Investigations into Relay Deployments within the LTE-Advanced Framework

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Content

- Introduction
- Goal
- System Parameters
- Considerations on Relay Deployment
  - Different Relay Realizations
  - Relay Site Planning
- Conclusions

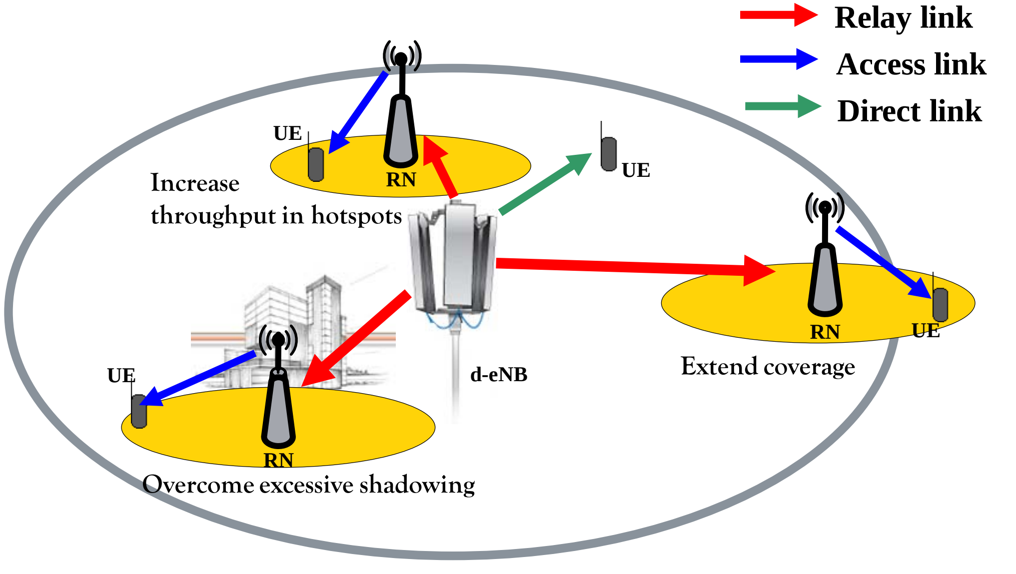
Introduction

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.

Relay Nodes

– Capacity enhancement.
– More homogeneous user experience.
– Cell coverage area extension.
– Low total cost of operation



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Goal

WHAT to deploy?

– Study the performance of AF and DF relay nodes

Limitations due to loop interference (LI) in full-duplex AF relay node deployments

Advantages of concurrent transmissions on the access link in half-duplex DF relay node deployments

WHERE & HOW to deploy?

– Optimize deployment via relay site planning

Considerations on deployment regions: Cell edge, Intermediate region, Cell center

Considerations on deployment strategies: Cell selection, Location selection

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System Parameters

System Parameters	System Layout	19 tri-sectored sites
	Carrier Frequency	2 GHz
	Bandwidth	10 MHz
	Traffic Model	Full Buffer
	Noise PSD	-174 dBm/Hz
	Penetration Loss	20 dB (direct & access links)

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

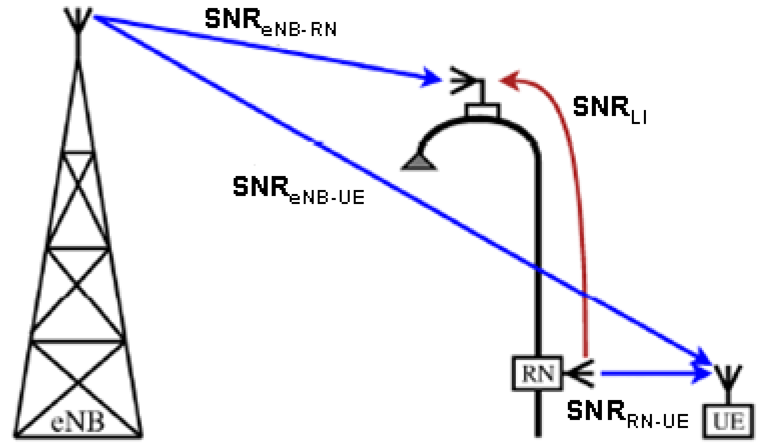
eNB Specific	Antenna height	25 m (above rooftop)
	Antenna configuration	2 Tx, 2 Rx
	Transmit Power	46 dBm
	Antenna gain	14 dBi
	Noise Figure	5 dB
	eNB Antenna Pattern (Horizontal)	$A_H(\theta) = -\min[12\ (\theta/\ \theta_{3dB})^2, A_m]$ $\theta_{3dB} = 70^o$ and $A_m = 25$ dB
	eNB Antenna Pattern (Vertical)	$A_V(\theta) = -\min[12\ (\theta-\theta_{tilt})/\ \theta_{3dB})^2, SLA]$ $\theta_{3dB} = 70^o$ and $SLA = 20$ dB $\theta_{tilt} = 15^o$

UE Specific	Antenna configuration	1 Tx, 2 Rx
	Noise Figure	9 dB
	UE drop	Indoor

Different Relay Realizations

Theoretic Framework
Amplify-and-Forward Relaying

Full-duplex AF Relaying



- Loop interference: leakage of transmit signal to receive antenna
  - SNR_{LI}: Loop interference signal to noise ratio
- Isolation from loop interference
  - Antenna isolation (outdoor-to-indoor arrangement, directive antennas)
- End-to-end SINR
  - Useful Signals on the direct link and access link
  - Relayed noise, loop interference and UE receiver noise

$$SINR_{AF} = \frac{SNR_{eNB-RN}.SNR_{RN-UE} + SNR_{eNB-UE}\left(1 + SNR_{LI} + SNR_{eNB-RN}\right)}{SNR_{eNB-RN} + \left(1 + SNR_{RN-UE}\right)\left(1 + SNR_{LI}\right)}$$

