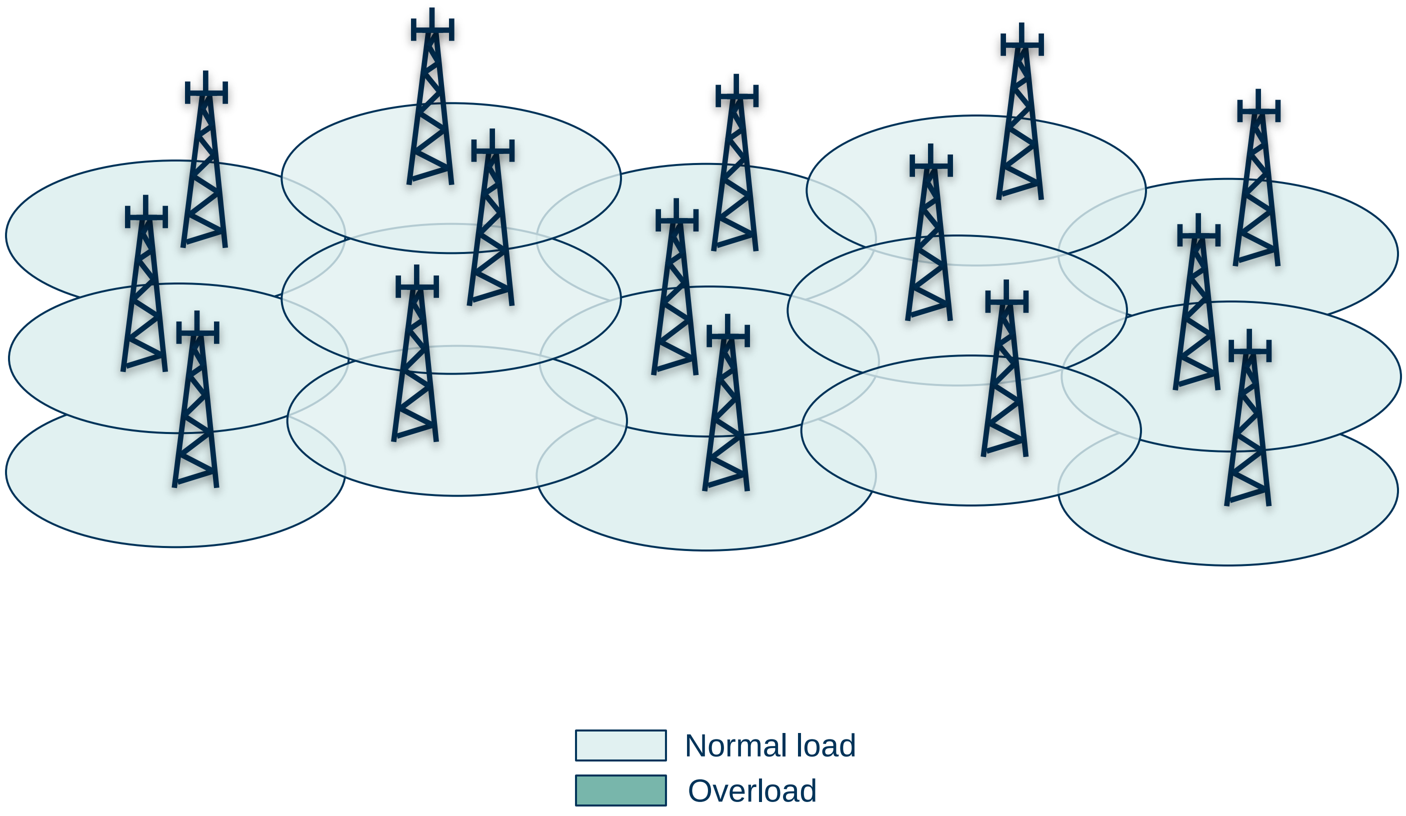
- RACH is an uplink unsynchronized channel for initial access or uplink synchronization
- RACH is involved in many situations
  - Connection setup, radio link failure, handover, etc.
- Delay to access to RACH influences many other tasks
  - Call setup/handoff delay and success rate
  - Capacity of the whole network (due to physical resources reserved for RACH)

