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Comparative Technical Analysis for 5G Fixed Wireless Access Rural Networks (2.6, 3.7 and 6.4GHz)

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SEPTEMBER 19-22 • PHILADELPHIA, PA

2022 Fall Technical Forum
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How capable is rural FWA as a broadband service?

- What speeds can be offered?
- Is it reliable?
- How many subscribers can FWA serve?
- Can FWA support broadband household usage today and in the future?
- Is it profitable?

CableLabs implemented a cross disciplinary approach:

- Develop a detailed technical analysis
- Use the technical analysis' KPIs to address the economics profitability

Introduction

The 5G FWA rural coverage (outdoor and O2I) is subject to different limitations*:

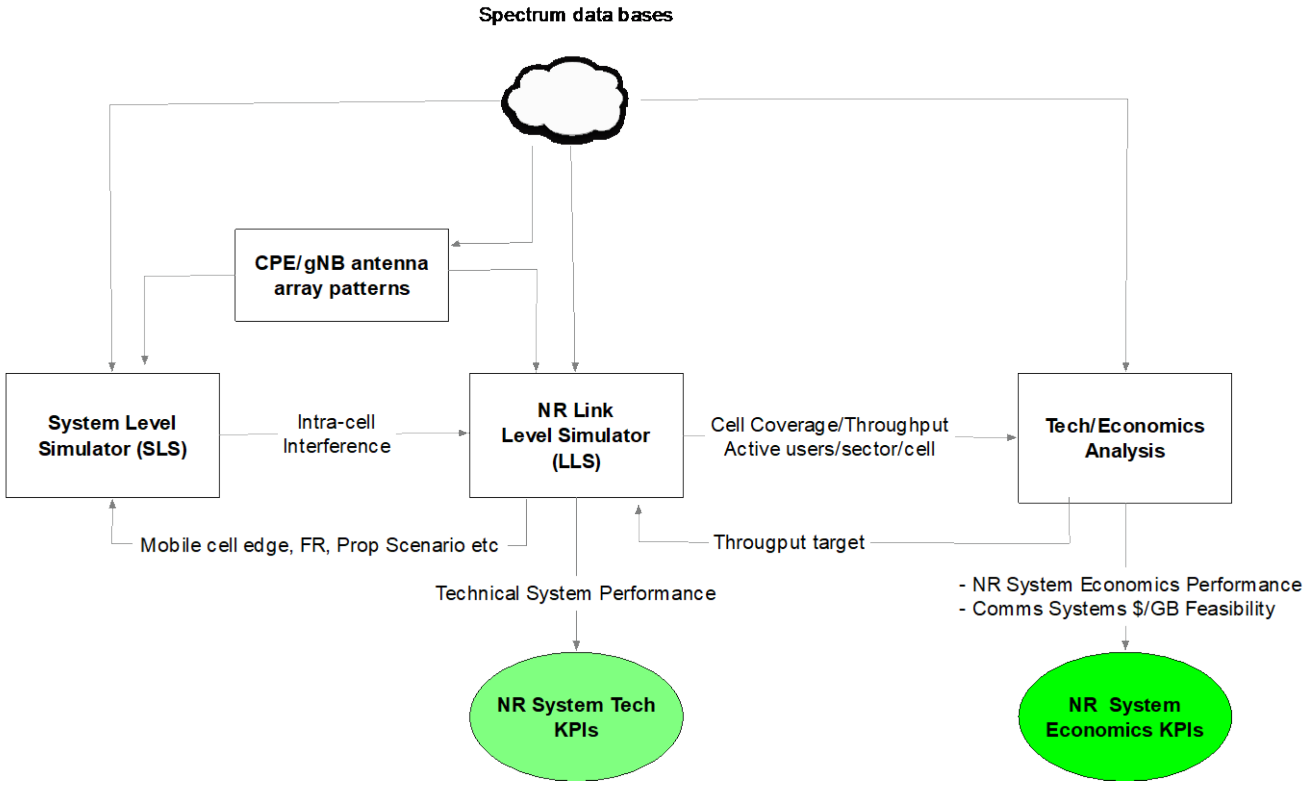
- Base Station (BS) and CPE advanced array antenna impact upon Frequency Reuse factor.
- BS antenna array tilt.
- Different frequency bands (2.6, 3.7 and 6.4GHz)
- Network load
- Different BS antenna heights (hBS=30m and 60m) upon coverage
- Small-scale, Large-scale fading and O2I loss mechanisms
- UL link EIRP limitations
- FWA user data thresholds
- Probability to deliver a target user link speed

Our companion papers analyze:

- The technical impact of these limitations upon FWA sector/cell coverage/throughput.
- The economics impact

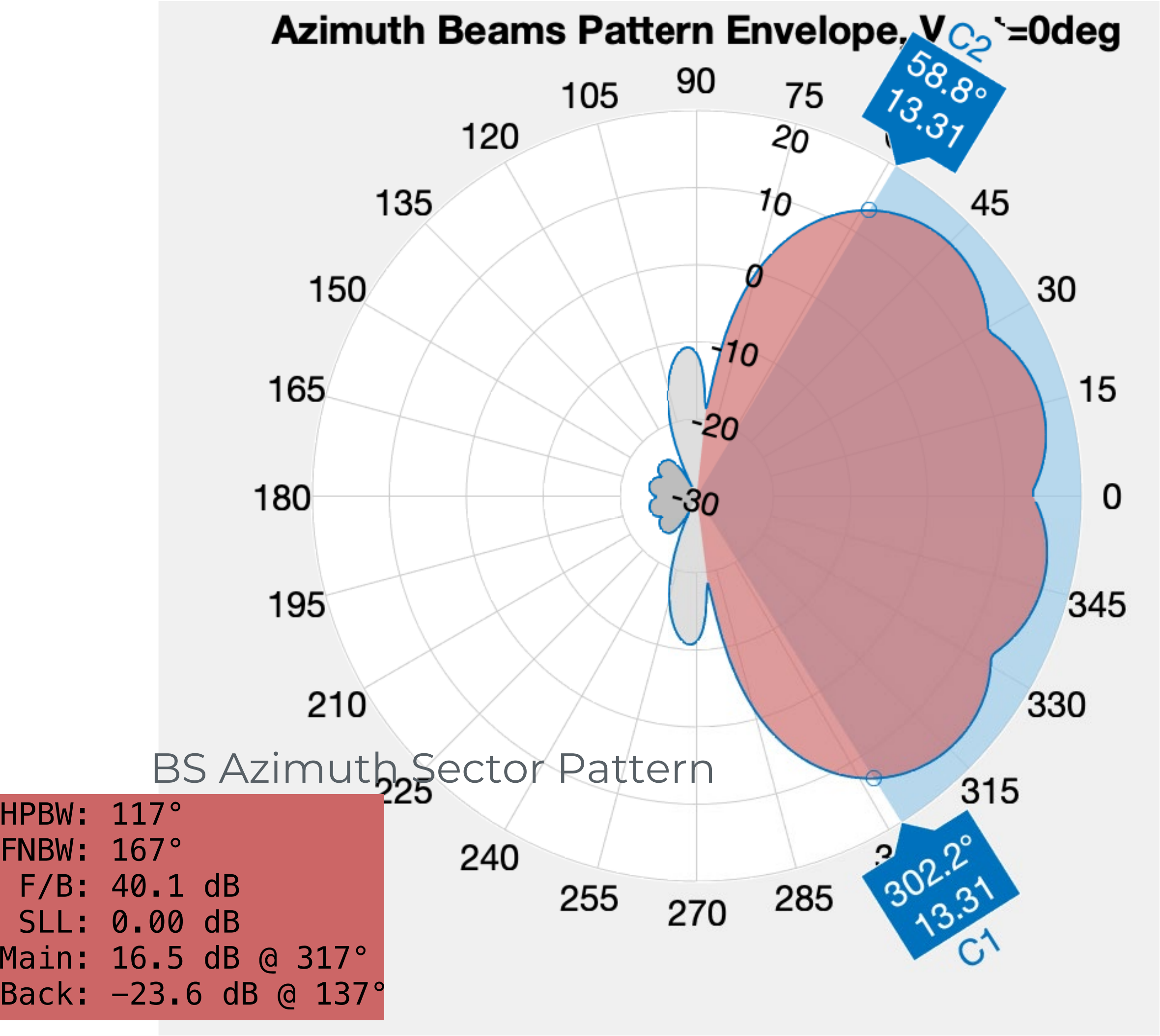
* The simulations assumptions are presented in the Appendix

