Uplink System Performance of LTE-Advanced Relay Deployments in Different Propagation Environments

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- Goal
- Uplink Radio Resource Management Strategies
  - Power Control
  - Resource Sharing & Co-scheduling
  - Relay Cell Range Extension
- Joint Optimization: Taguchi's Method
- Uplink Performance Evaluation
  - Propagation Environments
  - 3GPP Case 1 – ISD 500m
  - 3GPP Case 3 – ISD 1732m
- Conclusions

Goal

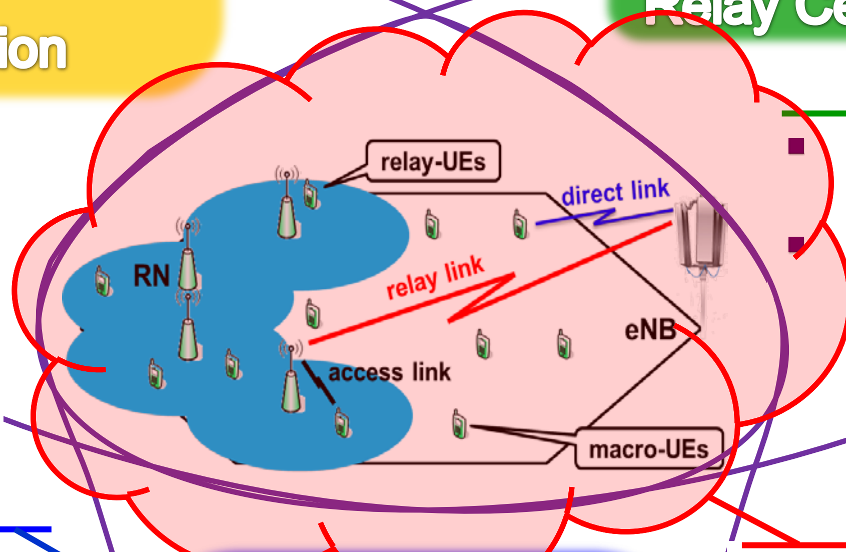
➢ Analyze uplink system performance of LTE-A Relay Deployments

Uplink Power Control Optimization

- On all links
- Mitigate Inter-cell interference
- Abide by Receiver Dynamic Range constraints

Relay Cell Expansion

- Balance the load between RN cells and macrocells
- Relax downlink-uplink imbalance



Multi-hop Resource Sharing and Co-scheduling

- Optimize resource splits between macro-UEs and RNs, and between relay-UEs
- Enable a fast adaptation to dynamic system conditions via co-scheduling

Joint Optimization of RRM strategies

- Joint Optimization of RRM strategies
- Different Propagation Environments

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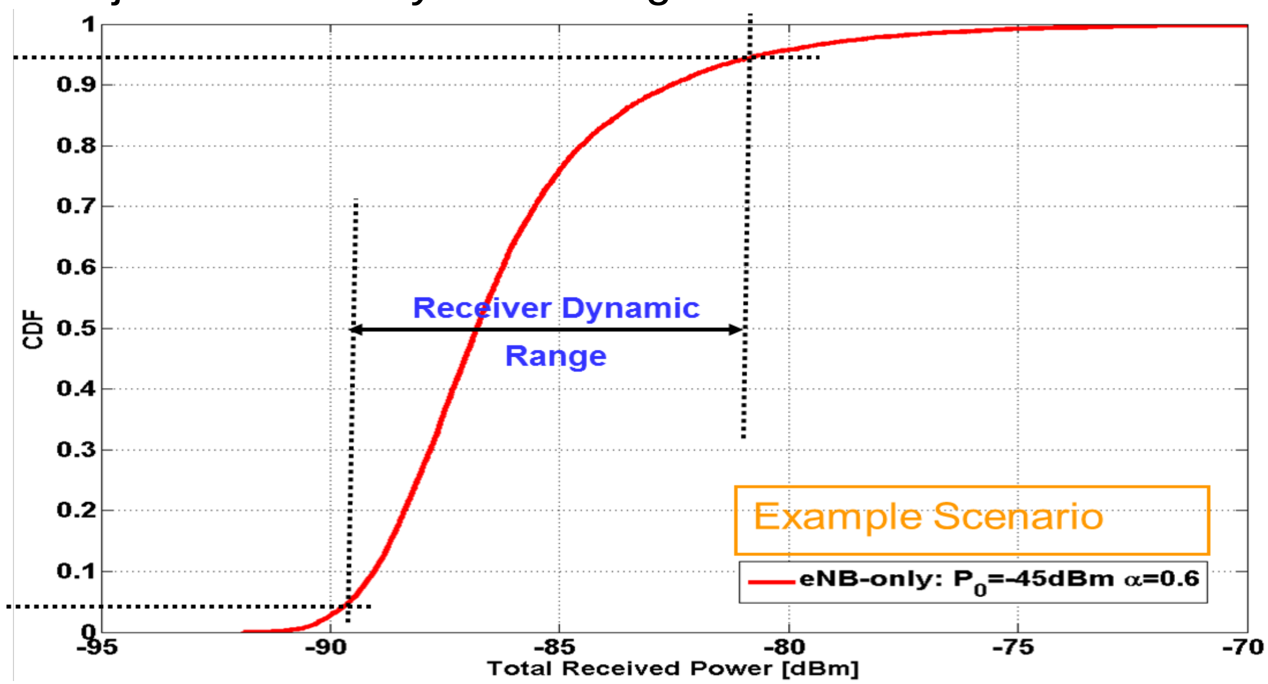
Power Control in Uplink

- LTE Rel.8 power control scheme applied in LTE-Advanced relay deployment for Physical Uplink Shared Channel (PUSCH) & Relay Specific PUSCH (R-PUSCH) *.
- Power control parameters are optimized to:
  - increase cell edge performance or system capacity.
  - mitigate inter-cell interference which increases due to RN deployment.
  - adjust receiver dynamic ranges at eNB and RNs.



* Applicability investigated in "Ö. Bulakci et al. , *Impact of Power Control Optimization on the System Performance of Relay based Heterogeneous Networks,* Journal of Communications and Networks, 2011".