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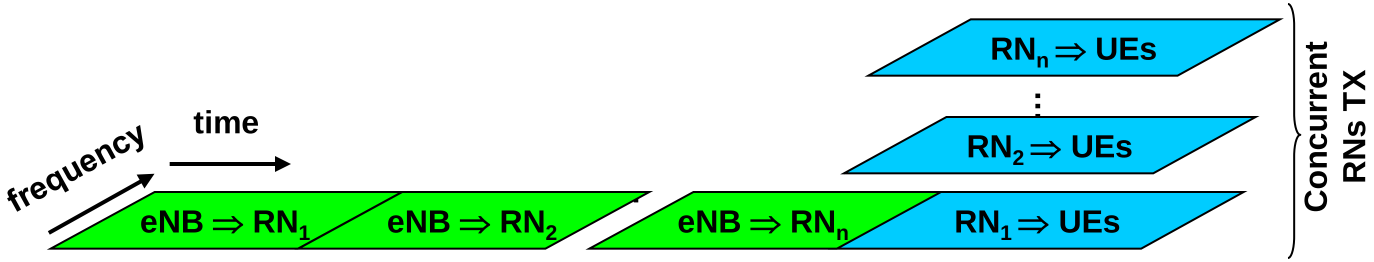
Theoretic Framework
Decode-and-Forward Relaying

Half-duplex DF Relaying

- Possibility of concurrent transmissions on the access link



- Assuming optimum resource partitioning

Single transmission

$$R_{e2e} = \min\left(\frac{T_{eNB-RN}}{T} R_{eNB-RN}, \frac{T_{RN-UE}}{T} R_{RN-UE} \right)$$

$$SE_{DF} = \left(\frac{1}{SE_{eNB-RN}} + \frac{1}{SE_{RN-UE}} \right)^{-1}$$

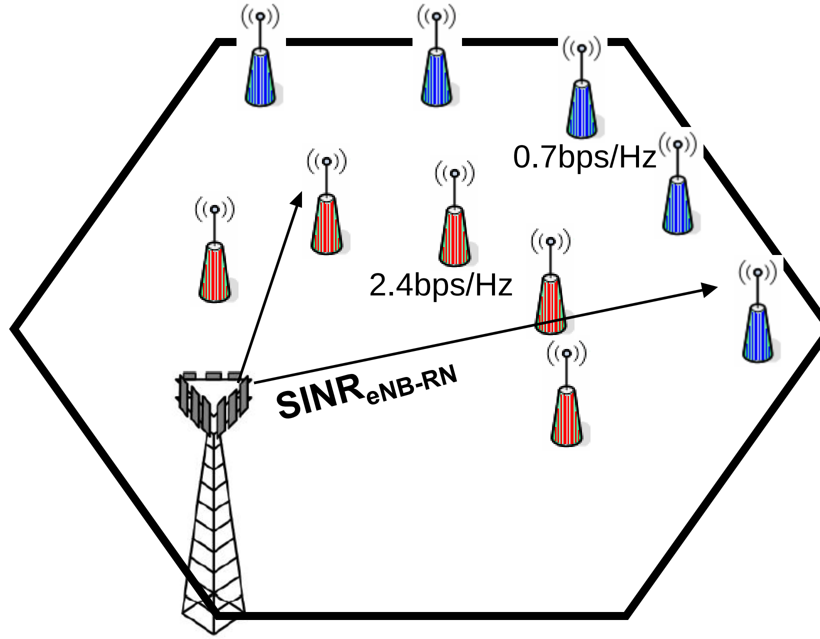
n concurrent transmissions

$$R_{e2e} = \min\left(\frac{T_{eNB-RN}}{T} R_{eNB-RN}, n \bullet \frac{T_{RN-UE}}{T} R_{RN-UE} \right)$$

$$SE_{DF} = \left(\frac{1}{SE_{eNB-RN}} + \frac{1}{n \cdot SE_{RN-UE}} \right)^{-1}$$

Assumptions

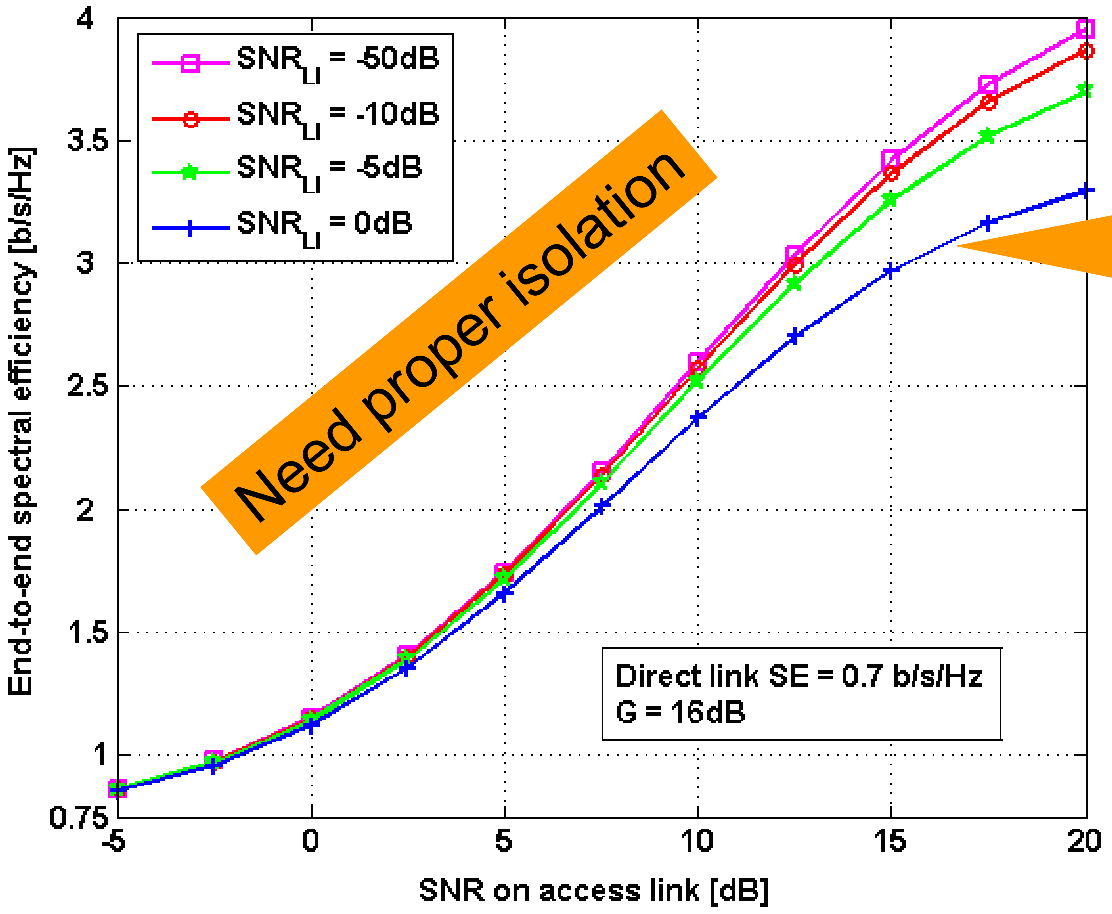
- Single user is distributed in the network with equal probability over cell area.
- Interference is neglected.
- Shadowing and fast fading are not explicitly considered (30dB margin).
- Cell edge UE spectral efficiency on the direct link is assumed to be 0.7b/s/Hz.
- Average spectral efficiency for cell middle UEs is assumed to be 2.4b/s/Hz.
- The SINR of eNB-RN link is assumed to be G times that of the eNB-UE link.



