May 2019

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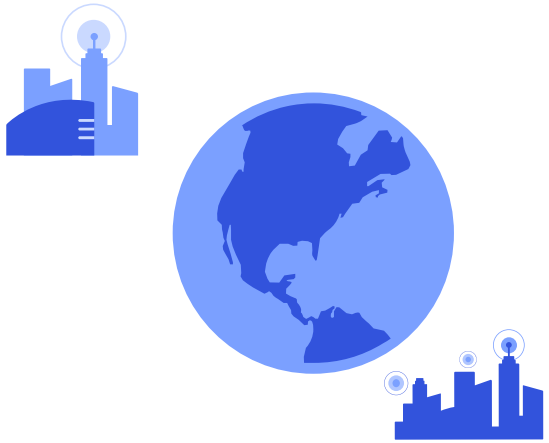
Qualcomm

5G NR mmWave outdoor and indoor deployment strategy

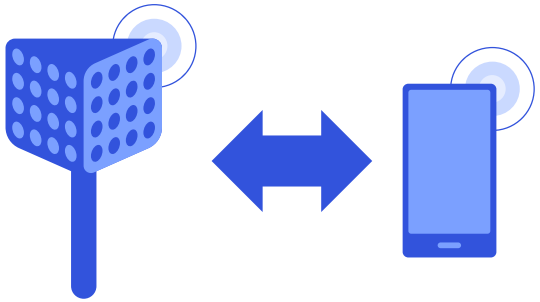
Collaborating with global operators to predict coverage

For 5G NR sub-6 GHz and mmWave



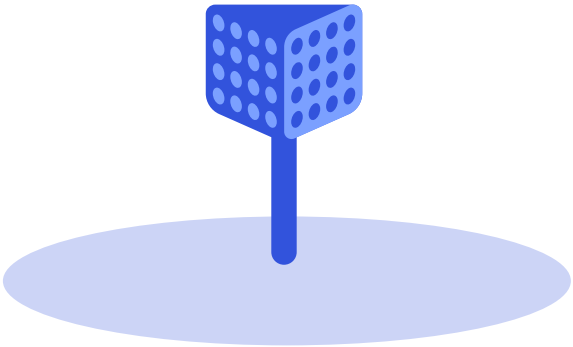
Defining geographic maps and site locations

Selecting dense urban areas of global cities that experience high mobile traffic



Establishing link budget and RF propagation model

Developing link budget for a target cell edge spectral efficiency

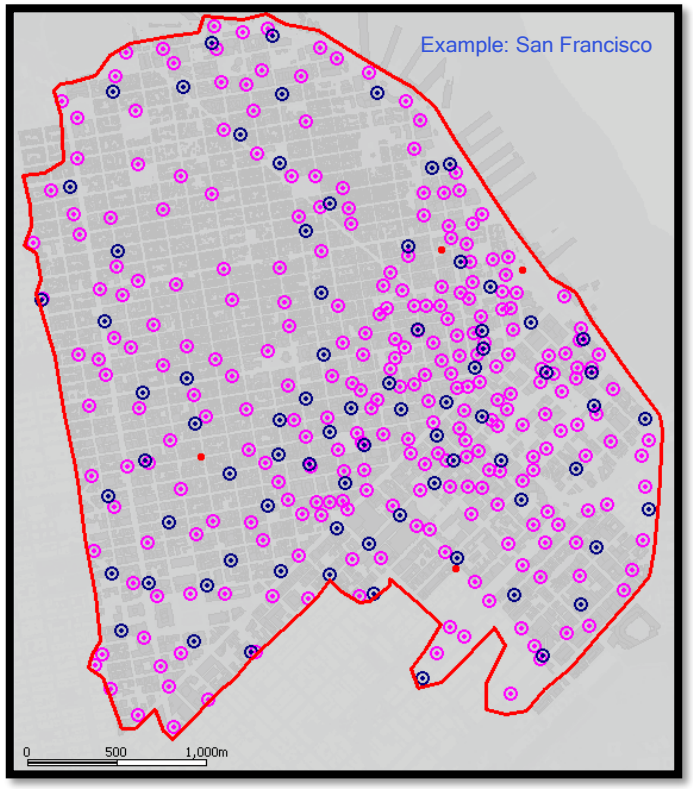


Predicting 5G NR coverage

Using a commercial planning tool to model 5G NR coverage and performance

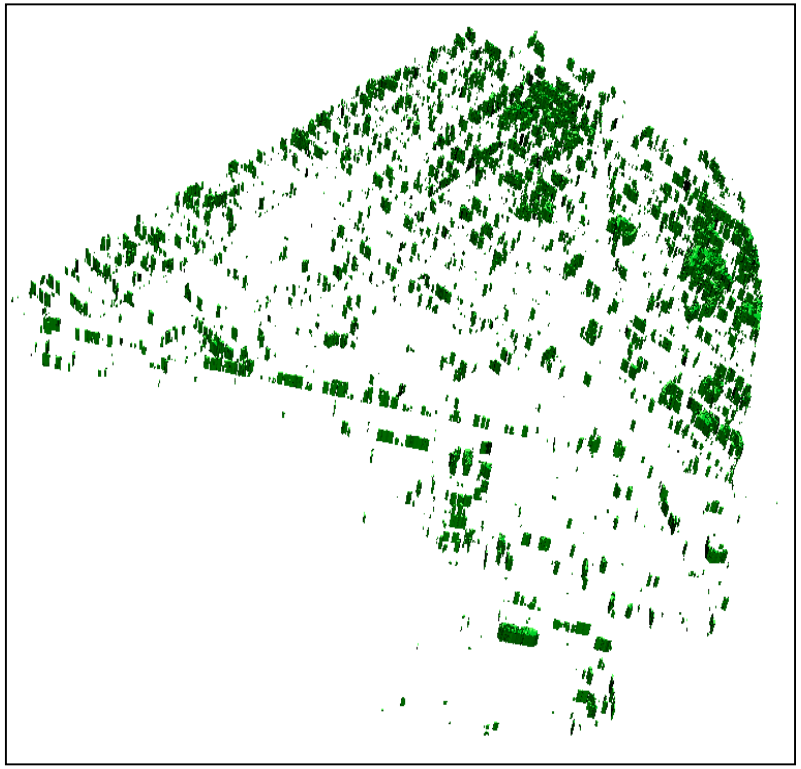
Accurately predicting 5G NR mmWave coverage

Map of existing LTE sites



3D model of buildings

3D model of foliage



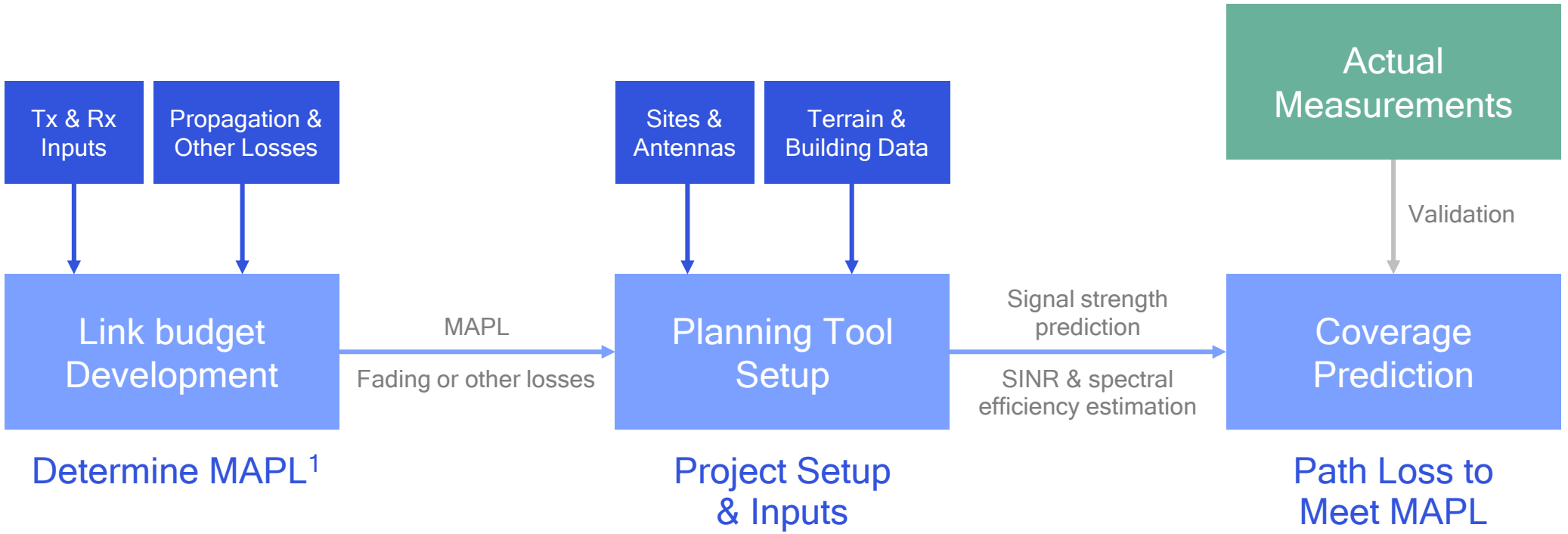
Utilizing geographically accurate 3D models
2m x 2m resolution with accurate and up-to-date information on buildings/foliage

Co-siting with 4G LTE sites in service today
Macro/small cell sites are used, including exact antenna height/orientation

Establishing baseline with potential to improve
No additional sites used in simulations (e.g., outdoor Wi-Fi) that can further improve coverage

5G NR mmWave coverage prediction methodology

Use of link budget & RF planning tool



1 Maximum Allowable Path Loss

Establishing link budget and RF propagation model

Example of high-level 5G NR mmWave link budget for outdoor deployment

5G NR mmWave link budget

28 GHz downlink outdoor coverage

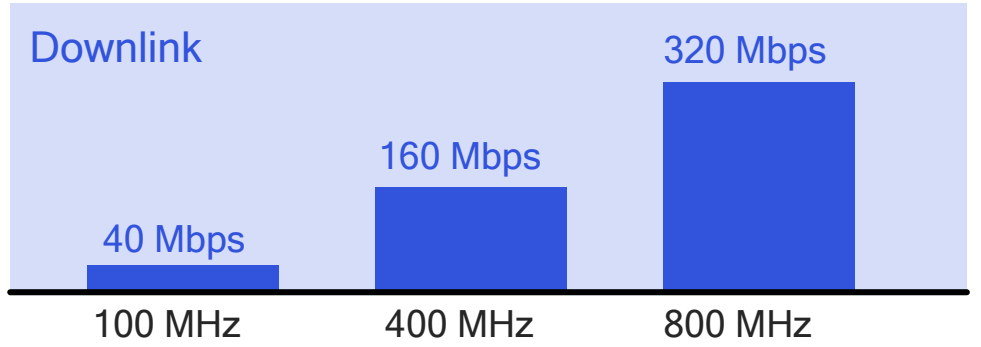
Effective Transmit Antenna Gain	26.1 dBi
Total EIRP[1] / 100 MHz	60.2 dBm
Receiver Sensitivity	-82.6 dBm[2]
Total Additional Gains & Losses	11.2 dB[3]
Maximum Allowable Path Loss (MAPL)	**131.6 dB**