LTE Rel.8 Fractional Power Control

- The Open-Loop Power Control formula is applied.

$$P = \min\{P_{max}, P_0 + 10 \cdot \log_{10} M + \alpha \cdot L\}$$

- P_{max} : Max allowed UE/RN transmit power [23/30 dBm]
- P_0 : Parameter to control received SNR target [dBm]
- M : # of PRBs allocated to one UE/RN
- α : Cell specific path loss compensation factor
- L : Downlink path loss estimated at UE/RN [dB]

- $\alpha \in$ [0.0, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1.0]
  - α = 0.6 Fractional Power Control (FPC)

FPC improves the performance of cell center users by inducing an acceptable inter-cell interference.

- P_0 can be selected from the set of [-116:1 dB:P_{max}] in dBm.

OPTIMIZE: P_0 values on all links

Relay-UEs @ Access Link

Macro-UEs @ Direct Link

@ Backhaul Link

RNs @ Backhaul Link

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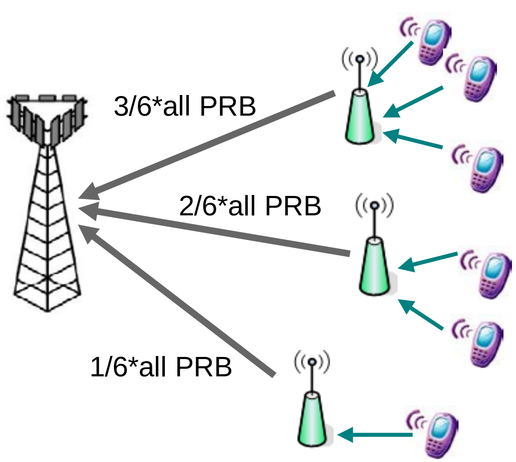
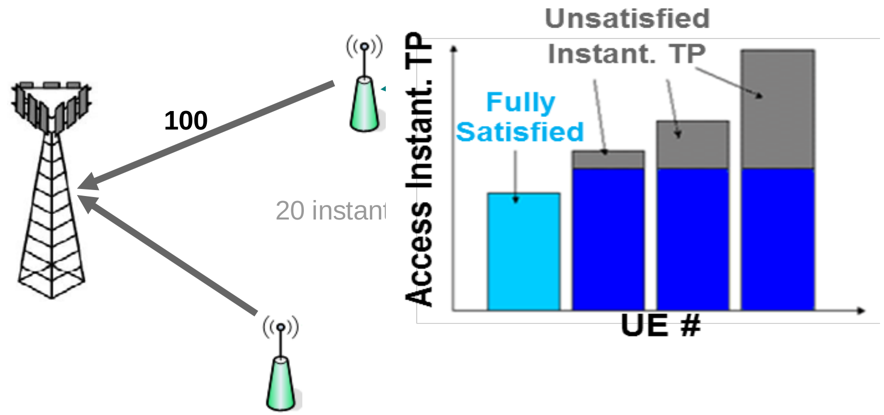
Resource Sharing & Co-scheduling *

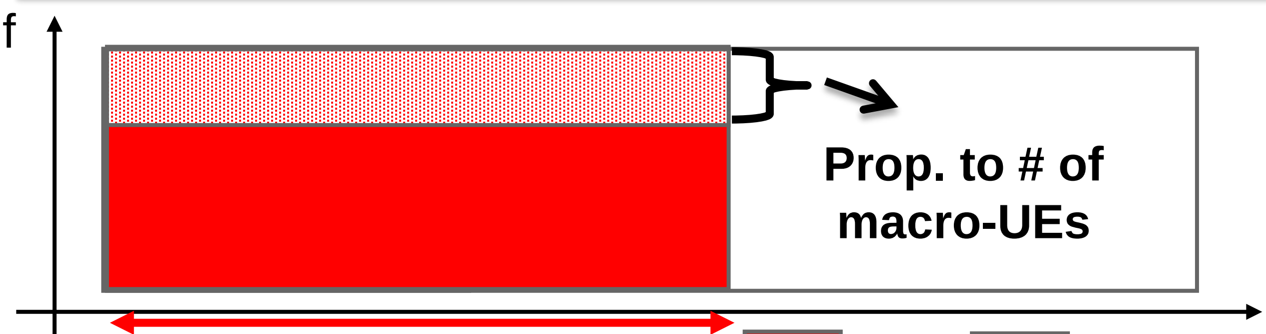
Number of attached relay-UEs



Max-Min Fairness



Hop-optimization Model



Macro-UEs are scheduled with RNs

Over-provisioned **Un Subframes** RNs Macro-UEs (Un) Macro-UEs (Uu)

Advantages:

Flexible & Efficient Resource Allocation.

Higher SINR values for co-scheduled macro-UEs.

OPTIMIZE:

# of Backhaul Subframes

* "Ö. Bulakci et al. , *Radio Resource Management in LTE-Advanced Relay Networks: Optimization Methods and Uplink Performance Evaluation,* Wiley ETT, 2012".

