Nokia Research in Spectrum Sharing:

With focus on simulation Studies of LTE/Radar Coexistence Analysis

ISART Conference

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3550-3650MHz Protection Zones (Federal)

Figure 1. Shipborne Radar Exclusion Zone Lower 48 States
(Yellow Line – Fast Track Exclusion Zone and Blue Line – Revised Exclusion Zone)

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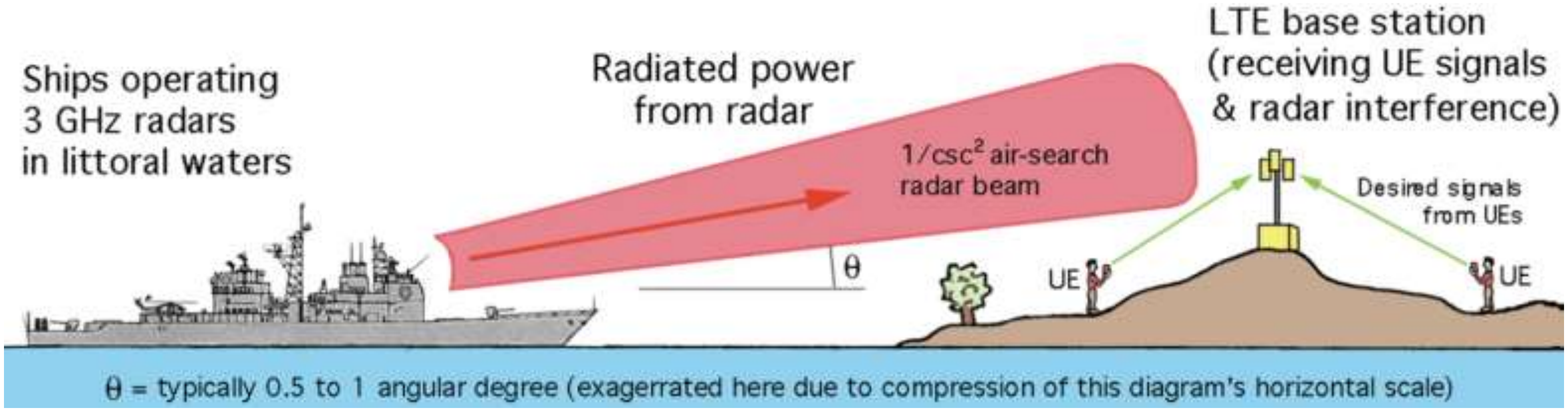
Interference Scenario

- 1- 10 GW peak effective isotropic power (EIRP) via tube type transmitters (TX)S.
- 10 -100 MW EIRP via solid state TXs with longer PWs.



Radar Simulation

• Radar parameters in the table are adopted from NTIA's Fast Track Report[1].

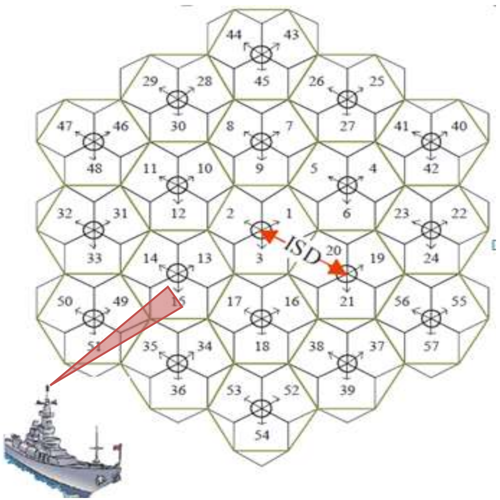
•Radar radiates on LTE at 50, 100, 150, and 200 km away.

• 83 dBm without antenna, and 83 + 45 = 128 dBm EIRP.

•360 deg horizontal scan.

[1]An Assessment of the Near-Term Viability of Accommodating Wireless Broadband Systems in the 1675-1710 MHz, 1755-1780 MHz, 3500-3650 MHz, 4200-4220 MHz and 4380-4400 MHz Bands" NTIA, U.S. Dept. of Commerce, Nov. 2010

Parameters	Value
Operating Frequency	3.5 GHz*
Peak Power	83 dBm
Antenna Gain	45 dBi
Antenna Pattern	Cosine
Antenna Height	50 m
Insertion Loss	2 dB
Pulse Repetition Interval	0.5 ms
Pulse-Width	78 µs
Rotation Speed	30 rpm*
Azimuth Beam-Width	0.81 deg*
Elevation Beam-Width	0.81 deg*
Azimuth Scan	360 deg
Distance to LTE	50, 100, 150, 200 km



