Mid-band NOI Technical Inputs

January 18th 2018

Topics

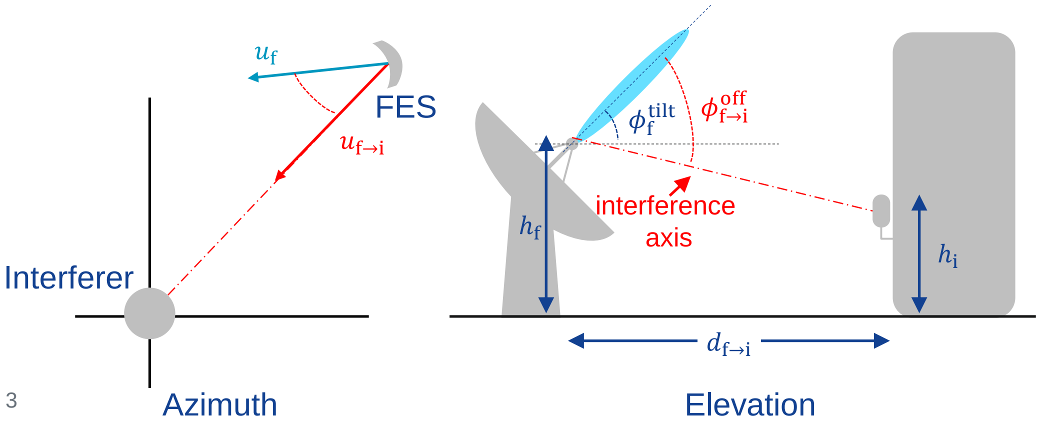
1. 5G Coexistence with FSS Earth Stations at 3.7-4.2GHz
2. FS Coexistence with FSS Earth Stations at 3.7-4.2GHz
3. Interference Criteria for Fixed Microwave
4. Microwave Equipment Capabilities

NOKIA

Interference Analysis

Methodology

- $A_{\mathrm{f}\to\mathrm{i}} = \min\left(A_{\mathrm{f}}\left(\theta^{\mathrm{off}}_{\mathrm{f}\to\mathrm{i}}\right) + A_{\mathrm{f}}\left(\phi^{\mathrm{off}}_{\mathrm{f}\to\mathrm{i}}\right), \mathrm{FTBR}_{\mathrm{f}}\right)$
  - $A_{\mathrm{f}}(\cdot)$: Attenuation for a given off-axis angle
  - $\theta^{\mathrm{off}}_{\mathrm{f}\to\mathrm{i}} = \mathrm{acos}(< u_{\mathrm{f}\to\mathrm{i}}, u_{\mathrm{f}} >)$
  - $\phi^{\mathrm{off}}_{\mathrm{f}\to\mathrm{i}} = \phi^{\mathrm{tilt}}_{\mathrm{f}} + \mathrm{atan}\left(\frac{h_{\mathrm{f}} - i}{d_{\mathrm{f}\to\mathrm{i}}}\right)$; $\phi^{\mathrm{tilt}}_{\mathrm{f}}$: Minimum elevation angle
  - $\mathrm{FTBR}_{\mathrm{f}}$: Front-to-back ratio loss (dB)