RACH Optimization

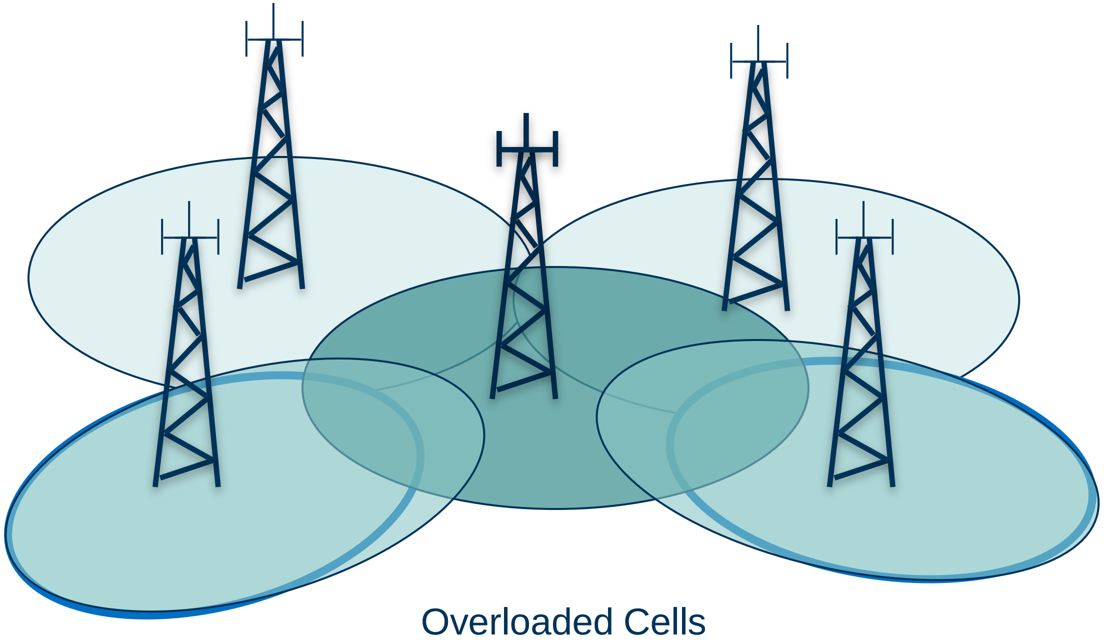
- Delay to access to RACH depends on current network parameters
  - Transmission power, handover threshold, etc. → **changing networks parameters requires optimizing the RACH**

- Solution
  - eNB does measurements
    - For instance, random access delay, random access success rate, random access load, etc.
  - Based on measurements results, RACH is optimized
    - Optimization is done by configuring parameters like RACH physical resources, RACH persistence level and backoff control, RACH transmission power control, etc.

Load Balancing



Load Balancing



Load Balancing Strategies

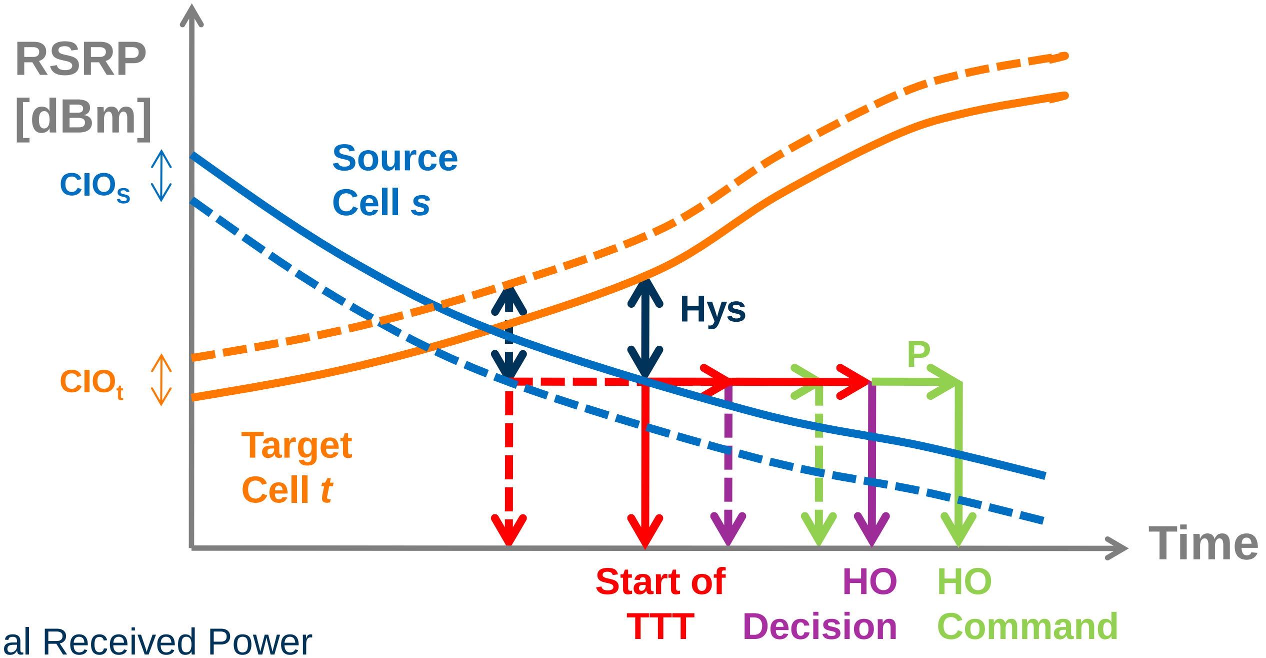
1. Downlink (DL) power modification, i.e. pilot power and/or antenna tilt
   - Degrades indoor coverage in reduced power cells
   - Requires over provisioning of power amplifiers in increased power cells
2. Handover (HO) parameter modification
   \+ Overcomes the cons of DL power modification method
   - Load balancing (LB) can only be achieved if neighbors have free resources

Mobility Load Balancing (MLB)

- LB optimization by modifying HO parameters
  - Advance HO in case of overloaded cell
  - Delay HO in case of normal loaded cell