Methodology



- System Level Simulator (SLS)
  - Based on a Monte Carlo simulation, generates statistical predictions of aggregated interference upon the victim cell for a cluster of 19 cells in two surrounding rings
- Link Level Simulator (LLS)
  - Predicts sector/cell coverage, user throughput of specific 5G waveforms in a simulated network interference environment, subject to environmental conditions.
- CPE/gNB antenna array patterns
  - Generates suitable array patterns to optimize
  - radio link performance.
- Economics analysis
  - Estimates the economic feasibility of the 5G FWA and service delivery network under consideration

BS Antenna Array Patterns



BS Azimuth Sector Pattern

Optimizing the sub-array Beam pattern, enhances Frequency Reuse 1 support

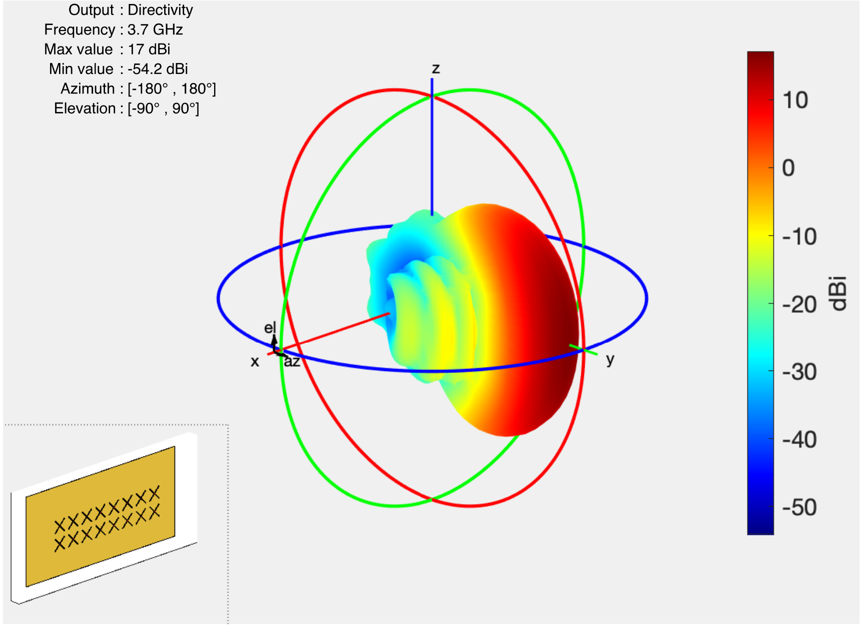
- Critical parameters: vertical tilt and elevation pattern

Optimizing the spatial division multiplexing, increases the cell throughput and optimizes coverage

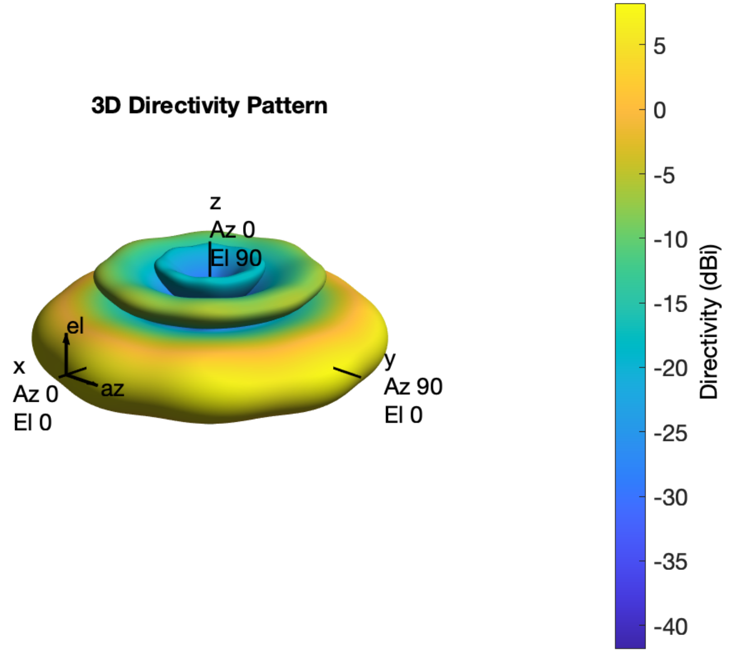
- Max gain: 16.4 dBi
- Azimuth half-power beamwidth: 29^o
- Elevation half-power beamwidth: 30^o

* Number of beams per sector: 4, Beam Azimuth HPBW: -29^0, Beam Elevation HPBW: 30^0

CPE Antenna Array Patterns



Outdoor CPE Array Pattern



Indoor CPE Array Pattern

Optimizing CPE beam pattern, enhances coverage and mitigates interference

- Max gain: 17 dBi
- Azimuth half-power beamwidth: 16º
- Elevation half-power beamwidth: 52º

Current indoor CPEs have an omni azimuth coverage

- Lower antenna gain reduces coverage
- Max gain: 8.2 dBi
- Elevation half-power beamwidth: 10º

Vertical BS Antenna Array Tilt* (0, -15 and -21deg)

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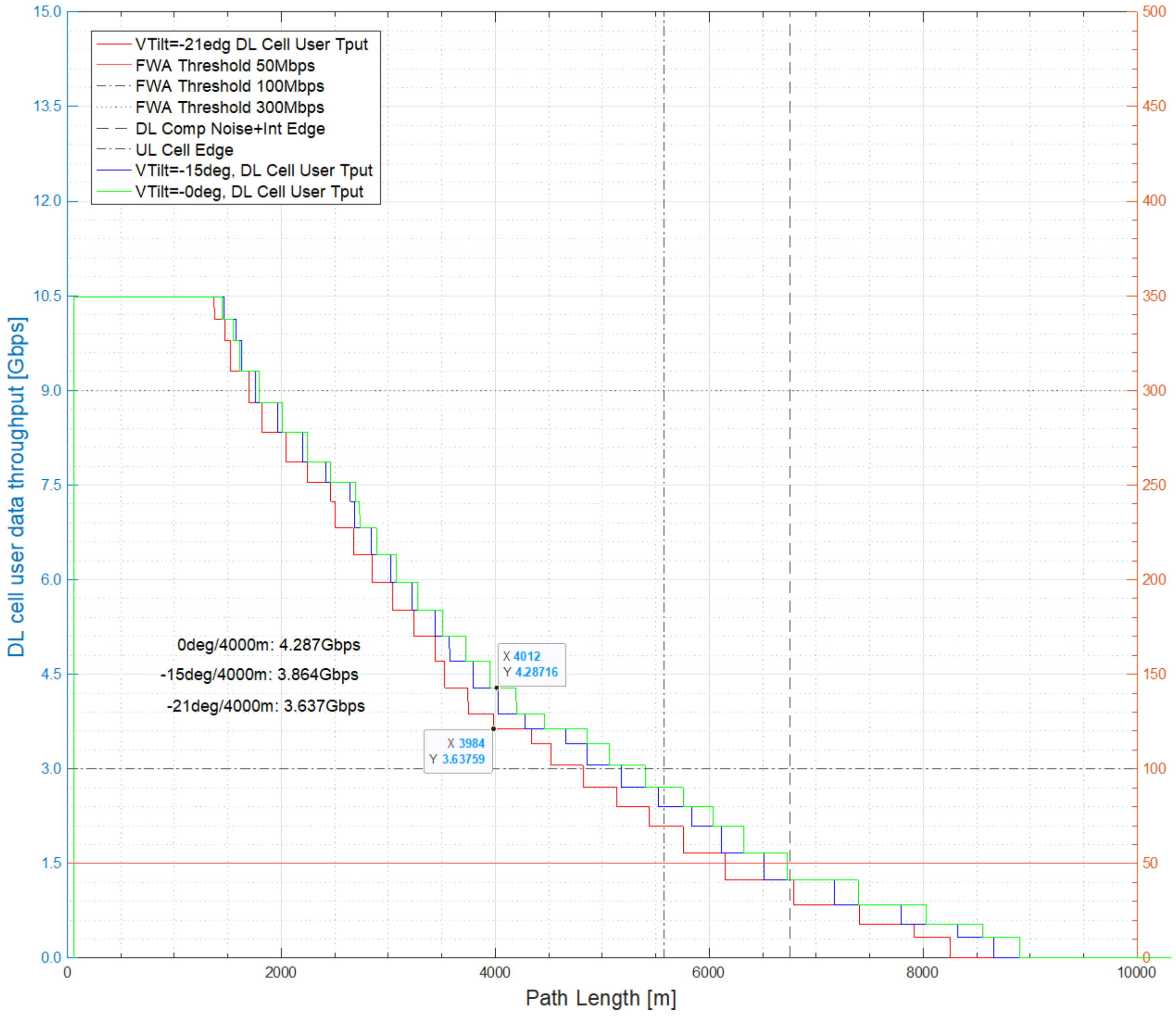
Comparative cell coverage vs. elevation antenna tilt (3.7GHz)