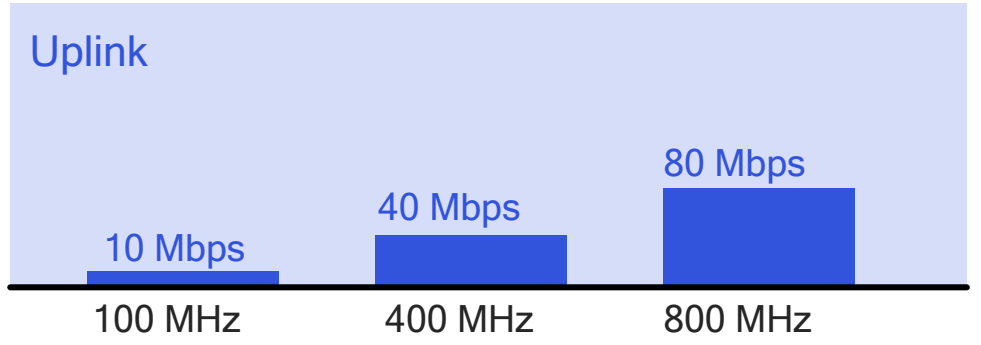
28 GHz uplink outdoor coverage

Effective Transmit Antenna Gain	6.0 dBi
Total EIRP[1] / 100 MHz	21.0 dBm
Receiver Sensitivity	-99.2 dBm[2]
Total Additional Gains & Losses	-5.3[3] dB
Maximum Allowable Path Loss (MAPL)	**125.5 dB**

Cell edge data rate

Based on target 0.4/0.1 bps/Hz DL/UL spectral efficiency[4]





1 Equivalent Isotropically Radiated Power; 2 Includes Rx noise figure of 5.7 dB; 3 Additional gains and losses include receiver effective antenna gain, hand loss, body loss, lognormal shadowing; 4 Peak throughputs achieved in actual deployments would be lower based on the DL:UL TDD configuration used in the network

Establishing link budget and RF propagation model

Example of high-level 5G NR mmWave link budget for indoor deployment

5G NR mmWave link budget

28 GHz downlink indoor coverage

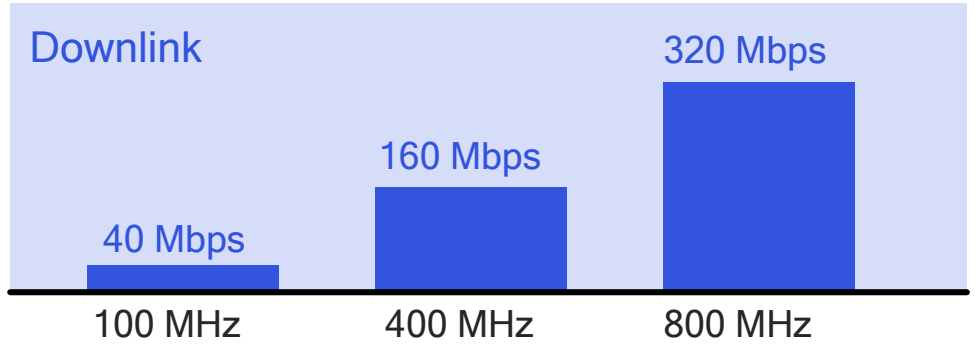
Total EIRP[1] / 100 MHz	52.0 dBm
Receiver Sensitivity	-82.6 dBm[2]
Total Additional Gains & Losses	11.2 dB[3]
Additional crowd loss	8 dB
Maximum Allowable Path Loss (MAPL)	**115.4 dB**

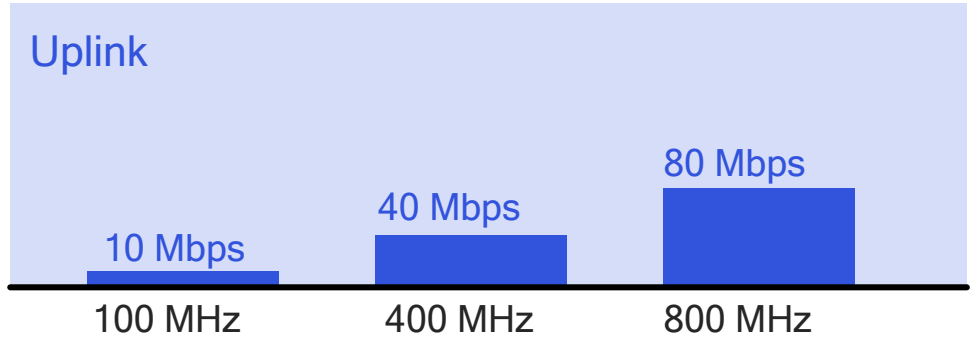
28 GHz uplink indoor coverage

Total EIRP[1] / 100 MHz	20.1 dBm
Receiver Sensitivity	-100.3 dBm[2]
Total Additional Gains & Losses	-4.9[3] dB
Additional crowd loss	8 dB
Maximum Allowable Path Loss (MAPL)	**117.3 dB**

Cell edge data rate

Based on target 0.4/0.1 bps/Hz DL/UL spectral efficiency[4]



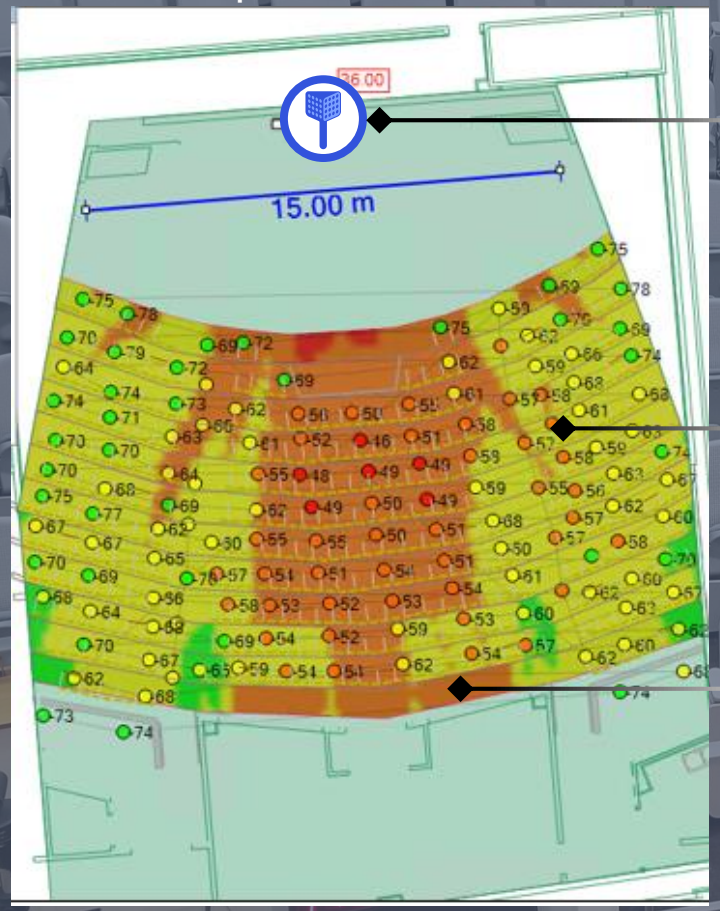


1 Equivalent Isotropically Radiated Power; 2 Includes Rx noise figure of 5.7 dB; 3 Additional gains and losses include receiver effective antenna gain, hand loss, body loss, lognormal shadowing; 4 Peak throughputs achieved in actual deployments would be lower based on the DL:UL TDD configuration used in the network

Performing actual measurements to develop accurate models

Modeling tuning using single-tone CW[1] for coverage measurements

Example: indoor stadium

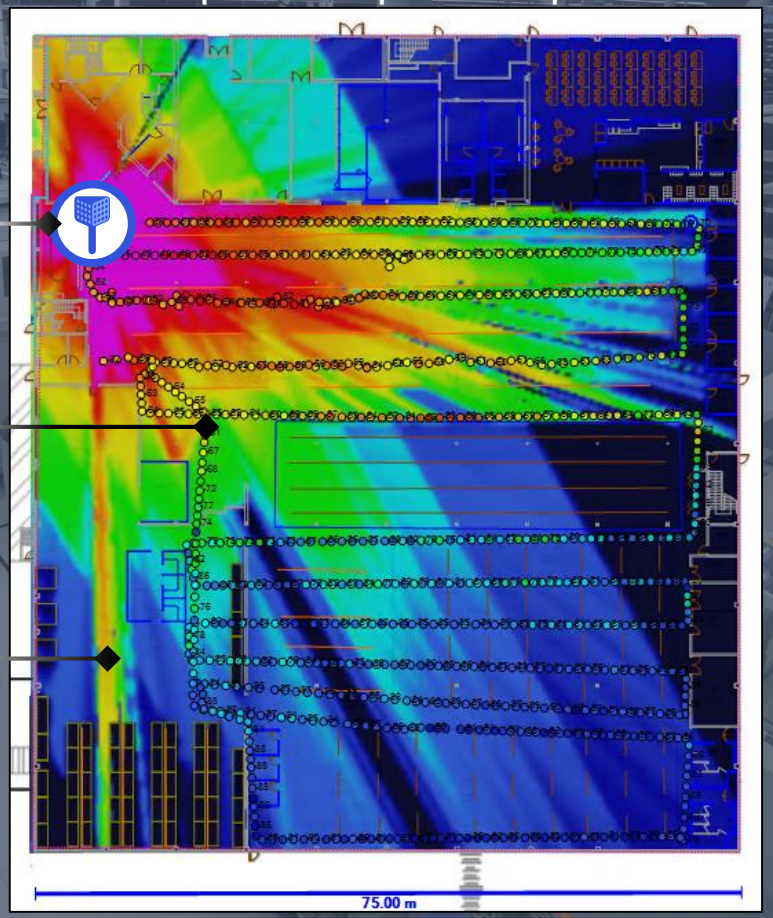


mmWave antenna
EIRP of 36dBm - 47dBm per polarization depending on beam shape

Actual measurements
Signal strength measured 1.5m above ground

Predicted coverage
Coverage from RF planning tool, with model tuned to match actual measurements

Example: enterprise shop floor



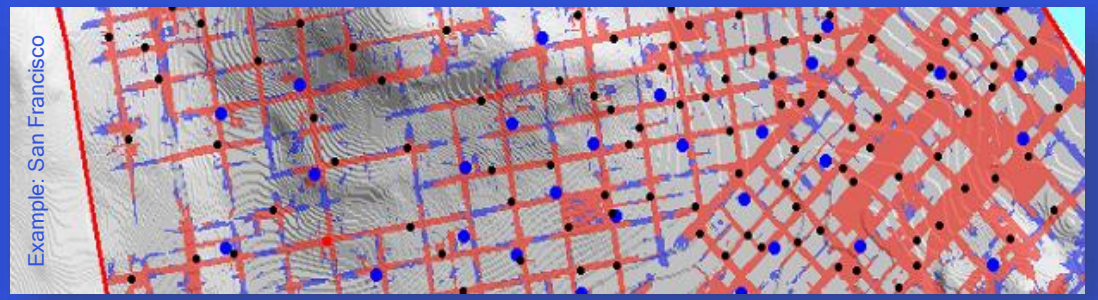
1 Continuous Wave

Empowering the 5G ecosystem

Advanced 5G Simulations

for network planning based on our extensive over-the-air testing and channel measurements

Collaborating with global operators to demonstrate significant 5G NR mmWave capacity & coverage



62%
Outdoor coverage

5x
Increase in capacity[1]

320 Mbps
Cell edge burst rate[2]

1.4 Gbps
Median burst rate

- Significant outdoor coverage, user experience and capacity gains utilizing existing LTE infrastructure (including LAA small cells for Gigabit LTE)
- Outdoor coverage only; frees up sub-6 GHz resources for out-to-indoor capacity
- Dual connectivity with LTE or aggregation with sub-6 GHz 5G NR ensures complete coverage