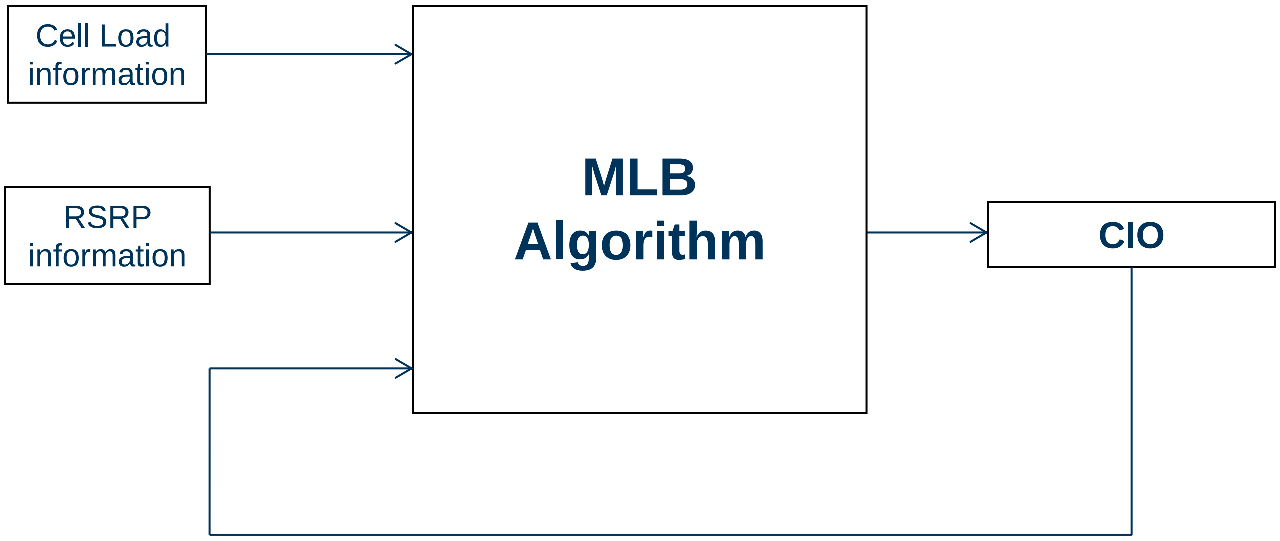
Handover Algorithm

$$(RSRP_t + CIO_t) - (RSRP_s + CIO_s) > Hys$$



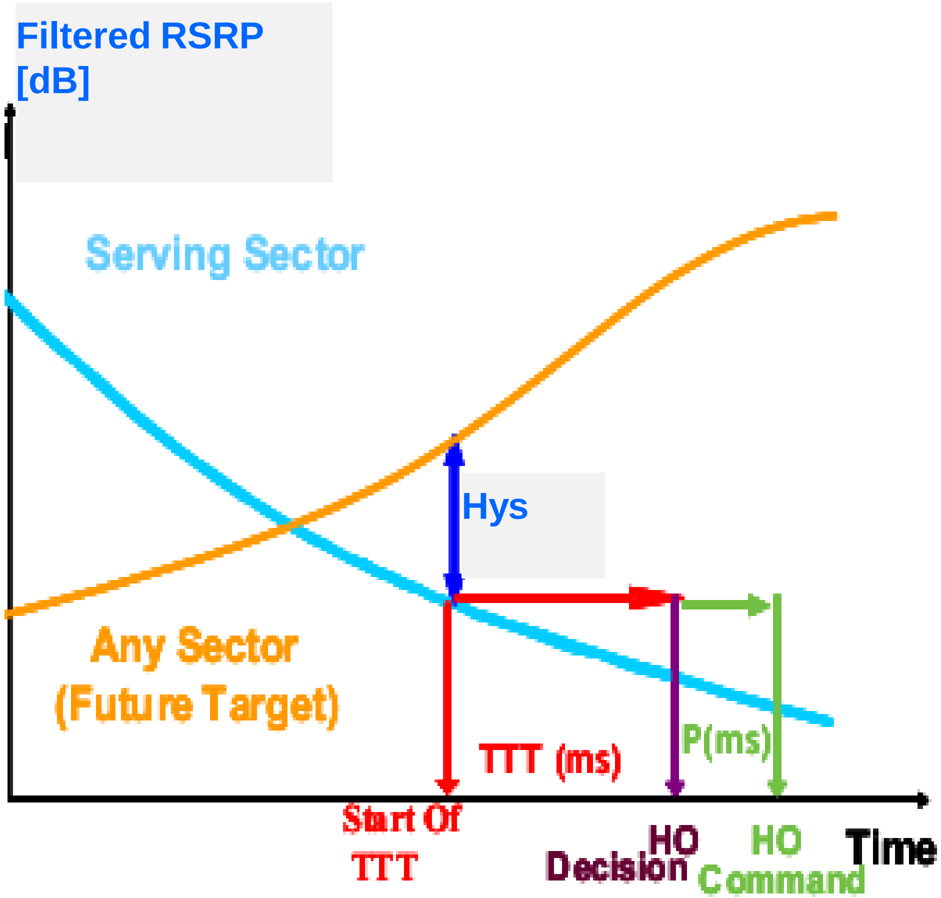
RSRP: Reference Signal Received Power
Hys: Hysteresis
CIO: Cell Individual Offset
TTT: Time to Trigger
P: Preparation time