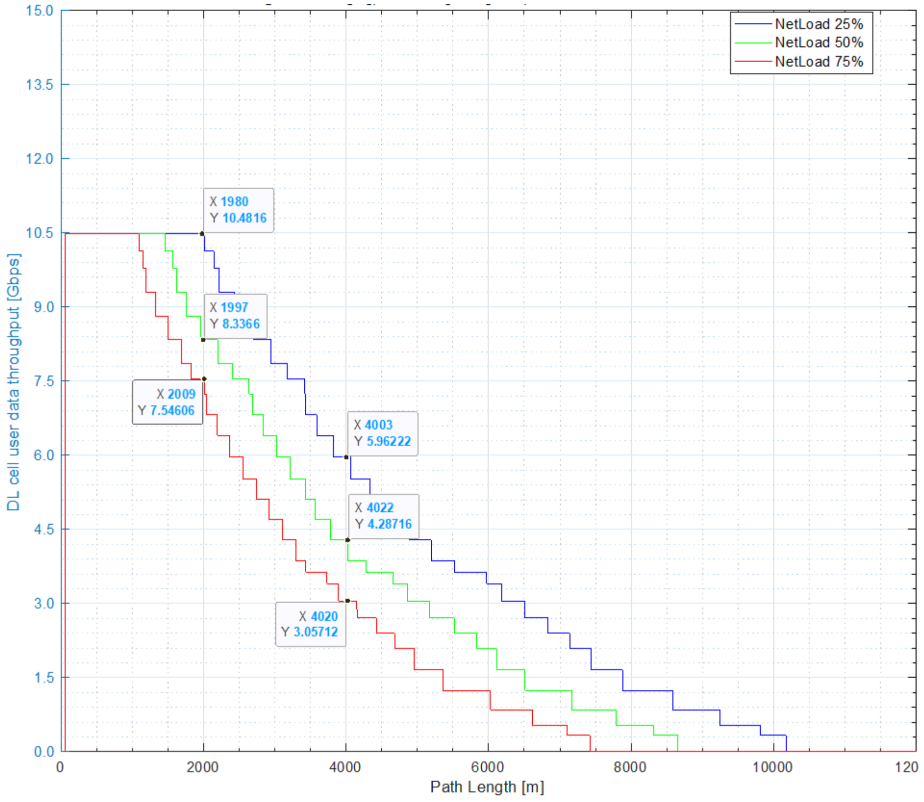
Vertical antenna tilt and the array pattern supports Frequency Reuse 1, maximizing the spectral efficiency, by trading-off network interference reduction against cell user throughput reduction:

- The network interference power impact upon the victim CPE is reduced by 3.7dB (average).
- DL cell throughput is reduced by 15.2%

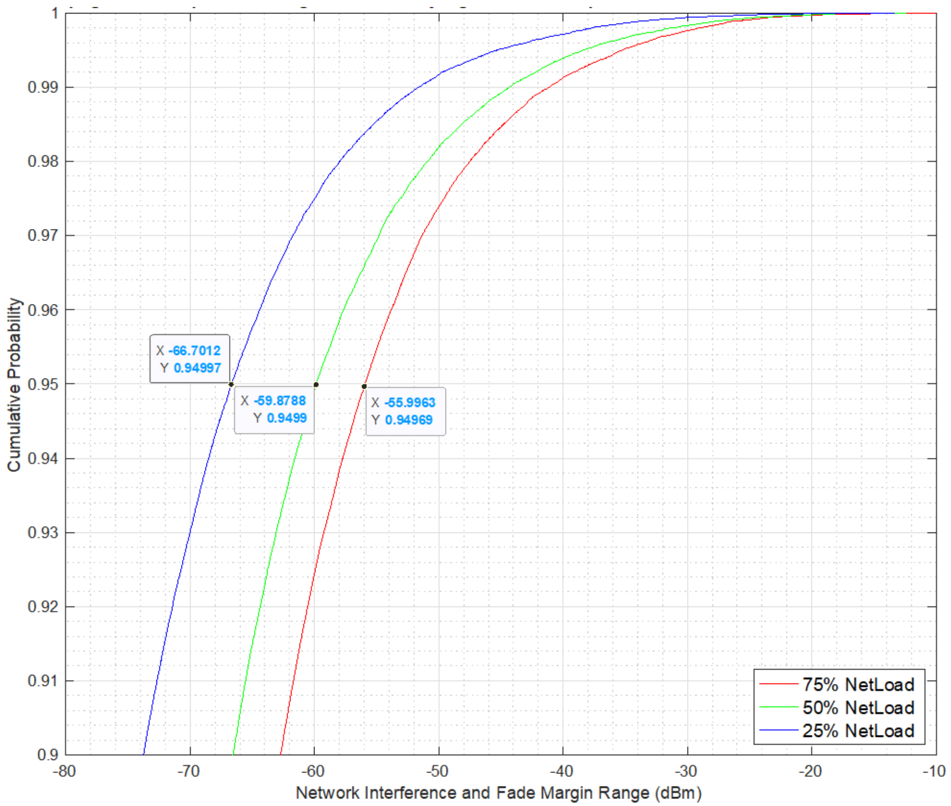
*Outdoor scenario, Fc=3.7GHz, hBS=60m, Link Availability=95%, Network Load 50%.

Network Load* (25%, 50% and 75%)

Comparative Coverage



Comparative CDF Network Interference



When network load is increased from 25% to 75%, cell user throughput is degraded by:

- 48.8% (hBS=60m, MobCellEdge=4000m) and
- 28.1% (hBS=30m, MobCellEdge=2000m).