$$SINR_{eNB-RN} = G \cdot SINR_{eNB-UE}$$

RN deployment, whether on cell edge or cell middle, is defined by the spectral efficiency on the direct link, which in turn defines $SINR_{eNB\text{-}UE}$.

Impact of Loop Interference (LI) for AF relays



Loop interference could have significant effect on the spectral efficiency.

Cell edge RN deployments

$$SINR_{eNB-RN} = G \cdot SINR_{eNB-UE}$$

$$G_{[dB]} = 16dB$$

Comparison AF RN vs. Single TX DF RN

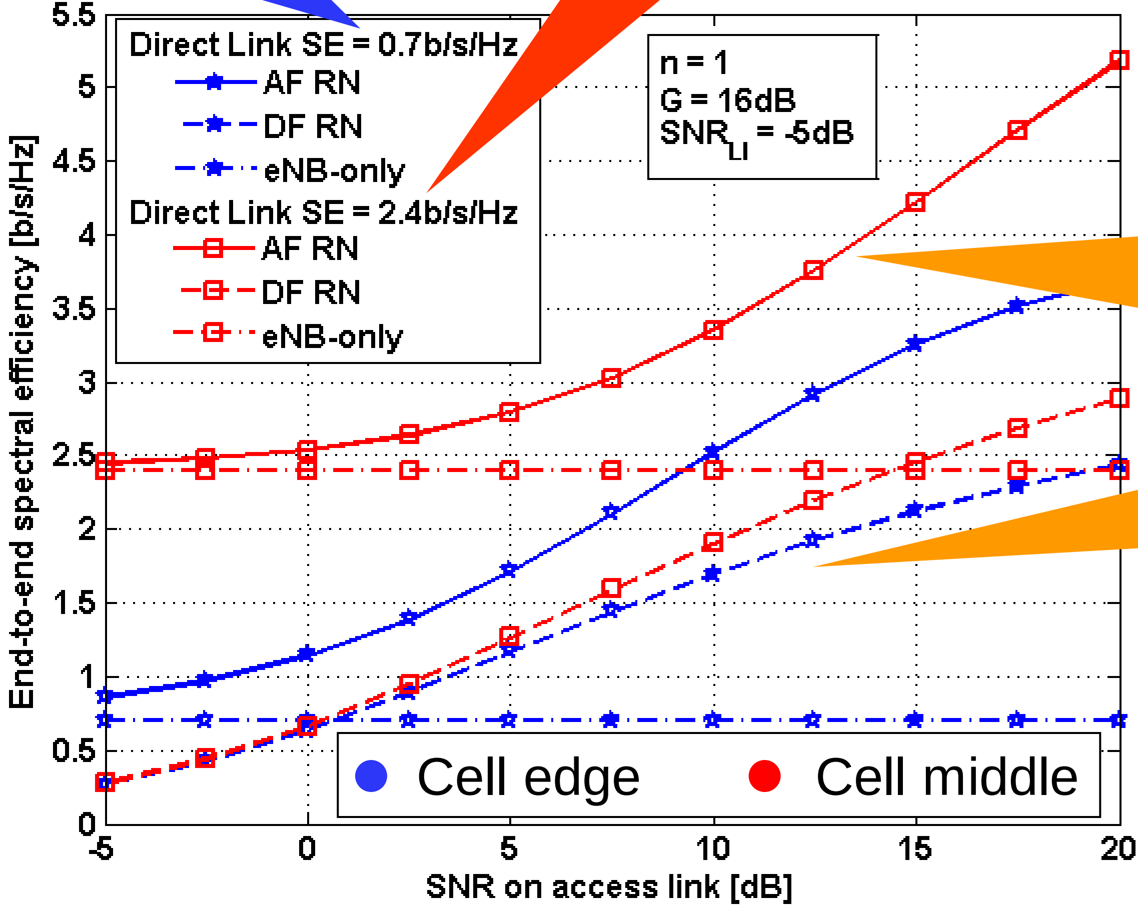
AF RN outperforms *SINGLE* TX DF RN

Single TX DF RN

$$SE_{DF} = \left(\frac{1}{SE_1} + \frac{1}{SE_2} \right)^{-1}$$

RN deployment at the cell edge

RN deployment at the cell middle



AF RN outperforms eNB-only both in the middle of the cell and on cell edge.

DF RN outperforms eNB-only for cell-edge deployments only.