Compute FES attenuation in azimuth and elevation

Compute Interferer's effective EIRP in azimuth and elevation

Compute NLOS/LOS due to blockage

Compute path loss between FES and interferer

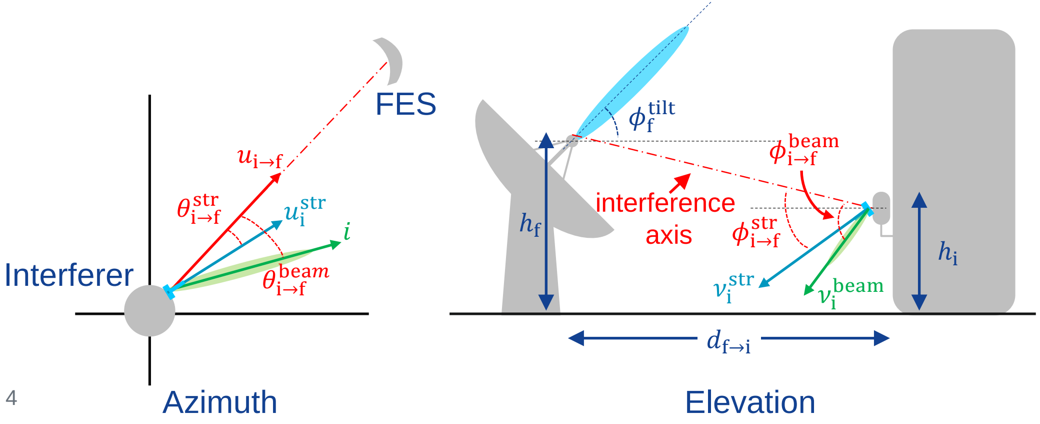
Compute aggregate interference

NOKIA

Interference Analysis

Methodology

- $A_{\mathrm{f\to i}} = A_{\mathrm{i,BP}}\left(\theta_{\mathrm{i\to f}}^{\mathrm{beam}}\right) + A_{\mathrm{i,BP}}\left(\phi_{\mathrm{i\to f}}^{\mathrm{beam}}\right)$
  $+\min\left(A_{\mathrm{g,EP}}\left(\theta_{\mathrm{i\to f}}^{\mathrm{str}}\right) + A_{\mathrm{g,EP}}\left(\phi_{\mathrm{i\to f}}^{\mathrm{str}}\right), \mathrm{FTBR_i}\right)$
  - $\theta_{\mathrm{i\to f}}^{(\cdot)} = \mathrm{acos}\left(< u_{\mathrm{i\to f}}, u_{\mathrm{i}}^{(\cdot)} >\right); \ \phi_{\mathrm{g\to i}}^{(\cdot)} = \mathrm{atan}\left(\frac{h_{\mathrm{f}}-h_{\mathrm{i}}}{d_{\mathrm{f\to i}}}\right) - \phi_{\mathrm{i}}^{(\cdot)}$
  - $\phi_{\mathrm{i}}^{(\cdot)} = \angle \nu_{\mathrm{i}}^{(\cdot)}$
- $\mathrm{EIRP_{f\to i}} = \left(P_{\mathrm{i,Tx}} + G_{\mathrm{i,max}}\right) - A_{\mathrm{f}\to i}$



Compute FES attenuation in azimuth and elevation

Compute Interferer's effective EIRP in azimuth and elevation

Compute NLOS/LOS due to blockage

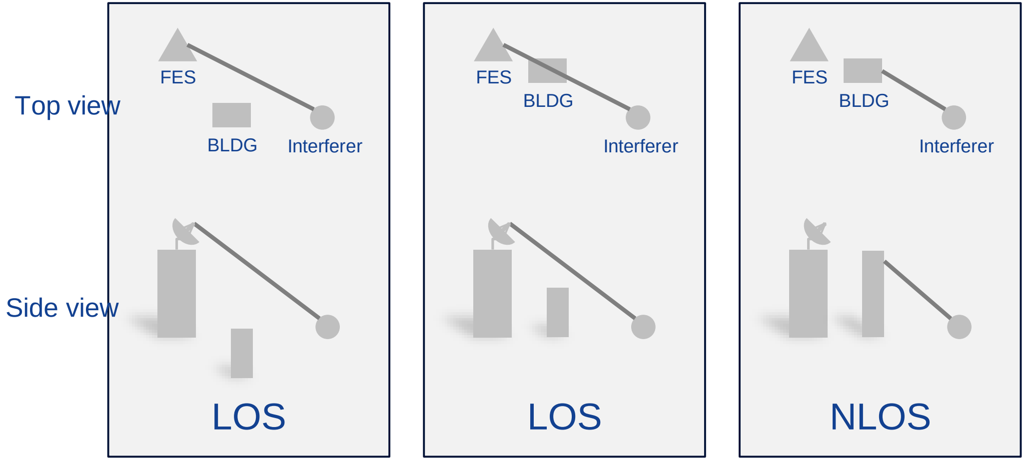
Compute path loss between FES and interferer

Compute aggregate interference

NOKIA

Interference Analysis
Methodology

- A LOS link is defined as a link with no building blockage between the FES and the interferer (in 3D)



Compute FES attenuation in azimuth and elevation

Compute Interferer's effective EIRP in azimuth and elevation

Find if link is LOS or NLOS

Compute path loss between FES and interferer

Compute aggregate interference

NOKIA

Interference Analysis

Methodology

- $\mathrm{PL} = \mathbf{1}_{(\beta=0)}\mathrm{PL}_{\mathrm{LOS}} + \mathbf{1}_{(\beta=1)}\mathrm{PL}_{\mathrm{NLOS}} + \mathcal{X}(\beta) + \mathrm{PL}_{\mathrm{i2o}} + \mathrm{PL}_{\mathrm{i}}$
  - β: Indicator variable to denote LOS/NLOS
  - $\mathcal{X}(\beta)$: Log-normal shadowing with std that depends on LOS/NLOS
  - $\mathrm{PL}_{\mathrm{i2o}}$: Penetration loss if UE is indoor
    - 3GPP 36.873 (3D-UMi): Assumes 20dB penetration loss
    - 3GPP 38.901 (NR-UMi): A function that randomizes environment, e.g., glass, concrete, etc.
  - PL_{i}: Indoor losses
    - Assumed to be 0.5dB per meter

- In 3GPP model, $\mathbf{1}_{(\beta=X)}$ is computed probabilistically, while here we use a building database

