Performance of Relays in LTE-Advanced Networks

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  - Power control
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Introduction (1/2)

Requirements for LTE-Advanced:

- 1 Gbps on the downlink and 500 Mbps on the uplink.
- Higher peak and average spectral efficiency.
- More homogenous distribution of the user experience over the coverage area.

Challenges:

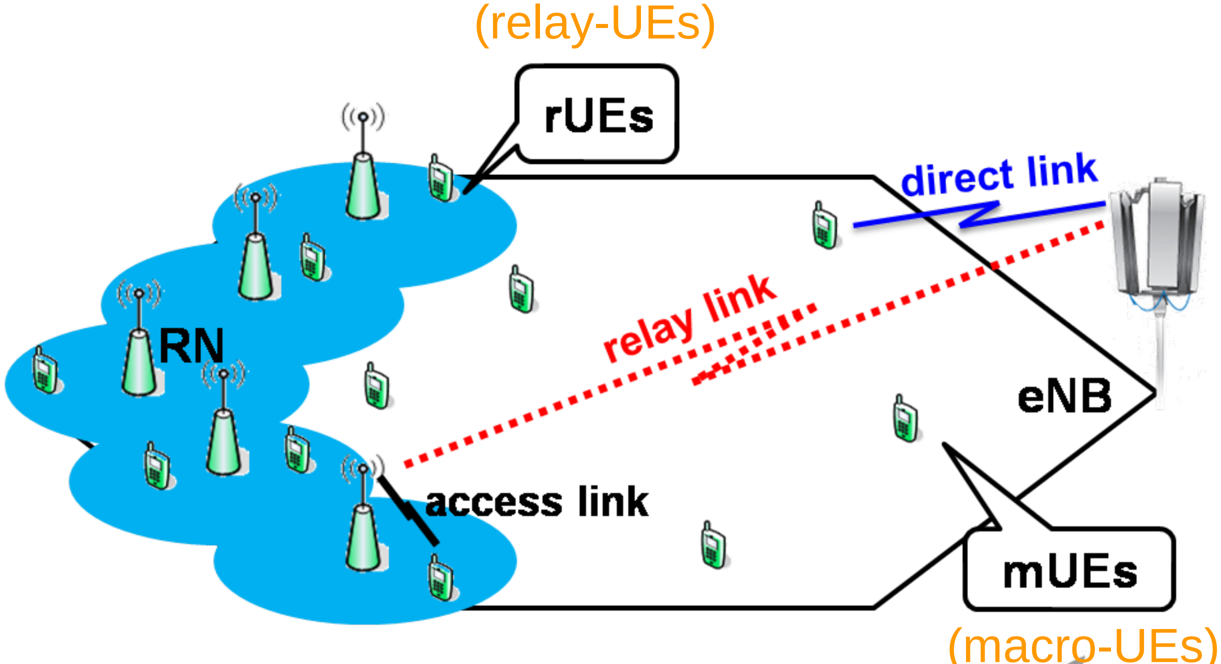
- Severe propagation losses at the cell edge, resulting in significant capacity and coverage problems.
- Straight-forward Solution: Smaller sectors or equivalently more eNBs.
  - Cost inefficient

Can we do better?

Introduction (2/2)

Yes, WE CAN!

- Promising Solution: Heterogeneous deployments – Decode and Forward Relay Nodes
  - Low total cost of operation.
  - More homogeneous user experience.
  - Cell coverage area extension.



Goal

- Investigate the performance of LTE-Advanced uplink in relay deployment
  - Apply standardized LTE Rel.8 power control on UE-eNB and UE-RN links.
  - Optimize power control parameters at eNBs and RNs.

- Investigate the performance of LTE-Advanced downlink in relay deployment
  - Study the impact of RN coverage extension via biasing in cell selection on the system performance.

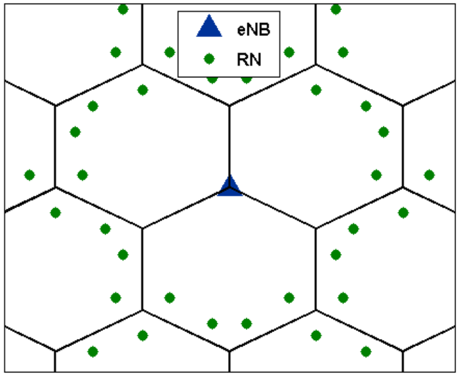
System Parameters

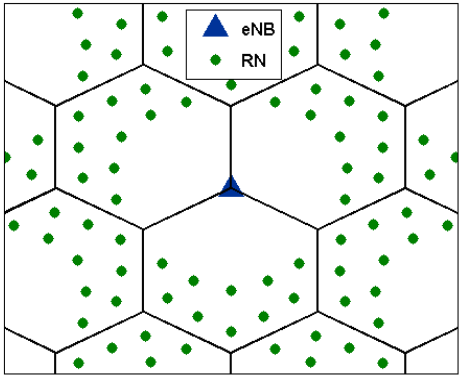
System Parameters

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

UE Specific

Antenna configuration	1 Tx, 2 Rx
Noise Figure	9 dB
UE drop	Uniform - 10 UEs per sector – Indoor





RN Specific

Antenna height	5 m (below rooftop)
Antenna configuration	2 Tx, 2 Rx Omni-directional
Transmit Power	30 dBm
RN-UE antenna gain	5 dBi
RN-eNB antenna gain	7dBi
Noise Figure	7 dB
Backhaul Link	Ideal

eNB Specific

Antenna height	25 m (above rooftop)
Antenna configuration	2 Tx, 2 Rx
Transmit Power	46 dBm
Antenna gain	14 dBi
Noise Figure	5 dB
eNB Antenna Pattern (Horizontal)	$-\min[12\,(\theta/\theta_{3dB})^2, A_m]$ $\theta_{3dB} = 70^o$ & $A_m = 25$ dB

Uplink Performance Evaluation

~ Power Control ~

Basics

I. LTE Rel.8 fractional power control (1/2)

- The Open Loop Power Control formula is investigated.

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

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

- P_0 can be selected from the set of [-116:1 dB:P_{max}] in dBm.
- We investigated P_0 in the range of [-113:2 dB:-7] in dBm.

Basics

I. LTE Rel.8 fractional power control (2/2)

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

No Power Control (No PC): Fixed Tx Power

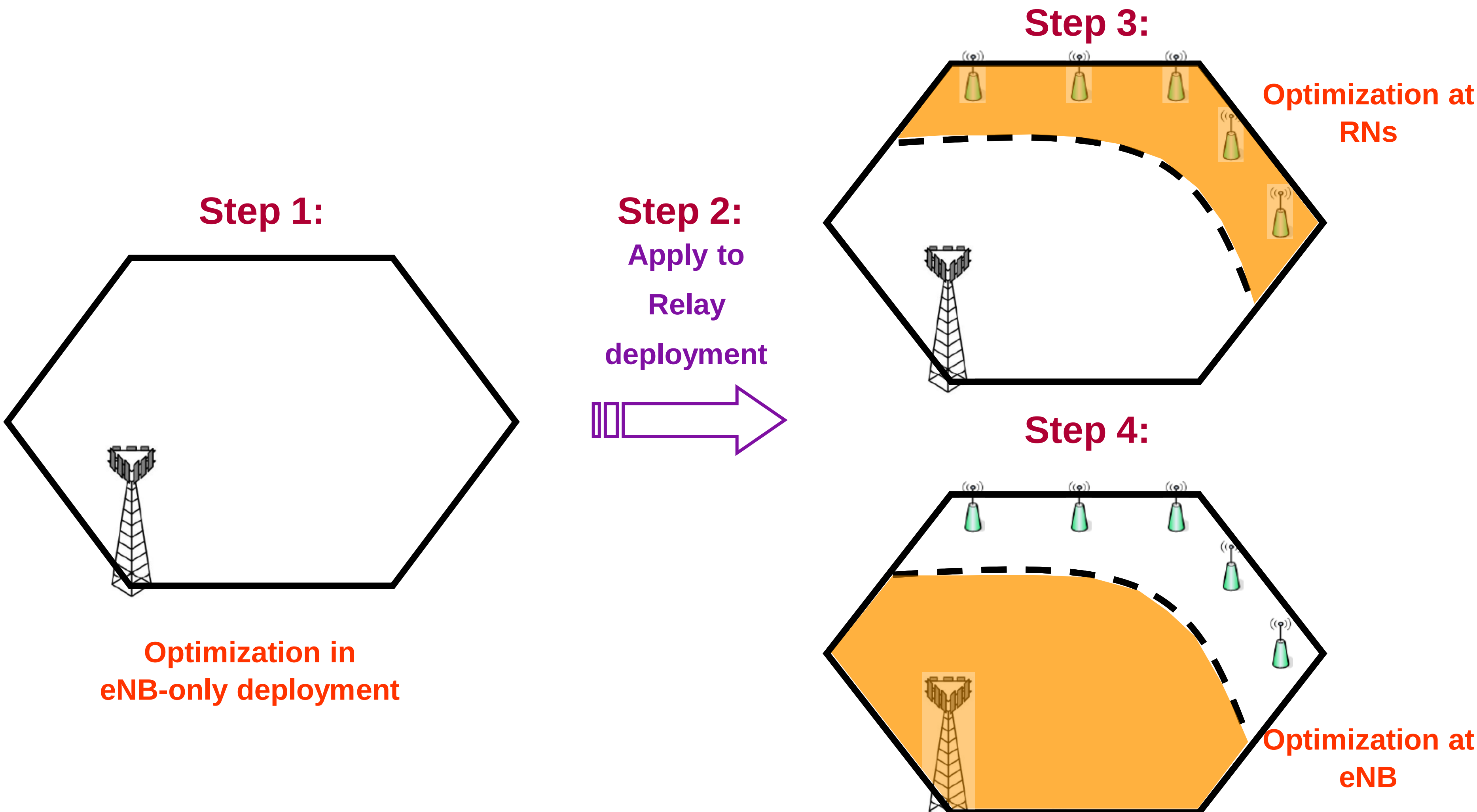
FCPC compensates the path loss fully and hence increases the performance of cell edge users.