MLB Optimization



RSRP: Reference Signal Received Power
CIO: Cell Individual Offset

Handover Optimization



- Optimize HO performance amidst mobility
  - Hence **Mobility Robustness Optimization**
- Control
  - Hysteresis (Hys)
  - Time to Trigger (TTT)
- A3 entry condition [1]

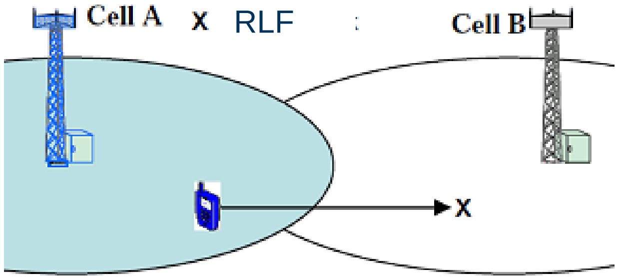
$(RSRP_t + CIO_t) - (RSRP_s + CIO_s) > Hys$

[1] 3GPP "E-UTRA Radio Resource Control (RRC) Protocol specification (Release 8)" TS 36.331 V8.16.0 (2011-12)

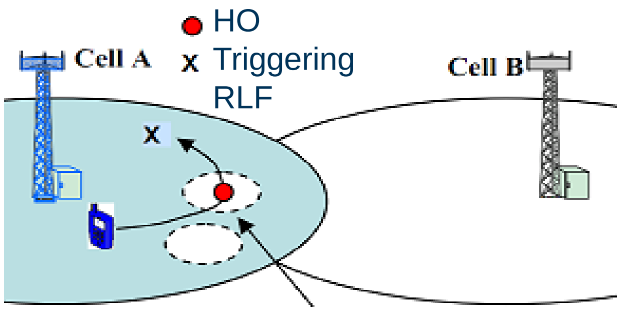
MRO

- Aim: Maintaining few HOs and HO oscillations (Ping-Pongs), minimize Radio Link Failures (RLF) due to [2]:

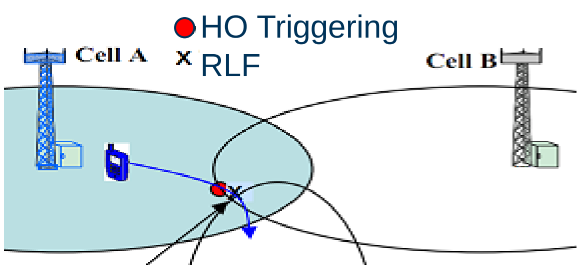
  – **Late HOs**: UE leaves coverage cell before HO is complete



  – **Early HOs**: island coverage of cell B inside cell A's coverage or UE handed over before cell B is steadily better than cell A



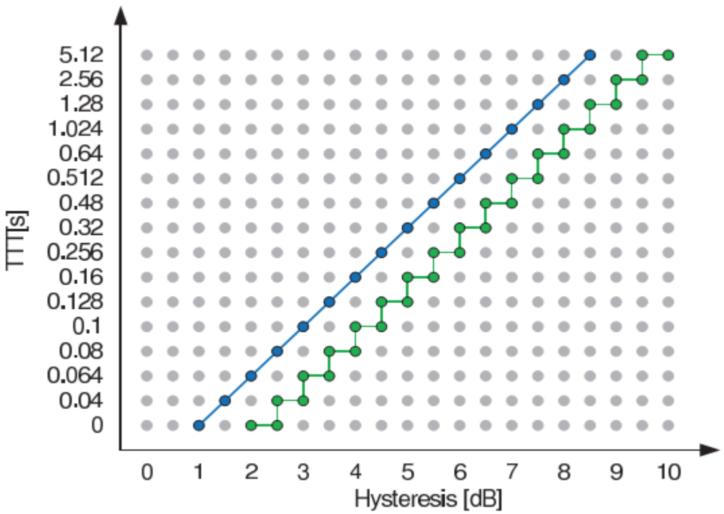
  – **HO to wrong cell**: improper settings between cells A and B → UE handed to cell C when should have been handed to cell B
    - E.g. due to PCI confusion



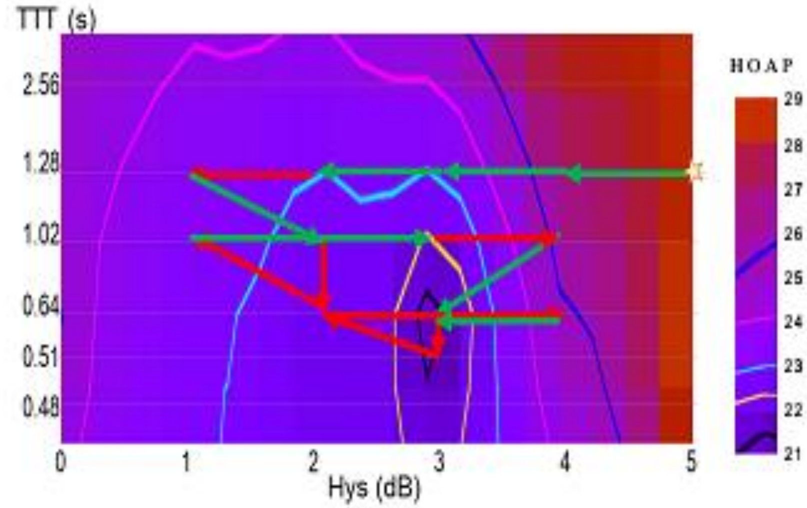
[2] 3GPP TR 36.902 V0.0.1, "Evolved Universal Terrestrial Radio Access Network (E-UTRAN); Self-configuration and self-optimizing network use cases and solutions"