Compute FES attenuation in azimuth and elevation

↓

Compute Interferer's effective EIRP in azimuth and elevation

↓

Find if link is LOS or NLOS

↓

Compute path loss between FES and interferer

↓

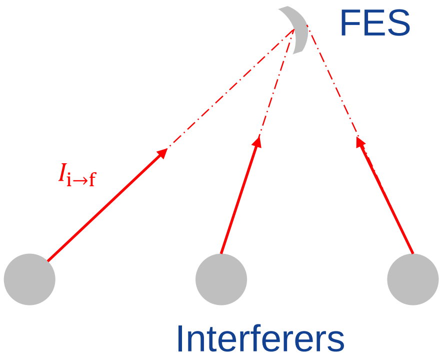
Compute aggregate interference

NOKIA

Interference Analysis
Methodology

- $I_{g \to f} = \text{EIRP}_{f \to i} + (G_{f,max} - A_{f \to i}) - \text{PL}$
  - $G_{f,max}$: Maximum FES antenna gain (dBi)

- $I_{g,Agg \to f} = 10 \log_{10}(\sum_i 10^{(I_{i \to f}/10)})$ in dBm/Hz



Compute FES attenuation in azimuth and elevation

↓

Compute Interferer’s effective EIRP in azimuth and elevation

↓

Find if link is LOS or NLOS

↓

Compute path loss between FES and interferer

↓

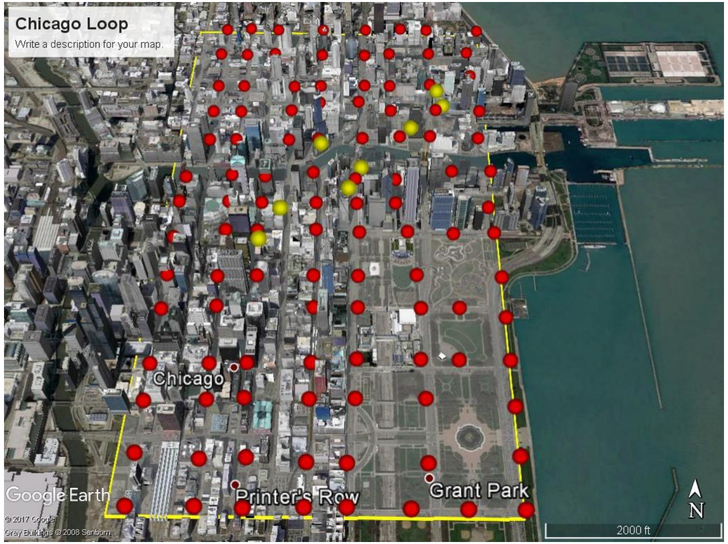
Compute aggregate interference