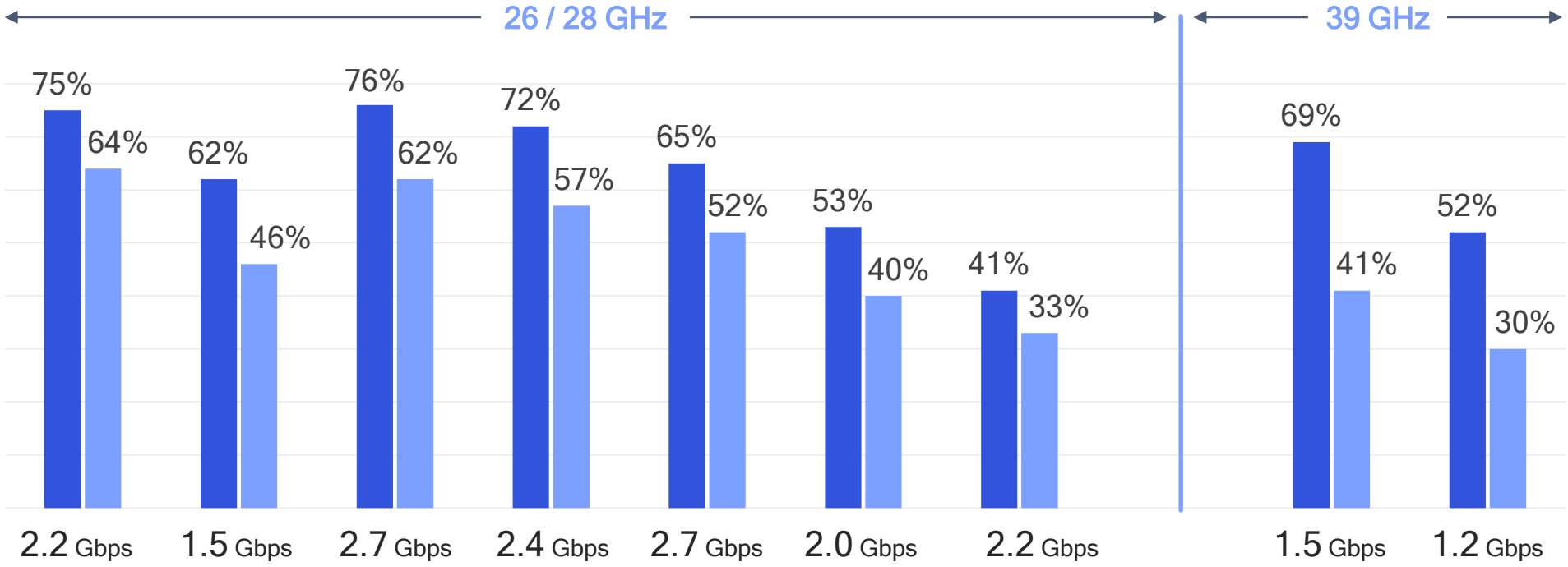
1 Compared to Gigabit LTE only with additional 800 MHz spectrum in 28 GHz; 2 Cell edge defined as 0.4 bps/Hz = 320 Mbps for 8x100 MHz channel bandwidth

Downlink

Uplink

Coverage %

Co-siting with LTE



Median Downlink Burst Rate (Gbps)

Site density (per km^2)	US City 1	US City 2	Korean City 1	Hong Kong	Japan City 1	Russia City 1	Europe City 1	US City 1	US City 2
Total	48	36	41	39	28	26	28	48	36
Macro	0	8	33	39	28	26	7	0	8
Small	48	28	8	0	0	0	21	48	28

Simulations assumptions: Based on MAPL (maximum allowable path loss) analysis with ray tracer propagation model and city/area specific models; minimum 0.4 bps/Hz and 0.2 bps/Hz for downlink data and control, out-to-out coverage only; Using 800 MHz DL bandwidth and 100 MHz uplink bandwidth with 7:1 DL:UL TDD

Significant 5G NR mmWave outdoor coverage via co-siting

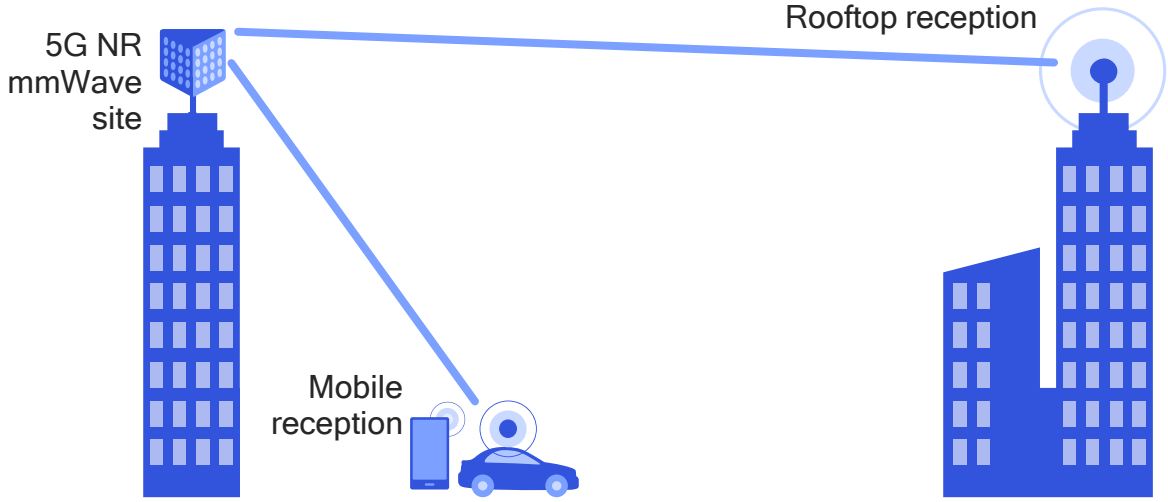
Simulations based on over-the-air testing and channel measurements

Deploying 5G NR mmWave for fixed wireless access

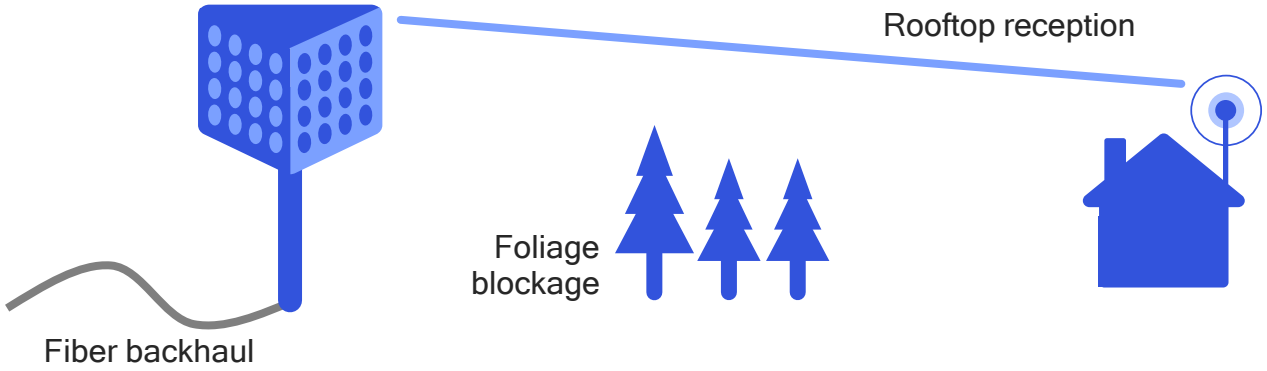
Co-siting 5G NR mmWave antennas with existing cellular LTE infrastructure

- Cost effective provision of fiber-like performance
- Rapid deployment in areas currently unserved by broadband
- Reuse of existing in-building distribution infrastructure in urban scenarios

Dense urban deployment



Suburban deployment



Co-siting with existing LTE sites to achieve significant coverage

80% of buildings with 1.6 Gbps downlink, 150 Mbps uplink

Equates to 400 Mbps DL, 10 Mbps UL service in homes[1]

Further densification to realize higher coverage and performance

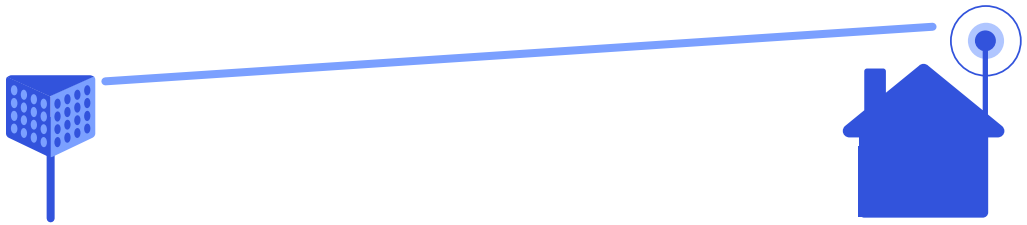
1 Using 10 story buildings with 4 families per floor in this cluster and assuming a 50% penetration with typical activity factors seen for DL and UL usage

5G NR mmWave fixed wireless access for urban city

Example: Metropolitan city in Latin America

- ~7 square km with dense urban morphology
- ~10m average building height with 90% buildings lower than 30m
- 149 LTE/5G NR mmWave small cells with ~300m ISD[1]

Roof-top antenna reception



- 28 GHz band – 800MHz DL, 100 MHz UL
- 256x2 element antenna with beamforming
- 64-QAM and 2x2 MIMO
- 3:1 DL:UL TDD ratio

1 Inter-site distance; Coverage simulation based on MAPL (maximum allowable path loss) analysis with ray tracer propagation model and measured material and propagation loss; 2 Using 10 story buildings with 4 families per floor in this cluster and assuming a 50% penetration with typical activity factors seen for DL and UL usage

Co-siting with existing LTE sites to achieve significant coverage

80% of buildings with 1.6 Gbps downlink, 150 Mbps uplink

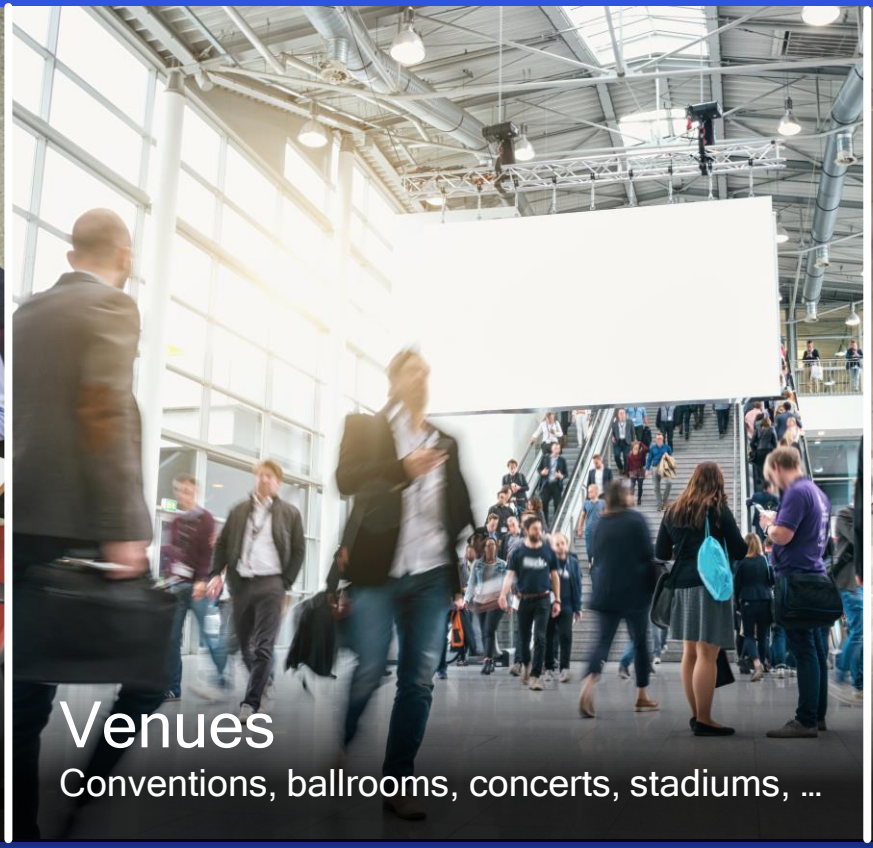
Equates to 400 Mbps downlink, 10 Mbps uplink services in homes[2]