FPC utilizes a partial compensation factor for the path loss and improves the performance of cell center users by inducing an acceptable inter-cell interference.

Basics

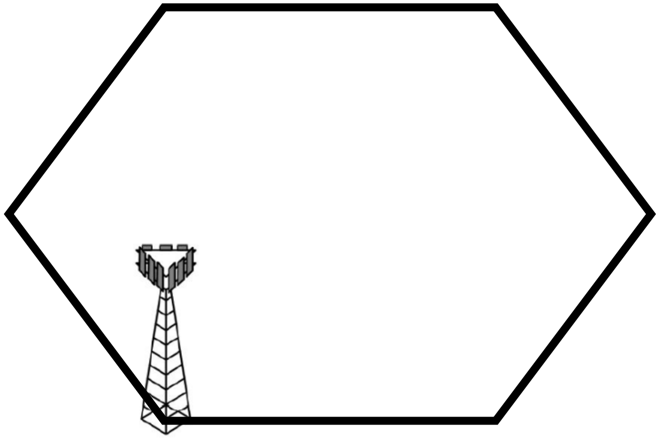
II. Methodology

- Power control parameter optimization in relay deployment is done in four steps.



Info Point

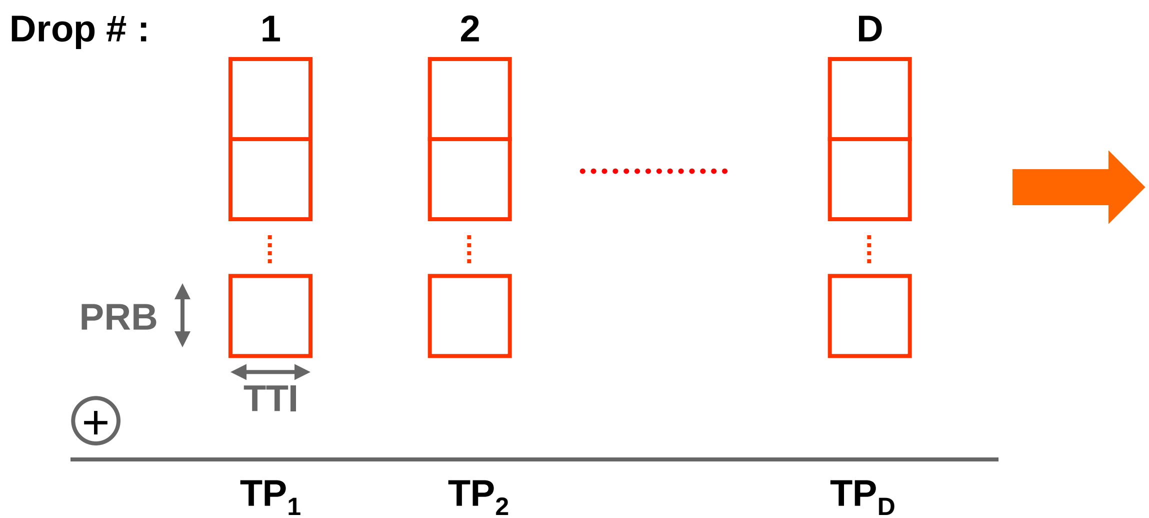
Step 1:



Optimization in eNB-only deployment

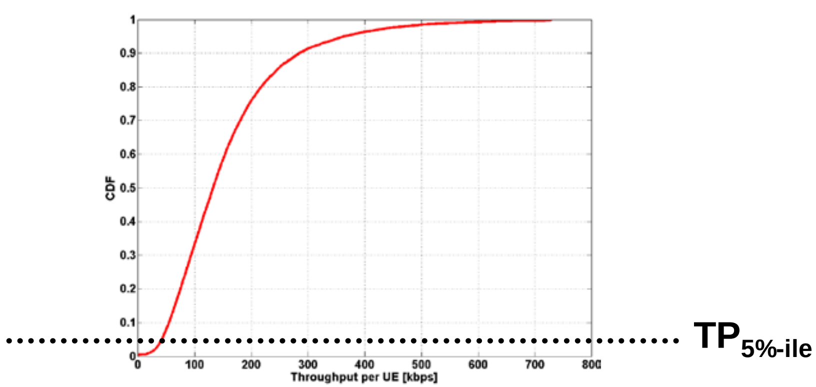
Performance Metrics

- Cell Capacity: Aggregate user throughput (TP) per TTI averaged over user drops.



Cell Capacity = mean(TP_1,TP_2,…,TP_D)

- Cell Coverage: 5^{th} %-ile user throughput multiplied by the number of users per sector.



Cell Coverage =

$TP_{5\%\text{-ile}}$ * numUE

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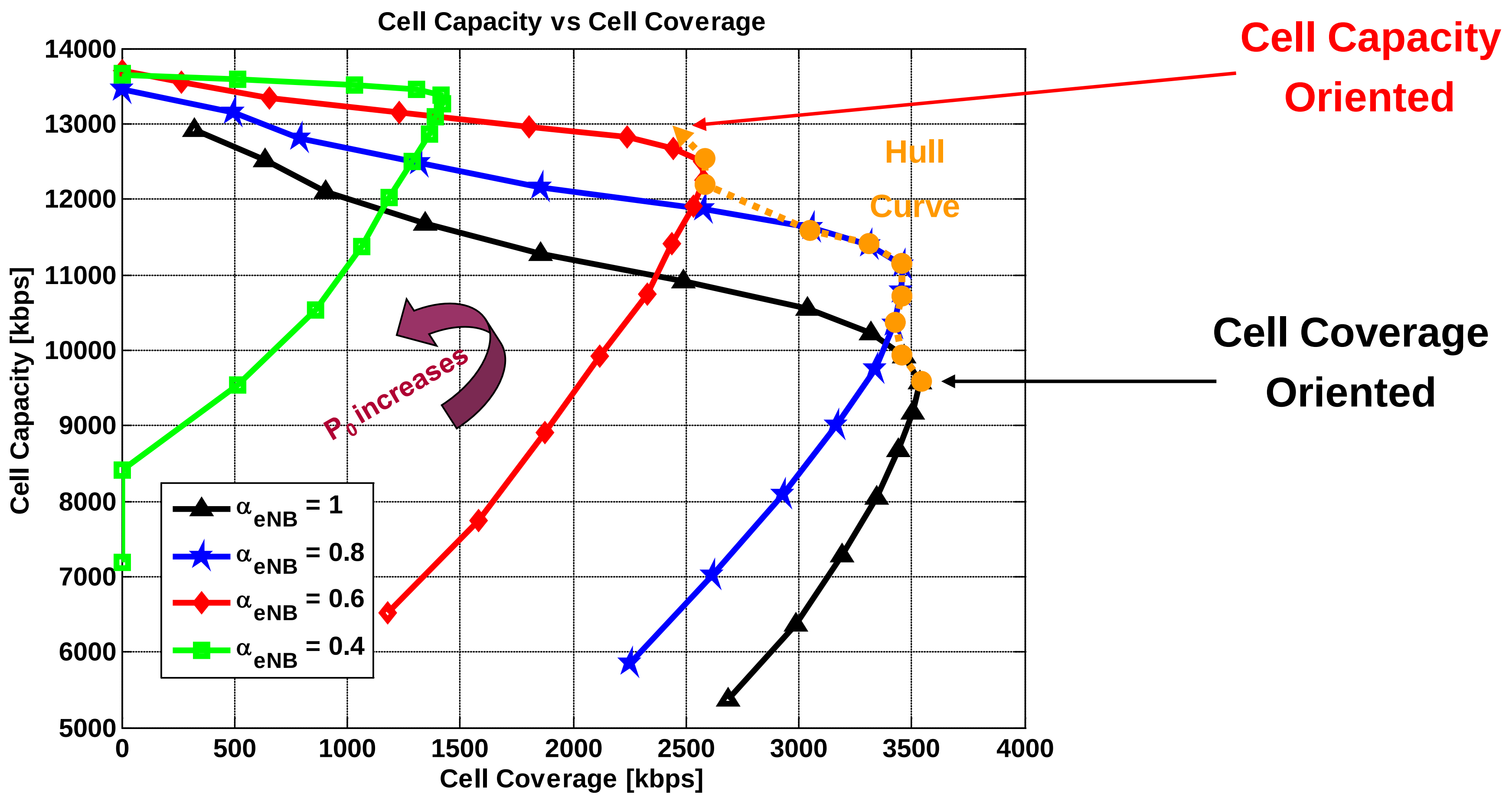
Parameter Optimization in eNB-only Deployment