MRO: Approaches in Literature

- Studies have applied expert knowledge control loops to search through the Hys-TTT parameter space [3,4,5,6]



Two possible Hys-TTT parameter search strategies – Diagonal & Diagonal - zigzag [4]



A typical search through parameter space by evaluating HO performance for different configurations [6]

[3] T Jansen, I Balan, I Moerman, T Kürner, “Handover parameter optimization in LTE self-organizing networks”, Proceedings of the IEEE 72nd Vehicular Technology Conference (VTC2010-Fall) (Ottawa, Canada, 2010).

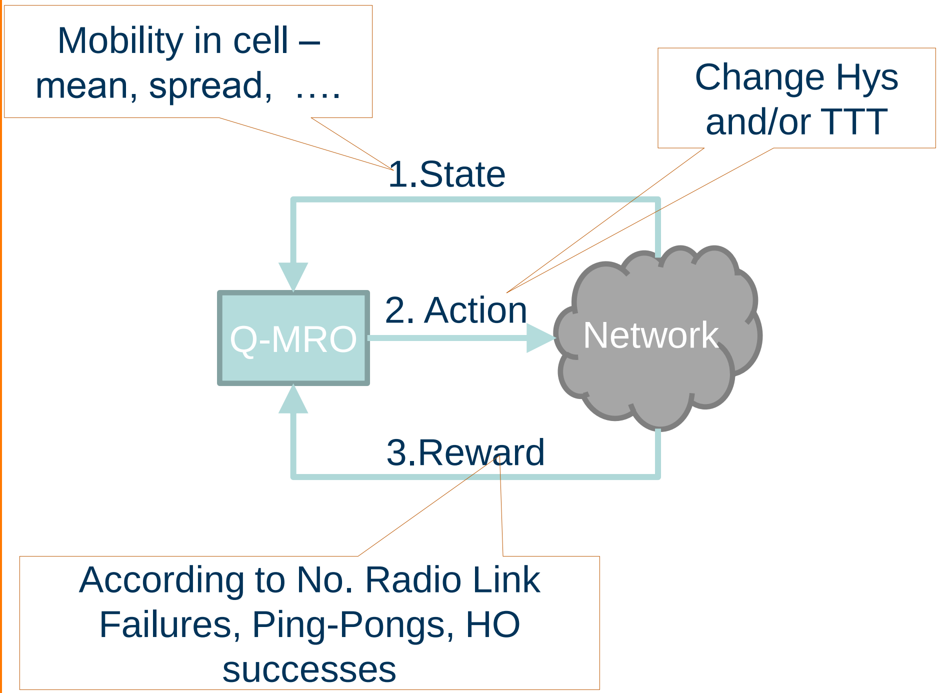
[4] I. Bălan, B. Sas, T. Jansen, I. Moerman, K. Spaey and P. Demeester, “An enhanced weighted performance-based handover parameter optimization algorithm for LTE networks” EURASIP Journal on Wireless Communications and Networking 2011, 2011:98.

[5] Gao Hui and Peter Legg, “Soft Metric Assisted Mobility Robustness Optimization in LTE Networks”, Proceedings of the 9th International Symposium on Wireless Communication Systems (ISWCS 2012), August 2012, pp.1-5.

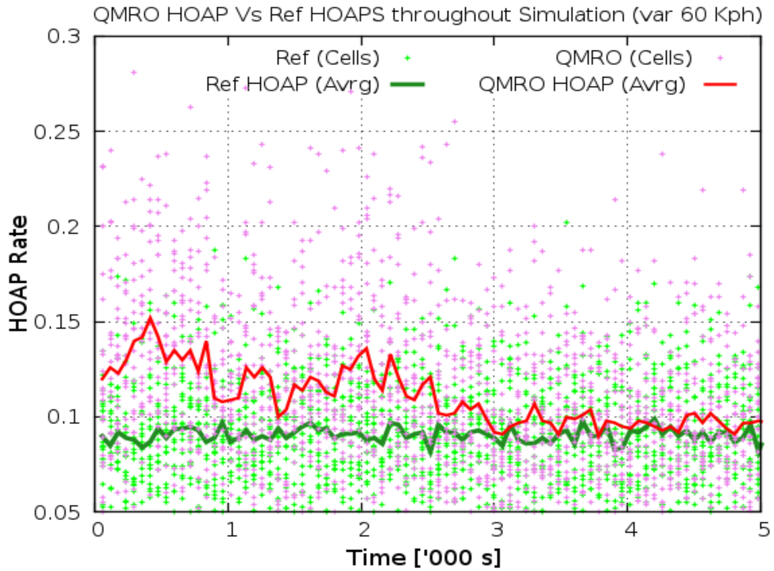
[6] S. Mwanje, N. Zia, A. Mitschele-Thiel, “Self organised Handover parameter configuration for LTE”, Proceedings of the 9th International Symposium on Wireless Communication Systems (ISWCS 2012), August 2012, pp.26-30.