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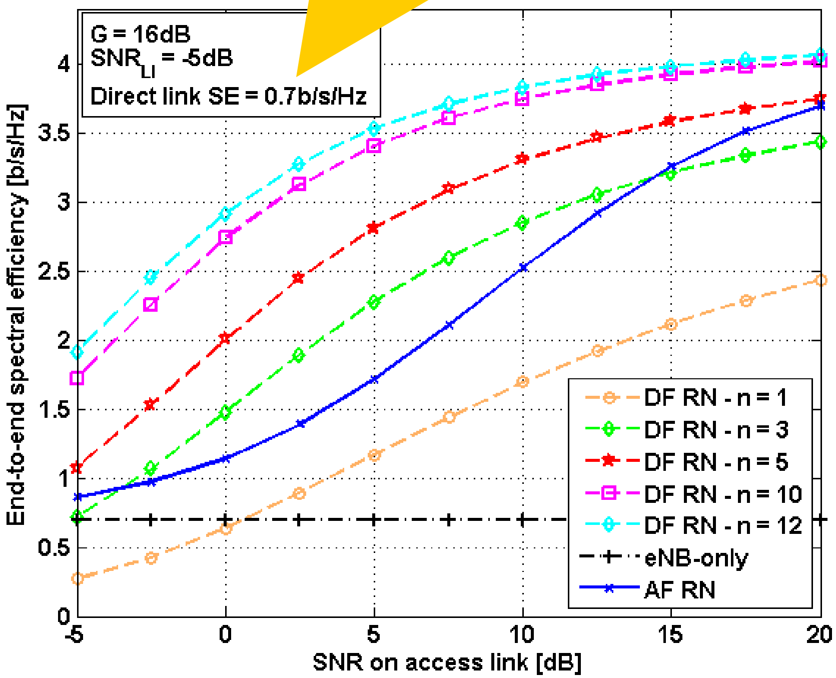
Concurrent TX DF RN

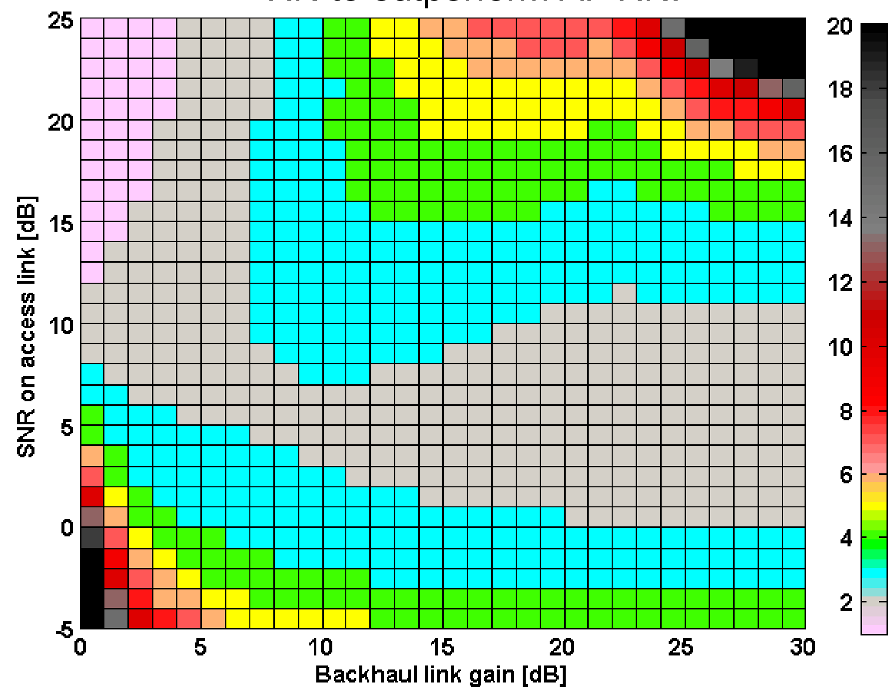
Significant gain from concurrent transmissions on the access link

- Interference is neglected

RN deployment at the cell edge



Number n of concurrent transmissions needed for DF RN to outperform AF RN.