Cell Capacity vs. Cell Coverage

- **Hull Curve: At the final point, the percentage-wise increase in cell capacity is higher than percentage-wise decrease in cell coverage.**



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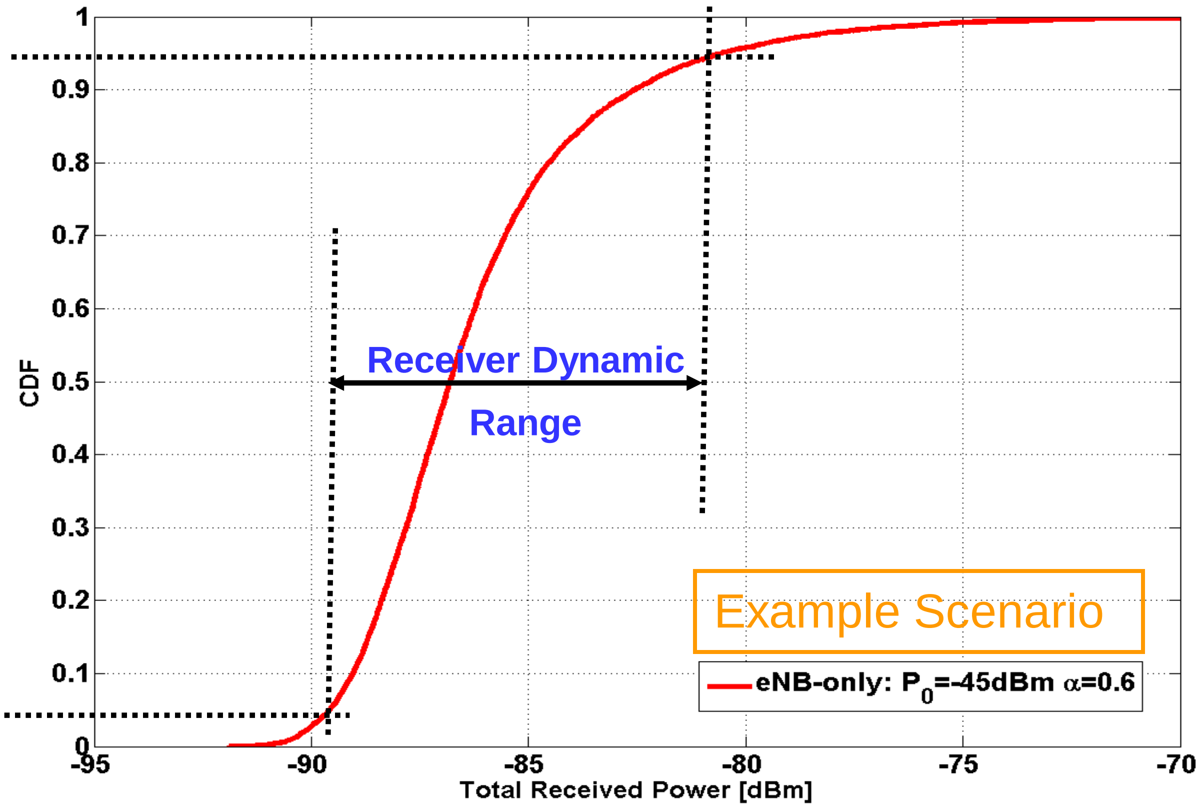
Performance Metrics

- Receiver Dynamic Range: The difference between the 5th%-ile and 95th%-ile of the CDF of the *total received power per PRB* (Wanted Signal Power + Interference Power).

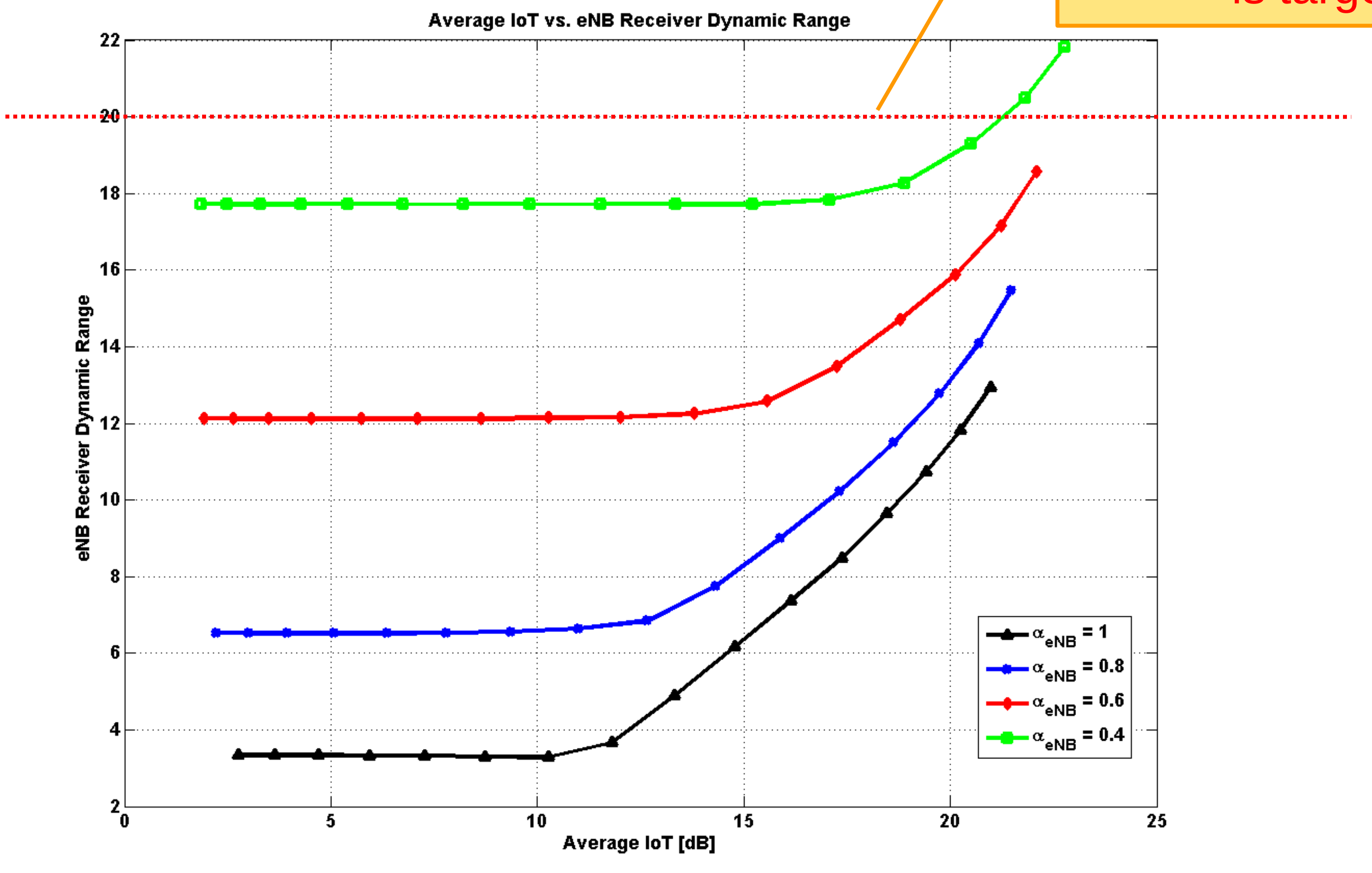


- Average Interference over Thermal Nose (avgIoT): Defines the operating point of the system.