MRO Alternative Approach: Q-Learning

- Challenge: Network Mobility changes with time
  - configurations should keep track
- Multiple Configurations for different mobility states.



- HO Aggregate Performance (HOAP) converges [7]



[7] Stephen S. Mwanje, Andreas Mitschele-Thiel, Distributed Cooperative Q-Learning for mobility sensitive Handover Optimization in LTE SON , Proceeding of 2014 IEEE Symposium on Computers and Communications (ISCC 2014) , Madeila, Portugal, Juni 2014

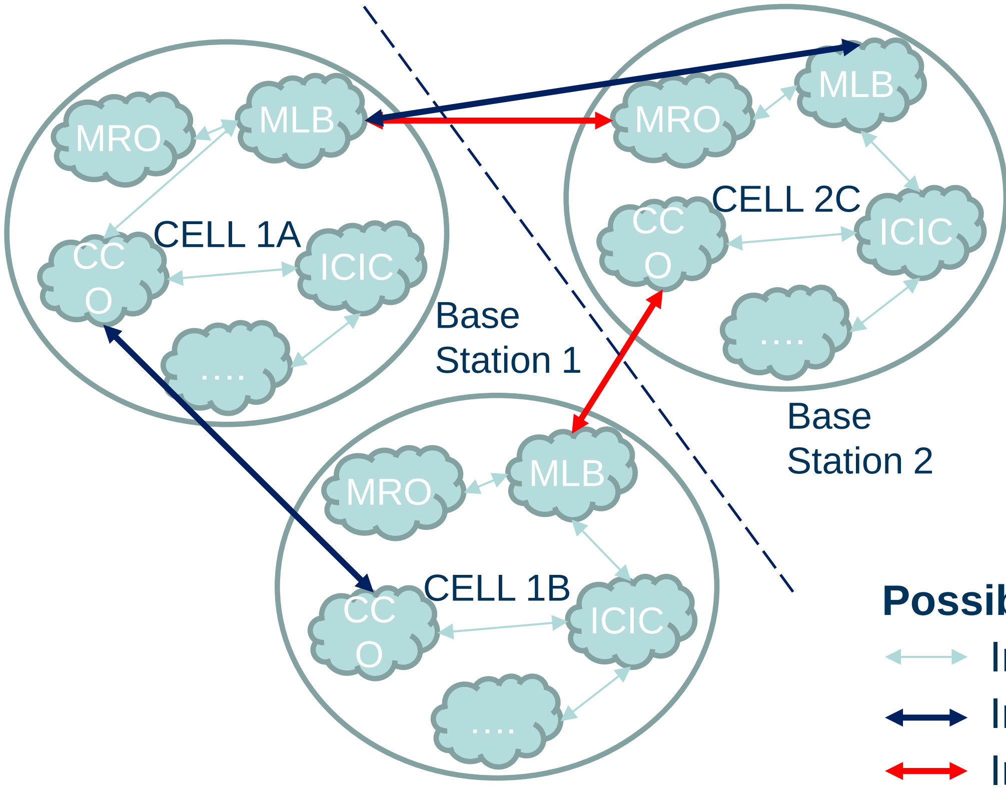
Impact of MLB on HO Performance

- MLB leads to worse link conditions for HO signaling because of advanced HOs
- HO performance optimization might counteract by changing HO parameters
- May lead to instabilities and oscillating behavior

Coordinating SON Use Cases

SON Design and Operational Challenge

- Use Cases (UCs) conflict within and across cells



Possible Conflicts / dependencies

Intra-cell

Inter cell, intraBS - same UC

Inter cell, intraBS - different UCs

NB: Inter BS == inter cell

MLB: Mobility Load balancing (MLB)

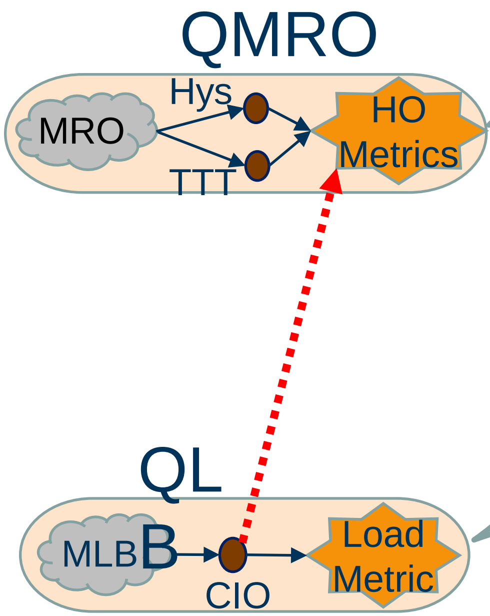
MRO: Mobility Robustness (Handover) Optimization