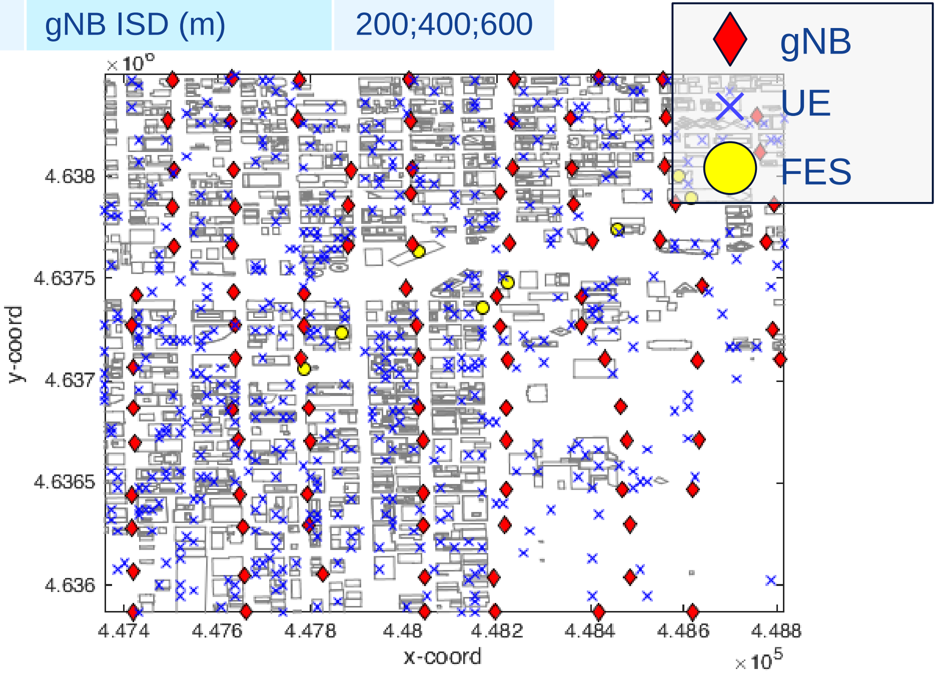
NOKIA

Simulation Scenario

Chicago Loop

Area (km2)z	1.5x2.6	Number of gNBs	108
Number of FESs	8	gNB ISD (m)	200;400;600

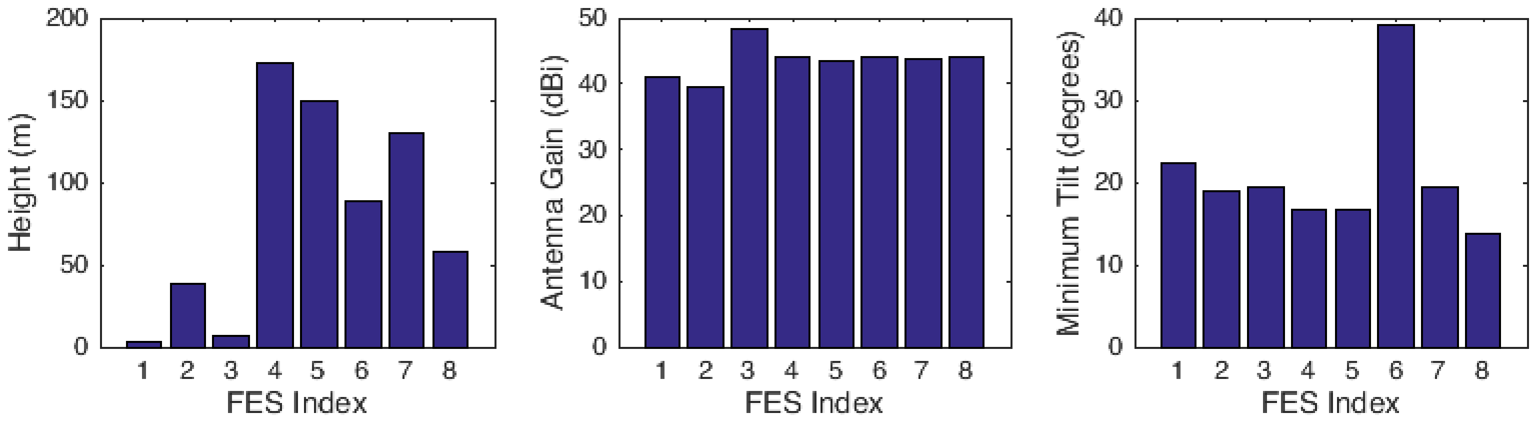




Simulation Scenario

FSS Earth Station (FES) data

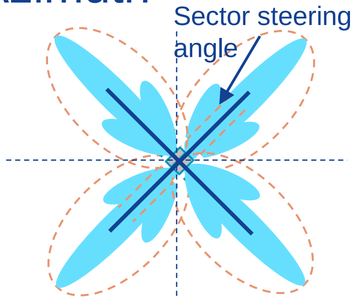
- Most of FESs are at high altitudes
- FESs have antennas pointing up with high gain



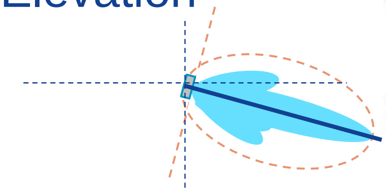
NOKIA

Simulation Scenario
gNB antenna parameters

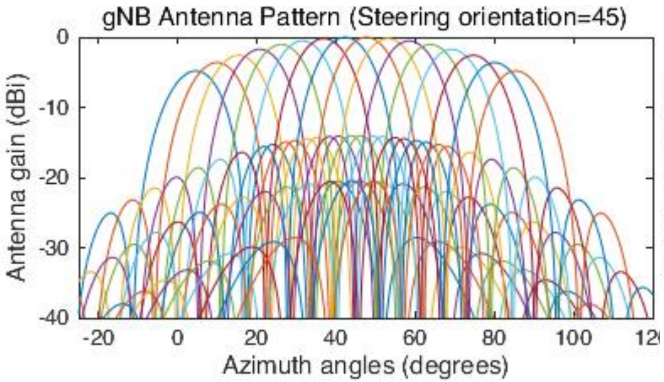
- Azimuth

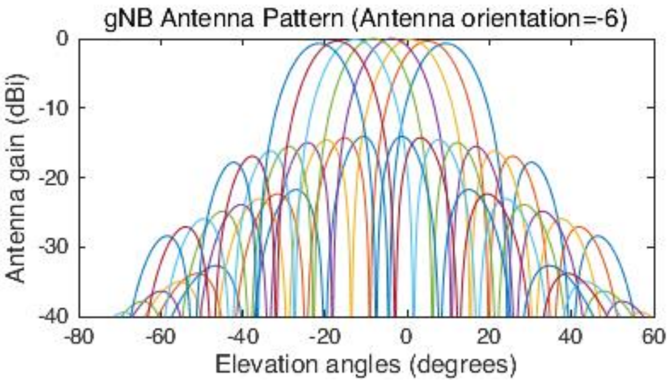


- Elevation



Parameter	Values	Parameter	Values
No. of sectors	4	Antenna tilt (°)	-6
Antenna array	8x4x2	Az/EL Beam pattern beamwidth (°)	12/25
No. of azimuth beams/sector	16	Element pattern beamwidth (°)	65
No. of elevation beams	8	FTBR (dB)	30