Parameter Optimization in eNB-only Deployment

Receiver Dynamic Range

The upper limit of 20 dB is targeted*.



*** B.E Priyanto et. al., "In-Band Interference Effects on UTRA LTE Uplink Resource Block Allocation," VTC Spring 2008, IEEE , no., pp.1846-1850, 11-14 May 2008**

Parameter Optimization in eNB-only Deployment

Selected Parameter Settings

	Cell coverage oriented	Cell capacity oriented
Alpha	1.0	0.6
P_0	-101 dBm	-55 dBm
Average IoT	10.0 dB	13.5 dB
Cell capacity	9576 kbps	12670 kbps
Cell coverage	3536 kbps	2444 kbps

32% Capacity Increase

31% Coverage Loss

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Info Point

Step 2:

Apply to Relay deployment

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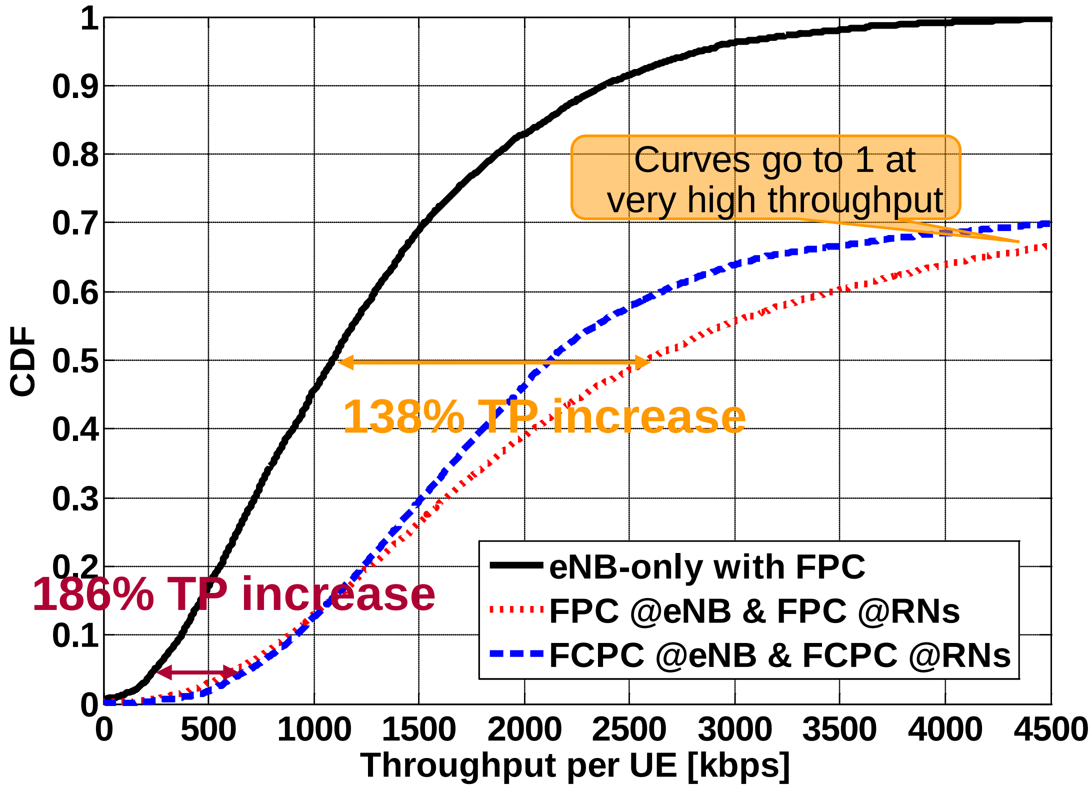
Parameter Optimization in Relay Deployment

Applying eNB-only Parameter Settings

- **Throughput Distribution at Sector**
  - ➢ The optimal parameter settings obtained in eNB-only deployment are assumed also for relay deployment.

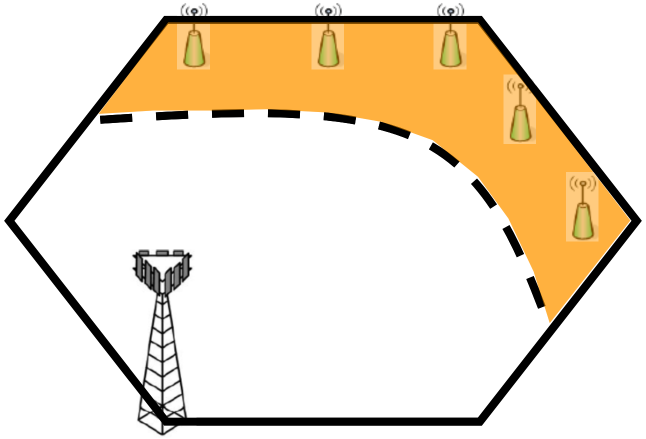


- NOTE: Although the relay link is considered ideal, 5%-ile user TP will not be affected from the non-ideal relay link.

- Relay deployment outperforms eNB-only.
- **Parameter settings can be re-adjusted to further improve the performance.**

Info Point

Step 3:



Optimization at RNs

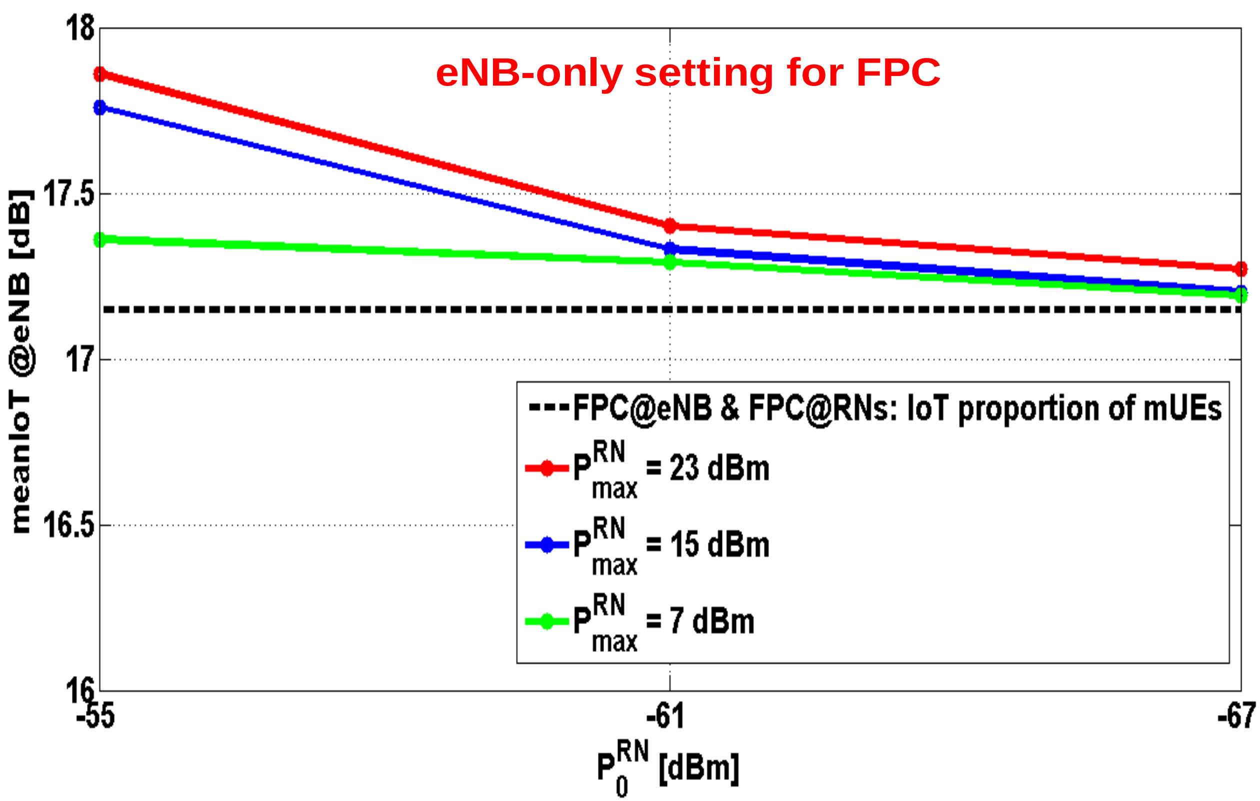
Parameter Optimization in Relay Deployment