Opportunity to further densify for higher coverage and performance

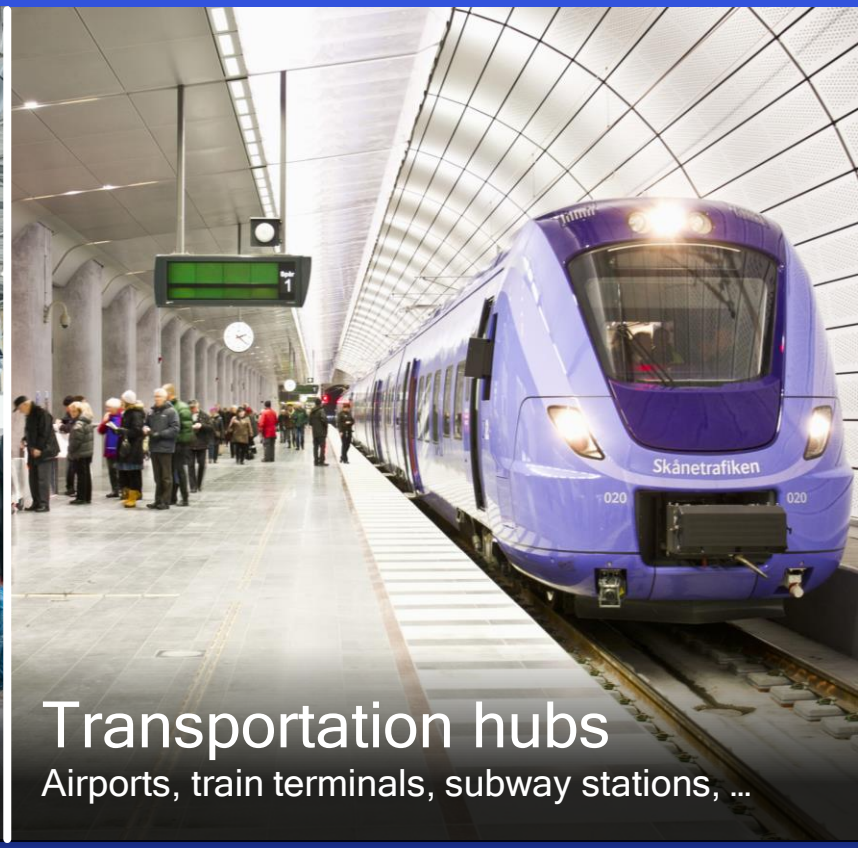
Extending 5G NR mmWave to indoor deployments

For new and enhanced experiences complementing existing Wi-Fi services

Enterprises
Offices, meeting rooms, auditoriums, …



Venues
Conventions, ballrooms, concerts, stadiums, …



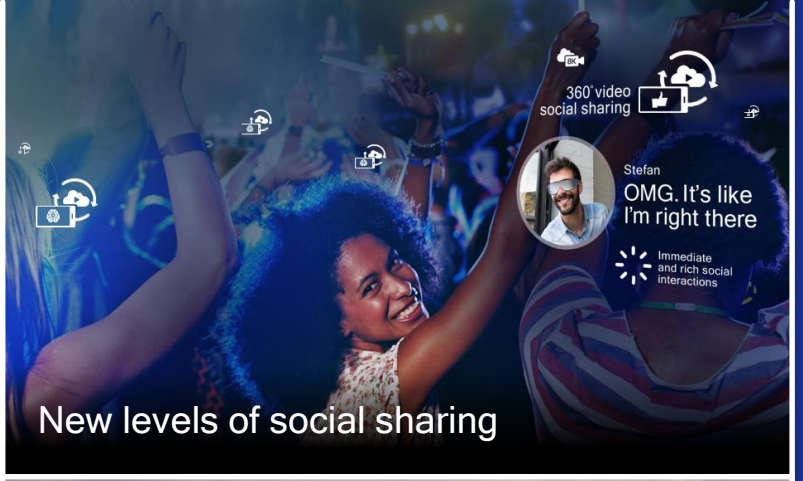
Transportation hubs
Airports, train terminals, subway stations, …

Bringing multi-Gigabit speed, low latency, and virtually unlimited capacity

Supporting devices beyond smartphones – tablets, XR, always-connected laptops

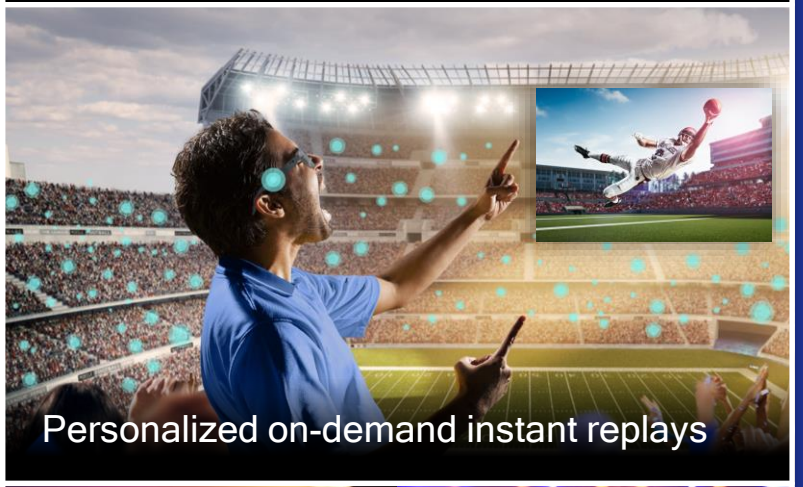
Leveraging existing Wi-Fi or cellular infrastructure by co-siting small cells


Rich media and interactive entertainment

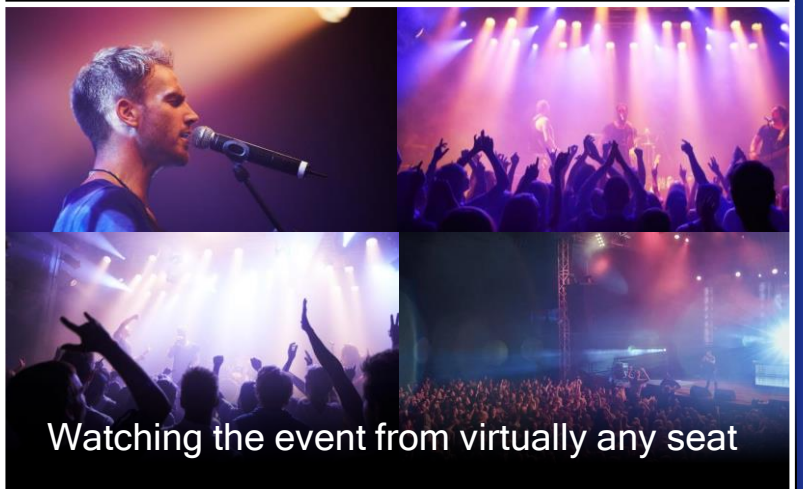


New levels of social sharing


Following your favorite player on the field


Personalized on-demand instant replays


Wireless screens virtually everywhere

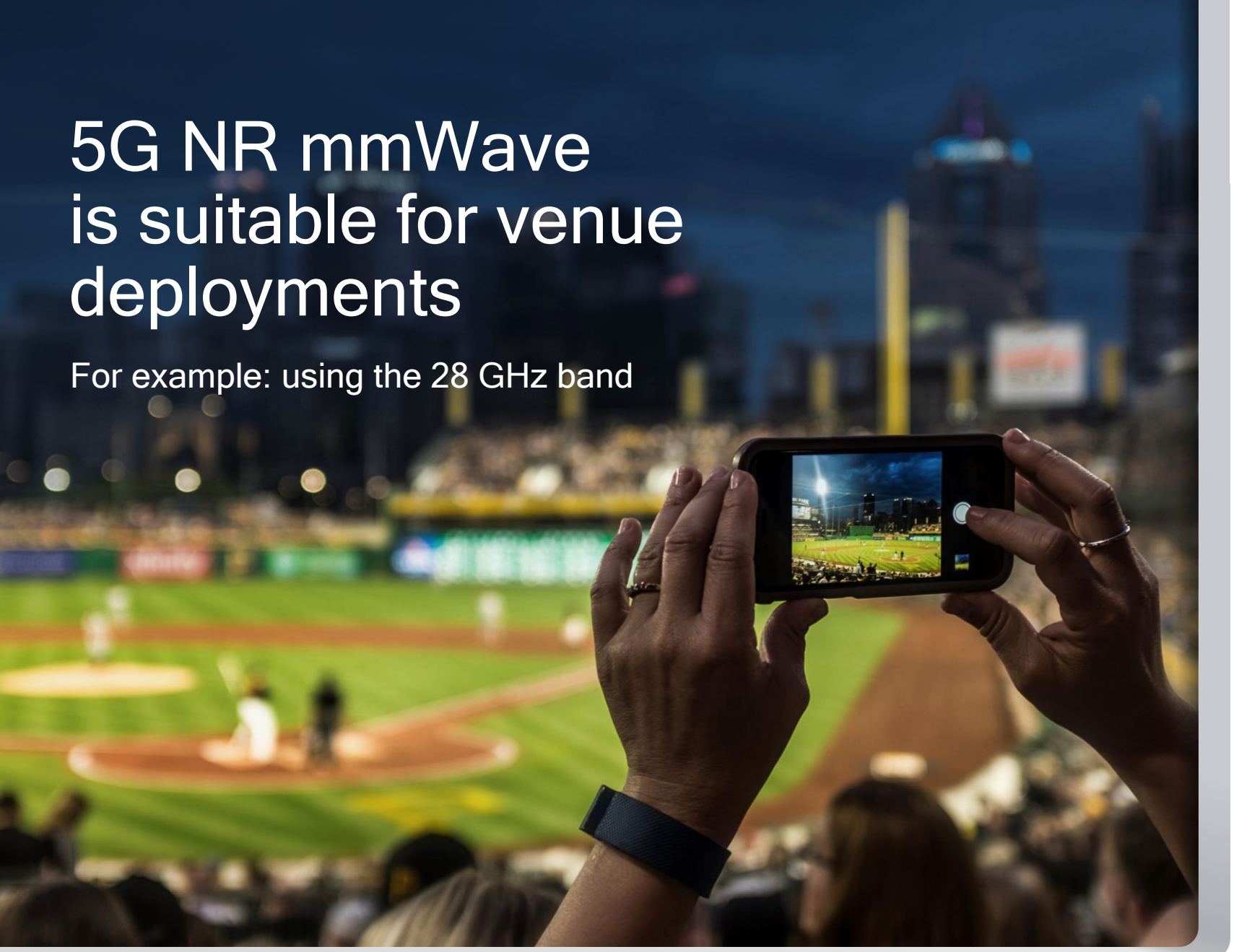

Watching the event from virtually any seat

5G NR mmWave for dense venue deployments

- Multi-Gigabit speeds with virtually unlimited capacity
- Personalized experiences exclusively at the venue
- New monetization opportunities during and after the event
- Easy and secure access over carrier networks

5G NR mmWave is suitable for venue deployments

For example: using the 28 GHz band



Excellent capacity solution

- Better antenna directivity
- Higher spectral efficiency
- Superior beamforming

Typical mmWave coverage challenges not of major concern

- No in-building penetration losses
- Rain and foliage attenuation is not a factor
- Signal decay likely not significant for short ranges