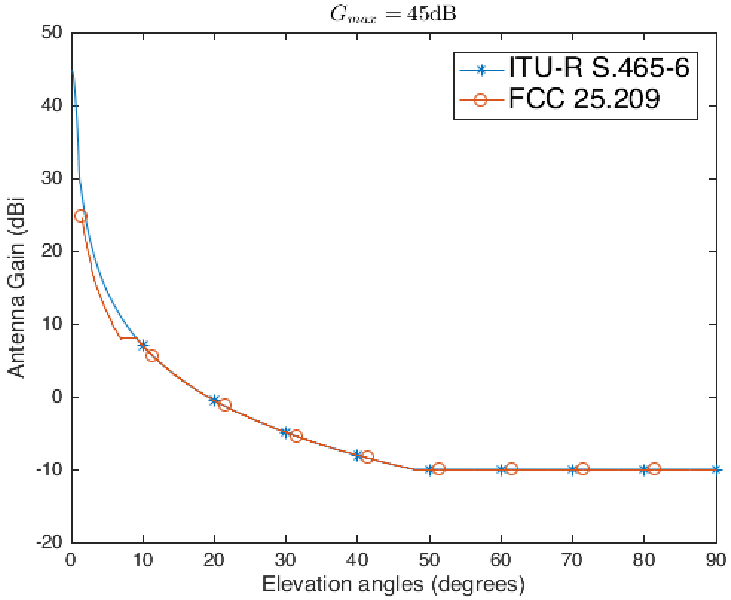




NOKIA

Simulation Scenario
FES antenna parameters

- FES beam pattern: Recommendation ITU-R S.465-6:
  - RECEIVING reference Earth station antenna pattern for earth stations in FSS in the frequency range from 2 to 31 GHz coordinated after 1993.
- FCC 25.209(a)(1) defined for off-axis angles >1.5°
  - Independent of operating frequency
  - Independent of receiver max antenna gain



Simulation Scenario
FES protection criterion

- Several protection criteria
  - One example: The 2-degree compatibility at C-band: I/N=1.1 dB

Interference criterion	
2-degree compliant EIRP density from 25.140[a.3.i] (dBm/Hz)	-3
FCC 25.209 off-axis gain at 2.2° (dB)	20.4
Min path loss from GSO at 3.7 GHz (dB)	194.9
2-degree compliant receive interference (dB)	-177.5
Typical C-band receive noise temperature (K)	100
Receive noise density (dBm/Hz)	-178.6
2-degree compliant I/N (dB)	**1.1**

NOKIA

Simulation Results
Parameters

- No. of spatial UE drops: 100 (new users locations)
- Static TDD:
  - UL Load: 25%
  - DL Load: 25% and 50%
- UE antenna height indoors depends on the building height

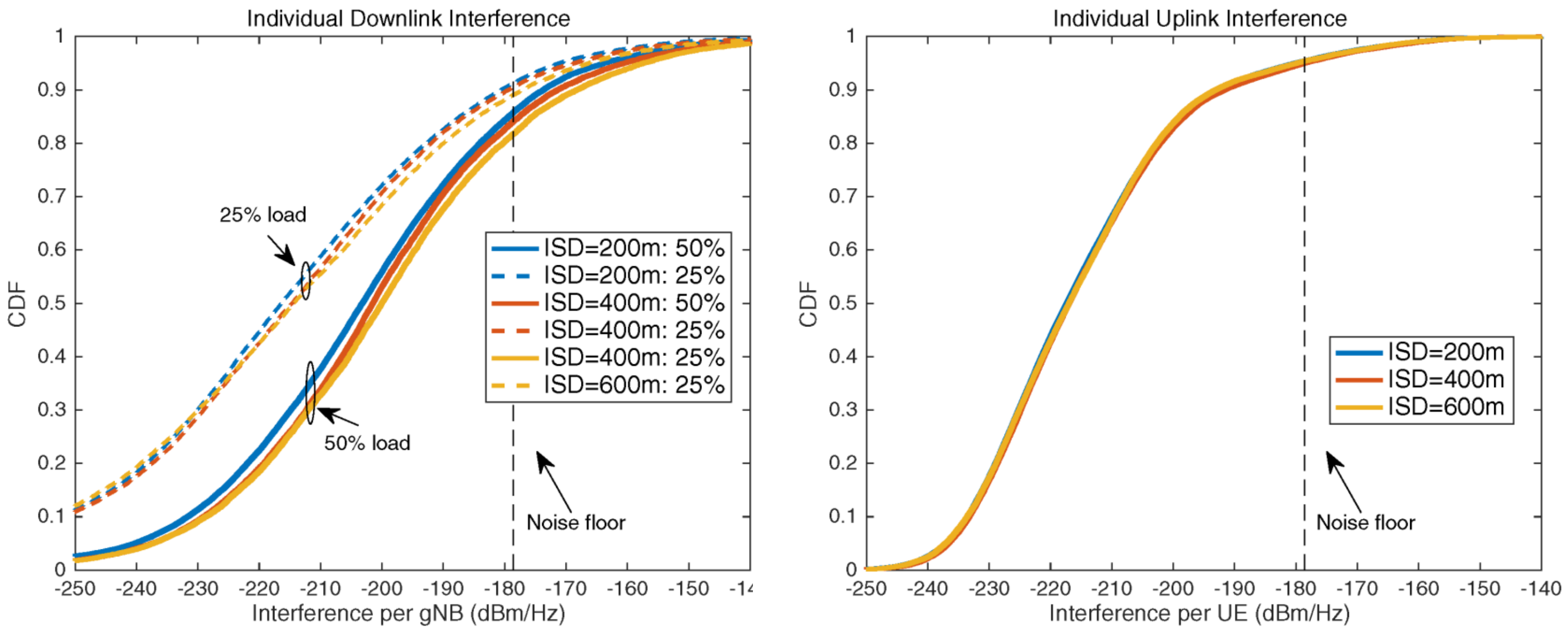
* The 66dBm/100MHz EIRP is based on
  - gNB with 64 antennas (8x4x2)
  - A transmit power of 46dBm/100MHz