The higher is the network load, the higher is the system Interference and the lower is the user data throughput

- Network load is optimized by BS antenna tilt and pattern

* Outdoor scenario, Fc=3.7GHz, hBS=60m, Link Availability=95%

BS Antenna Array Height

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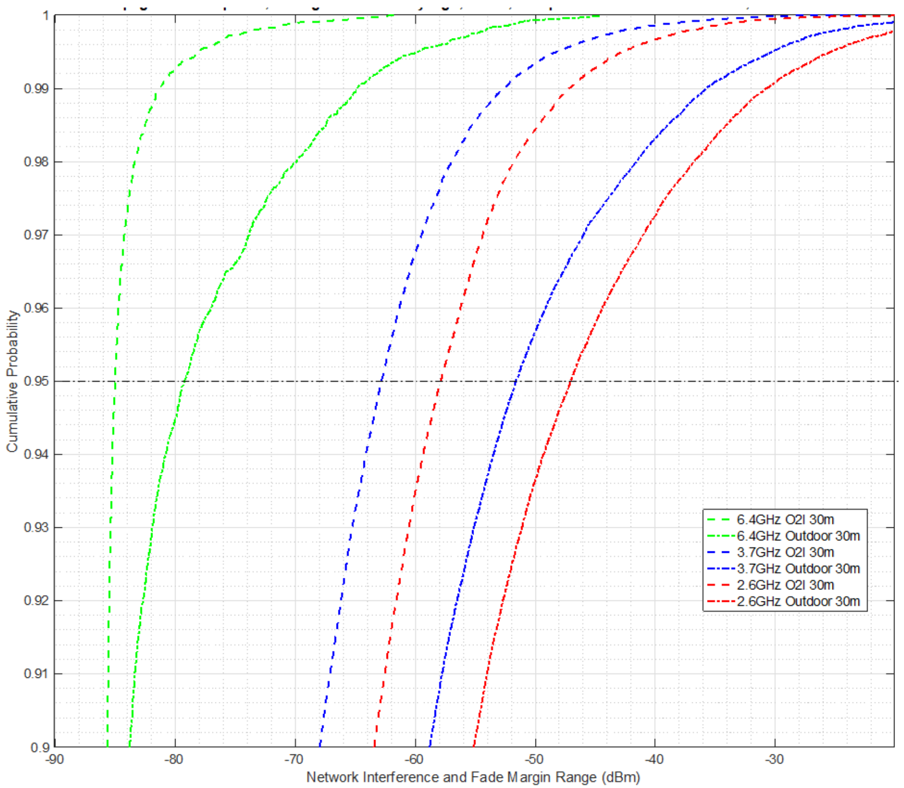
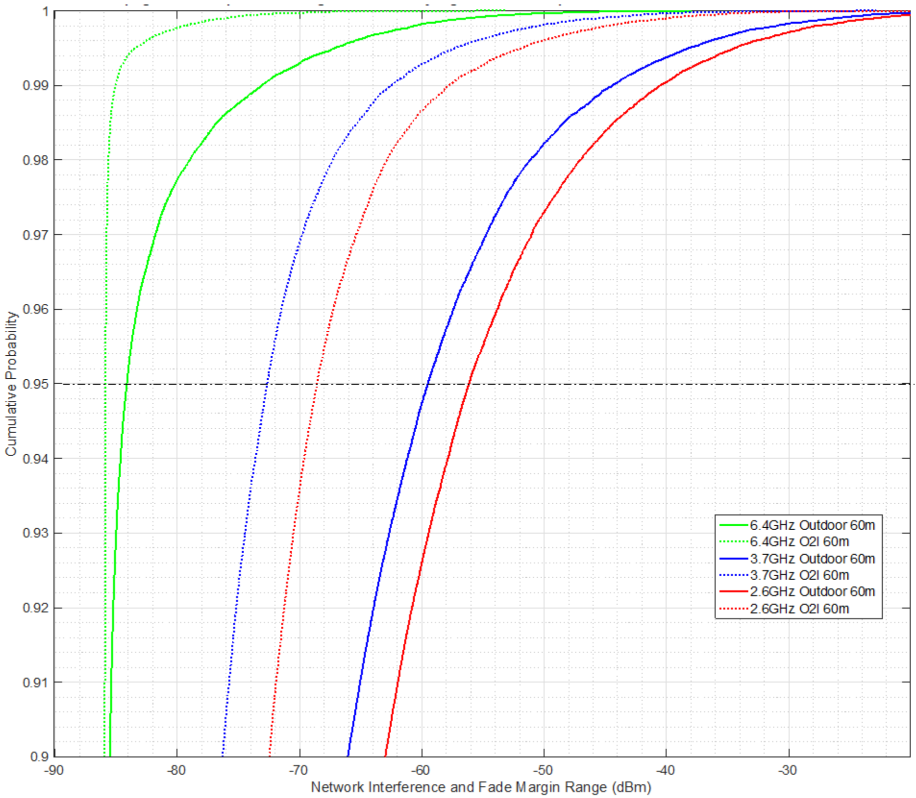
hBS=30m



hBS=60m



The lower antenna height (hBS=30m) triggers a higher System interference due to the smaller MobCellEdge (2000m):

- Outdoor: 9dB (2.6GHz), 8.3dB (3.7GHz) and 4.7dB (6.4GHz)
- O2I: 10.6dB (2.6GHz), 9.9 (3.7GHz) and 0.8dB (6.4GHz)

2.6GHz system is subject to the highest network Interference:

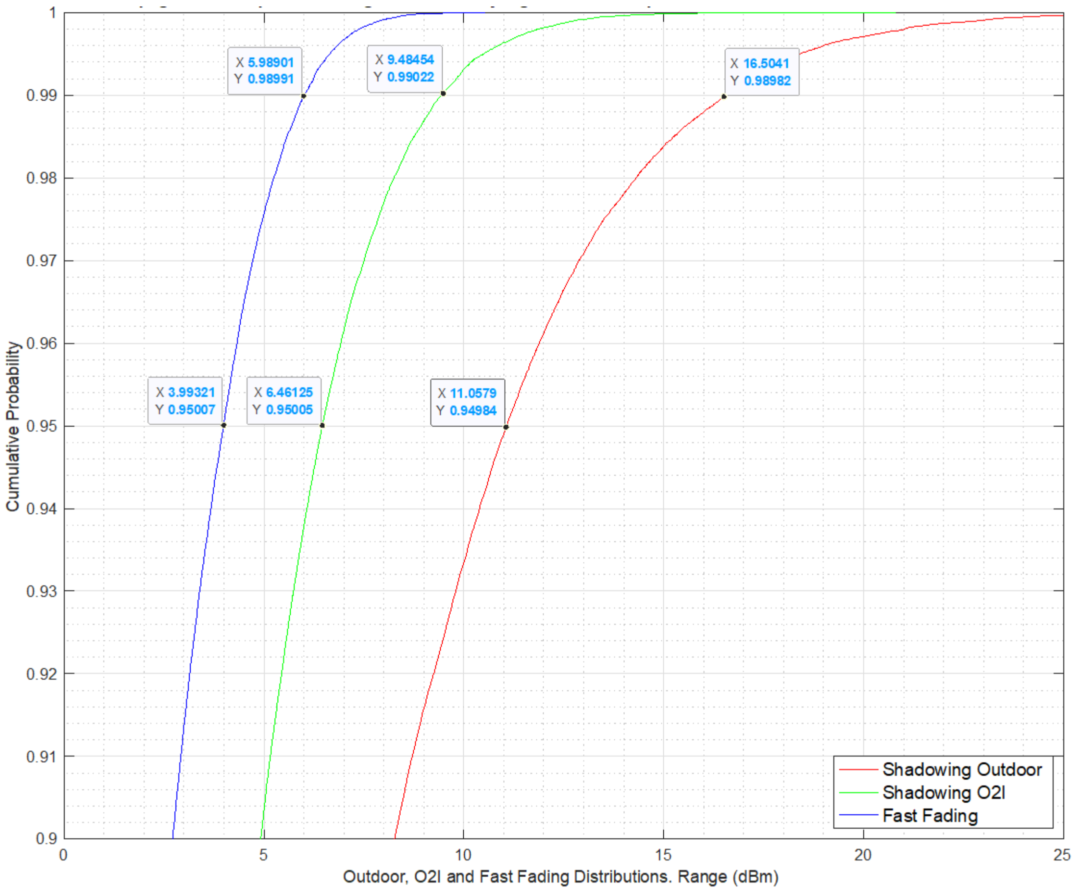
- Lowest propagation losses vs. 3.7 and 6.4GHz cases.