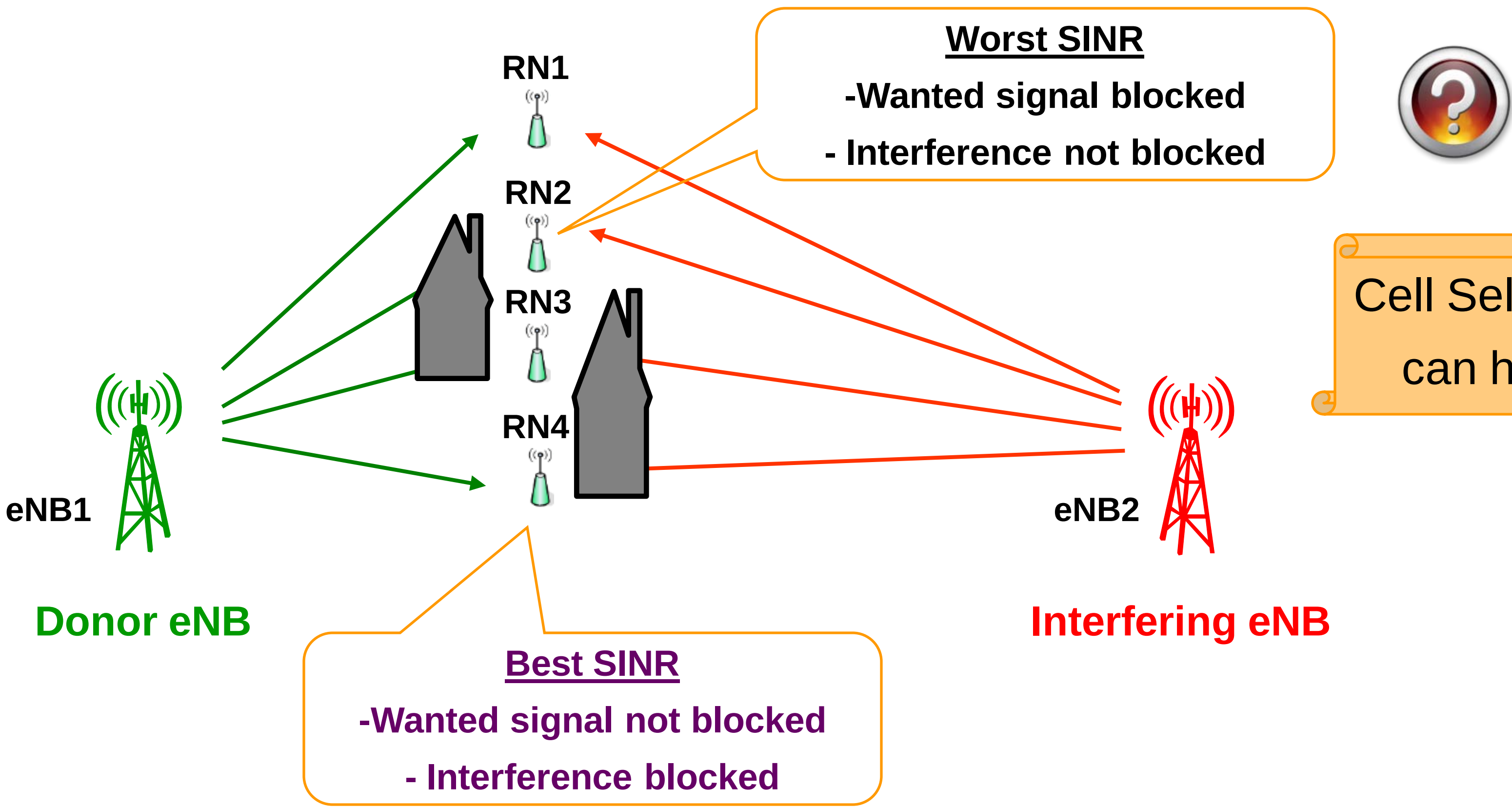


Varying the direct link SE (relay deployment at different distances from the eNB)

Overall, a small number of concurrent DF transmissions is required to outperform AF RN deployments.

Relay Site Planning

The Basic Principle



Cell Selection can help.

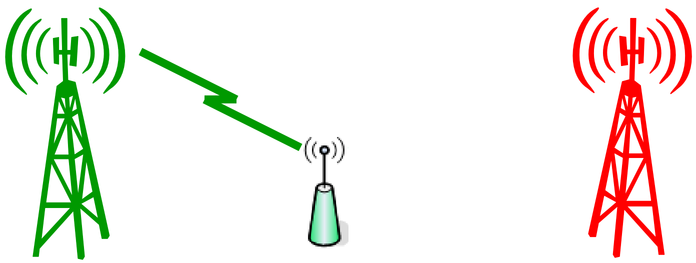
Location Selection can be beneficial.

Approaches

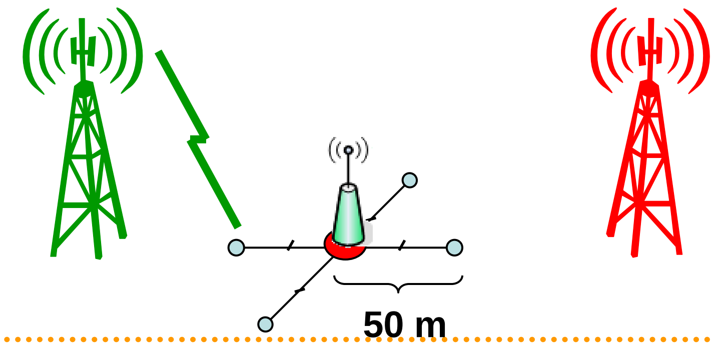
A: Cell Selection

B: Location Selection

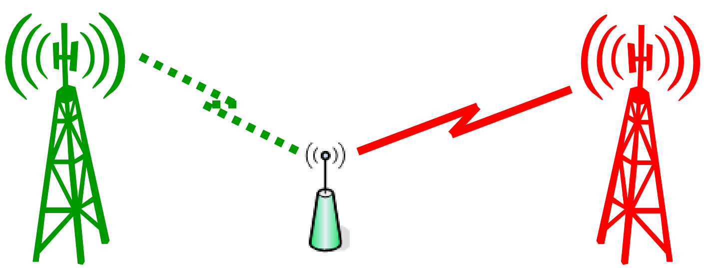
(A1,B1): Reference
- One possible location
- Relay connects to the closest eNB



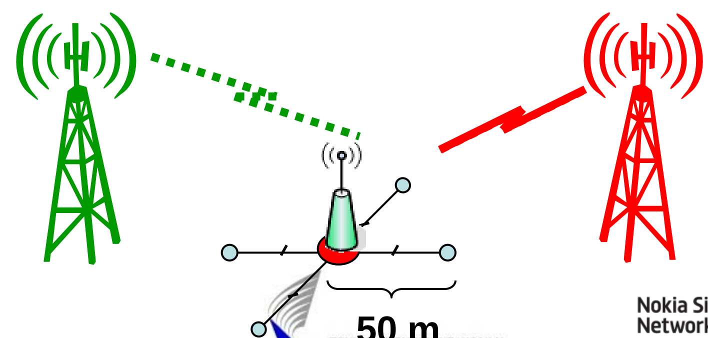
(A1,B2):
- ***M*** **possible locations**
- **Relay connects to the closest eNB**



(A2,B1):
- **One possible location**
- **Relay connects to the best eNB**



(A2,B2):
- ***M*** **possible locations**
- **Relay connects to the best eNB**



Selection Criteria

- SNR and SINR based criteria

$$SNR_{m,k} = \frac{P_k}{P_N L_{m,k}}$$

$$SINR_{m,k} = \frac{P_k / L_{m,k}}{P_N + \sum_{k' \neq k} P_{k'} / L_{m,k'}} = \frac{SNR_{m,k}}{1 + \sum_{k' \neq k} SNR_{m,k'}}$$

P: Signal Power

P_N: Noise Power

L: Path-loss including shadowing

m: *m*th relay candidate location from the set of [1,*M*]

k: *k*th eNB

max { SNR or SINR }

(A1,B1): *m*=1 & *k*=1 "Reference"