* Comparing to typical LTE deployments

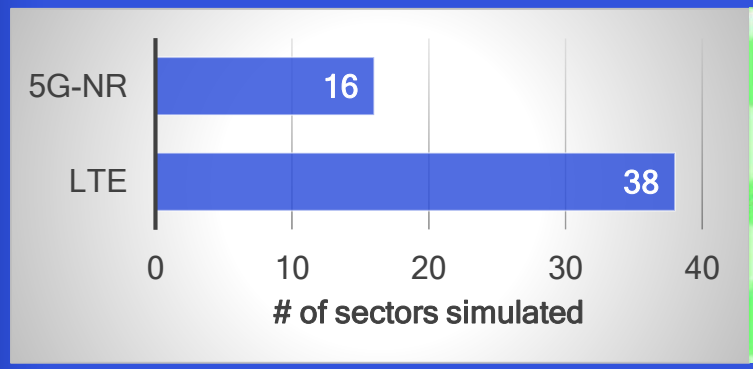
Predicting 5G NR mmWave coverage for

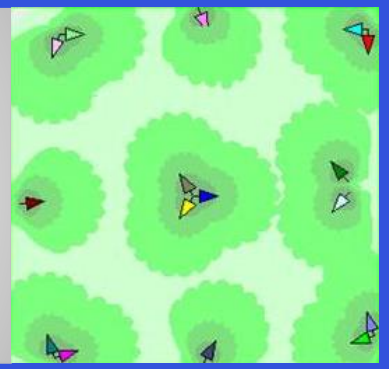
Music Concert Venue

based on actual venue layout and network model

1 Cell edge defined as 0.4 bps/Hz
2 Comparing Gigabit LTE using 50 MHz spectrum with an initial 5G-NR mmWave deployment using 800 MHz spectrum and 7:1 DL-UL configuration and 10% 5G-NR capable device penetration

Deploying 5G NR mmWave for dense outdoor venues





95%
Outdoor coverage[1]

10x
Increase in capacity[2]

233Mbps
Median burst rate[2]

100x
Improvement in throughput[2]

- Leveraging existing LTE infrastructure that includes LAA small cells for Gigabit LTE
- Initial deployments can deliver significantly higher capacity even with fewer sectors (i.e., mmWave at a subset of LTE sites)
- Enabling new mobile experiences powered by multi-Gbps throughput and ultra-low latency

Deploying 5G NR mmWave for indoor convention centers

Co-siting 5G NR mmWave antennas with existing cellular / Wi-Fi deployments[1]

Achieve downlink and uplink coverage comparable to Wi-Fi

Realize multi-Gigabit median burst rate with much wider bandwidths (e.g., 800 MHz)

Complementing indoor Wi-Fi deployments

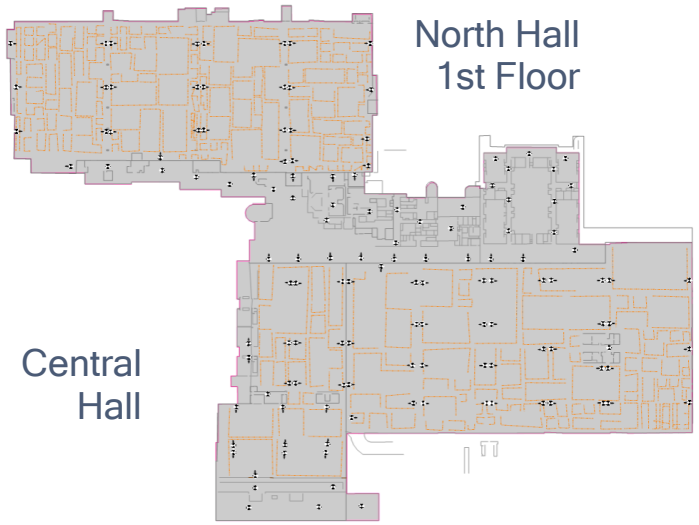
Higher density deployment

Las Vegas Convention Center

~1.3 million square feet

134 LTE/3G DAS antennas[2]

~9.8k square feet per DAS antenna



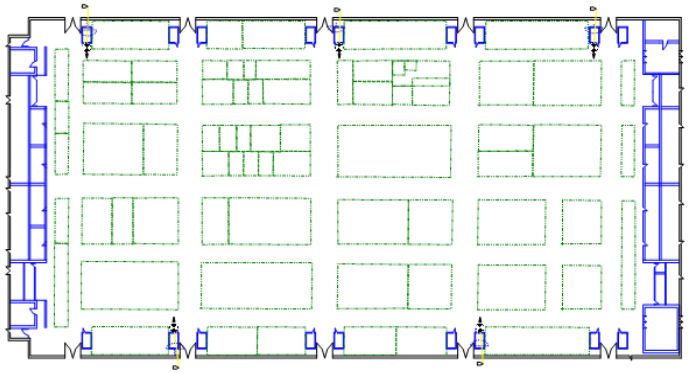
Lower density deployment

Convention Center

~180k square feet

5 Wi-Fi APs

~36k square feet per Wi-Fi AP



1 AP: Access Point and DAS: Distributed Antenna System; 2 LVCC has an even denser ~1100 Wi-Fi AP deployment

5G NR mmWave for higher density convention centers

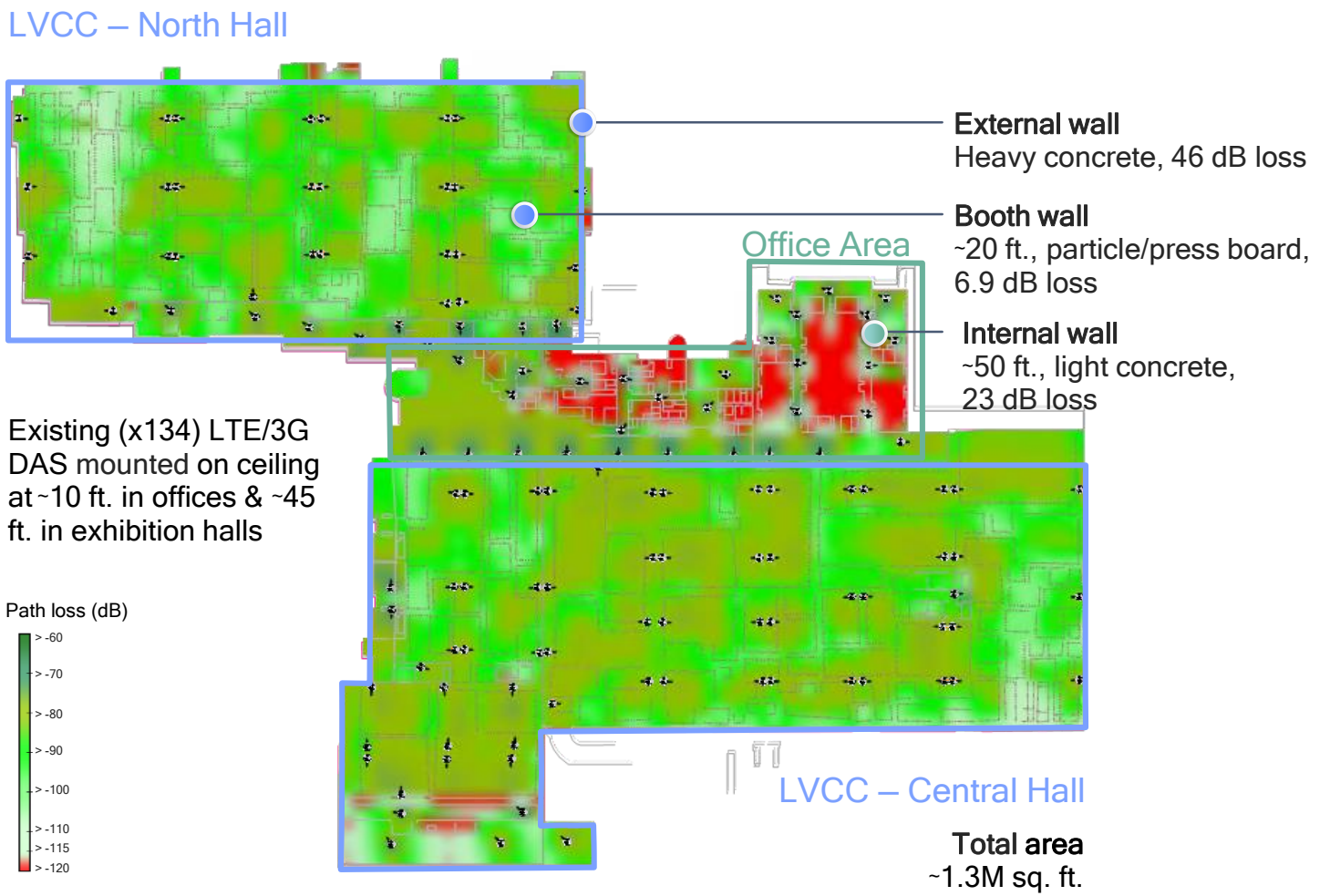
Co-siting 5G NR mmWave gNodeB antennas with 3G/LTE DAS

Achieving significant coverage at 28 GHz[1]

- Downlink coverage of **~95%** with 115 dB MAPL[2]
- Uplink coverage of **~95%** with 117 dB MAPL

Realizing multi-gigabit user experience[3]

- Downlink median burst rate of **5 Gbps**



1 Coverage simulation based on MAPL (maximum allowable path loss) analysis with ray tracer propagation model and measured material and propagation loss; minimum 0.4/0.1 bps/Hz for downlink/uplink data and control; 2 Maximum Allowable Path Loss; 3 Using 800 MHz DL bandwidth and 100 MHz uplink bandwidth with 7:1 DL:UL TDD

5G NR mmWave for lower density convention centers

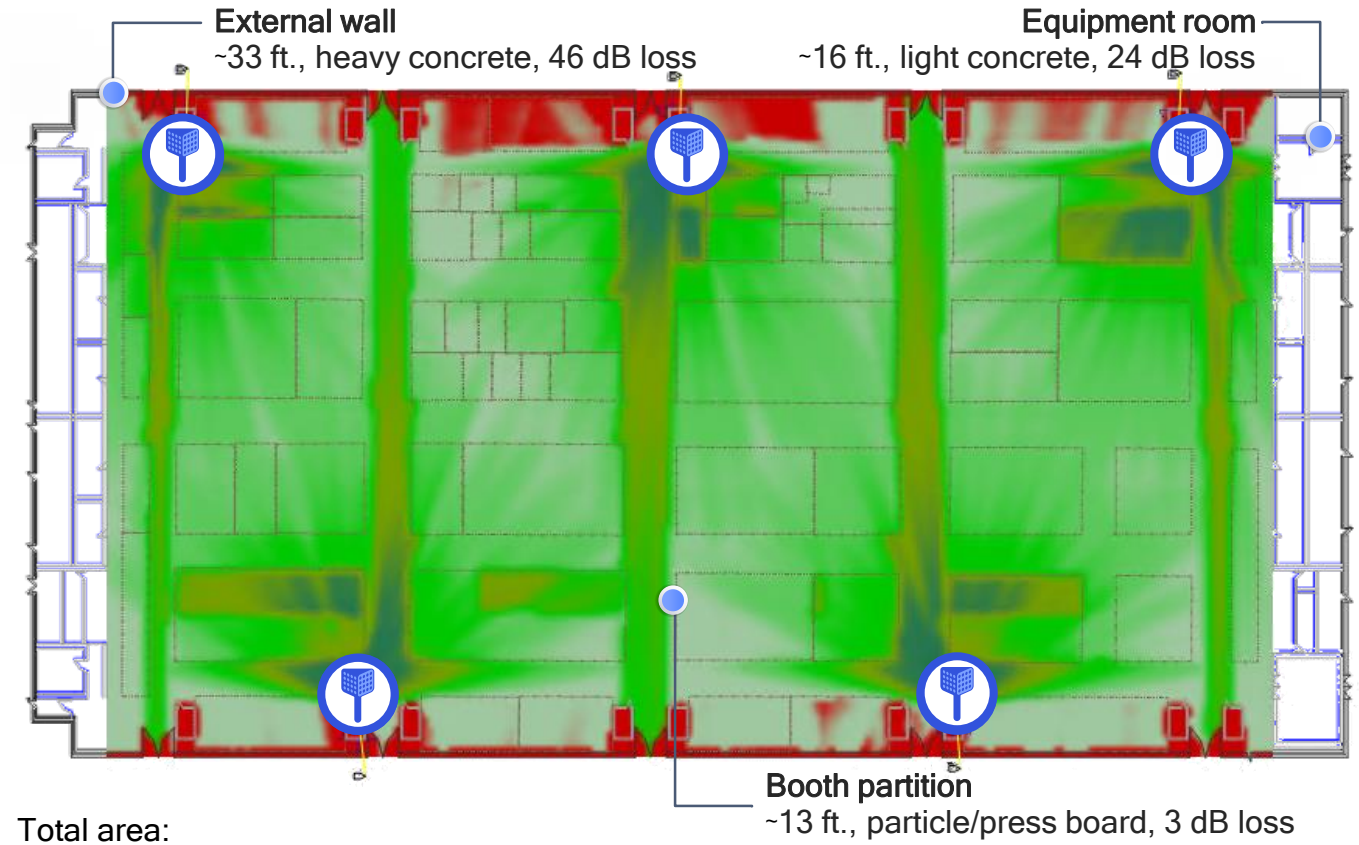
Co-siting 5G NR mmWave gNodeB antennas with existing Wi-Fi access points

Achieving significant coverage at 28 GHz[1]

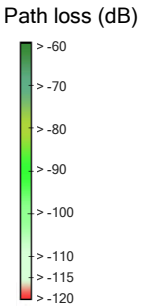
- Downlink coverage of **~87%** with 115 dB MAPL[2]
- Uplink coverage of **~92%** with 117 dB MAPL

Realizing multi-gigabit user experience[3]

- Downlink median burst rate of **1.5 Gbps**



Total area:
~180k sq. ft.