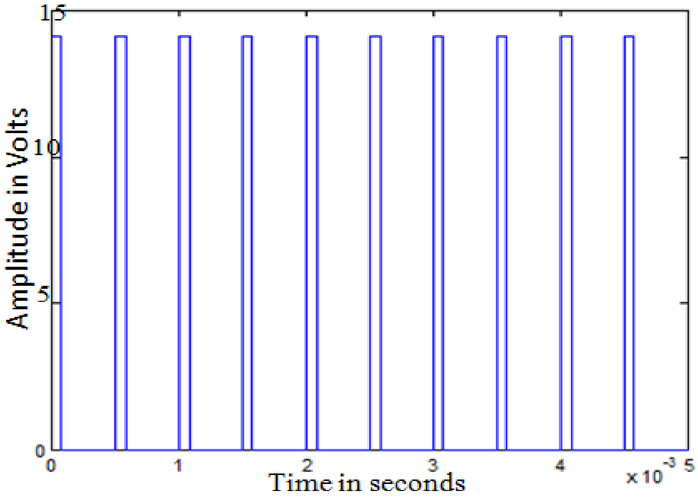
Radar Simulation

- Radar circulates at 30 rotation per minute (rpm).
  - Horizontal scan time is2 seconds
  - 360 deg / (0.81 deg beamwidth) = 445 beam positions
  - Antenna beam dwell time is therefore 2 sec /445 = 4.5 ms.
  - Pulse Rep. Interval (PRI) = 0.5 ms gives 9 pulses during the dwell time.
  - So each BS under radiation is hit by 9 pulses
  - 4000 (2 secs x 1/0.5 ms/pulse) pulses (each 83 + 45 dBm) are radiated in a rotation of the antenna.

•At distance *R* radar radiation diameter becomes:

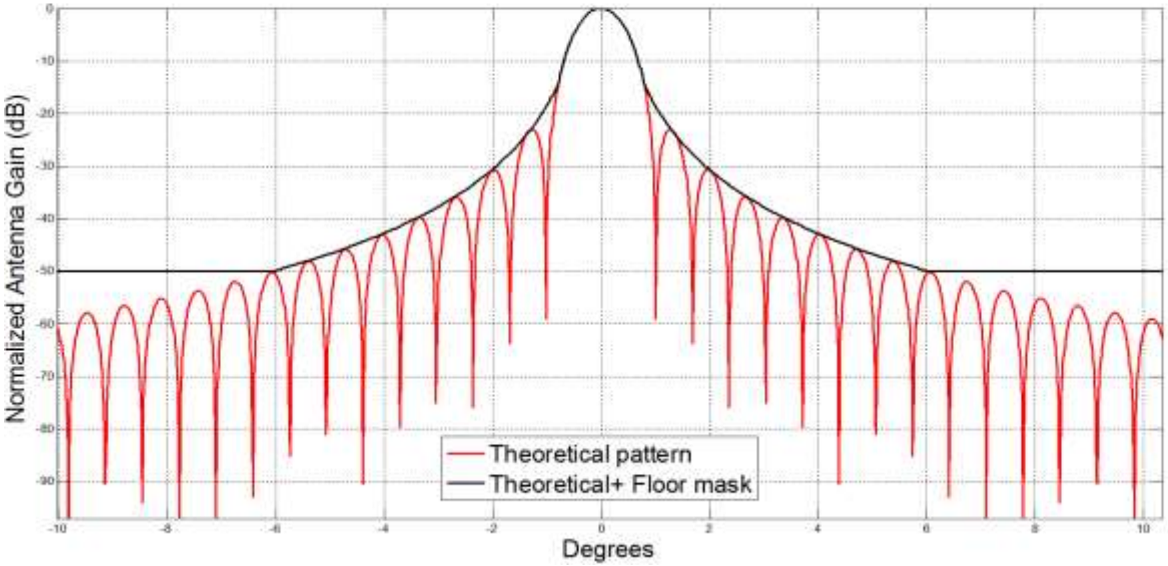
$$d = 2R\tan(\theta_a) \approx 0.03R$$

- 1.5, 3.0, 4.5, 6.0 km radiation diameter when radar is 50, 100, 150, and 200 km away.



Radar Simulation

- Antenna back-lobe -50 dB vs. the main lobe.
- Based on ITU-R M.1851 (mathematical model for radar antenna used in NTIA Fast Track Report).



$$G(\theta) = \begin{cases} \dfrac{\pi}{2}\left(\dfrac{\cos\left(\dfrac{68.8\pi\sin(\theta)}{\theta_{3dB}}\right)}{\left(\dfrac{\pi}{2}\right)^2 - \left(\dfrac{68.8\pi\sin(\theta)}{\theta_{3dB}}\right)^2}\right) \\ -17.51\log_e\left(\dfrac{2.33|\theta|}{\theta_{3dB}}\right) \\ -50\,dB \end{cases}$$

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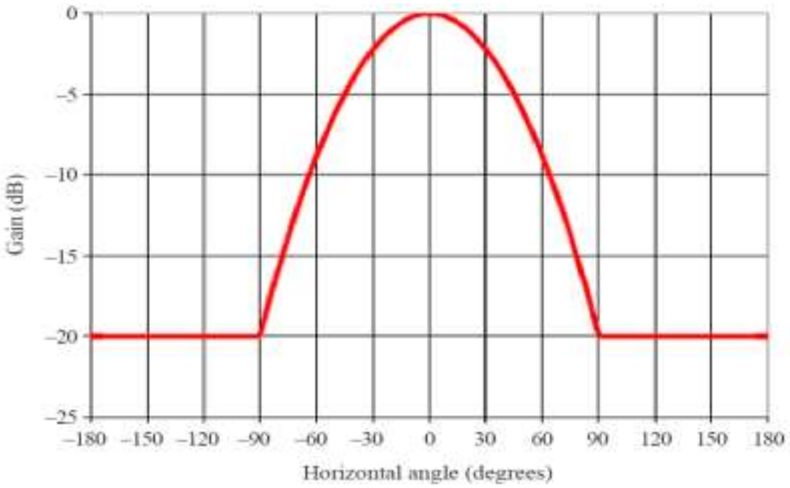
LTE Simulation (Macros, Outdoor Small Cells)