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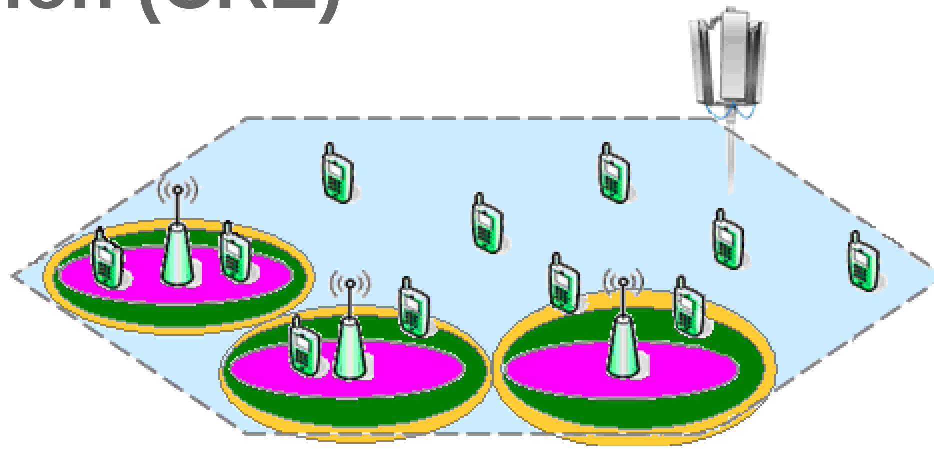
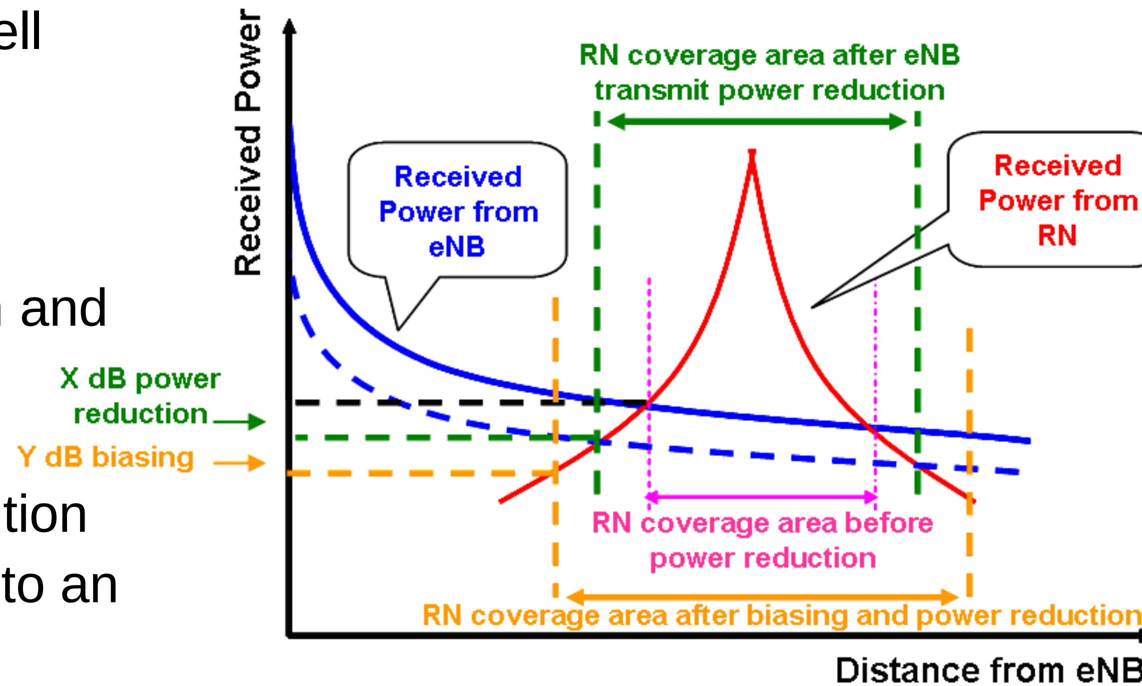
Relay Cell Range Extension (CRE)

- **Motive**
  - High competition on resources in the macrocell
  - Inefficient use of resources in the under-loaded RN cell
- **Methodology**
  - DeNB Transmit power reduction on direct link.
  - Biasing in cell selection and handover thresholds
- **Outcome**
  - Better resource distribution
  - Bring more UEs closer to an access point

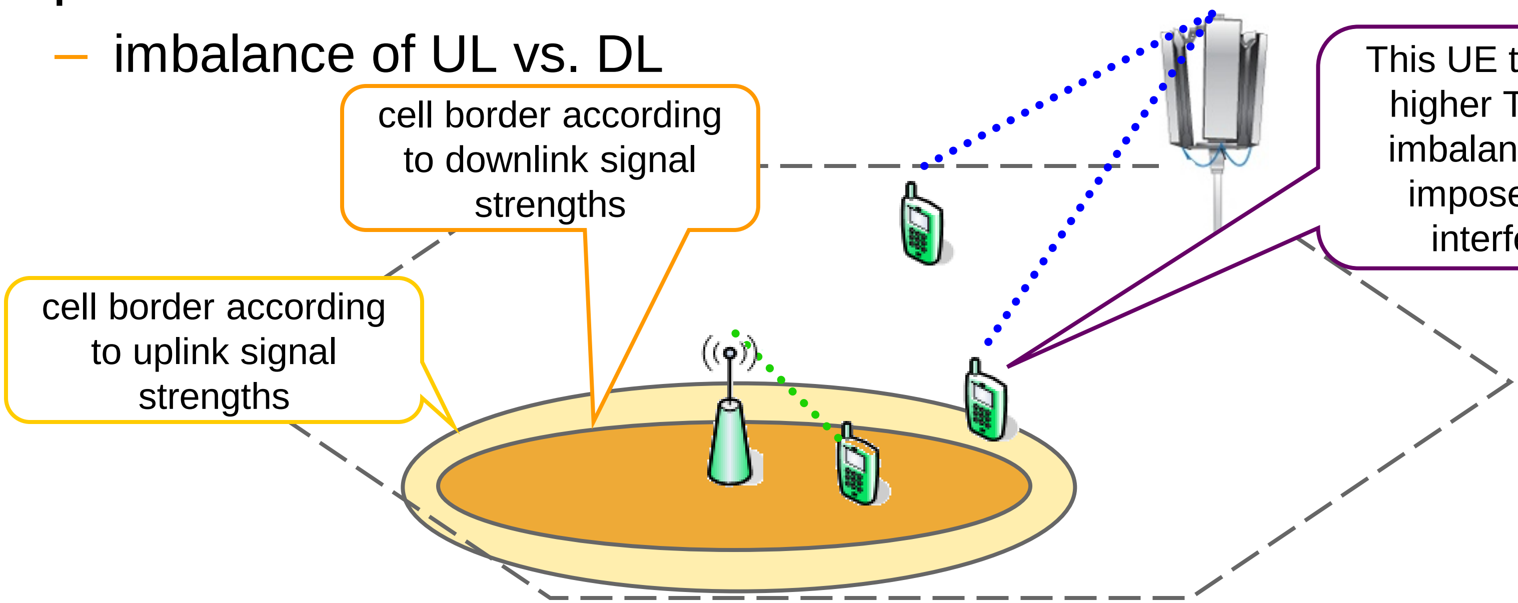




* "A. Bou Saleh et al. , *On Cell Range Extension in LTE-Advanced Type 1 Inband Relay Networks, submitted journal paper*, 2012".

Motivation for CRE in Uplink

- DeNBs and RNs have different Tx power in DL, while UE Tx power in UL is the same.
  - imbalance of UL vs. DL



Potentially higher gains in UL than DL.

NOTE: @ DL > "X dB" DeNB power reduction & "Y dB" biasing=

@ UL > "X + Y dB" effective biasing

OPTIMIZE:

Value of Effective Biasing

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Joint Optimization: Taguchi's Method

Methodology Overview *

- Let x_t where t = 1, 2, 3, 4 denote configuration parameters and γ be any performance measure. The optimization problem is:

$$\{x_1^{(opt)}, x_2^{(opt)}, x_3^{(opt)}, x_4^{(opt)}\} = \arg\max_{x_1, x_2, x_3, x_4} y(\gamma)$$

  where $y(\gamma)$ is the optimization function.