(A2,B1): *m*=1 & maximize over *k*

(A1,B2): maximize over *m* & *k*=1

(A2,B2): maximize over *m* & *k*

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Assumptions

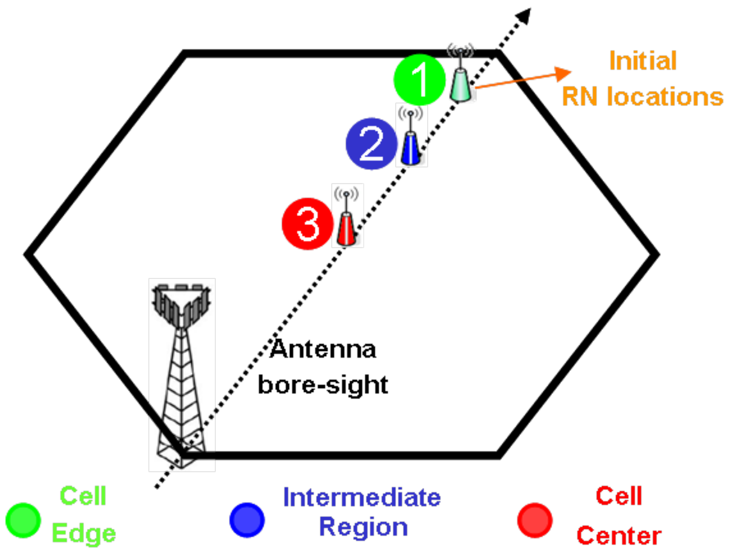
- Both 3GPP Case 1 (ISD 500 m) and 3GPP Case 3 (ISD 1732 m) are analyzed.
- Relays are deployed outside, hence no penetration loss.
- Shadowing correlation between candidate relay locations decreases with an exponential rate. Normalized auto correlation function is given as:

$$R(\Delta x) = e^{-\frac{|\Delta x|}{d_{cor}}}$$

$|\Delta x|$: distance between candidate locations

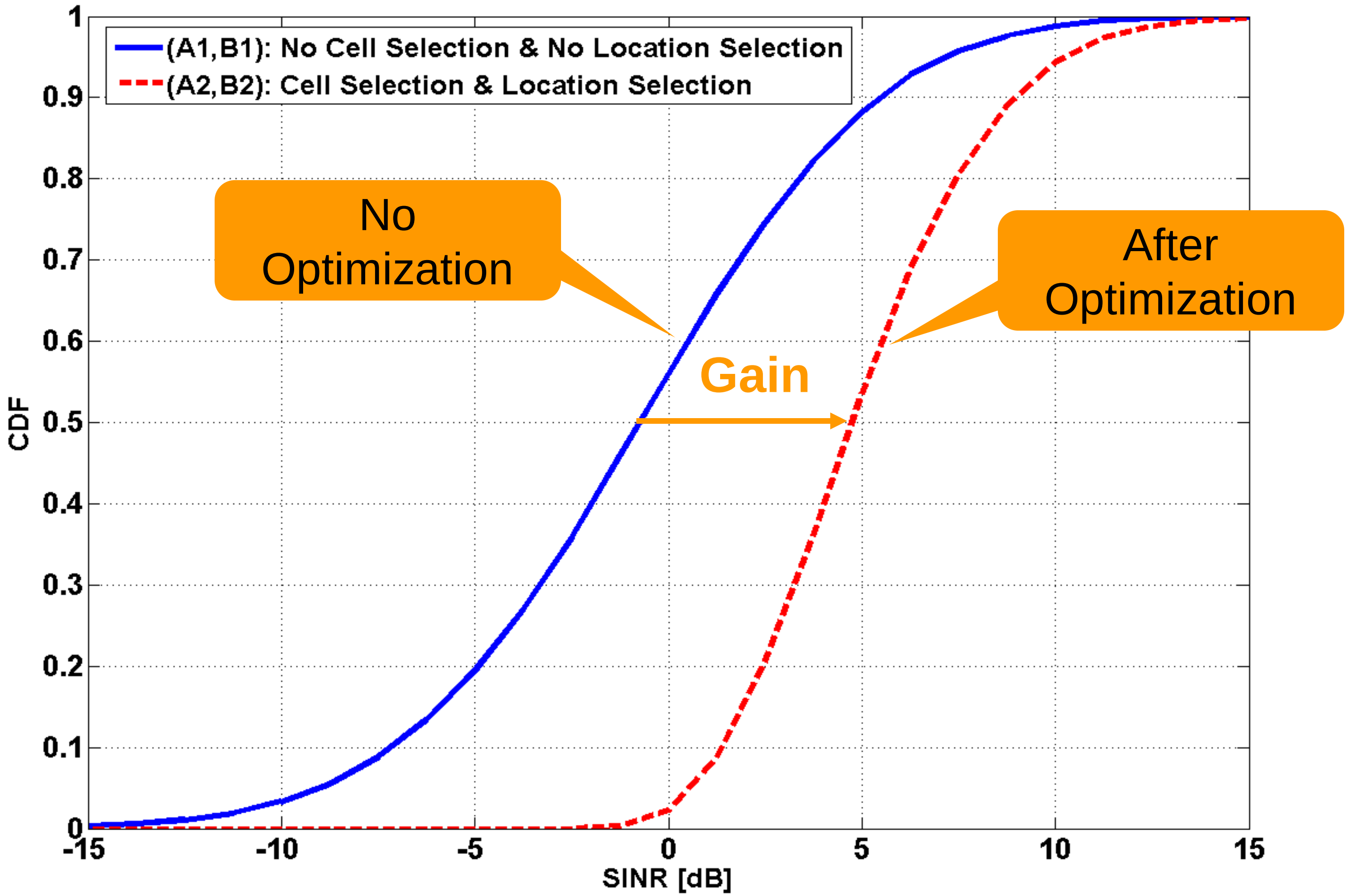
d_{cor} : de-correlation distance (50 m)

- Three relay deployment areas are considered:



Simulation Results

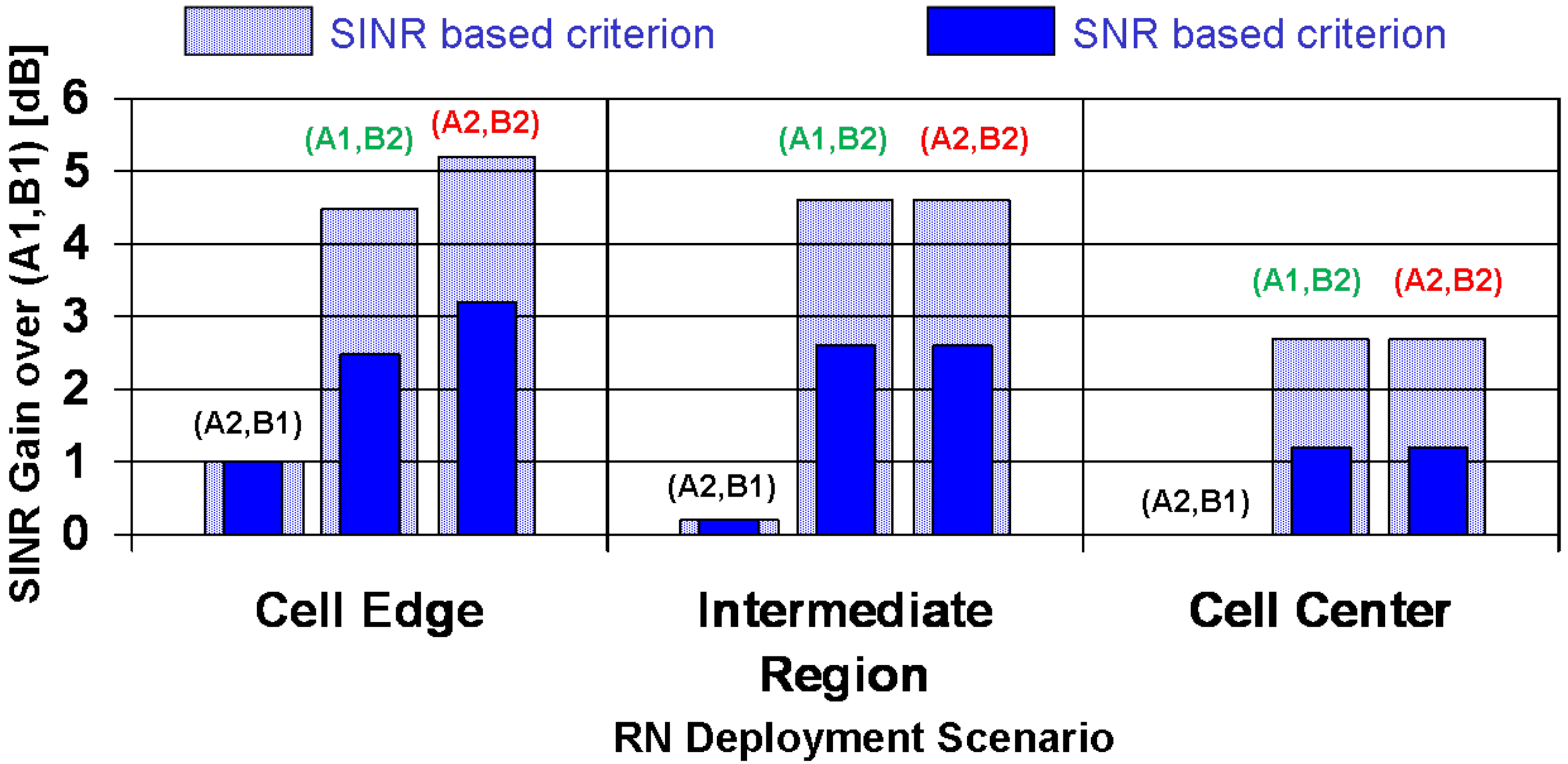
- Metric: SINR Gain relative to reference (A1,B1)



Simulation Results

(A2,B1): Cell Selection & No Location Selection
(A1,B2): No Cell Selection & Location Selection
(A2,B2): Cell Selection & Location Selection

- Case 1 (ISD 500 m)