Existing Wi-Fi APs mounted on ceiling at 20 ft.

Co-sited 5G NR mmWave antenna locations (each 128 x 2 elements & 16 horizontal beams)

1 Coverage simulation based on MAPL (maximum allowable path loss) analysis with ray tracer propagation model and measured material and propagation loss; minimum 0.4/0.1 bps/Hz for downlink/uplink data and control; 2 Maximum Allowable Path Loss; 3 Using 400 MHz DL bandwidth and 100 MHz uplink bandwidth with 7:1 DL:UL TDD

Predicting 5G NR mmWave coverage for indoor stadiums

Catwalk antenna location (i.e., higher mount) is optimum for mmWave coverage

Achieving significant coverage at 28 GHz[1]

- Downlink coverage of **100%** with 110 dB MAPL[2]
- Uplink coverage of **100%** with 112 dB MAPL[2]

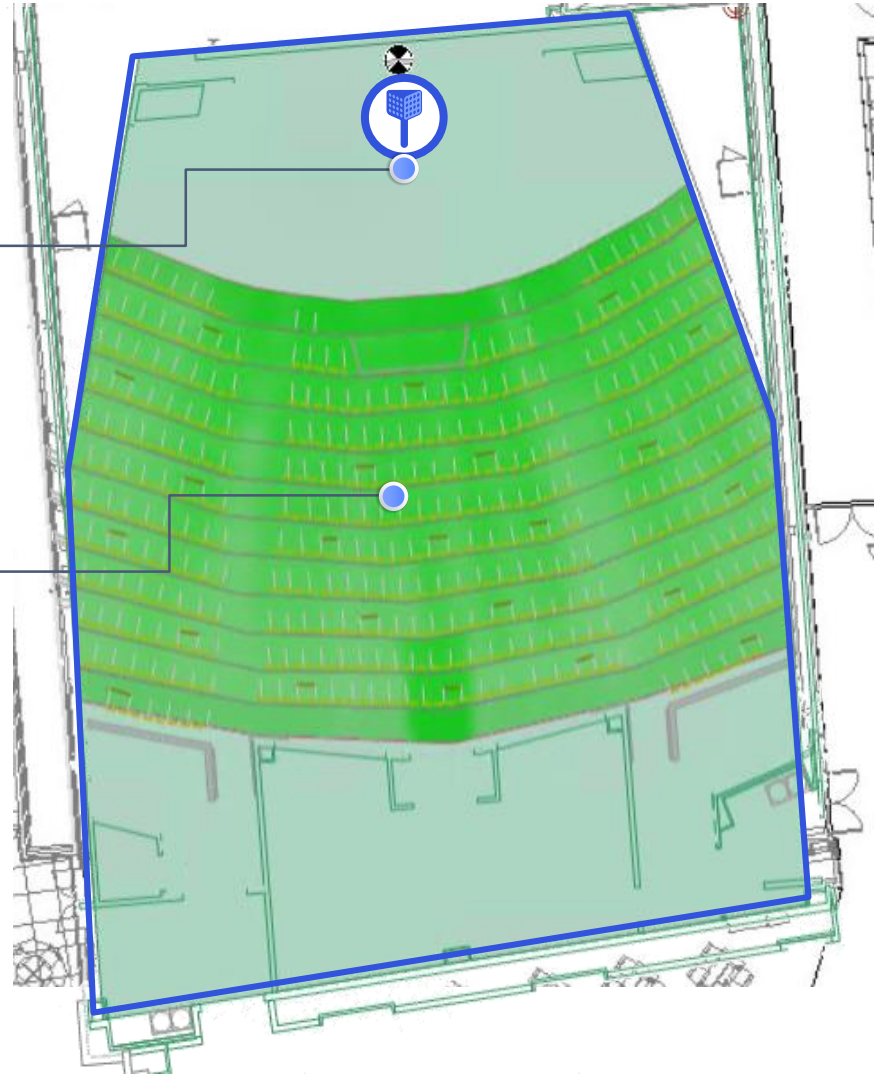
Realizing multi-gigabit user experience[3]

- Downlink median burst rate of **4.0 Gbps**

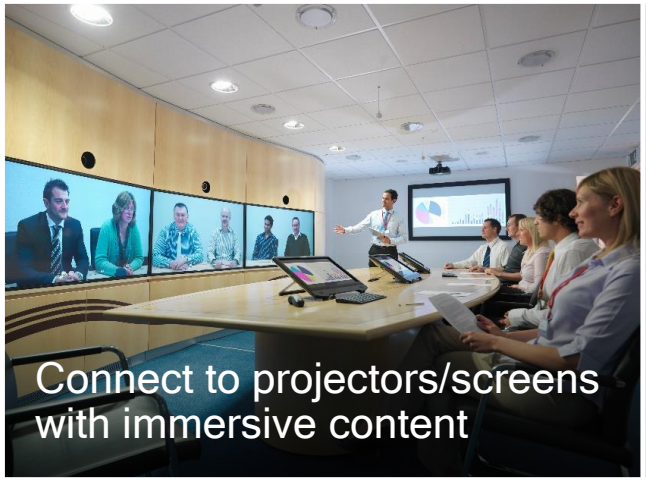
Catwalk antenna
6 meters above ground, 128 x 2 elements & 16 horizontal beams

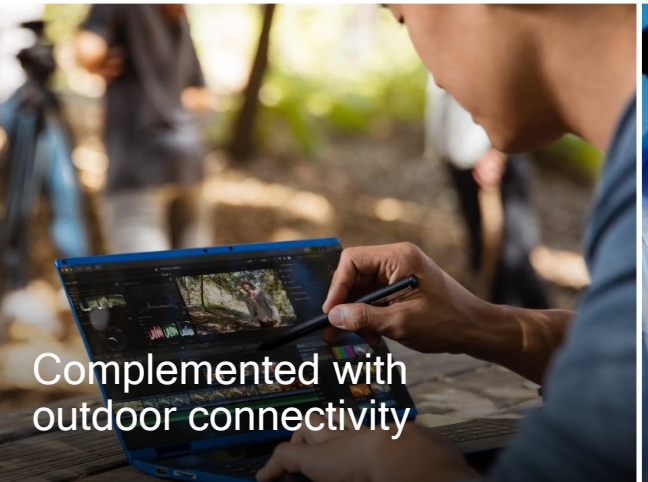
Stadium seating
Crowd loss is likely dependent on seating area slope with respect to mmWave antenna height

Total area:
~3000 sq. ft.



1 Coverage simulation based on MAPL (maximum allowable path loss) analysis with ray tracer propagation model and measured material and propagation loss; minimum 0.4/0.1 bps/Hz for downlink/uplink data and control; 2 Including additional crowd loss of 5 dB (13 dB total) due to multiple bodies blocking in standing crowd; 3 Using 800 MHz DL bandwidth and 100 MHz uplink bandwidth with 7:1 DL:UL TDD





Enterprise networks: 5G NR mmWave + Wi-Fi

Always connected laptops and tablets[1]

- Multi-Gigabit speeds with virtually unlimited capacity
- Reuse licensed spectrum– in-/outside mmWave isolation
- Private 5G NR indoor network with cellular grade security

1 Requires network connectivity; 2 Expected coverage in typical office environments, actual coverage and performance depends on propagation and deployment.

Deploying 5G NR mmWave for indoor enterprises

Co-siting 5G NR mmWave antennas with existing Wi-Fi deployments[1]

- Achieve downlink and uplink coverage comparable to Wi-Fi using 1:1 or partial co-site
- Realize multi-Gigabit median burst rate with much wider bandwidths (e.g., 800 MHz)
- Complementing indoor Wi-Fi deployments

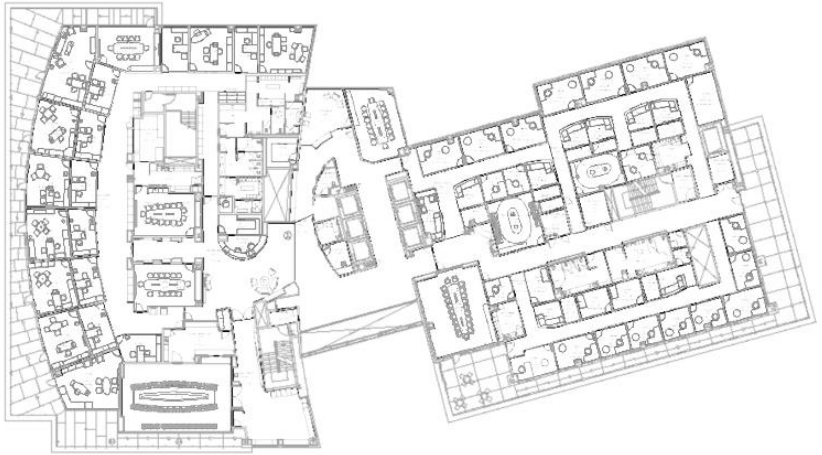
Higher density deployment

Offices, meeting rooms, and boardroom

~27.6k square feet

20 Wi-Fi APs

~1.4k square feet per Wi-Fi AP



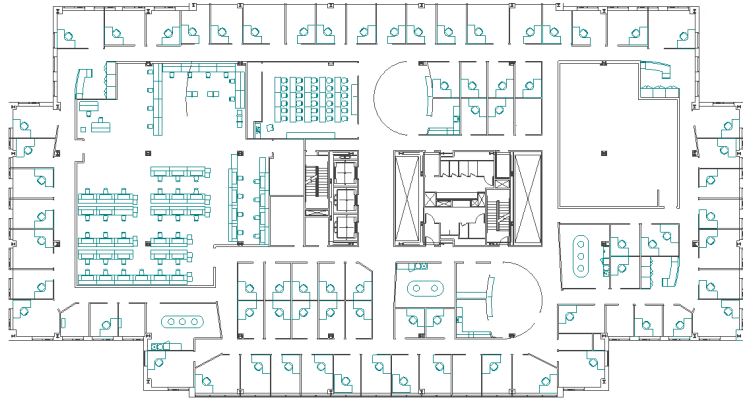
Lower density deployment

Ceiling-to-floor walled offices

~24.6k square feet

7 Wi-Fi APs

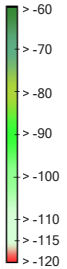
~3.5k square feet per Wi-Fi AP



1 Can include AP: Access Point and DAS: Distributed Antenna System

Total area:
~27.6k ft^2

Path loss (dB)



Existing Wi-Fi access point locations – co-sited with 5G NR mmWave antenna locations (each 128x2 elements & 16 horizontal beams)