Parameter	Values
Path loss	
Carrier frequency (GHz)	3.95
Channel model	3D-UMi
5G gNB	
Deployment	Street-level
EIRP (dBm/100MHz)*	66
Antenna height (m)	6
ISD (m)	200, 400, and 600
5G UE	
Deployment	3GPP (20% outdoors)
EIRP (dBm/100MHz)	33
Antenna height (m)	Outdoor: 1.5; Indoor: Vary
FES	
Locations/height	From database
Antenna gain/tilt	
Noise temperature (K)	100
Noise density (dBm/Hz)	-178.6
Bandwidth (MHz)	36

Simulations results

Distribution of DL/UL interference

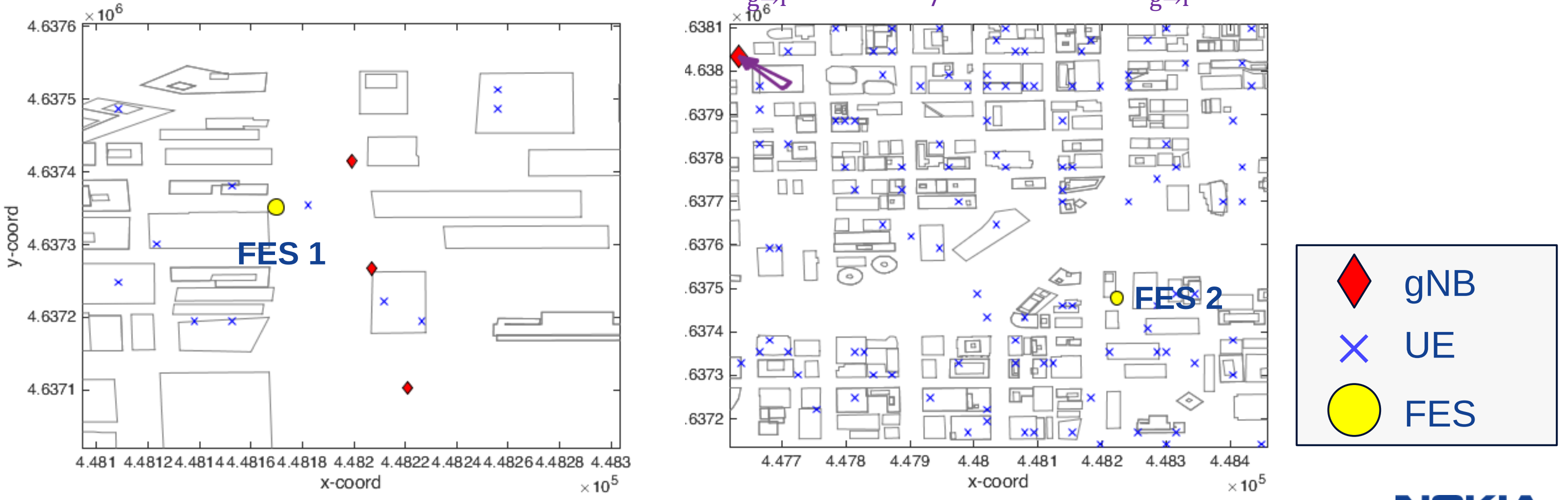
- Interference is dominated by few gNBs/UEs



Contribution of Interference

- Interference is due to:
  - Some gNBs are close to FESs (e.g., FES 1 in left figure)
  - High gNB antenna gain in the direction of the FES even if far (e.g., FES 2 in right figure)

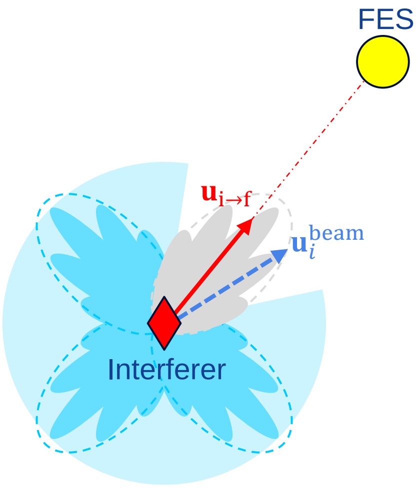
$\mathrm{EIRP}_{\mathrm{g}\rightarrow\mathrm{f}} = 64\mathrm{dBm}/100\mathrm{MHz}$ and $d_{\mathrm{g}\rightarrow\mathrm{f}} = 860m$