Optimization at RNs (for FPC): Interference Mitigation

- **The effect of reducing power levels on the interference proportions.**
  - By means of decreasing P_{max} and P_0 @ RNs, the interference caused by relay users can be decreased significantly.

$$avgIoT = avgIoT_{mUEs} + avgIoT_{rUEs} - 1$$

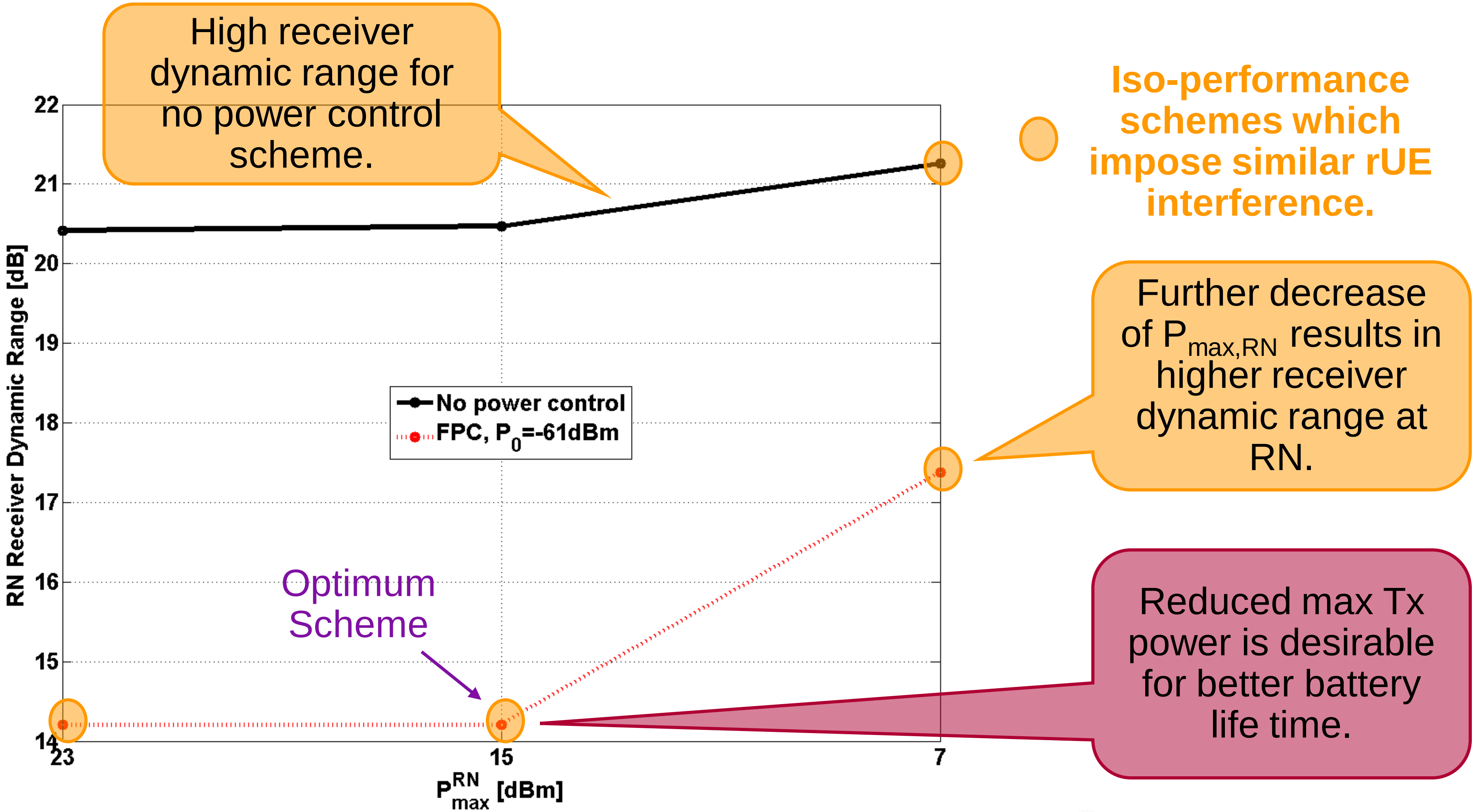
Total IoT at eNB vs. P_0^{RN}



Parameter Optimization in Relay Deployment

Optimization at RNs (for FPC) : Receiver Dynamic Range

- **Receiver Dynamic Range of RN**



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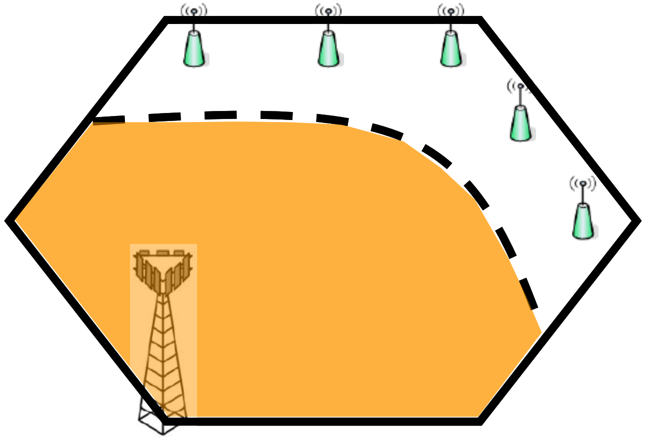
Info Point

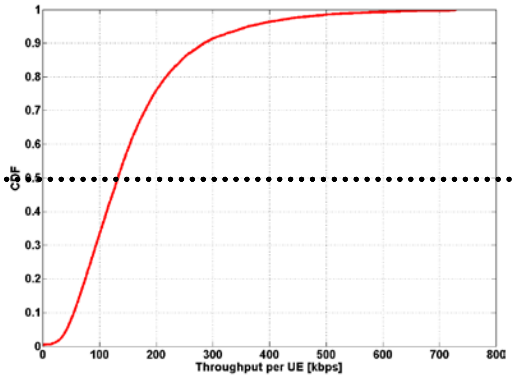
Step 4:

Optimization at eNB



Performance Metrics

- 50%-ile User Throughput: 50th %-ile user throughput multiplied by the number of users per sector.

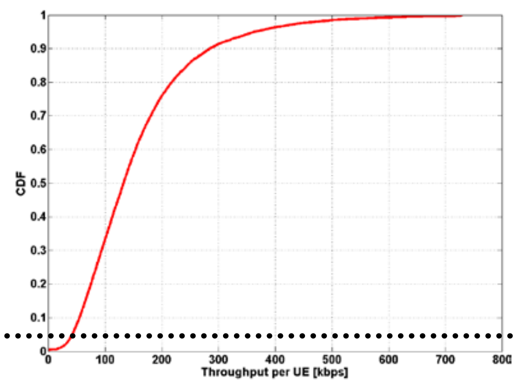


$TP_{50\%\text{-ile}}$

50%-ile user TP =

$TP_{50\%\text{-ile}}$ * numUE

- Cell Coverage: 5th %-ile user throughput multiplied by the number of users per sector.