6.4GHz is subject to the lowest system interference

* NetLoad=50%, Link Availability=95%

Fading and Loss Mechanisms

hBS=60m



Large-scale fading (shadowing)

- Due to obstruction of the main paths (e.g. shadowing).
- The path loss is calculated separately

Small-scale fading

- Due to multipath propagation.

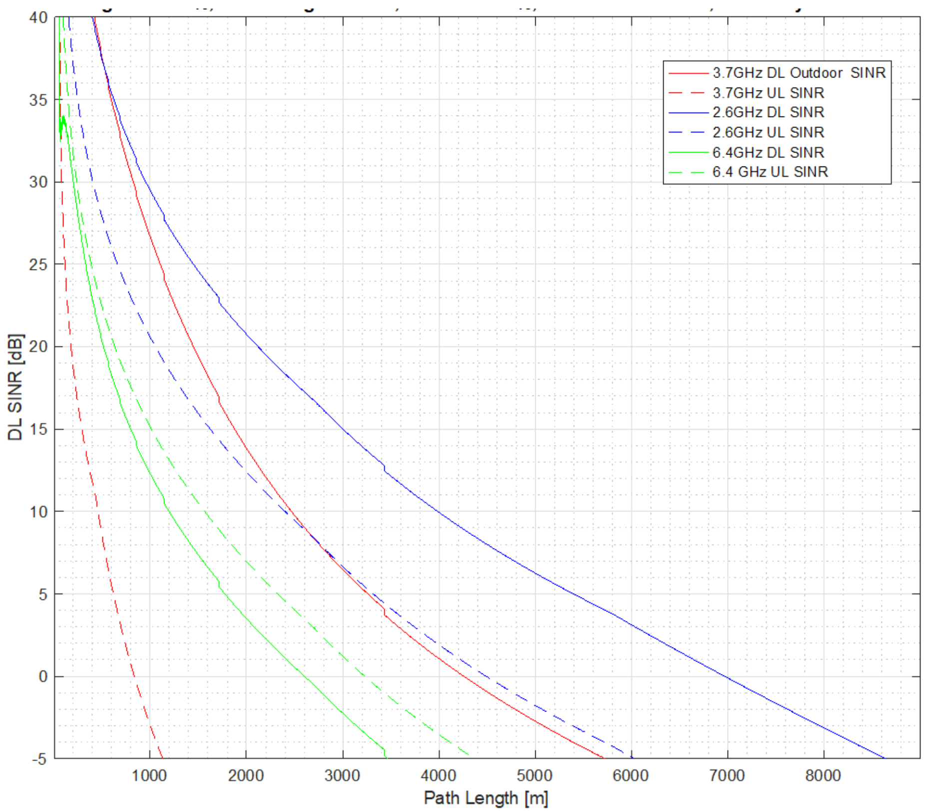
O2I loss

- Gaussian distribution centered on the median outer wall loss
- Not occurring in the outdoor scenario.
- Lead factor if CPE is positioned inside a house

- Large Scale fading is the driving factor of the composite fading, due to the NLOS propagation (Rayleigh type fading).
- The higher the target link availability, the higher the composite fading impact upon the link budget.
- O2I becomes a lead composite fading/loss factor if CPE is positioned deep inside the house and/or due to the house wall materials/glass composition.

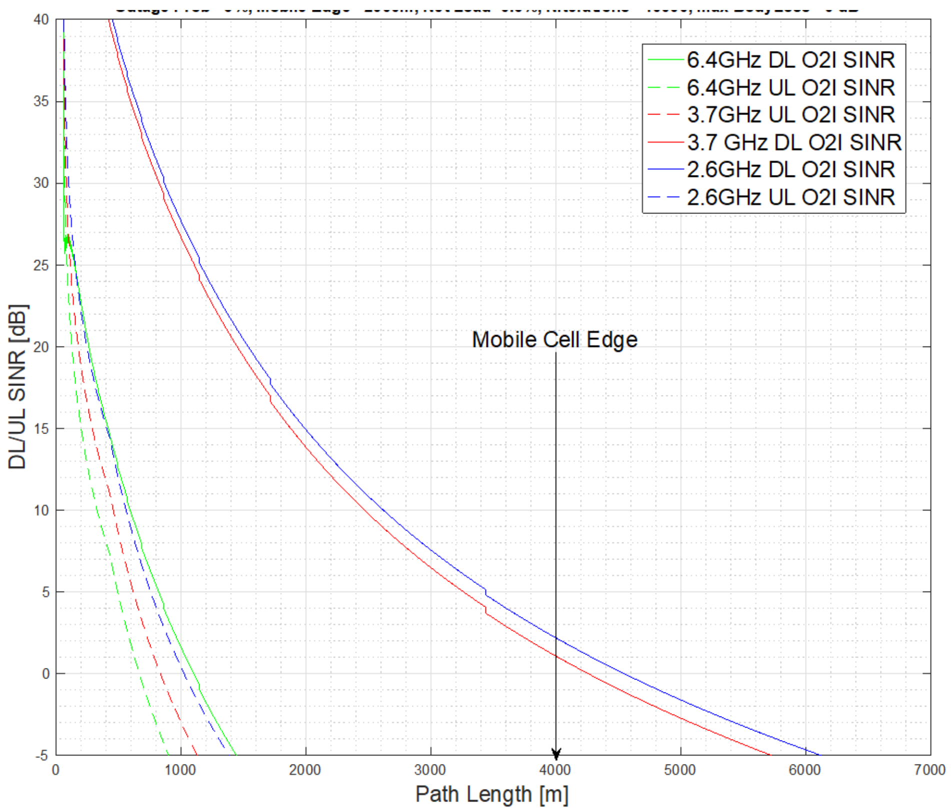
UL SINR and Frequency Band Impact

Outdoor Scenario



- Outdoor 2.6GHz coverage is slightly larger.
- DL outdoor interference limits 6.4GHz cell coverage, due to narrow DL/UL EIRP difference (6dB/10MHz) and increased UL coverage.

O2I Scenario



O2I coverage is severely limited by the UL coverage

- Poor UL link budget due to the additional O2I Loss.