•Antenna Pattern for Macro LTE BS

$$G_i(\theta_i) = -\min\{12(\frac{\theta_i - \theta_{i,t}}{\theta_{3dB}})^2, A_m\}, i \in \{A, E\}$$

$$G = -\min\{-(G_A(\theta_A) + G_E(\theta_E), A_m\}$$



Parameters	Value
Operating Frequency	3.5 GHz
Layout	Hexagonal macro cell grid, clustered small cells
Mode	TDD
Macro/Small Cells BS TX Power	46/30 dBm
UE Transmit (TX) Power	23 dBm
Macro-cell sites/cells	7/21 (3 cells per site)
Small cells	84 (4 per macro cell)
Indoor UE ratio for Macro / Small cells	80% / 20%
Bandwidth for Macro / Small cells	20 MHz
BS Antenna Gain for Macro / Small cells	17/ 5 dBi
UE Antenna Gain	0 dBi
Macro Inter-site Distance (ISD)	500 m
Minimum UE-BS Distance for Macro / Small cells	25 / 5 m
BS Antenna Downtilt for Macro	12 deg
BS Antenna for Small Cells	Omni-directional
BS Antenna Height	25 (macro), 10 (outdoor small cells)
UE Antenna Height	1.5m
UE Distribution for Macro / Small cells	Uniform/Clustered
UE Mobility	3 km/h, uniform direction
BS/UE Noise Figure (NF)	5/9 dB
Thermal Noise	-174 dBm/Hz
Service Profile	Full buffer best effort
UEs per Cell for Macro / Small cells	10 / 30
Channel Model for Macro / Small cells	UMa / UMi [1]

[1]3GPP TR 36.814 V9.0.0 (2010-03), "Further advancements for E-UTRA physical layer aspects", Release 9.

UMa = Urban Macro
UMi = Urban Micro

LTE Simulation (Indoor Small Cells)

Parameters	Value
Operating Frequency	3.5 GHz
Layout	Indoor hall
Mode	TDD
BS TX Power	30 dBm
UE Transmit (TX) Power	23 dBm
Indoor Small cells	2
Indoor UE	100%
Bandwidth	20 MHz
BS Antenna Gain	5 dBi
UE Antenna Gain	0 dBi
BS Antenna	Omni-directional
BS Antenna Height	6 m
UE Antenna Height	1.5m
UE Distribution	Uniform
UE Mobility	3 km/h, uniform direction
BS/UE Noise Figure (NF)	5/9 dB
Thermal Noise	-174 dBm/Hz
Service Profile	Full buffer best effort
UEs	20 (10 per indoor small cell)
Channel Model for Small cells	InH[1]

InH = Indoor Hot Spot

[1]3GPP TR 36.814 V9.0.0 (2010-03), “Further advancements for E-UTRA physical layer aspects”, Release 9.

LTE System Simulation Model

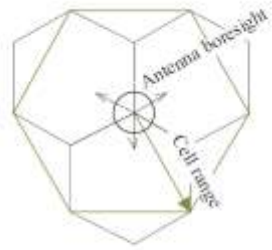
- 3GPP-compliant system-level simulator.
- 3GPP-defined macro, small-cell and indoor scenarios.
- Utilizes proportional-fair scheduler in both time and frequency domains.
- Detailed UL air interface modeling, UL MIMO, and receiver diversity.
- Non-ideal link adaptation with Hybrid ARQ and Exponential Effective SINR Mapping (EESM) link-to-system mapping.