$TP_{5\%\text{-ile}}$

Cell Coverage =

$TP_{5\%\text{-ile}}$ * numUE

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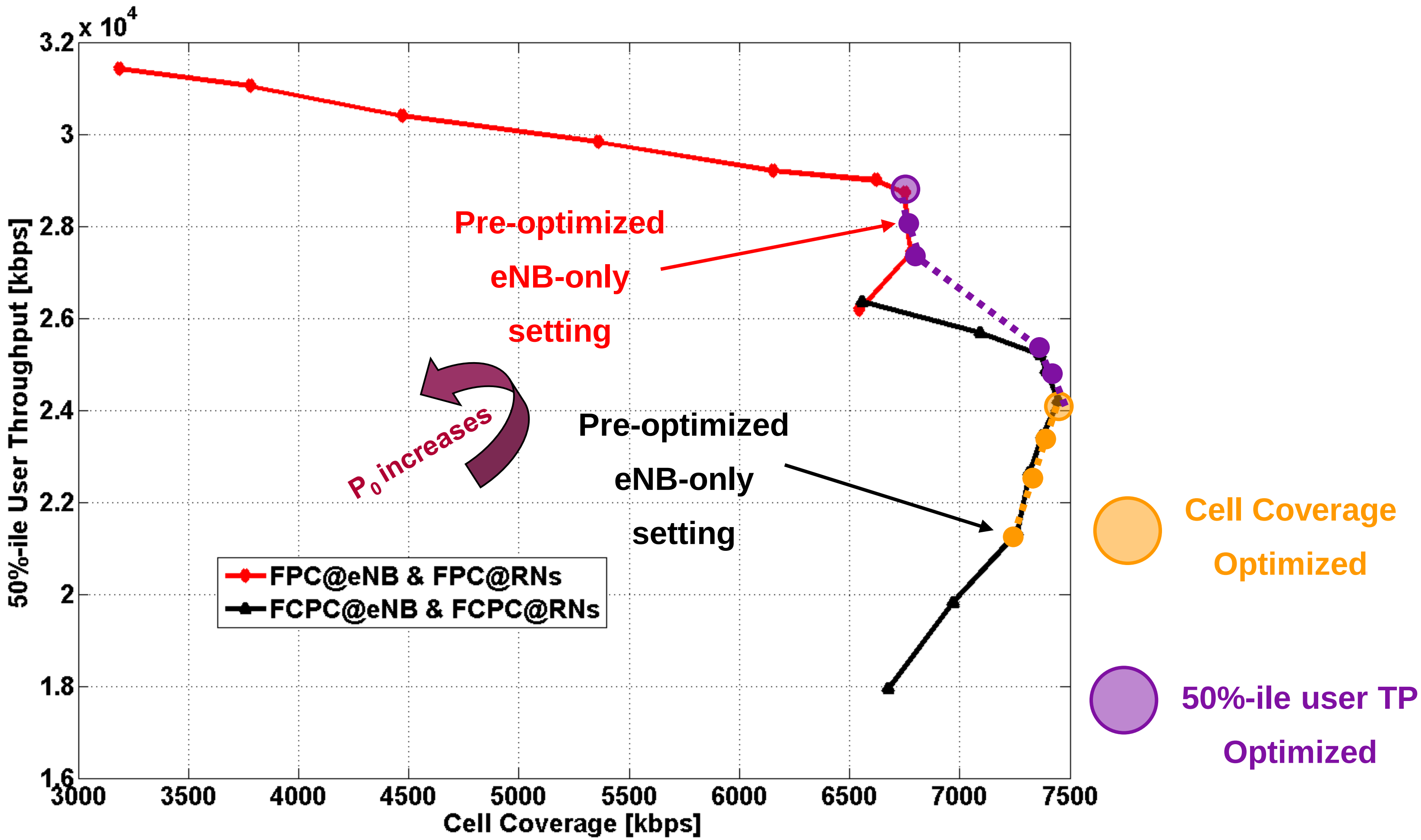
Parameter Optimization in Relay Deployment

Further Optimization: Tuning Parameters at eNB

- **Performance Metrics: 50%-ile User Throughput vs. Cell Coverage**



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Parameter Optimization in Relay Deployment

Further Optimization: Tuning Parameters at eNB

Parameters	50%-ile user TP Oriented		Cell Coverage Oriented	
	eNBs	RNs	eNBs	RNs
P_0 [dBm]	-53	-61	-95	-101
alpha	0.6	0.6	1.0	1.0
P_{max} [dBm]	23	15	23	15

⋮ ⋮ ⋮

TP gain w.r.t. eNB-only		
@ 50%-ile	164%	122%
@ 5%-ile	178%	204%

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Downlink Performance Evaluation

~ RN Coverage Extension ~

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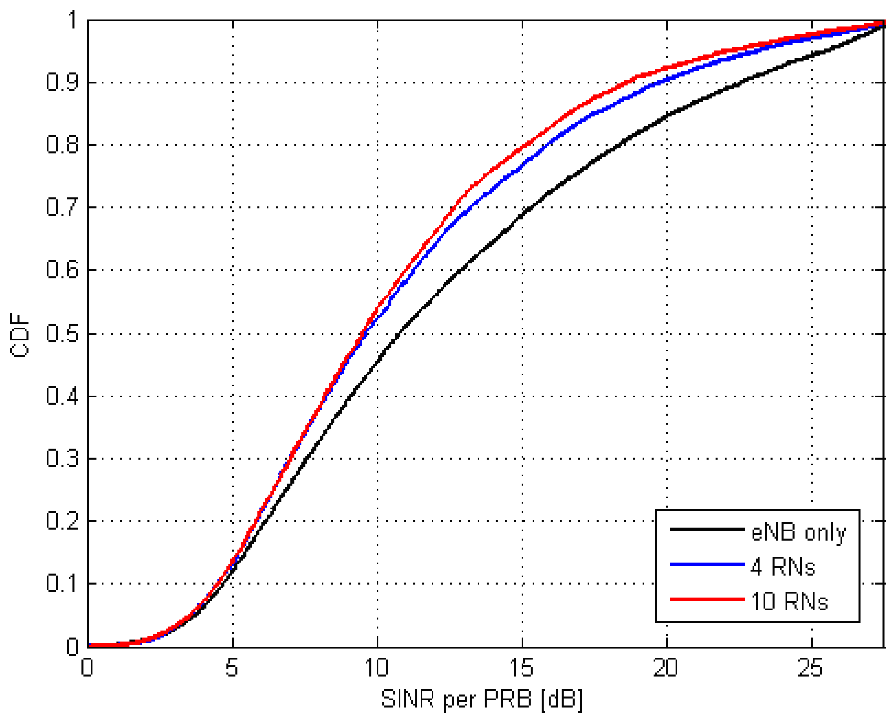
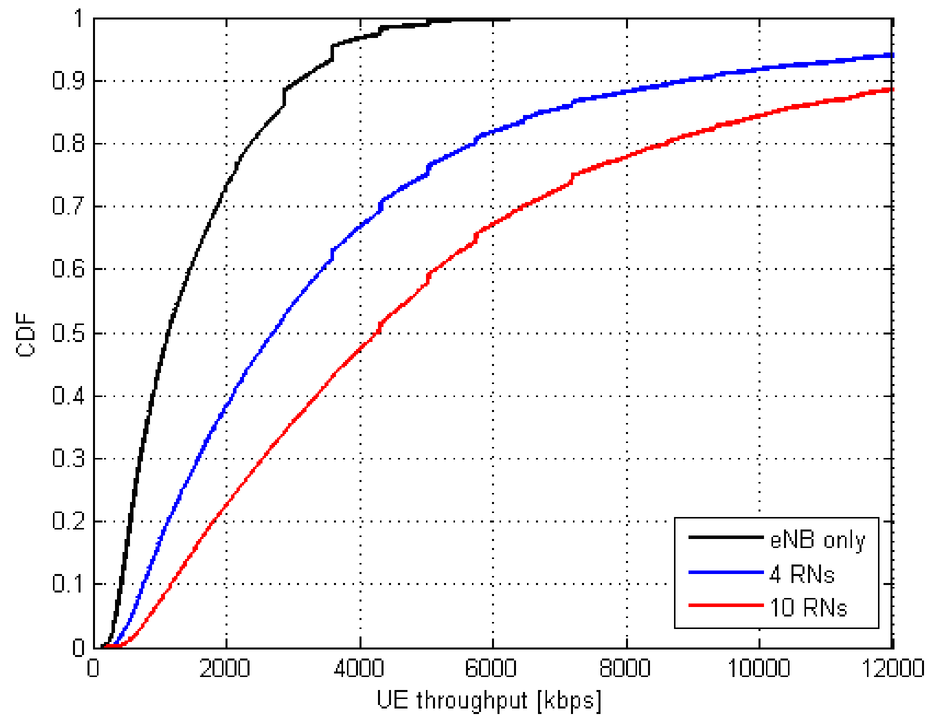
Simulation Results
RN deployment - ISD 500m