- **Assume** each parameter can take *N* values. To find the global optimum, we need to test all N^4 combinations.
- Instead, Taguchi's method extracts a subset of parameter combinations from the full search space to select nearly-optimal parameter setting.
- Taguchi's method employs an iterative algorithm and different parameter combinations are evaluated using a *performance metric*.

<u>*Opinion:*</u> Taguchi's method requires a small number of input parameters (3), and hence it is comparatively easier to be utilized than, e.g. Simulated annealing.

* Details in "Ö. Bulakci et.al. , *Automated Power Uplink Power Control Optimization in LTE-Advanced Relay Networks, submitted journal paper*, 2012".

Joint Optimization: Taguchi's Method

Performance Metric

- Conventional performance metrics: 5%-ile, 50%-ile UE TP CDF levels.

Inverse UE TP CDF

Percentile

$$y = \Gamma_{q\%} = \mathrm{F}_s^{-1}\left(\frac{q}{100}\right)$$

Conventional Performance Metrics

- In our example, we utilize a new performance metric: weighted arithmetic mean of the conventional metrics.

Weights to set priority

$$y = \Gamma_{\mathrm{AM}}^{(w_1, w_2, w_3)} = \frac{w_1 \cdot \frac{\Gamma_{5\%}}{\kappa_{5\%}} + w_2 \cdot \frac{\Gamma_{25\%}}{\kappa_{25\%}} + w_3 \cdot \frac{\Gamma_{50\%}}{\kappa_{50\%}}}{\sum_{j=1}^{3} w_j}$$

Particularly useful for large-ISD scenarios

Normalization w.r.t. eNB-only

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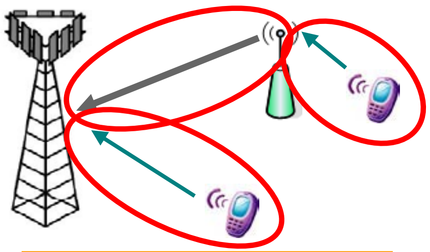
Propagation Environments

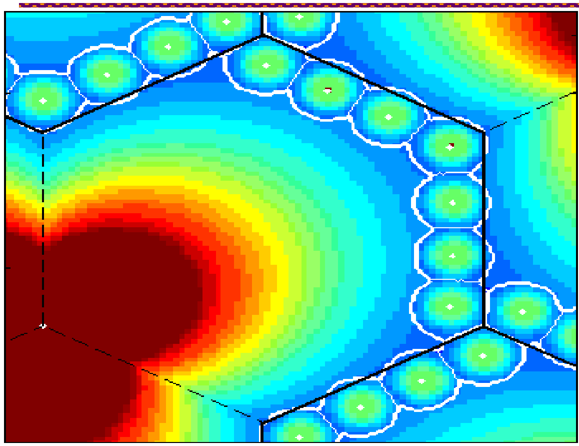
Scenario 1 (Sc1)



ALL links are NLOS.

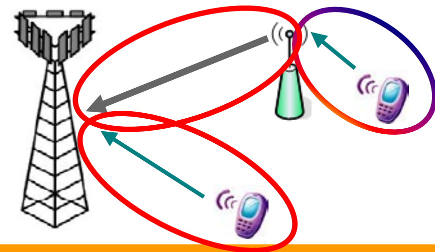
$$PL = PL_0 + 10 \cdot n \cdot \log_{10}(R)$$

Single-slope model



DL Rx. Power (No CRE)

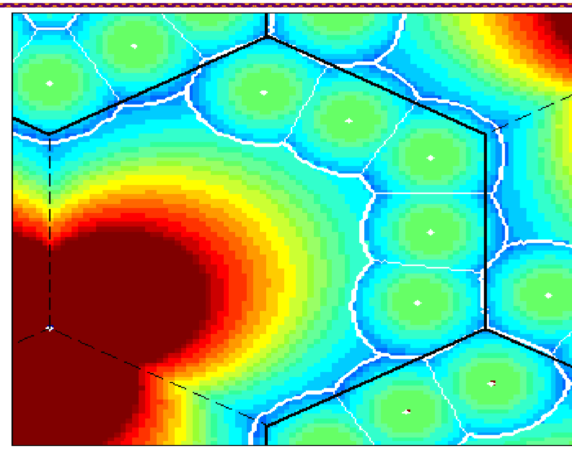
Scenario 2 (Sc2)



Mixed LOS/NLOS on the access link.

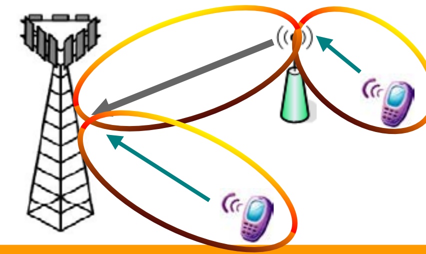
$$PL = \Pr(LOS) \cdot PL_{LOS} + \Pr(NLOS) \cdot PL_{NLOS}$$

Dual-slope model



DL Rx. Power (No CRE)

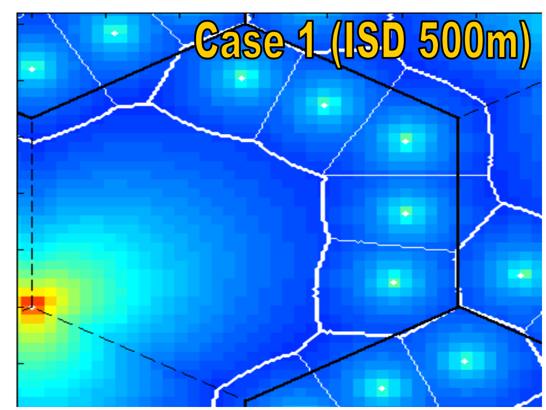
Scenario 3 (Sc3)



Any link can be either LOS or NLOS.