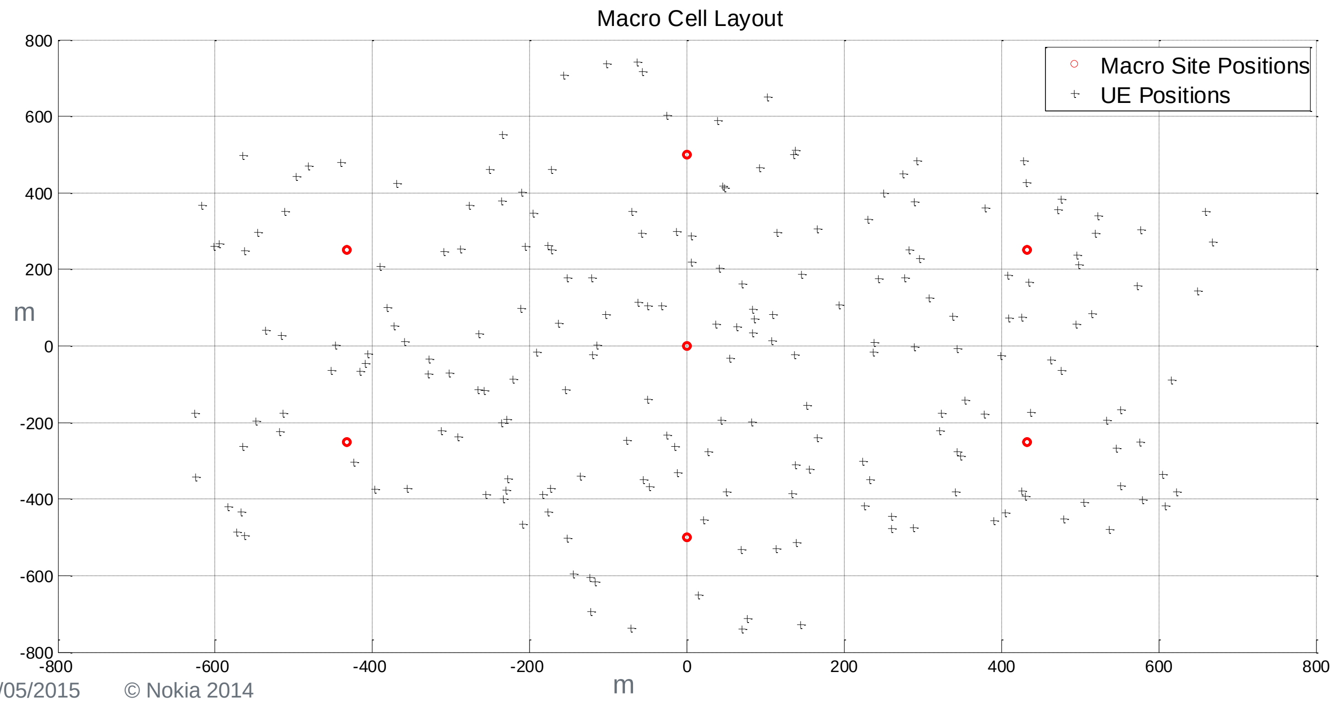
LTE Model Enhancements

- Modeling RF receiver saturation threshold
- More precisely modeling Turbo decoder saturation
- Updated SC-OFDMA SINR calculation with radar interference present
- Explicitly using pilot symbols for Base Stations interference measurements

Macro Cells Layout

- Macro cell layout for 7 sites.
- 500 m ISD.





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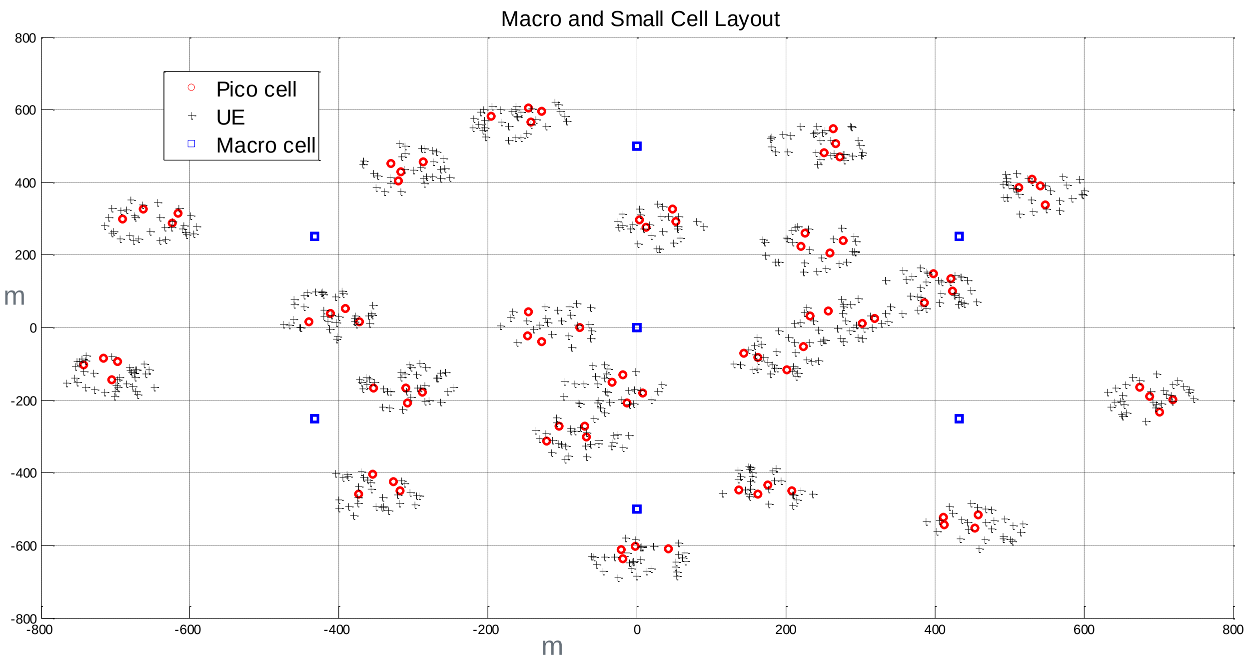
Outdoor Small Cells Layout