Significant gains from RN deployments

		4 RN	10 RNs
Throughput Gain [%] (Reference: eNB-only)	5%-ile	65	145
	50%-ile	139	275

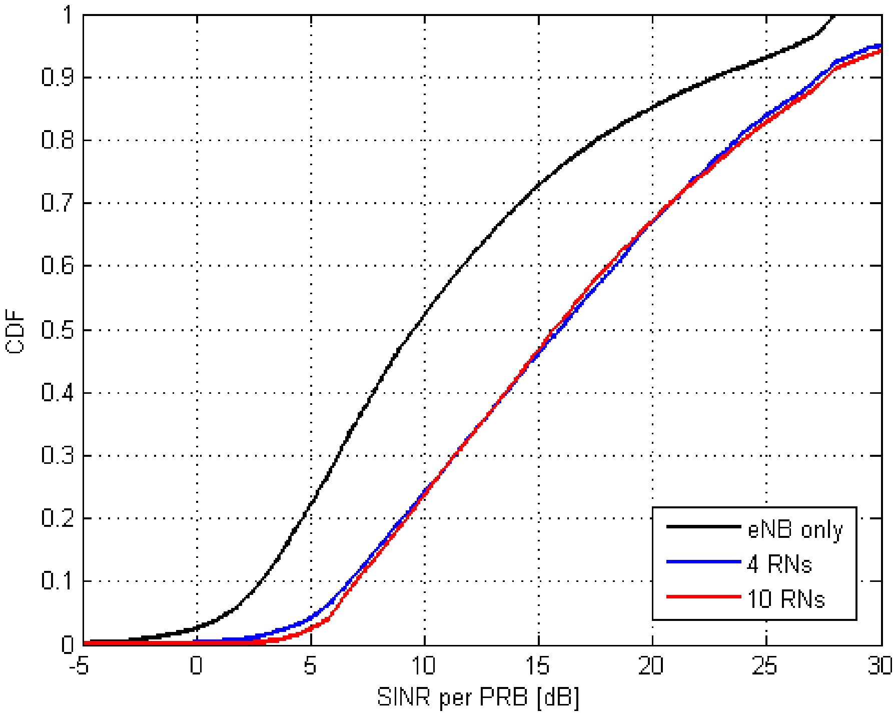


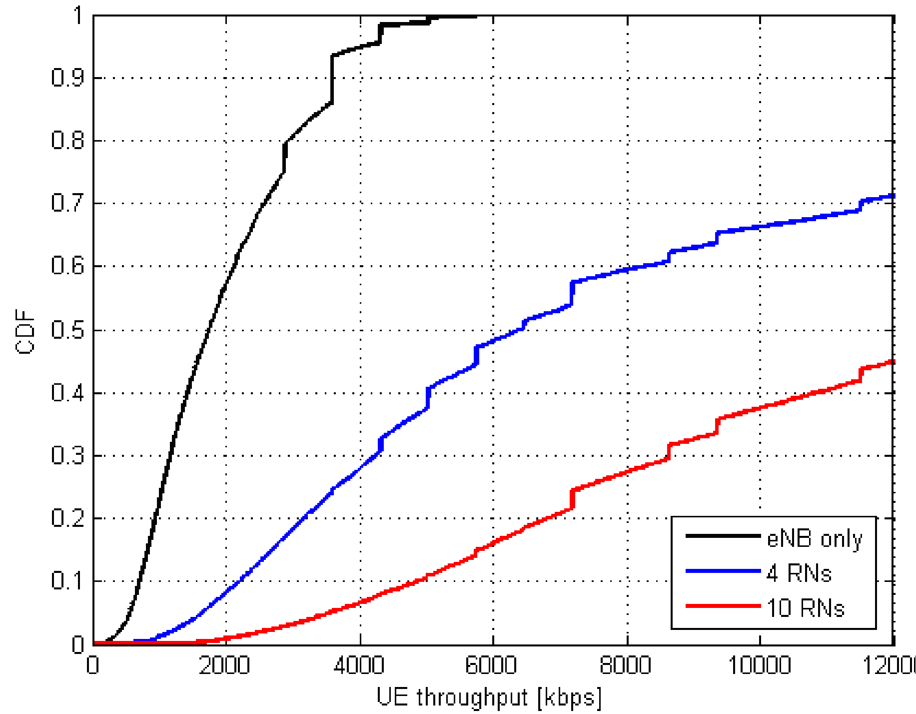


Simulation Results
RN deployment - ISD 1732m

Huge gains from RN deployment in Suburban environments

		4 RN	10 RNs
Throughput Gain [%] (Reference: eNB-only)	5%-ile	194	541
	50%-ile	267	612





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Further Improvement in the Downlink

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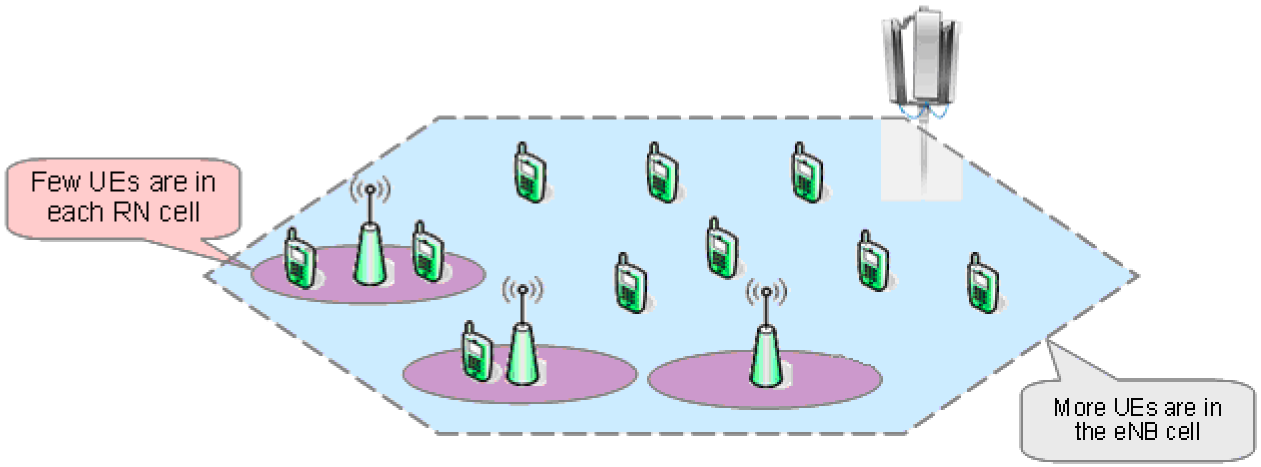
Motive

Relays are small nodes with low transmission power, and hence, small coverage areas.



Motive

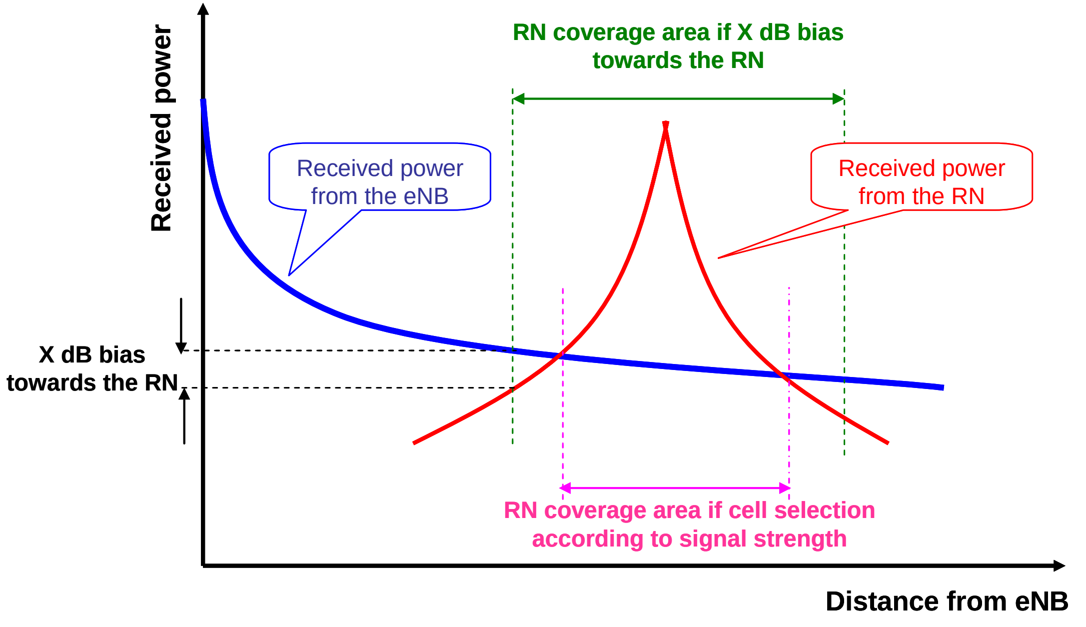
– Inefficient use of resources in the under-loaded RN cell
– High competition on resources in the macro cell

<u>Cost-free Solution</u>

Increase RN coverage area through biasing in cell selection and handover thresholds.