Probabilistic

Dual-slope model



DL SINR (No CRE)

RN LOS - DeNB NLOS

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Uplink Performance Evaluation
System Model / Simulation Parameters

System Parameters

System Layout	19 tri-sectored sites
Bandwidth	10 MHz
Traffic Model	Full Buffer
Noise PSD	-174 dBm/Hz
Shadowing	σ_{macro} = 8 dB $\sigma_{rn\ cell}$ = 10 dB $\sigma_{relay\ link}$ = 6 dB
Penetration Loss	20 dB for UEs only
Highest MCS (AMC)	64-QAM – R: 9/10
Resource partitioning	Reuse 1

eNB Specific

Antenna configuration	2 Tx, 2 Rx
Transmit Power	46 dBm
Antenna gain	14 dBi
eNB Antenna Pattern (Horizontal)	$-\min[12\,(\theta/\theta_{3dB})^2, A_m]$ $\theta_{3dB}=70^o$ & $A_m=25$ dB

(No CRE)

RN Tiers per sector	Scenario	Number of RNs	Total RN coverage area [%]	
			ISD 500 m	ISD 1732 m
1 Tier	Sc 1	7	19.5	21
	Sc 2	4	32.8	35.3
	Sc 3	4	29.5	43.5
2 Tiers	Sc 1	14	33	36.5
	Sc 2	10	65	61.5
	Sc 3	10	45.5	67

UE Specific

Antenna configuration	1 Tx, 2 Rx
Antenna gain	0 dBi
Noise Figure	9 dB
UE drops	Uniform - 25 UEs per sector – Indoor

RN Specific

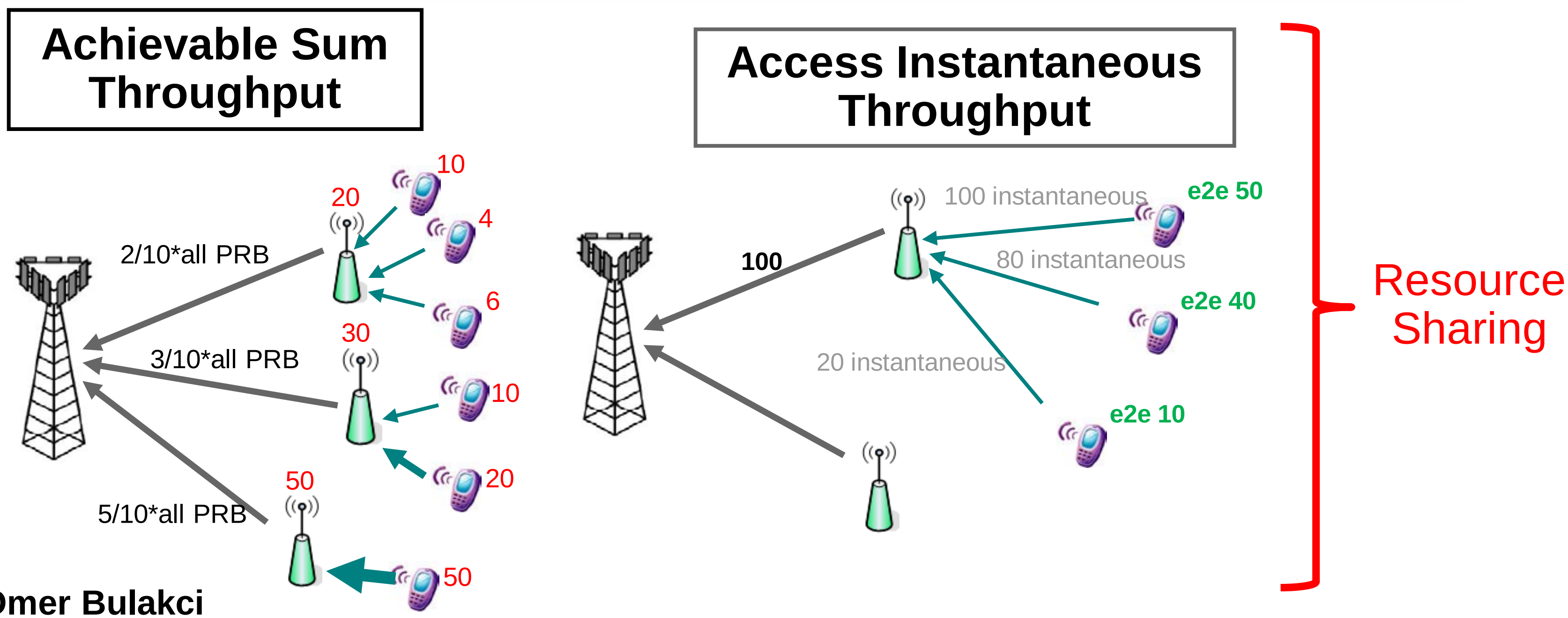
Antenna configuration	2 Tx, 2 Rx
Transmit Power	30 dBm
RN-UE antenna gain	5 dBi
RN-eNB antenna gain	7dBi
Noise Figure	5 dB

Reference Scenario: Before Optimization

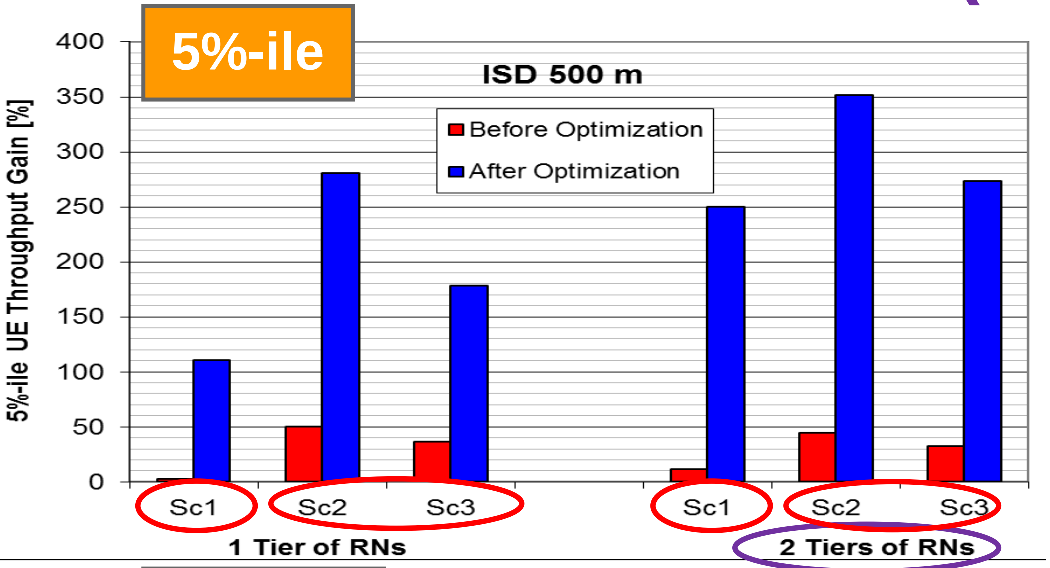
- Power control parameters obtained in macrocell-only deployments are applied on all links.
- No Relay Cell Range Extension.
- The number of backhaul subframes is determined according to the average RN coverage area.