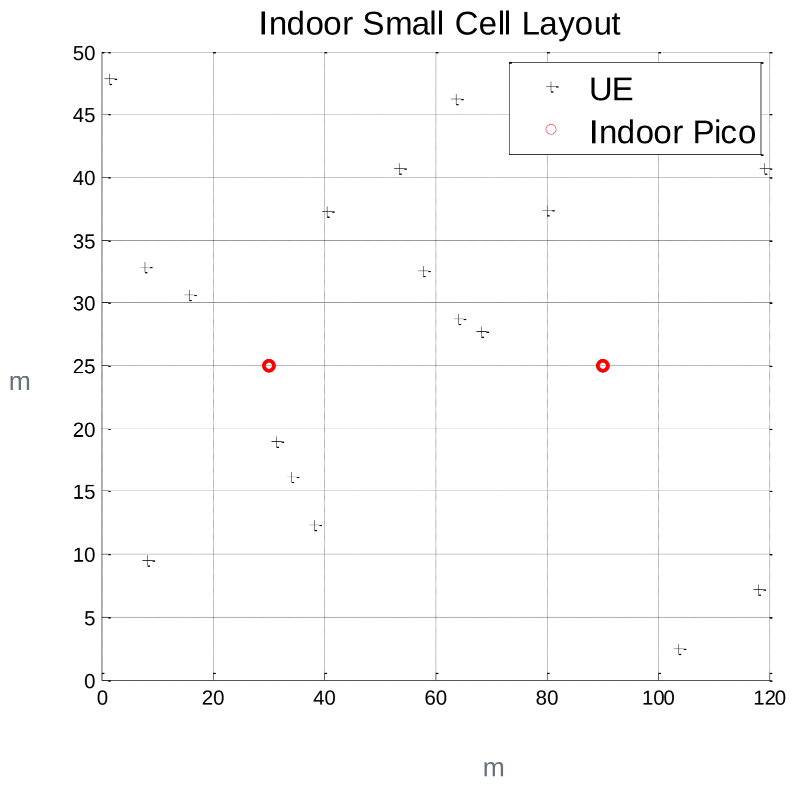


Indoor Small Cells Layout

- For an UE at a distance R (km) from the LTE BS:
  - PL_{LoS} = 89.5 +16.9 log (R)
  - PL_{NLoS} = 147.4+43.3log(R)

- The LoS probability is:

$$\begin{cases} 1 & R \leq 0.018 \\ \exp(-(R-0.018)/0.027), & 0.018 < R < 0.037 \\ 0.5 & R \geq 0.037 \end{cases}$$



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Propagation Models (radar-LTE path)

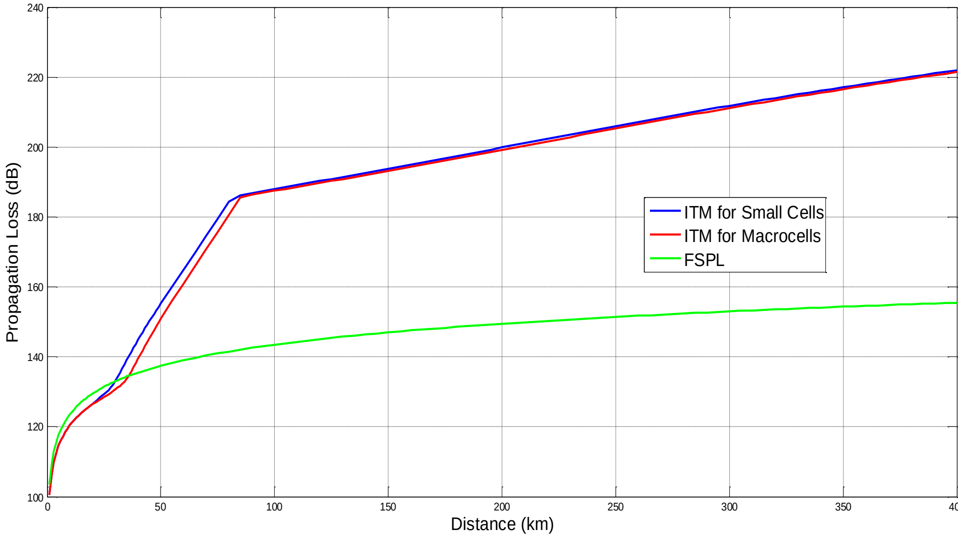
- In LoS, FSPL represents the loss radar signal undergoes.

$$L_{dB,\,FSPL}(r) = 20\log(f) + 20\log(r) + 32.45,\, r < r_{LoS}$$

$$r_{LoS} = 4.1(\sqrt{h_{radar}} + \sqrt{h_{LTE}})$$

- In NLoS region, ITM model represents the loss.

Parameters	Value
Operation Mode	Area Prediction Mode
Small, Macro cells LTE/Radar Antenna Height	10, 25/50 m
Dielectric Constant	15
Conductivity	0.005 S/m
Refractivity	301 N-units
Climate	Continental Temperate
Variability Mode	Single Message
Surface Refractivity	15
Sitting Criteria	Random