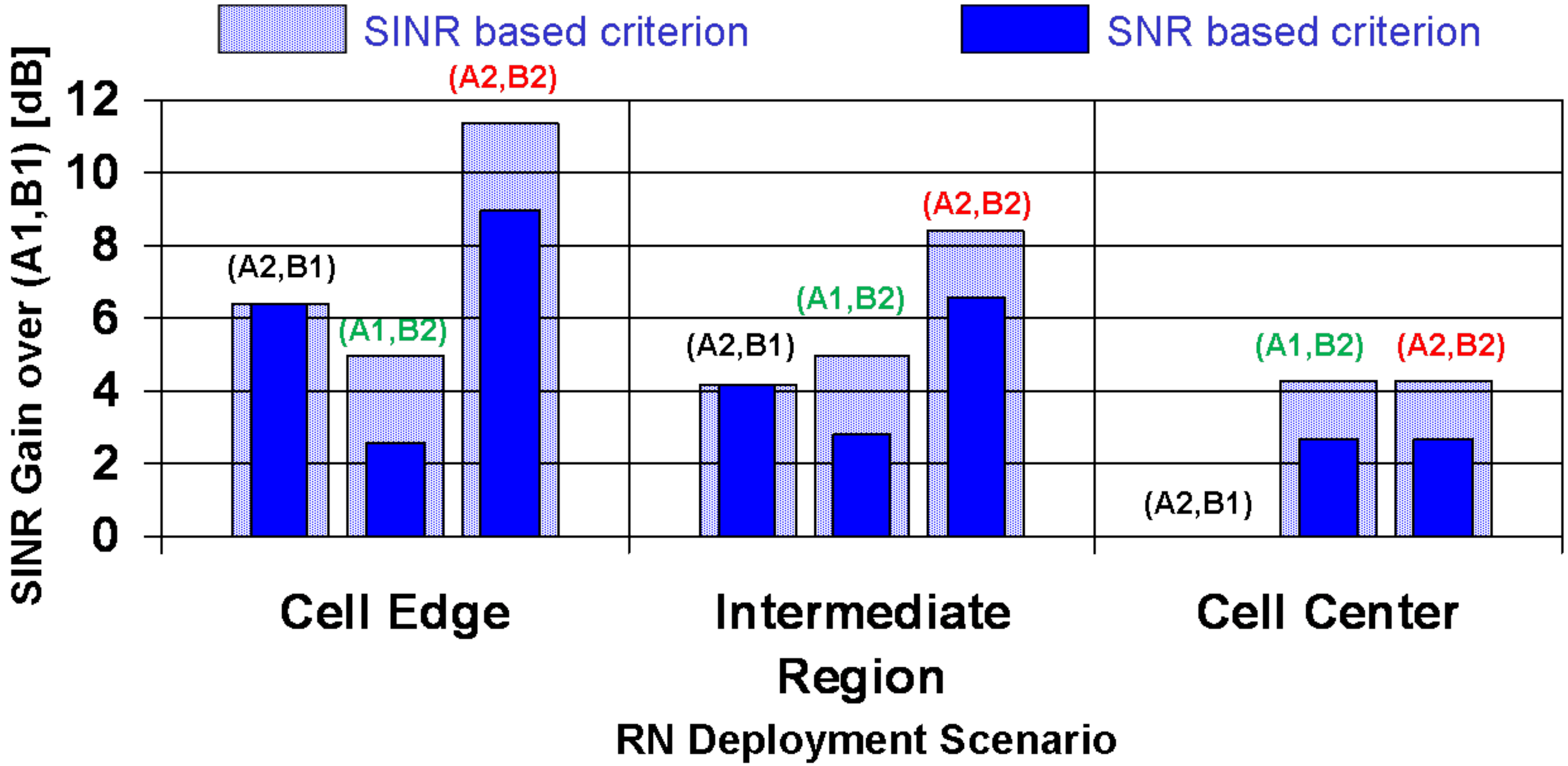


- (A2,B2) performs best.
- The highest gain is achieved in case of cell edge deployment.
- SINR based criterion yields higher gains than the SNR based criterion.

Simulation Results

- Case 3 (ISD 1732 m)

(A2,B1): Cell Selection & No Location Selection
(A1,B2): No Cell Selection & Location Selection
(A2,B2): Cell Selection & Location Selection



- (A2,B2) performs best.
- The highest gain is achieved in case of cell edge deployment.
- SINR based criterion yields better gains than the SNR based criterion.
- The performance difference of SNR & SINR based criteria is smaller compared to Case 1 due to lower interference.

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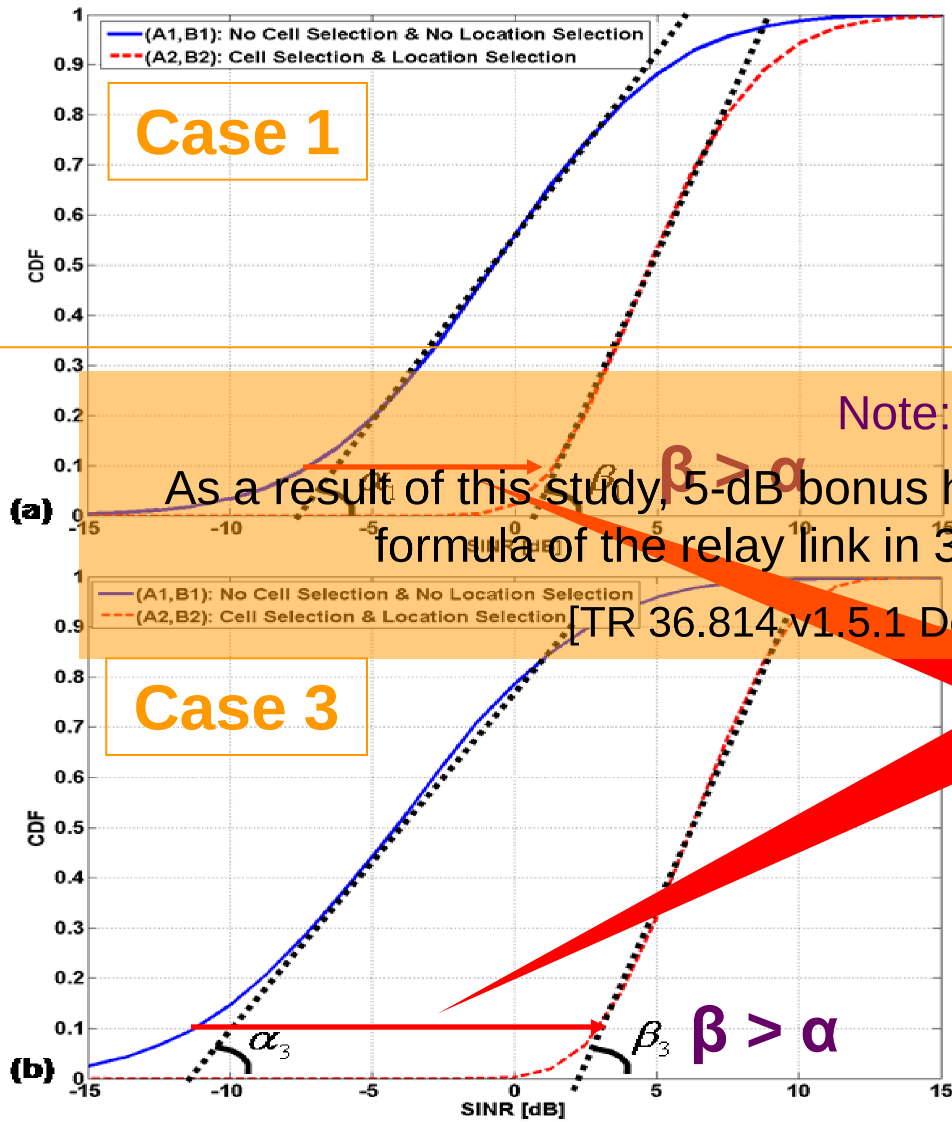
Simulation Results

Decrease in shadowing standard deviation



2 dB reduction

Note:

As a result of this study, 5-dB bonus has been added to the path loss formula of the relay link in 3GPP standardization.

[TR 36.814 v1.5.1 December 2009]

Significant SINR gains in low percentile

2.9 dB reduction

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Conclusions

- Decode-and-forward RNs outperform Amplify-and-Forward RNs
  - High loop interference could considerably decrease the performance of AF relaying.
  - AF RN outperforms Single Tx DF RN
  - AF RN deployments outperforms eNB-only both at cell middle and edge, whereas Single Tx DF RNs perform better only for cell edge deployments.
  - A small number of concurrent DF transmissions is required to outperform AF RN deployments.

- Significant SINR gains on the relay link can be achieved via relay site planning.
  - Relay Nodes will be deployed reasonably by operators. Hence, favorable relay locations will be selected rather than random deployments.
  - The standard deviation of the shadowing after the relay site planning can be reduced effectively which also boosts the SINR performance at low percentiles.

Thank you for your attention!

Q&A