CCO: Coverage and Capacity Optimization

ICIC: Inter Cell Interference Coordination

Example: Load Balancing vs. MRO

- Metric Value Conflict (MVC)



- Radio Link Failure rates
  - Late HO (F_L)
  - Early HO (F_E)
- Ping-Pong rate (P)
- HO rate (H)

HO Aggregate Performance

$$\boldsymbol{HOAP = w_1 \mathrm{H} + w_2 P + w_3 F_E + w_4 F_L}$$

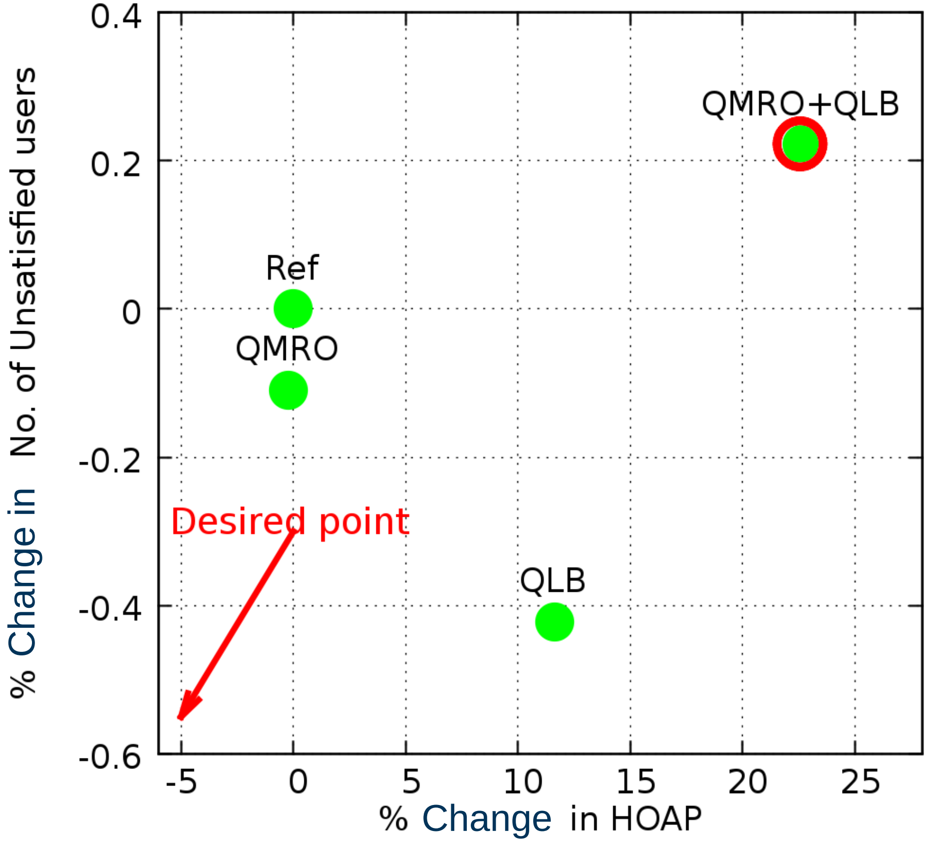
- Overload leads to
  → Reduced throughput
  → user dissatisfaction

$$\textbf{No. of Unsatisfied Users } (\boldsymbol{Nus})$$

Example: Need for Coordination

- Both No. Unsatisfied users and HOAP performance degrade

Post learning: HO degradation vs. change in no. of Unsatisfied users [8]

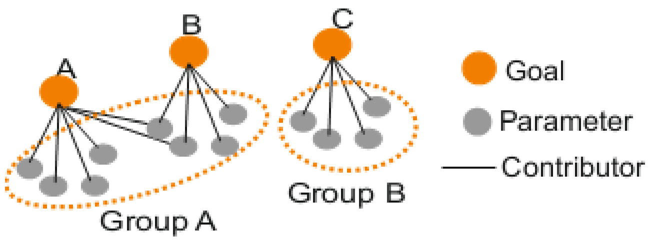


System	Description
Ref	Reference System with good HO performance
QMRO	Q-learning MRO solution
QLB	Q-learning LB solution
QMRO+ QLB	Both solution simultaneously active

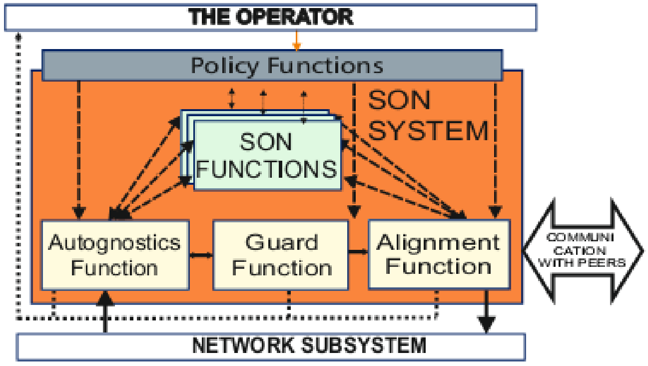
[8] Stephen S. Mwanje „Coordinating Coupled Self-Organized Network Functions in Cellular Radio Networks“, Doctoral Thesis, submitted Sept. 2014.