5G NR mmWave for higher-density indoor enterprise

Co-siting 5G NR mmWave gNodeB antennas with existing Wi-Fi access points

Existing Wi-Fi access points on ceiling

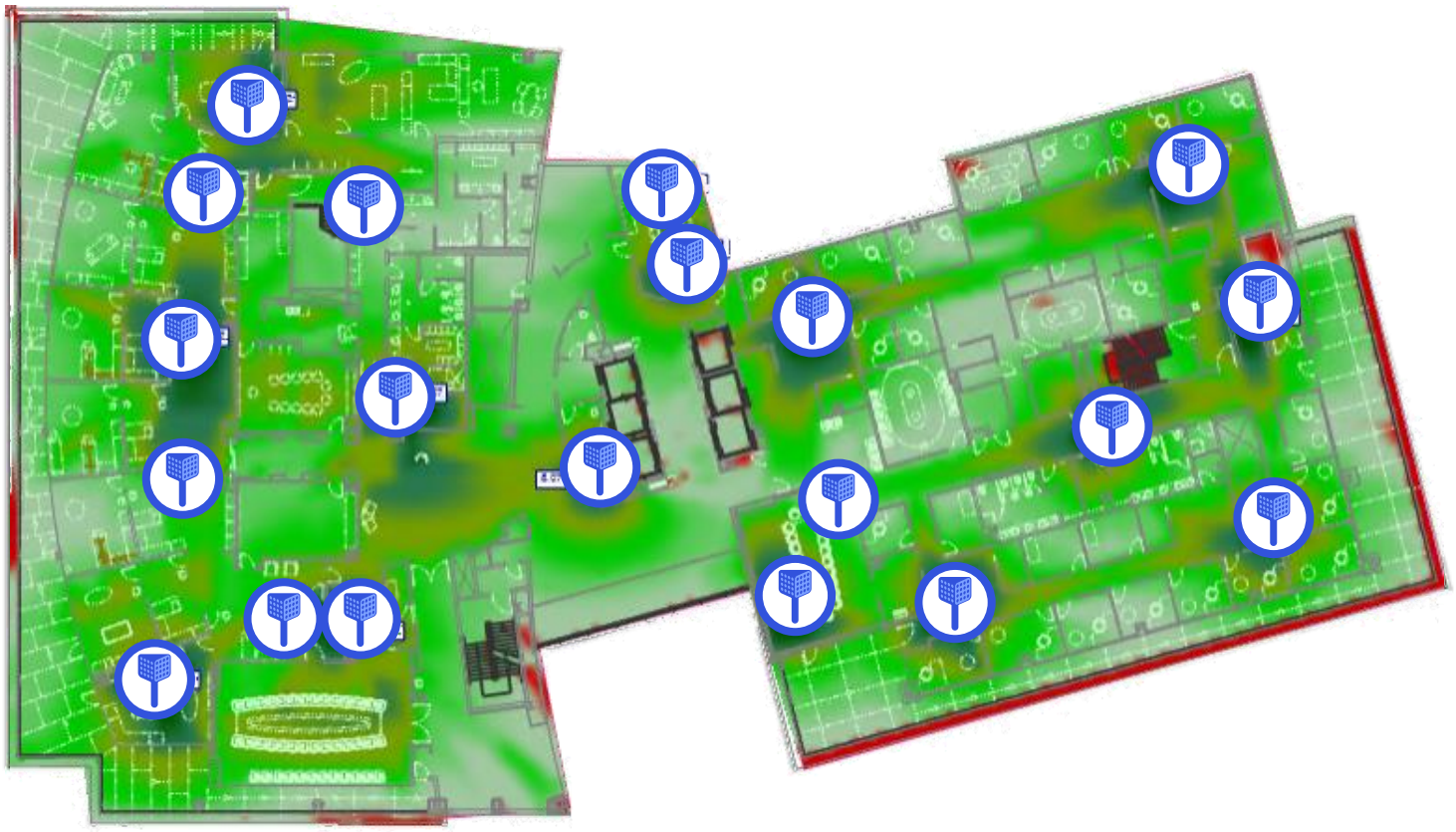
Achieving significant coverage at 28 GHz[1]

- Downlink coverage of ~**98%** with 115 dB MAPL[2]
- Uplink coverage of ~**99%** with 117 dB MAPL[2]

For always-connected enterprise use cases

- Downlink median burst rate[3] of **5 Gbps**
- Extreme capacity for unlimited data access fueling laptops, tablets, smartphones, and more

1 Coverage simulation based on MAPL (maximum allowable path loss) analysis with ray tracer propagation model and measured material and propagation loss; minimum 0.4/0.1 bps/Hz for downlink/uplink data and control; 2 Maximum Allowable Path Loss; 3 Using 800 MHz DL bandwidth and 100 MHz uplink bandwidth with 7:1 DL:UL TDD



Path loss (dB)

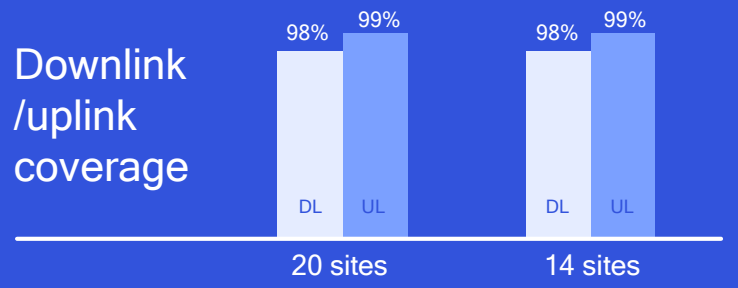
> -60
> -70
> -80
> -90
> -100
> -110
> -115
> -120

Existing Wi-Fi access point locations – co-sited with 5G NR mmWave antenna locations (each 128x2 elements & 16 horizontal beams)

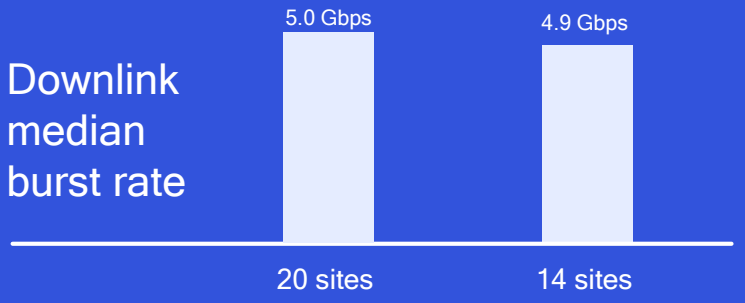
Achieving comparable performance with fewer APs

Deploying 5G NR mmWave at 14 out of 20 possible Wi-Fi locations

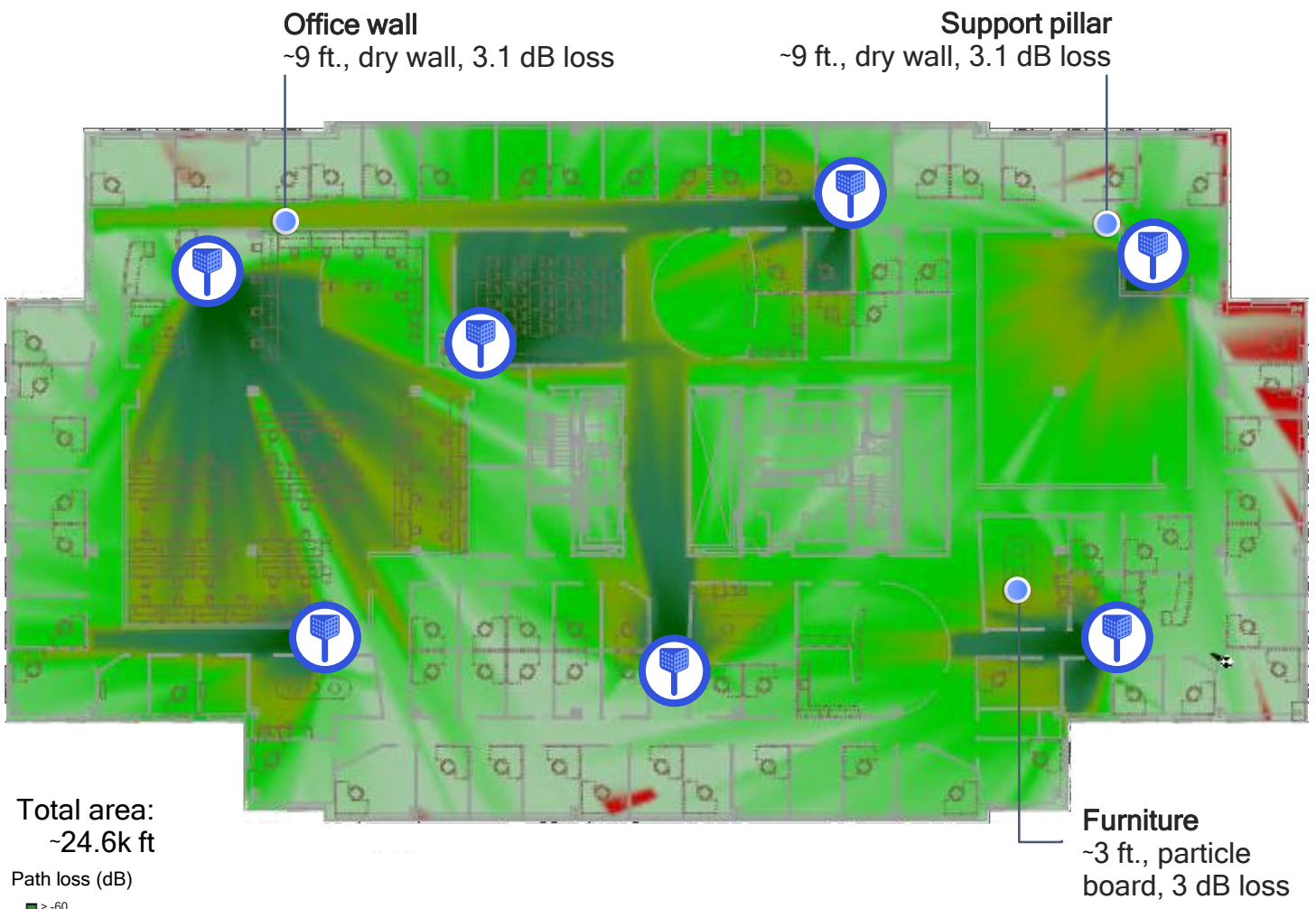
Downlink /uplink coverage



Downlink median burst rate



1 Coverage simulation based on MAPL (maximum allowable path loss) analysis with ray tracer propagation model and measured material and propagation loss; minimum 0.4/0.1 bps/Hz for downlink/uplink data and control; 2 Using 800 MHz DL bandwidth and 100 MHz uplink bandwidth with 7:1 DL:UL TDD