Cell and User (Data) Throughput*

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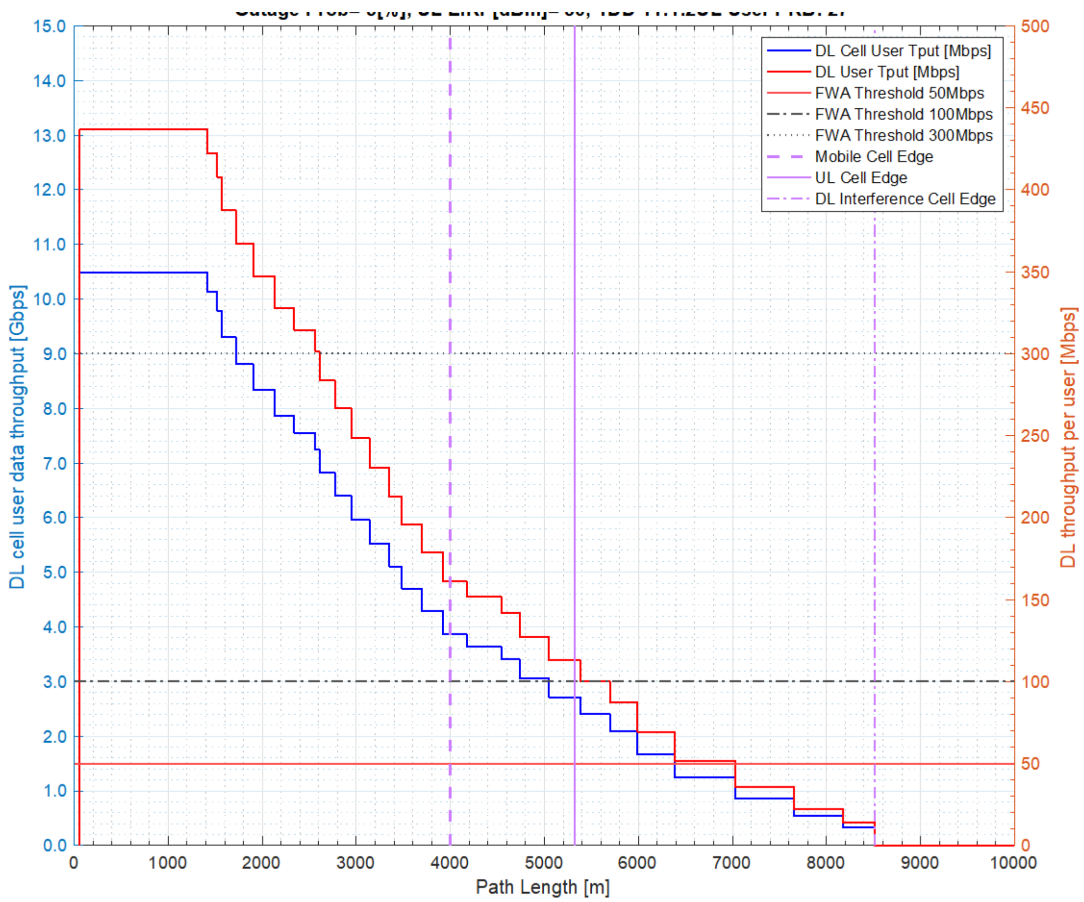
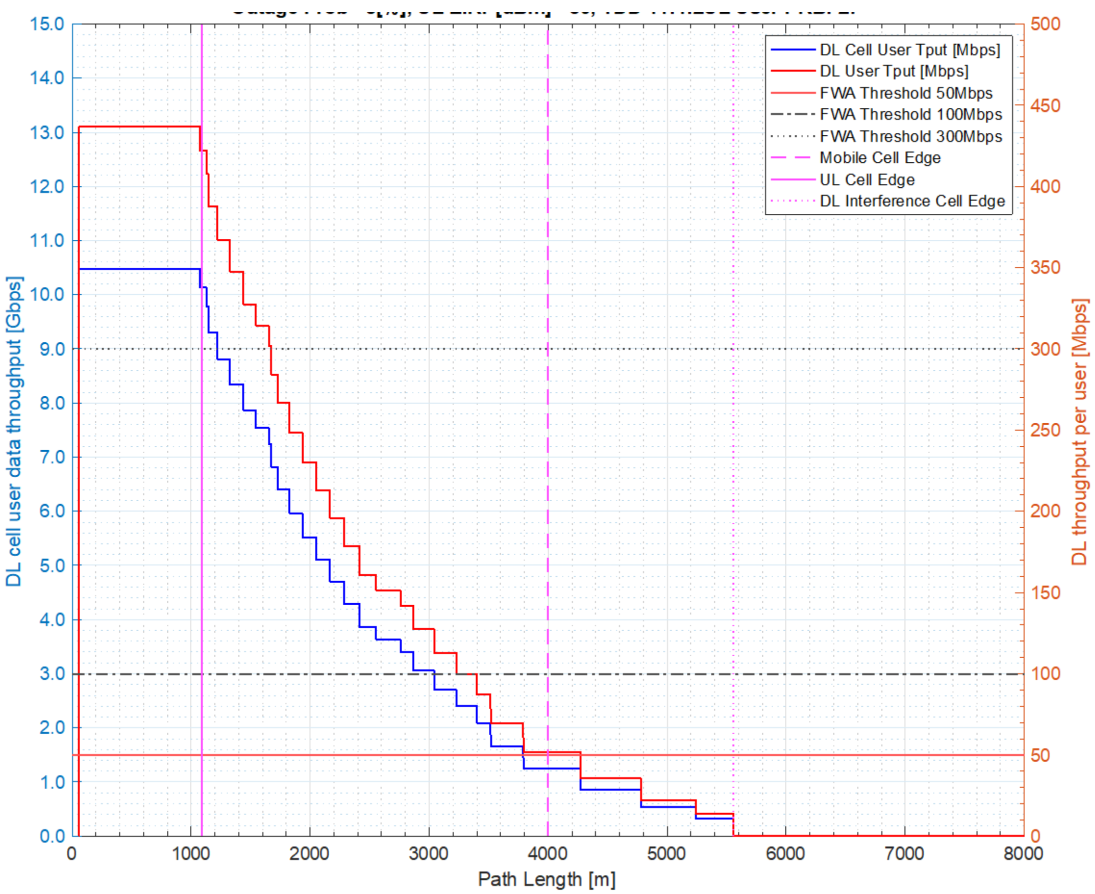
Outdoor**



O2I**



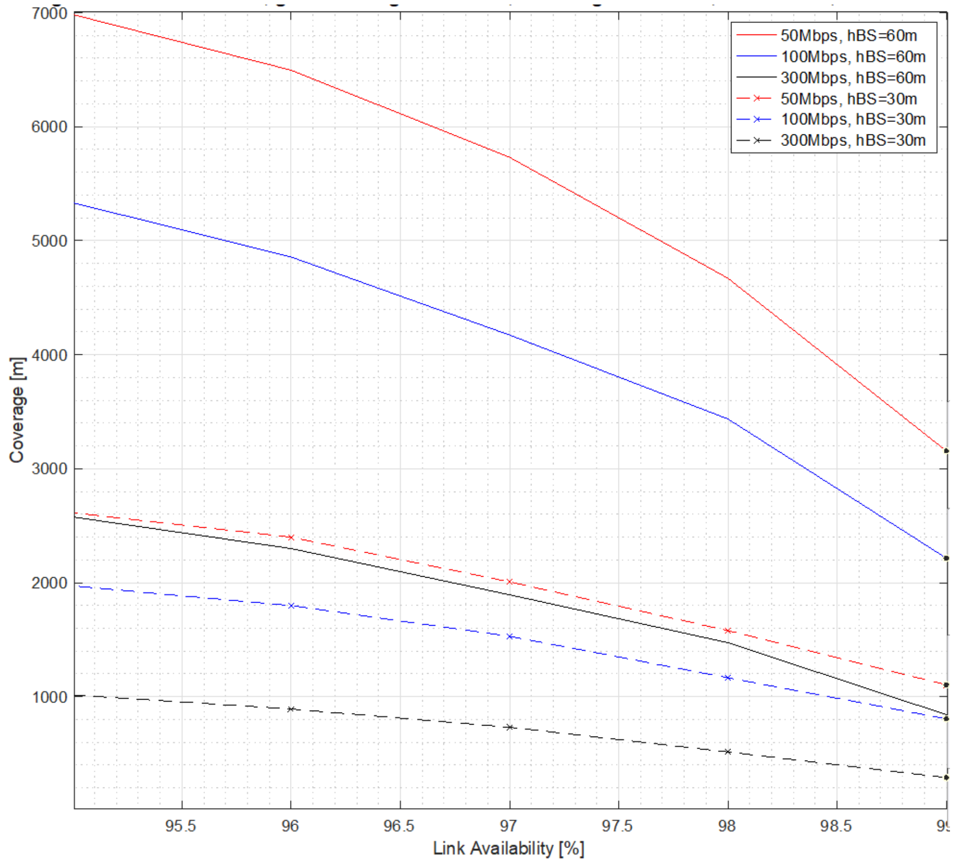
- O2I UL propagation severely limits the coverage
- 100Mbps cell coverage may be feasible** for the outdoor scenario

* hBS=60m, 3.7GHz, Link Availability=95%, NetLoad=50%. See Appendix for the other assumptions.