Proposed Approaches

- Functional parameter Groups [9,10]
  - Many parameters belong to a single group



- Coordination and Control [9,10]
  - Rules required for each set of UCs and relationship



- Temporal separation [11,12]
  - Suboptimal performance in disallowed UCs

[9] T. Jansen, et al, "Embedding Multiple Self-Organization Functionalities in Future Radio Access Networks", 69th Vehicular Technology Conference, VTC2009-Spring, Barcelona, Spain, 2009

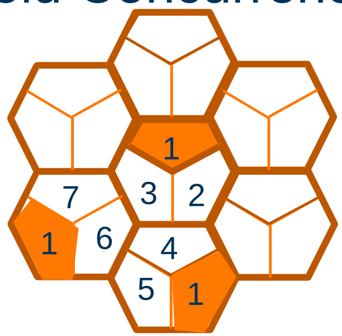
[10] SOCRATES Deliverable D5.9: "Final Report on Self-Organization and its Implications in Wireless Access Networks", EU STREP SOCRATES (INFSO-ICT-216284), Dec2010

[11] Tobias Bandh , Lars Christoph Schmelz, "Impact-time Concept for SON-Function Coordination", in Proceedings of the 9th International Symposium on Wireless Communication Systems (ISWCS 2012), August 2012, pp.16-20.

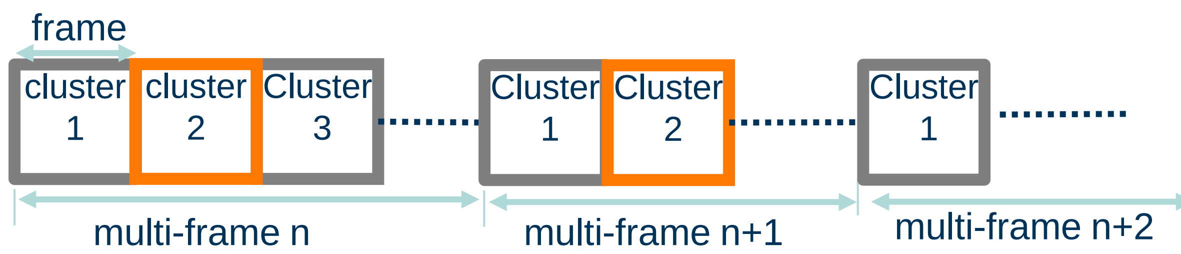
[12] Kostas Tsagkaris, et al, "SON Coordination in a Unified Management Framework", in Proceedings of the 77th Vehicular Technology Conference, VTC2013-Spring, Dresden, Germany, 2013

Alternative: Spatial-Temporal scheduling

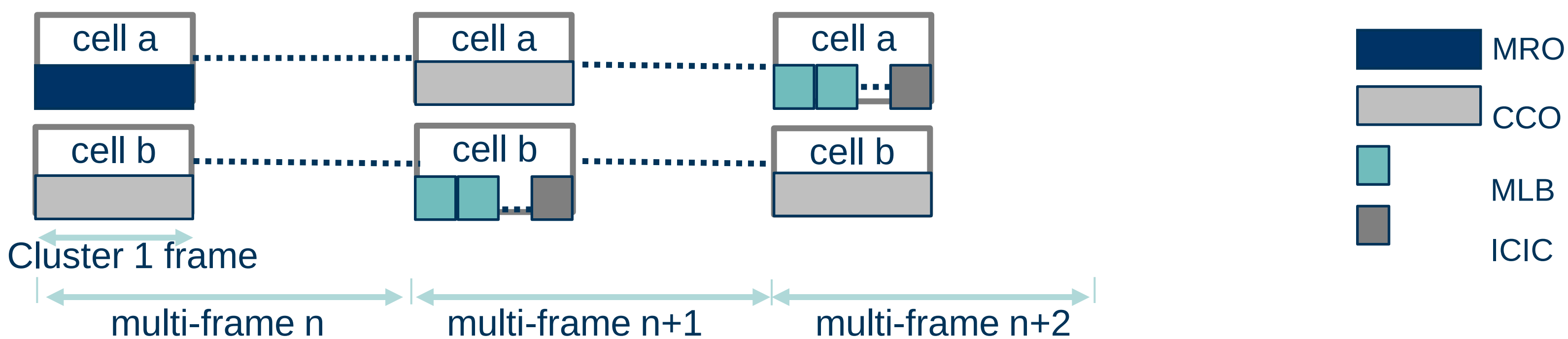
- Spatio-Temporal scheduling with “ UC accounting for effects to others”
- Avoid Concurrency among cells - Cluster cells in a Multi-frame



1 in very 7 cells is active



- Avoid Concurrency among UCs - Allocate UCs Time slots in a frame



Conclusions

- Future mobile communication networks will be much more dynamic and hard to manage → SONs are a necessity
  - Optimize the performance
  - Reduce OPEX
- Three Architecture for SON
  - Centralized, distributed and Hybrid
- Algorithms for SON Functions & UCs are active problems
  - New solutions/approaches are required and expected
- Very important: SONs should allow the network operator to be the instance capable of doing any required changes

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