Balancing cell loads

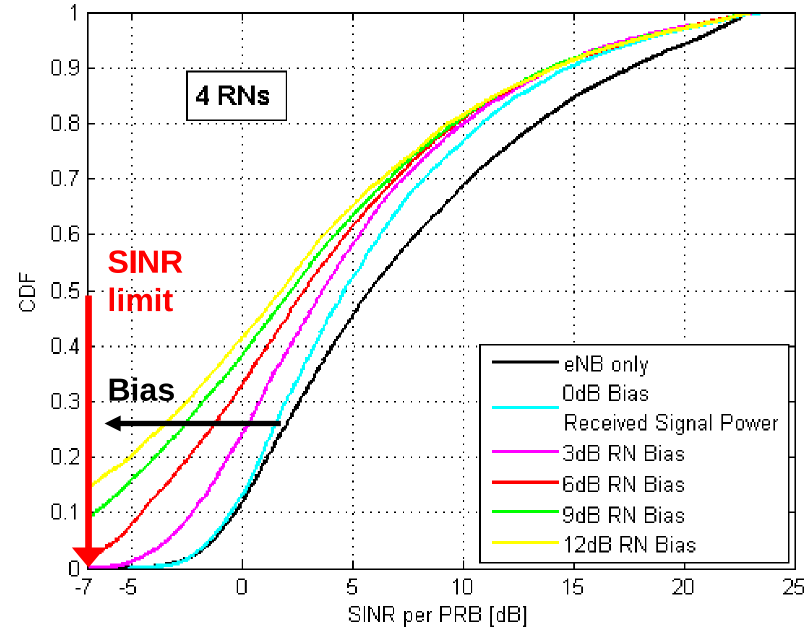
- Default: Cell is selected according to received signal strength.
- Adding a bias in cell selection and handover thresholds increases the RN cell area, and hence its load.
- UEs, which moved to the RN cell, will face less competition on resources.

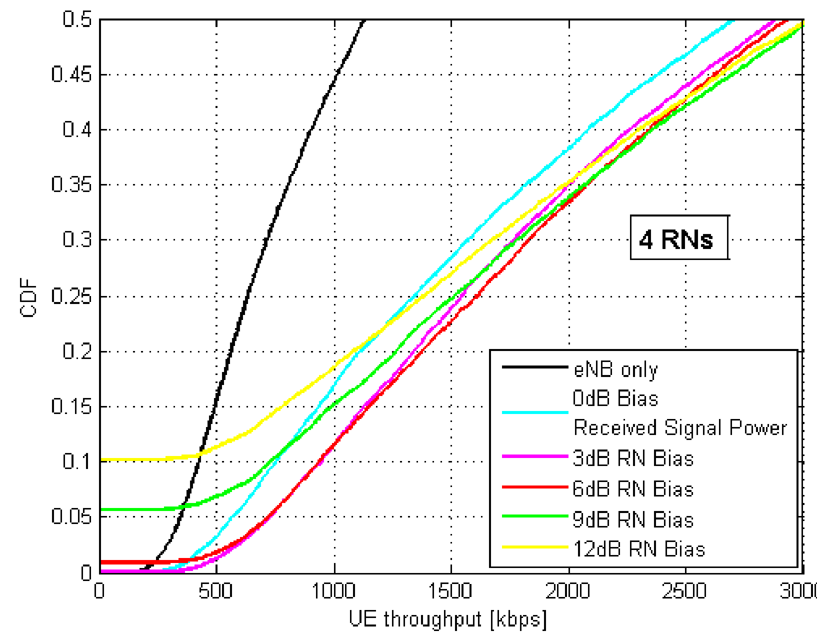


Simulation Results
Biasing - ISD 500m

Significant gain from 3dB biasing in cell selection

RN bias		3dB	6dB
5%-ile Throughput Gain [%] **Reference: No bias in cell selection**	**4 RNs**	**29**	**27**
	10 RNs	**36**	**26**
50%-ile Throughput Gain [%] **Reference: No bias in cell selection**	**4 RNs**	**6.5**	**8.5**
	10 RNs	**3**	**6.5**





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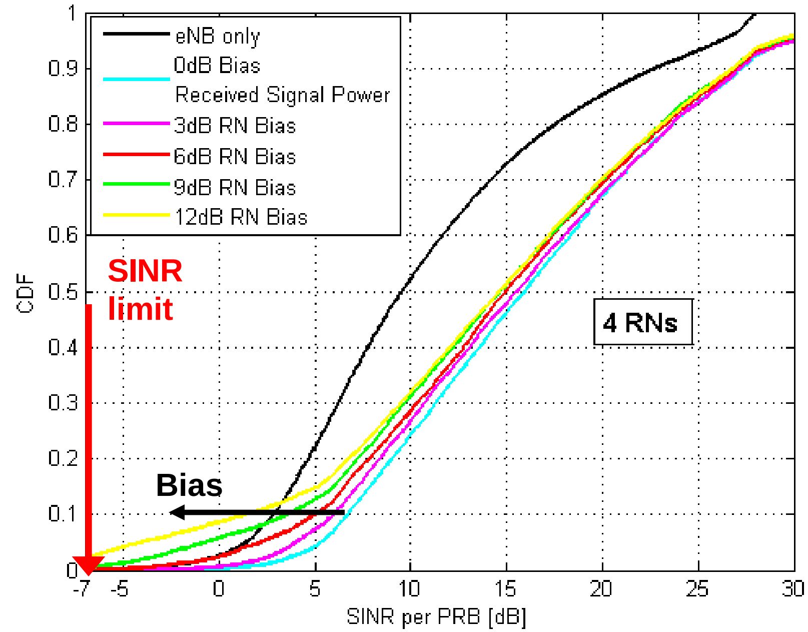
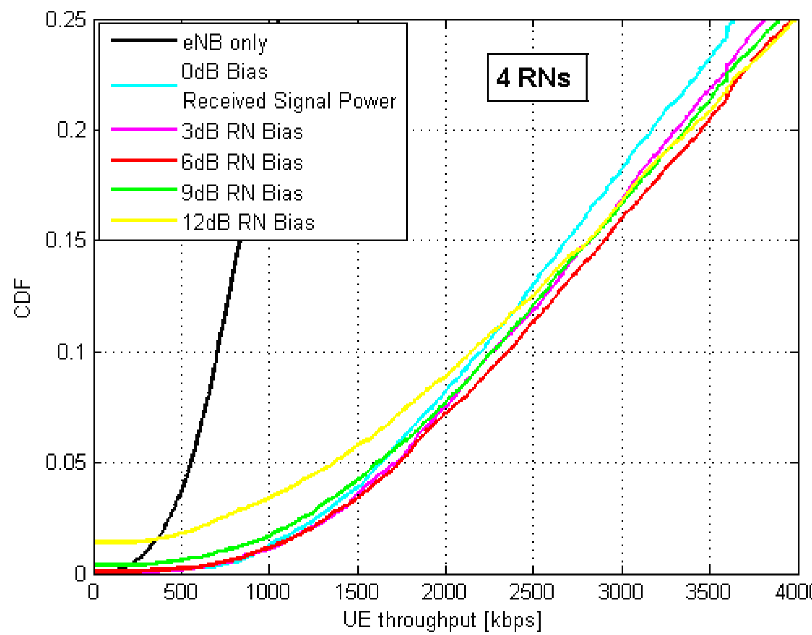
Simulation Results Biasing - ISD 1732m

Moderate gain from 6dB biasing in cell selection

RN bias		3dB	6dB
5%-ile Throughput Gain [%] Reference: No bias in cell selection	4 RNs	5.5	6.5
	10 RNs	8	8.5
50%-ile Throughput Gain [%] Reference: No bias in cell selection	4 RNs	1.1	1.1
	10 RNs	2.5	2.7





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Conclusions

- Relay deployments enhance system performance.
- Power control parameter optimization offers significant improvement in the uplink.
  - Power control in relay deployment is a good means to mitigate interference, and to abide by the dynamic range limitations.
- RN coverage area extension offers further improvement in the downlink.
  - RN cell extension via biasing in cell selection offers significant gains in ISD 500m scenarios.
  - Biasing cell selection in ISD 1732m scenarios results in moderate gains.

Thank you for your attention!

Q&A

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Parameter Optimization in Relay Deployment

Interference Proportions

BACK-UP

- **Interference caused by Cell Center UEs and Cell Edge UEs can be analyzed separately.**

$$\tilde{IoT}_{linear} = \frac{\tilde{I} + N}{N} = \frac{\tilde{I}_{mUEs} + \tilde{I}_{rUEs} + N}{N}$$

$$= \frac{\tilde{I}_{mUEs} + \tilde{I}_{rUEs} + N + N - N}{N}$$

$$= \frac{\tilde{I}_{mUEs} + N}{N} + \frac{\tilde{I}_{rUEs} + N}{N} - 1$$

$\tilde{I}_{mUEs}$ and $\tilde{I}_{rUEs}$ are two independent random variables.

$$\Rightarrow E\left\{\tilde{IoT}\right\} = E\left\{\tilde{IoT}_{mUEs}\right\} + E\left\{\tilde{IoT}_{rUEs}\right\} - 1$$

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