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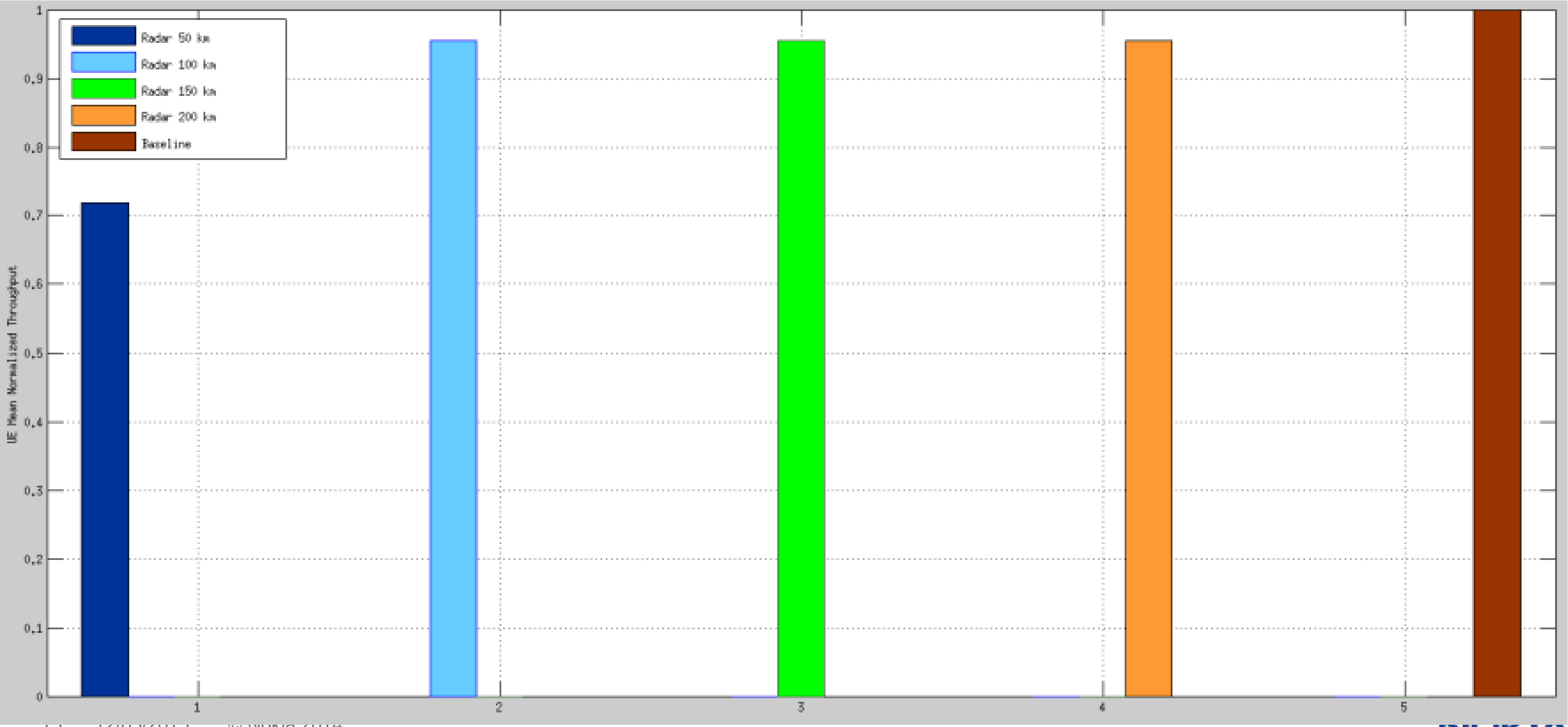
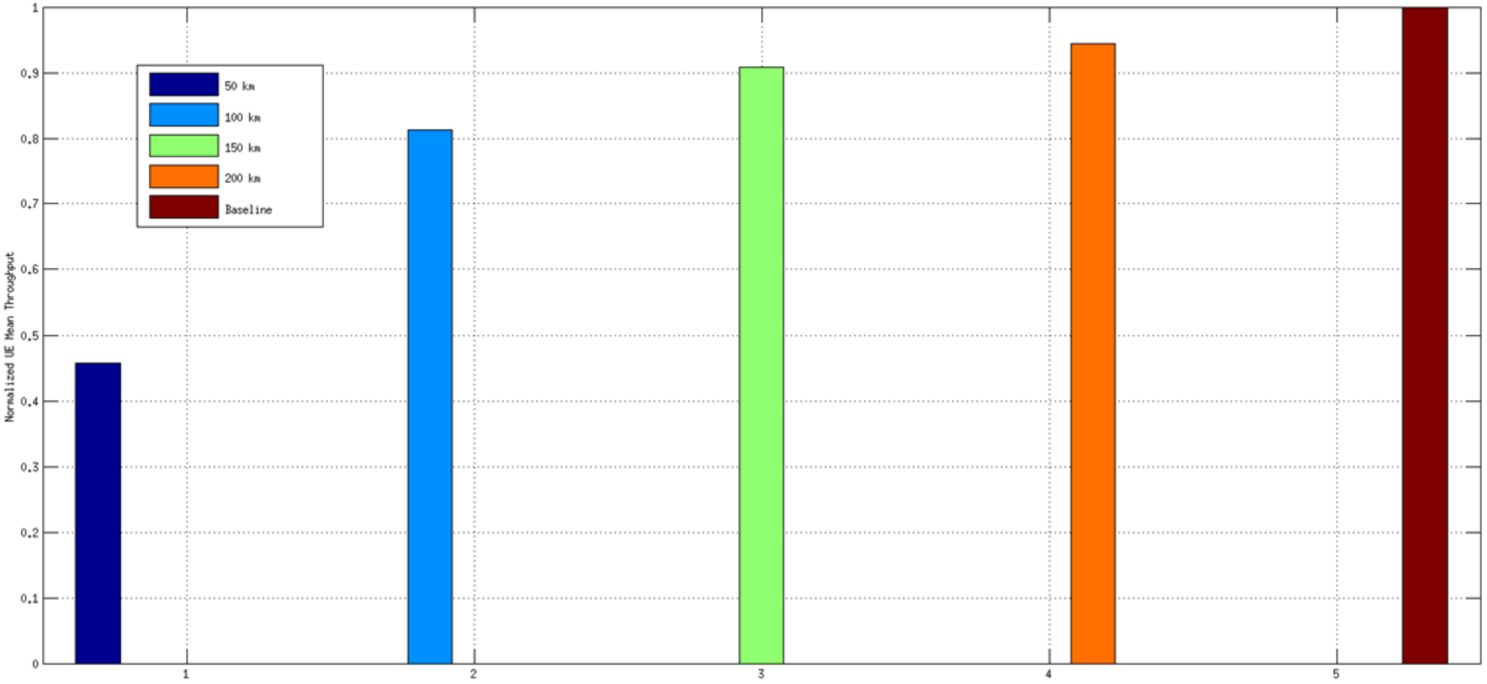
Simulation Results (Macro Cells-UMa)

• Normalized Throughput.