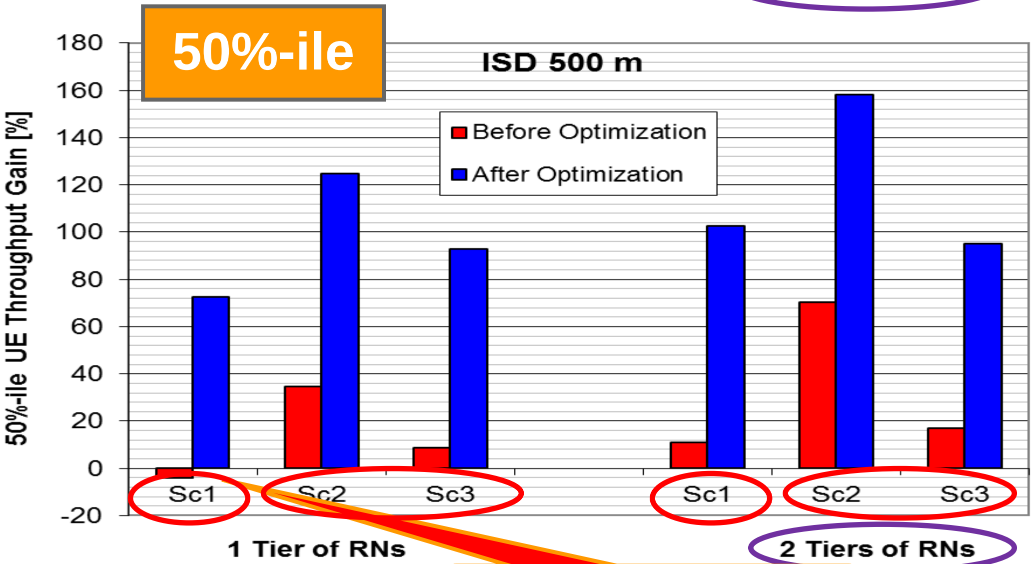
  Ex: 35.3% → 4 Backhaul Subframes

- No Co-scheduling.



Uplink Performance Evaluation
3GPP Case 1 – ISD 500m (Urban)





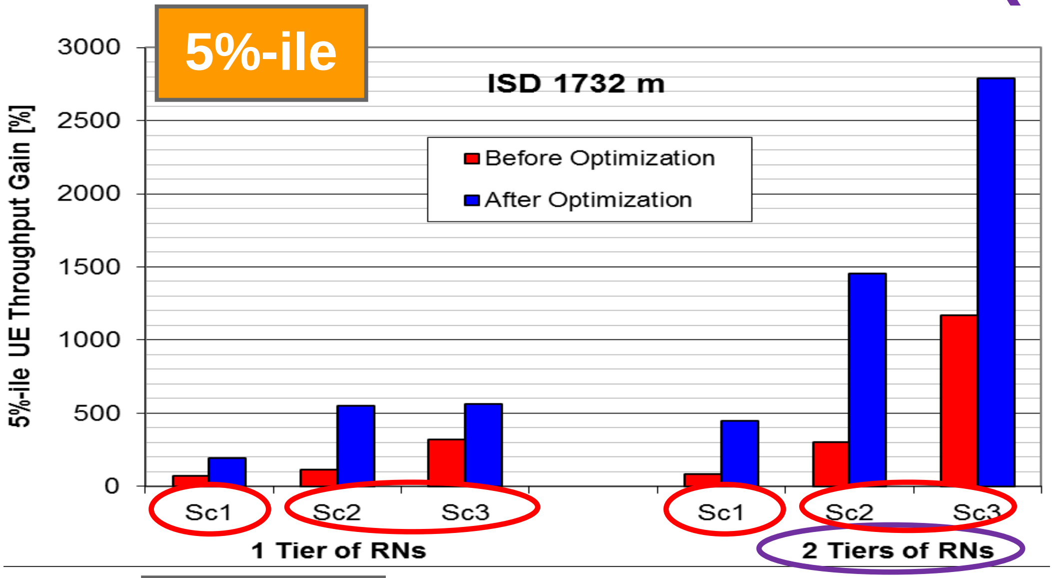
Performance Degradation

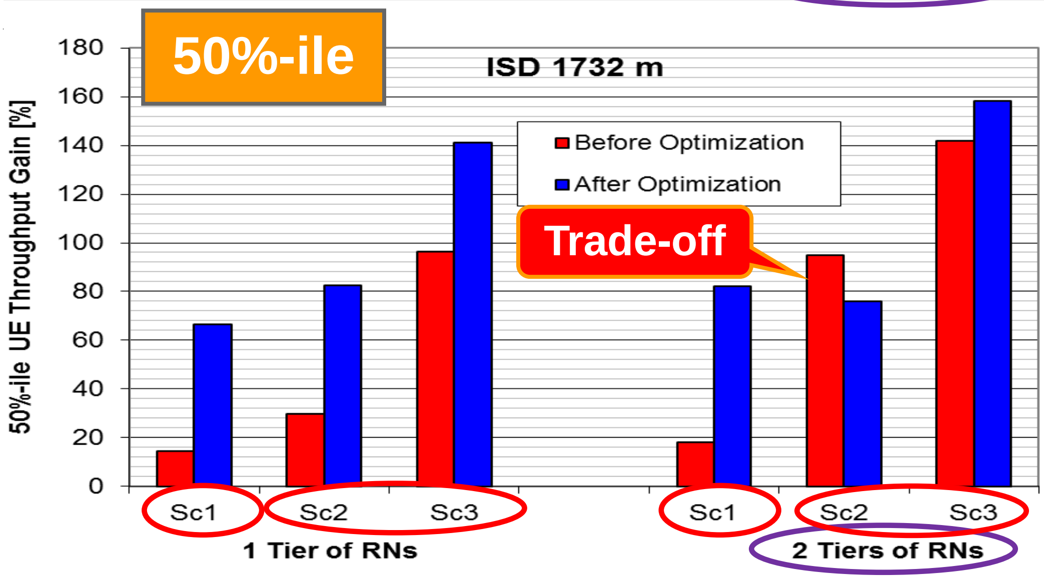
- RN Deployments significantly enhance the system performance over macrocell-only deployments especially at low throughput regime.
- With more RNs performance can be further enhanced.
- Joint RRM optimization yields significant gains over "Before Optimization".