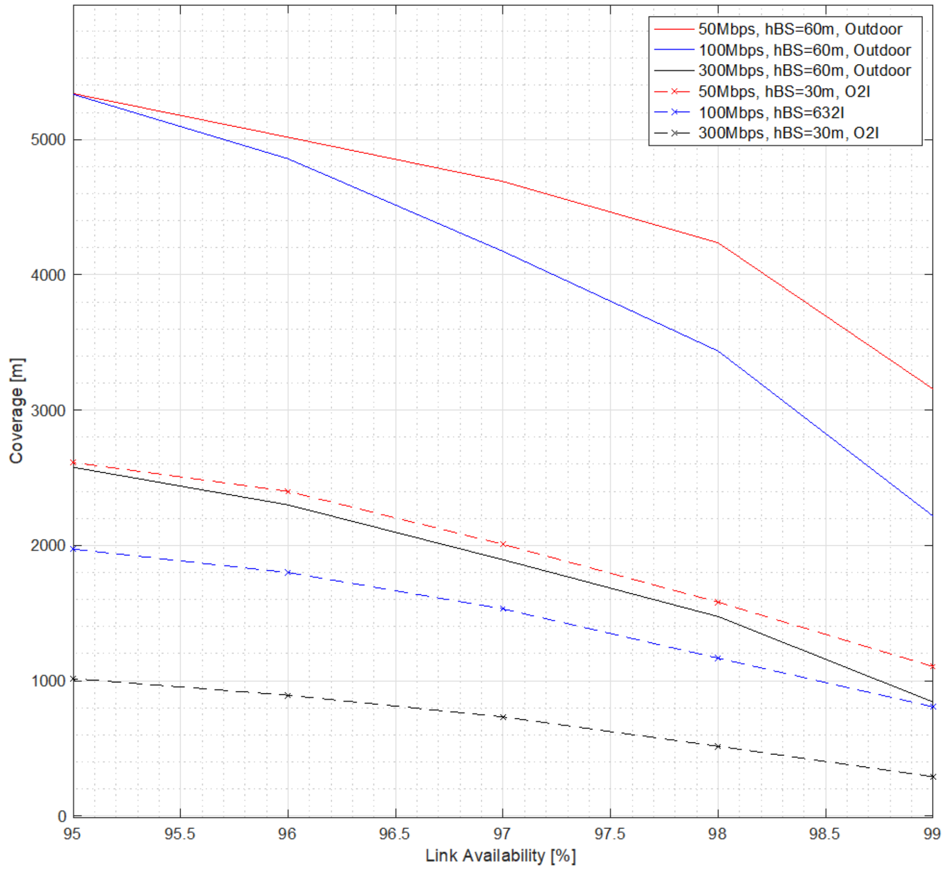
** For other frequency bands see the paper

Service Availability (Outdoor) *

DL Coverage



UL Limited Coverage



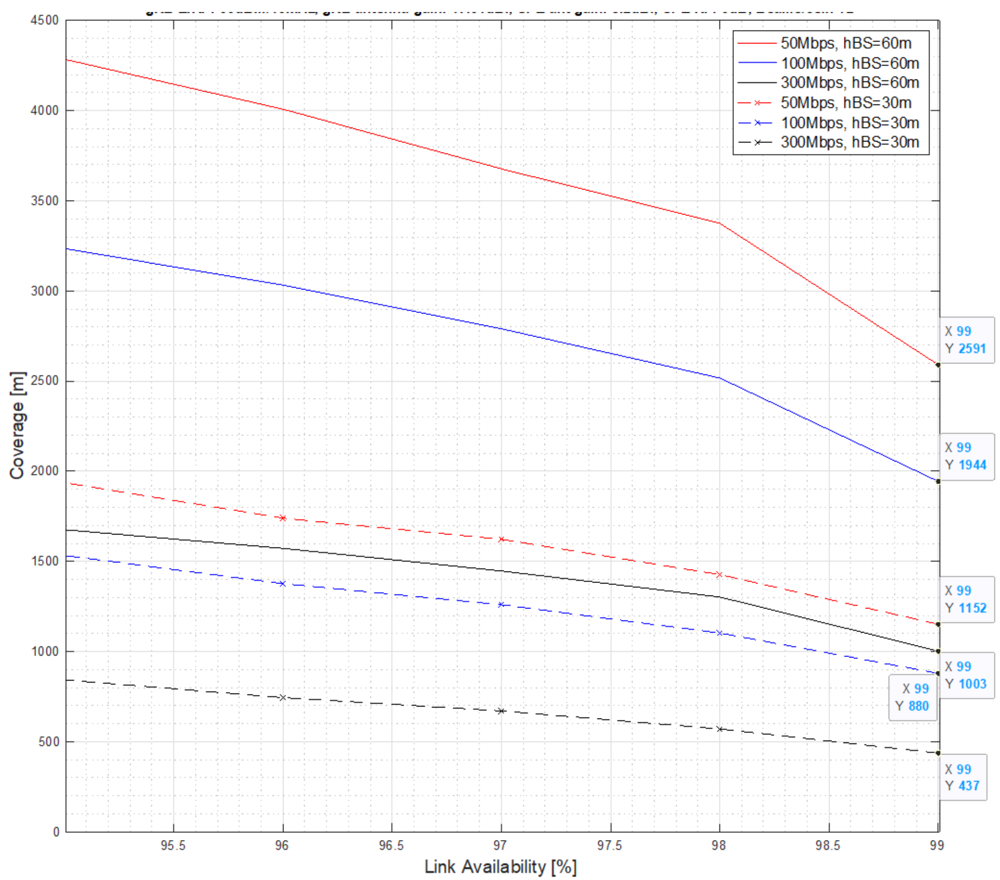
- 50 and 100Mbps coverage is subject to UL link budget limitations for link availability < 99%
- If service availability is increased from 95% to 99%, the coverage is reduced by 80.6% (50Mbps) and 90.2% (300Mbps)**

* hBS=30m and 60m, 3.7GHz. See Appendix for other assumptions.

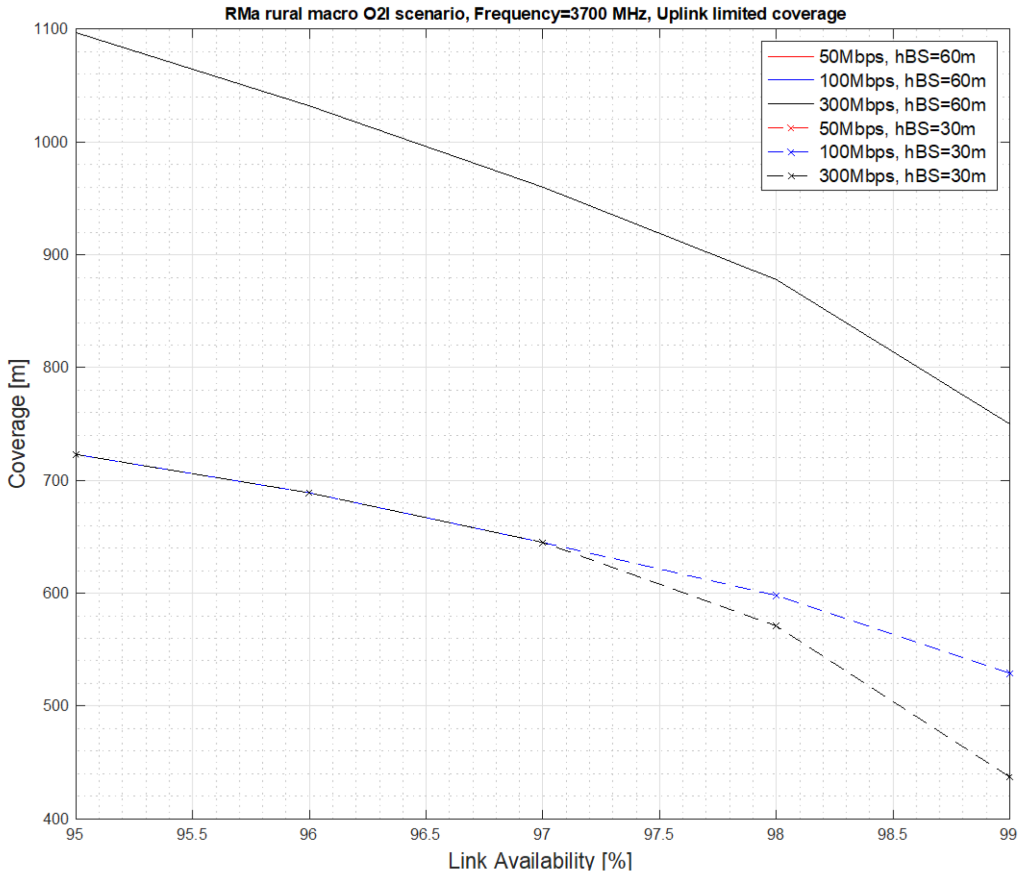
** See the paper for more a more comprehensive analysis