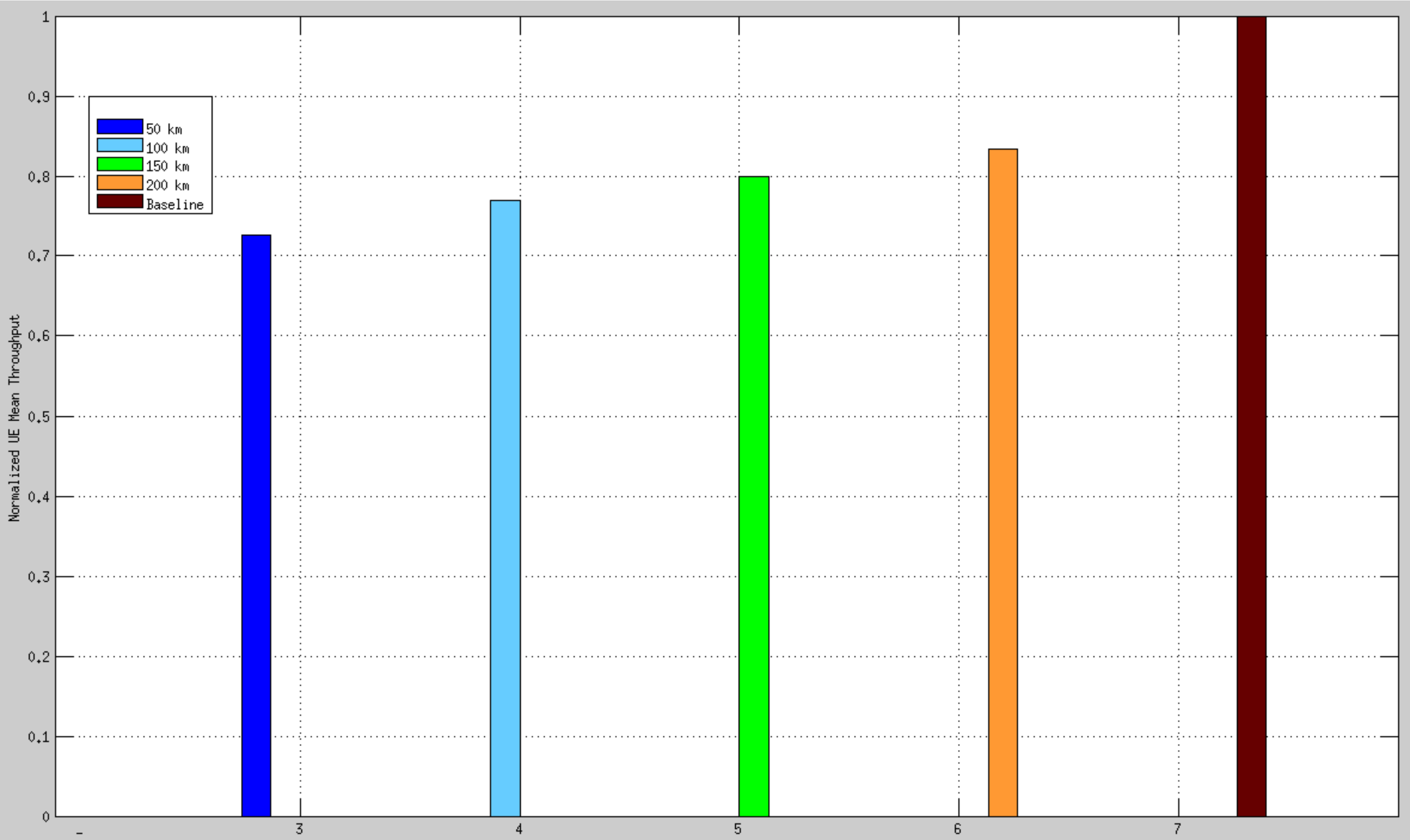
Simulation Results (Outdoor Small Cells-UMi)

•Normalized Throughput.



Simulation Results (Indoor Small Cells-InH)

- Normalized Throughput.