- Least overall gains are observed in Scenario 1 (Sc1) due to NLOS connections.
- Higher gains are observed in Scenario 2 (Sc2) and Scenario 1 (Sc1) thanks to the LOS components in the path loss model.
- Relative gains are lower in Scenario 3 (Sc3) w.r.t. Scenario 2 (Sc2) due to increased performance of macrocell-only.

All Gains w.r.t. macrocell-only deployments.

Uplink Performance Evaluation
3GPP Case 3 – ISD 1732m (Suburban)





- RN Deployments can effectively cope with coverage limitation of suburban scenarios and boost the performance especially at low throughput regime.
- With more RNs overall performance can be further enhanced.
- Joint RRM optimization yields significant gains over “Before Optimization”.
- Least overall gains are observed in Scenario 1 (Sc1) due to NLOS connections.
- Higher gains are observed in Scenario 2 (Sc2) and Scenario 1 (Sc1) thanks to the LOS components in the path loss model.
- Relative gains are <u>higher</u> in Scenario 3 (Sc3) w.r.t. Scenario 2 (Sc2) due to lower performance of macrocell-only & LOS component on the relay link.

All Gains w.r.t. macrocell-only deployments.

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Conclusions

- RN deployments offer significant performance enhancements over macrocell-only deployments
  - Especially at low throughput regime
  - Achieved gains can be significantly different in different propagation environments
    - Least gains are observed when all links are NLOS
    - Higher overall gains are observed when a LOS connection is taken into account.

- The system performance can be further increased when the joint optimization of the proposed RRM strategies is applied.

Thank you for your attention!

Q & A

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BACK-UP

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Power Control: Automated Optimization

Methodology: Taguchi's Method

- Let the variable x_t where t = 1, 2, 3, 4 designate configuration parameters and γ be any performance measure. The optimization problem is:

$$\{x_1^{(opt)}, x_2^{(opt)}, x_3^{(opt)}, x_4^{(opt)}\} = \arg\max_{x_1, x_2, x_3, x_4} y(\gamma)$$

  where $y(\gamma)$ is the overall optimization function.

- **Assume** 4 parameters and each can take 3 values. To find the global optimum, we need to test all 3^4 = 81 combinations.
- Instead, Taguchi's method uses orthogonal array (OA) that extracts 9 parameter combinations (experiments) from the search space to select nearly-optimal parameter setting.

➢ OAs are difficult to construct and your required OA may not exist.

✓ Hence, we use nearly orthogonal array (NOA):

  - Easier to construct.
  - Can be constructed for any number of experiments
  - Reduces computational complexity.
  - Provides similar performance to an OA.

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Power Control: Automated Optimization

Taguchi's Method: Based on OA

Experiment	x_1	x_2	x_3	x_4	Measured Response	SN Ratio
1	1	1	1	1	y_1	SN1
2	1	2	2	3	y_2	SN2
3	1	3	3	2	y_3	SN3
4	2	1	2	2	y_4	SN4
5	2	2	3	1	y_5	SN5
6	2	3	1	3	y_6	SN6
7	3	1	3	3	y_7	SN7
8	3	2	1	2	y_8	SN8
9	3	3	2	1	y_9	SN9

1- SN Ratio = $10 \cdot \log_{10} (y_i^2)$.

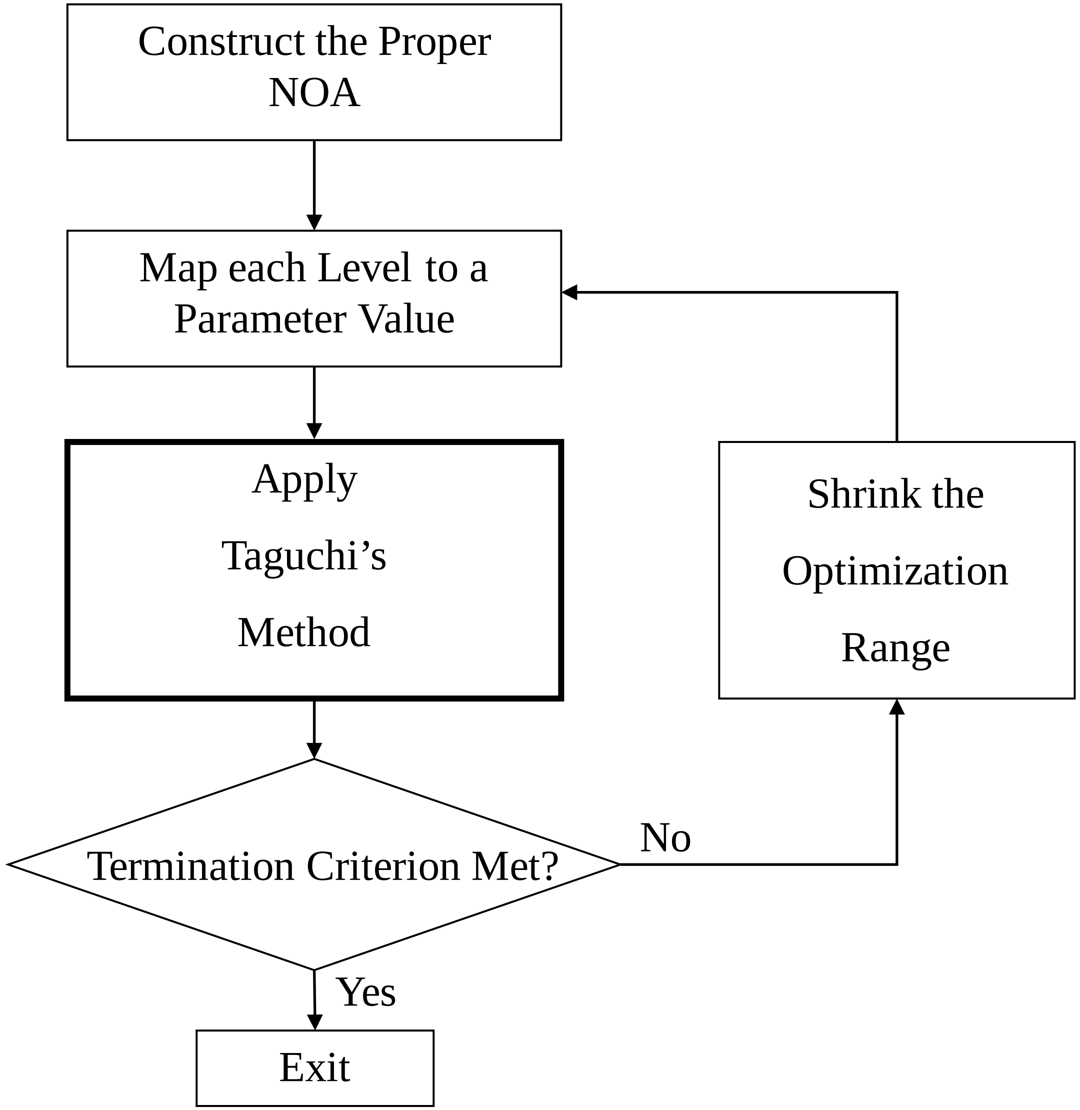
2- Compute the average SN ratio for each level of a parameter. For instance, the mean SN ratio for x_1 at level 1 is computed by averaging over SN1, SN2 and SN3.