NOKIA

Interference management

- DL and UL: Non Co-channel allocation instead of co-channel
- Exclusion zones:
  - 1st: Over space
  - 2nd: Over the angular domain
- Power control:
  - 1st approach: Meet target UL SNR
  - 2nd approach: Fractional power control

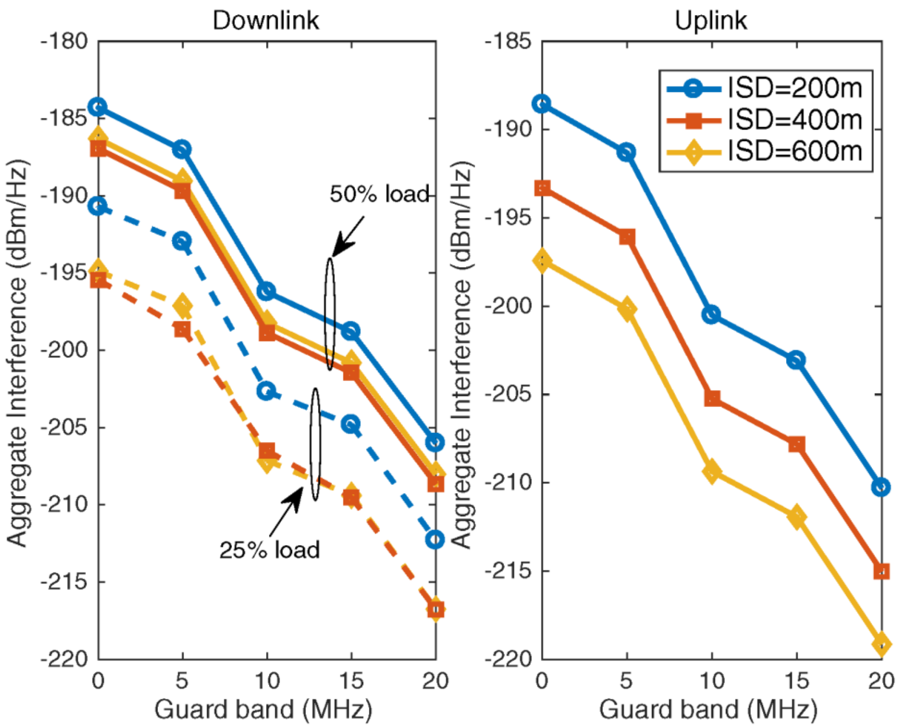


Angular exclusion zones
Beams pointing toward FES are switched off

Simulations results

Impact of guard bands on the DL and UL median aggregate interference

- Guard band of 0MHz: Median I/N < -6 dB for UL and DL (50% load)
- Guard band of 5MHz: Median I/N < -10 dB for UL and DL (50% load)
- Increasing ISD does not provide tangible gains

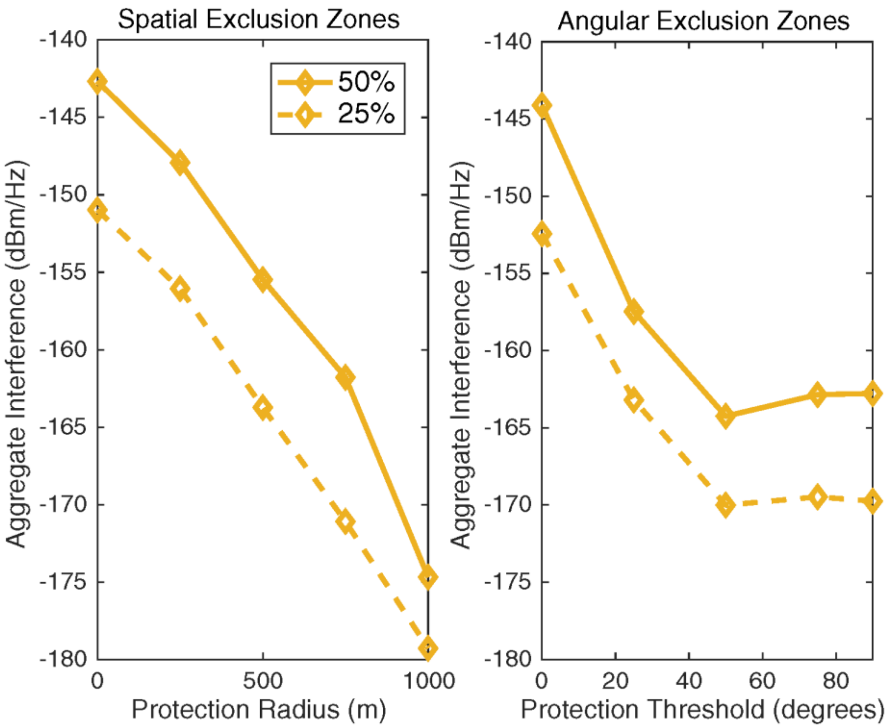


NOKIA

Simulations results

Impact of exclusion zones on median aggregate interference

- Spatial exclusion zone is effective
- Angular exclusion zone is effective
- A combination of both could be used for small protection radius
  - Using a protection radius of 500m and protection angle of 50deg reduces median agg. Interference from -155dBm/Hz to -176dBm/Hz