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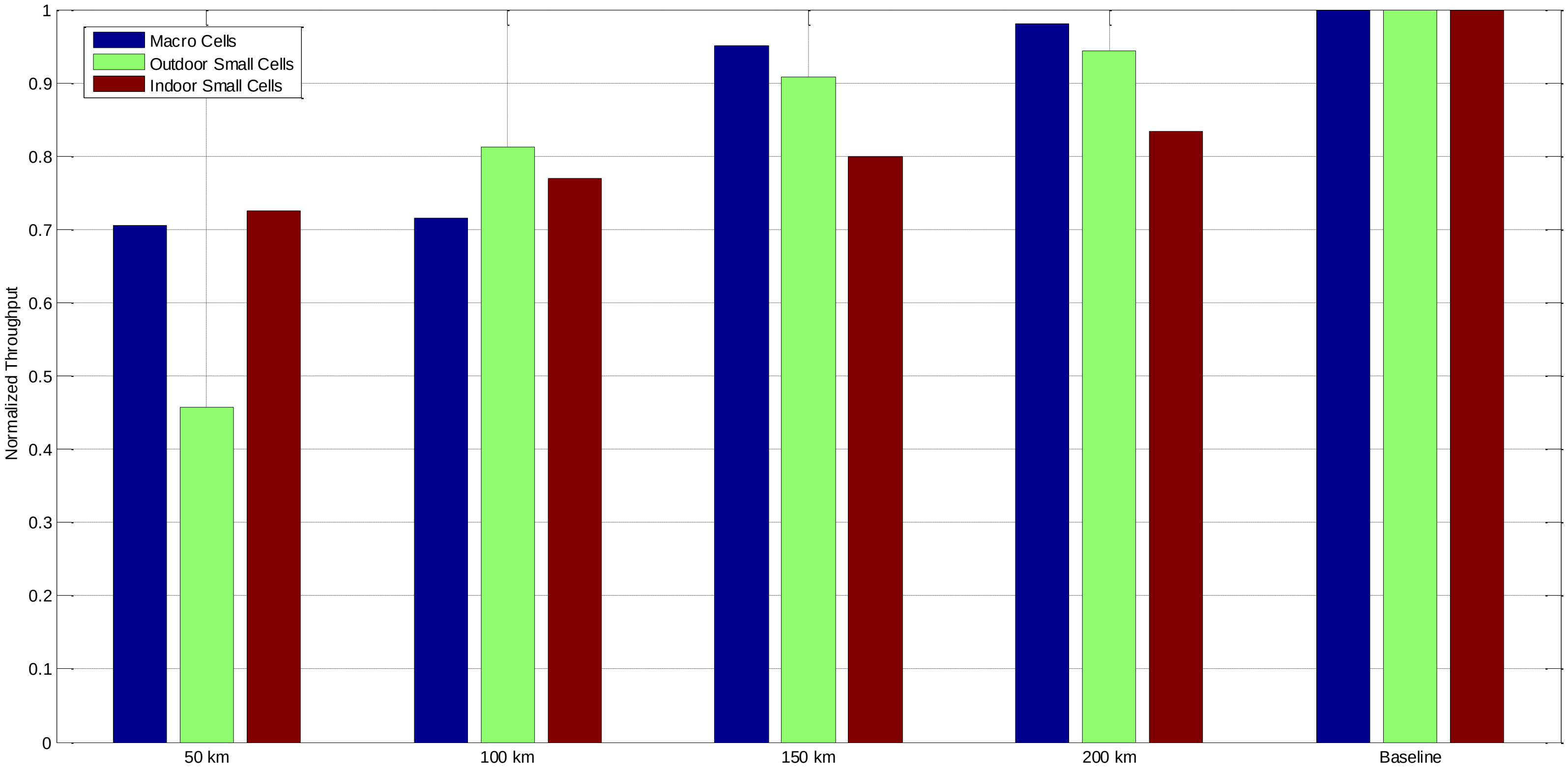
Simulation Results (Comparison of indoor/outdoor/macros)



Interference from LTE into Radar Example

- Interference due to a large number of outdoor small cells
  - 399 sectors dropped in an area (500 m ISD)
  - Each sector contains two clusters of 4 small cells
  - Total number of small cells > 3000
  - Assume ALL small cells are loaded on the DL
  - Aggregate interference at the radar site is calculated as a function of the radar beam position

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Interference from LTE into Radar Example

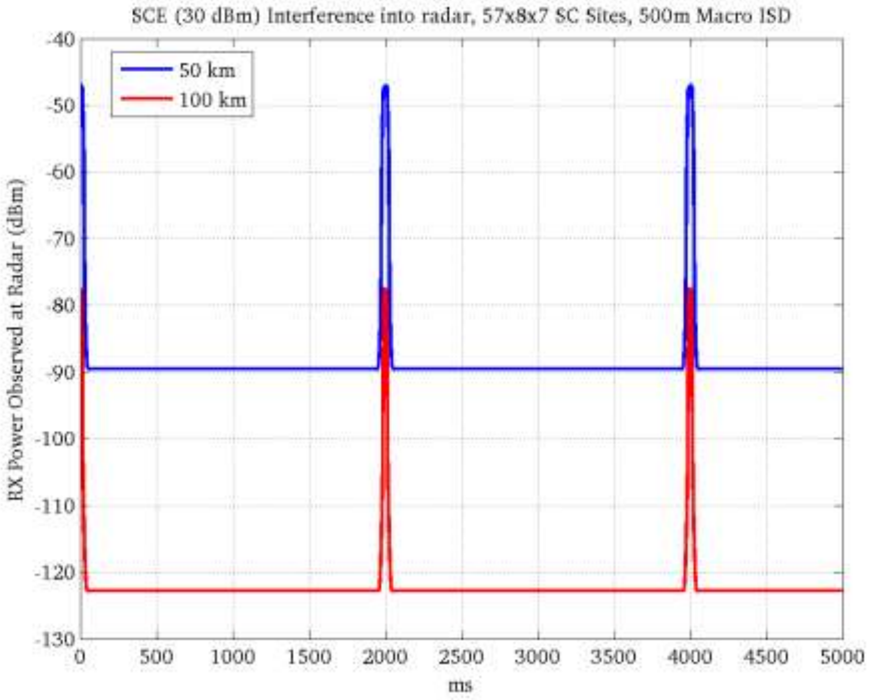

Table 4-5. Interference Thresholds for Radar Systems

Radar Type	Receiver Noise Level (dBm)	I/N Criteria (dB)	Interference Threshold (dBm)
Ground-Based Radar – 1	-103	-6	-109
Ground-Based Radar -3	-96	-6	-102
Shipborne Radar – 1	-108	-6	-114
Shipborne Radar -2	-95	-6	-101
Shipborne Radar - 3	-94	-6	-100

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Key Take-Aways

- Understanding eNB-radar propagation model is key
- Exclusion zones need more analysis
- Most affected LTE cells are the outdoor small-cells
- Beyond 100 km, the effect of interference on LTE seems to be negligible

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