Link Availability (O2I) *

DL Coverage



UL Limited Coverage



- O2I coverage is severely UL limited due to the limited UL EIRP (30dBm).

* hBS=30m and 60m, 3.7GHz. See Appendix for the other assumptions.
** For the 6.4GHz case, see the paper

Rural FWA. Conclusions

- BS antenna pattern and vertical tilt are critical for optimizing Spectrum Efficiency (Frequency Reuse 1 support).
  - A BS array tilt 6dB below the horizon, decreases the system interference by 3.7dB but the user throughput is decreased only by 0.6% vs. 0^o deg Bs array tilt case.
  - The system interference could be dynamically controlled if BS array tilt is controlled as a function of network load.
- The outdoor CPE directive antenna array increases the coverage into adjacent cells and reduced the system interference impact upon the victim.
- The higher is the network load, the lower is the cell coverage and cell/user throughput. A ~50% network load could provide a reasonable cell throughput/coverage trade-off.
- DL SINR is degraded when RH height is reduced to 30m, mainly due to the reduced Mob Cell Edge (2000m) vs. 60m case.
- The 6.4GHz system operates in noise limited coverage mode (almost interference-free), due to limited EIRP.
- The large-scale fading is the driving fading/loss component impacting the link budget.
  - O2I loss could become dominant if different building materials used and/or deep inside the house CPE operation.
- O2I coverage is UL limited.
  - The indoor CPE should use a higher EIRP and/or a directive antenna array.
- All Outdoor service availability links below 99% (3.7GHz, hBS=60m) are UL limited.
- Outdoor 6.4GHz is subject to no UL limitations, due to the lower Dl/UL EIRP asymmetry (6dB).
- The higher the service availability target, the shorter is the coverage due to the higher path loss.
  - Coverage is severely reduced when service availability is increased from 95% up to 99%.
- A network planning targeting 95% service availability and 50% network load provides a reasonable cell coverage/user throughput trade off.

Rural FWA. Summary

- What speeds can be offered?
  - Outdoor 100Mbps could be provided* (2.6 and 3.7GHz) for the entire cell area.
  - O2I 50Mbps could be provided* (2.6/3.7GHz) for 100% coverage (hBS=60m) and for 33% cell coverage (hBS=30m).
  - 6.4GHz coverage could be used in dual coverage models.
- Is it reliable?
  - Service Availability 95% is achievable** (outdoor mode, 2.6/3.7GHz).
  - Higher service availability rates will increasingly reduce coverage**.
  - O2I mode is UL limited and requires higher power Fixed CPEs for better performance
- How many subscribers can rural FWA serve?
  - The modeled cases were based on 24 active users/cell***.
- Can rural FWA support broadband household usage today and in the future?
  - Yes for today, subject to a heavy set of assumptions and dependent on the target user speed.
  - Tomorrow's FWA usage is addressed by the Economics analysis (dependent on non-technical factors)
- Is it rural FWA profitable?
  - Subject to the Economics Analysis

* Service Availability=95%, NetLoad=50%, MobCellEdge(hBS 60m)=4000m, MobCellEdge(hBS 60m)=4000m
** Based on the model's assumptions
*** Cell area (hBS 60m)=50.24km, Cell Area (hBS 30m)=12.5km. Assumed oversubscription ratio 1/10

System and Cell Assumptions

SYSTEM	VALUE		CELL	VALUE
System interference	Per SLS feed		Service Availability (%)	95
Cluster of cells PLOS	As defined by [20]		Sector/Cell	3
Network traffic load (%)	25/50/75		Beam/Sector	4
O2I propagation scenario	O2I residential (TR38.901)		Carrier aggregation	1
Channel model	3GPP TR38.901		Cell edge SINR (AWGN driven) (dB)	-4.54
Number of SLS iterations	100,000		MIMO	2×2
Max body loss (dB)	Not enabled		Air layer (MIMO) EIRP reduction MIMO x2 [dB]	-3
NLOS small-scale fading	Rayleigh		O2I path length (behind outer wall) (m)	1
LOS small-scale fading	Rice, K=12 dB		O2I wall material	Wood
O2I large-scale fading	N{mean 9.35, sigma 4.4}		Glass/outer wall ratio	0.3
RF Waveform polarization angle	Cross-Polarized		Central frequency (MHz)	2596/3700/6400
NR band	n41, n77, n96		Link Adaptation	Enabled
Mobile cell edge (m)	2000 (hBS=30m); 4000 (hBS=60m)		Modulation implementation loss	3
ISD [m]	3640 (hBS=30m) 6920 (hBS=60m)		Channel Bandwidth (2.6, 3.7GHz) [MHz]	100
Frequency Reuse	1		Channel Bandwidth (2.6, 3.7GHz) [MHz]	80
Interference model	DL			

BS and CPE Array Assumptions

BS	VALUE
Antenna array	Array of Subarrays [2 2]
Subarray	4x4x2
DL MIMO rank	2x2
Antenna element	Cross-Dipole
SubArray structure	4x4x2
Antenna height above clutter (m)	30 or 60
Antenna array Tilt [º]	-15
Subarray boresight gain 3.7GHz [dBi]	17.0
Subarray Azimuth HPBW	29

CPE	VALUE
Indoor Antenna array	UCA 4×4
Outdoor Antenna array	URA 2x8x2
Outdoor antenna element	Cross-Dipole
Indoor CPE height [m]	2
Outdoor CPE height [m]	4
Outdoor array boresight Gain (3.7GHz)	16.4
Outdoor Azimuth HPBW [deg]	16.4
Indoor antenna gain (3.7GHz)	8.2
Outdoor Azimuth HPBW [deg]	360

PHY/RF Assumptions

BS	VALUE
rmsEIRP/10MHz	50 dBm/10 MHz
Active users/beam	2
Sub Carrier Spacing [kHz]	30
Slots/Subframe	2
Subframes/Frame	10
TDD ratio	11:2:1
DL Control (PCCh+DMRS) syms	2

CPE	VALUE
rmsEIRP (dBm)	30
Noise figure (dB)	6
PHY Oversampling ratio	×4
DMRS symbols	1
User symbols	1

Atmospheric/Environmental Conditions

ATMOSPHERIC		ENVIRONMENT	
ITU rain region	Disabled	Average House Height [m]	8
Slanted path profiles	Disabled	Average Street Width [m]	20
Crane rain region	B2	Average clutter height	1
Atmospheric pressure	Sea level		

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Thank you

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