3- Determine the level of each parameter having the highest SN ratio.

4- Having determined the level, the best value of a parameter is determined using the mapping function that assigns a value for each level.

Power Control: Automated Optimization

Taguchi’s Method: Optimization Procedure



Power Control: Automated Optimization

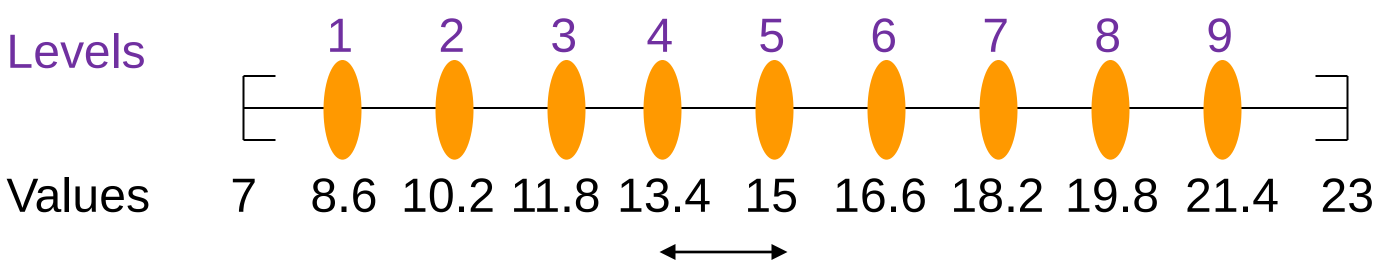
Taguchi's Method: Construct the proper NOA

- The number of columns in NOA is equal to the number of configuration parameters.
- The number of experiments *N* and levels *s* are input parameters that need to be selected.
  - Typically, the higher *N* or *s* the better the performance.
  - However, the computational complexity increases with increasing *N*
    → Trade-off between performance and complexity.

Power Control: Automated Optimization

Methodology: Taguchi's Method

- In order to perform the experiments, the levels of the NOA should be mapped to testing values.
- In each iteration, the levels of NOA are mapped to new testing values based on the candidate solution found in previous iteration.
- **Example:** Consider $P_{max}^{relay\text{-}UE}$ [7, 23] dBm and an NOA having s = 9 levels. In the first iteration,

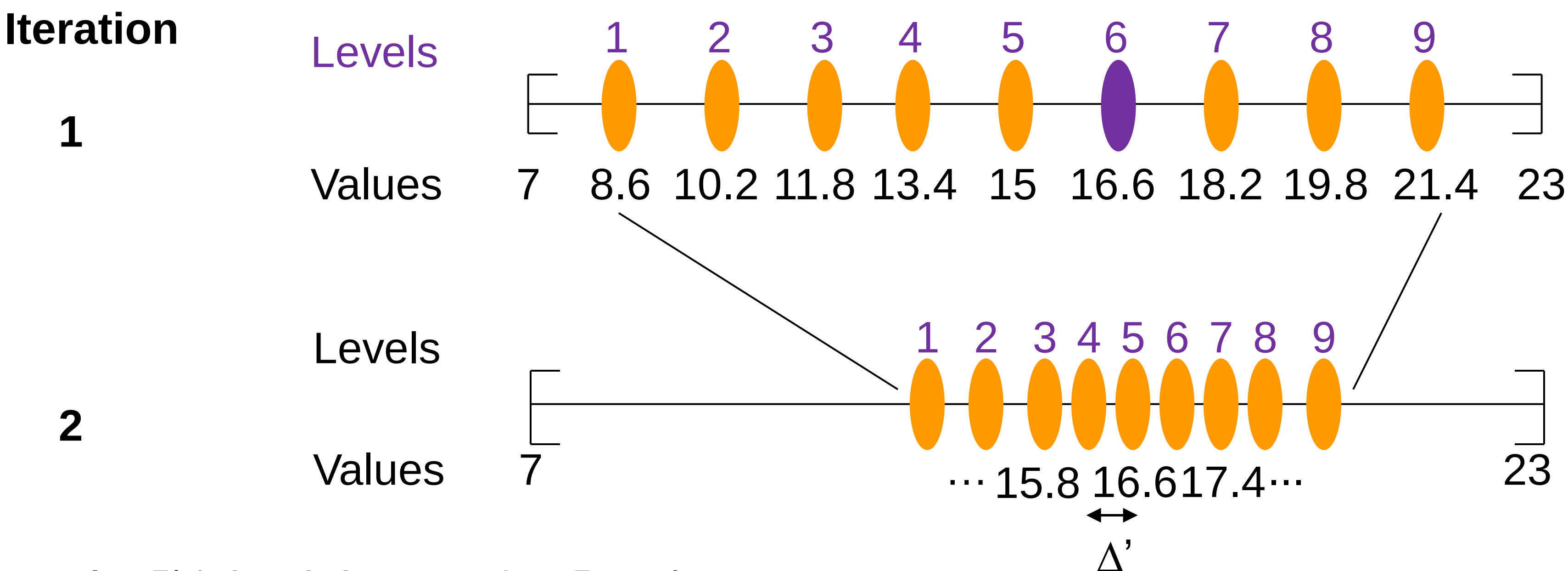


Δ = (23-7) / (9 +1) =1.6

Power Control: Automated Optimization

Methodology: Taguchi's Method

- After applying Taguchi's method, new values are selected for each parameter.
- Then, the termination criterion $\Delta < \varepsilon$ is checked. If not satisfied, the optimization range for each parameter is reduced.



$\Delta' = \zeta * 1.6 = 0.8$ assuming $\zeta = 1/2$