NOKIA

Simulations results

Impact of power control on median aggregate interference from 5G UL

Method	Median Aggregate Interference (dBM/Hz)	Median UL SNR (dB)
Target-SNR	-183.9	5.0
Fractional power control	-183.0	4.6

- Reducing the aggregate interference further is still achievable via power control at the expense of affecting the 5G system performance.

NOKIA

Summary (1/2)

- Co-channel deployment could incur interference when close by
  - Even when density of BSs is low
  - Even when the load is 25%
  - Even when UEs use UL power control

- Power control can limit interference from the 5G UL but at the expense of degrading 5G performance

- Guard band between FSS and 5G within 3.7-4.2GHz band helps

Summary (2/2)

- Since co-channel 5G/FSS operation in proximity may be an issue, goal is to avoid 5G co-channel with FSS close to the FSS earth stations.
- In order to do that:
  - FCC Should Apply Policies That Do Not Overprotect FSS Operations (get rid of full band full arc requirement, clean up FSS database, do not protect non-existing FSS, etc)
  - FCC Should Require FSS Licensees To Update and make available Their Operating Parameters, including spectrum block being used
    - That would enable more accurate interference assessment and interference mitigation, if needed (not worse-case)
    - 5G could operate non co-channel with FSS in proximity, then co-channel at a certain distance
    - Repacking and clearing of FSS to be considered

NOKIA

Topics

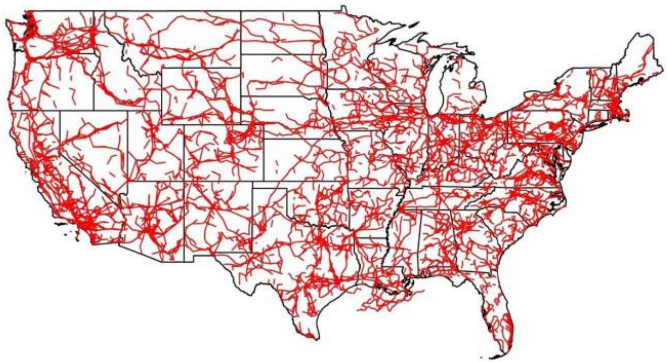
1. FS Coexistence with FSS Earth Stations at 3.7-4.2GHz
2. Interference Criteria for Fixed Microwave
3. Microwave Equipment Capabilities

FS coexistence with FSS in 3.7-4.2 GHz Band

- FSS Earth stations authorized for every frequency in the band, so there is no clear frequency at any location
- Earth stations authorized for every azimuth in the arc
- Approximately 4500 Earth Stations in the 4 GHz band
- Distance separation required to achieve the required interference levels under the conditions above has made coordination of fixed links virtually impossible anywhere in the continental US.
- As a result, long-haul microwave used the next lowest bands of L6 (5.925-6.425 GHz) and U6 (6.425-7.125 GHz).

Use of L6 and U6 GHz

- Fixed microwave is using L6 and U6 GHz as the go-to band for long-haul links.
- Approximately 18000 fixed microwave links in these bands



Lower 6 GHz Fixed Point to Point Terrestrial Microwave Networks

Upper 6 GHz Fixed Point to Point Terrestrial Microwave Networks

NOKIA

Interference Criteria for Fixed Microwave

- Theoretical noise floor of -99.2 dBm in a 30 MHz channel
- With noise figure of just over 3 dB, the noise floor is around -96 dBm.
- Co-channel interference levels need to be 6 dB below noise floor or -102 dBm.
- High gain radios and radios with 5 MHz channel sizes may need slightly lower interference levels as low as -114 dBm.
- There are older radios in even smaller channels with lower tolerance still.
- Interference mitigation well-understood with frequency coordination of fixed links, but the source of interference from unlicensed units can not be identified or located
- Result can be increased outages without explanation or resolution mechanism

NOKIA

Microwave Equipment Capabilities

- Adaptive or Fixed Modulation from 4-2048 QAM increasing to 4096 QAM
- Channel sizes from 5-60 MHz
- Throughputs up to 434 Mb/s on a single channel
- Link aggregation of up to 8 channels with traffic priority queuing
- Frequency bands from 4-39 GHz, 60, 70, 80 GHz
- XPIC, Ring
- All-packet radios

Why Protect the 6 GHz Band?

- Band used for mission-critical Utility and Public Safety traffic
- Transfer-Trip for Power Grid control
- LMR traffic for police/fire/ambulance communications

NOKIA

NOKIA