5G NR mmWave for lower-density indoor enterprise

Co-siting 5G NR mmWave gNodeB antennas with existing Wi-Fi access points

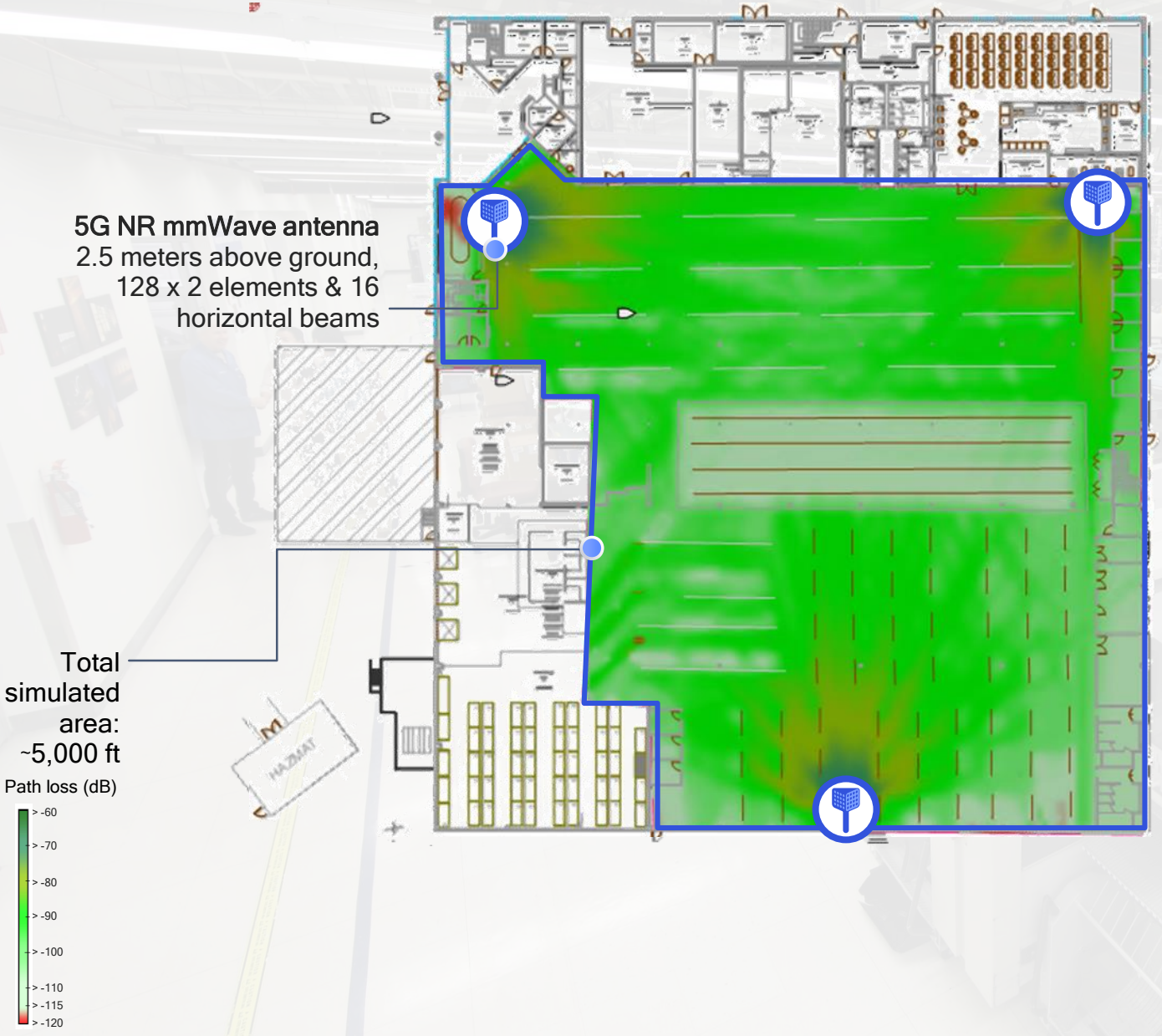
Achieving significant coverage at 28 GHz[1]

- Downlink coverage of ~**98%** with 115 dB MAPL[2]
- Uplink coverage of ~**99%** with 117 dB MAPL

For always-connected enterprise use cases

- Downlink median burst rate[3] of **4.9 Gbps**
- Extreme capacity for unlimited data access fueling laptops, tablets, smartphones, and more

1 Coverage simulation based on MAPL (maximum allowable path loss) analysis with ray tracer propagation model and measured material and propagation loss; minimum 0.4/0.1 bps/Hz for downlink/uplink data and control; 2 Maximum Allowable Path Loss; 3 Using 400 MHz DL bandwidth and 100 MHz uplink bandwidth with 7:1 DL:UL TDD



Deploying 5G NR mmWave for enterprise shop floors

Taking into account of environment challenges

Line-of-sight

Non-line-of-sight

Non-line-of-sight with reflections

Achieving significant coverage at 28 GHz[1]

- Downlink coverage of **100%** with 115 dB MAPL
- Uplink coverage of **100%** with 117 dB MAPL

For always-connected enterprise use cases

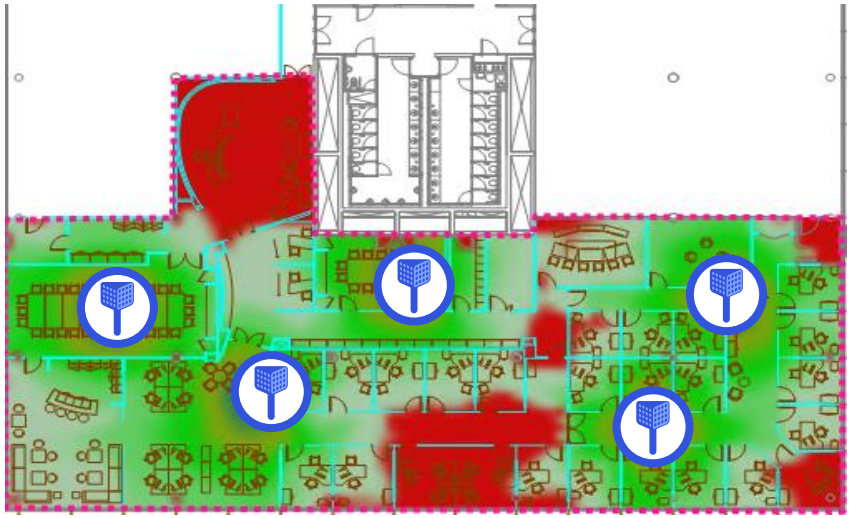
- Downlink median burst rate[3] of **4.2 Gbps**

1 Coverage simulation based on MAPL (maximum allowable path loss) analysis with ray tracer propagation model and measured material and propagation loss; minimum 0.4/0.1 bps/Hz for downlink/uplink data and control; 2 Using 800 MHz DL bandwidth and 100 MHz uplink bandwidth with 7:1 DL:UL TDD

5G NR mmWave for indoor offices – more examples

Office L

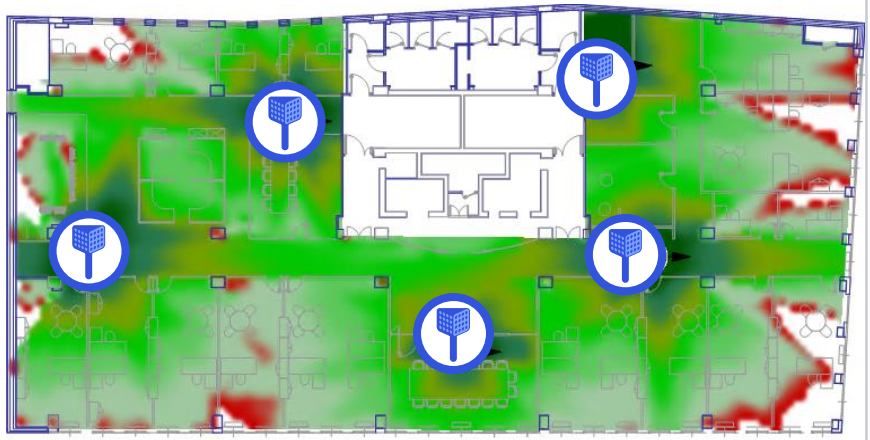
9844 sq. ft. (~2k sq. ft. per small cell)



- Coverage[1]: **~88%** downlink, **~88%** uplink
- Median downlink burst rate[2]: **4.5 Gbps**

Office R

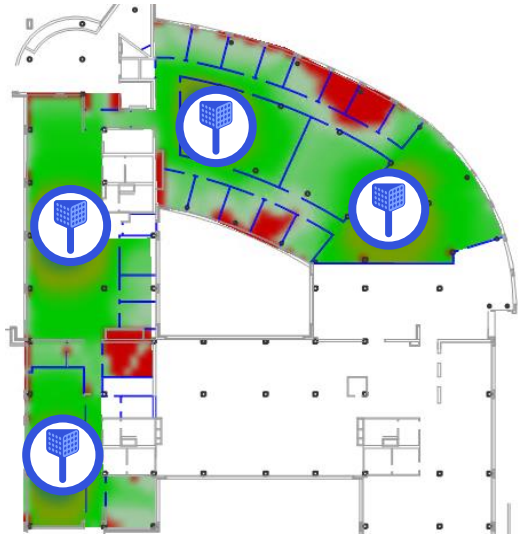
9200 sq. ft. (~1.8k sq. ft. per small cell)



- Coverage[1]: **~88%** downlink, **~89%** uplink
- Median downlink burst rate[2]: **4.5 Gbps**

Office F

5941 sq. ft. (~1.4k sq. ft. per small cell)



- Coverage[1]: **~95%** downlink, **~95%** uplink
- Median downlink burst rate[2]: **5 Gbps**

Simulations using different office layouts with Wi-Fi co-siting all show similar level of coverage & performance – densification can expand coverage further

1 Coverage simulation based on 117.3dB UL and 115.4dB DL MAPL (maximum allowable path loss) analysis with ray tracer propagation model and measured material and propagation loss; minimum 0.4/0.1 bps/Hz for downlink/uplink data and control; 2 Using 800 MHz DL bandwidth and 100 MHz uplink bandwidth with 7:1 DL:UL TDD

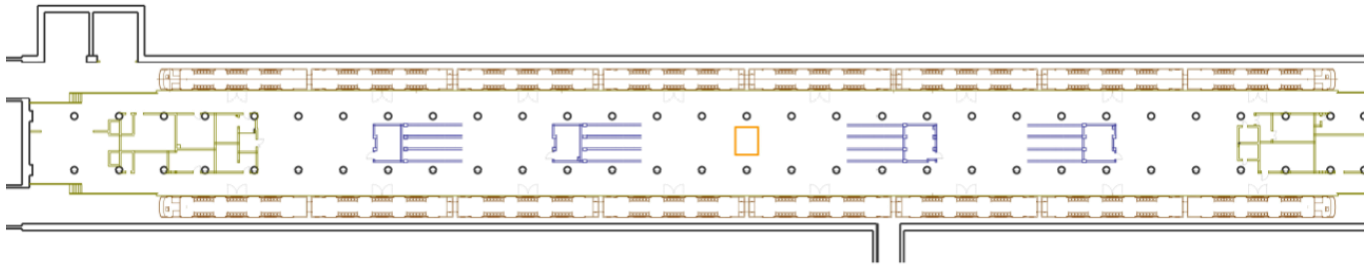
Deploying 5G NR mmWave for transportation hubs

Co-siting 5G NR mmWave antennas with existing Wi-Fi deployments[1]

- Achieve downlink and uplink coverage comparable to Wi-Fi using 1:1 or partial co-site
- Realize multi-Gigabit median burst rate with much wider bandwidths (e.g., 800 MHz)
- Complementing indoor Wi-Fi deployments

Higher density deployment

Subway station



~20.7k square feet

13 Wi-Fi APs / LTE DAS

~1.6k square feet per small cell

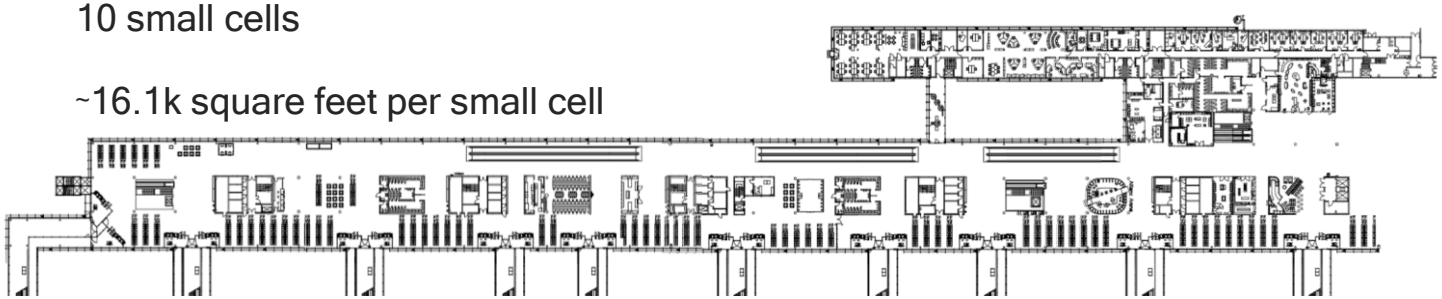
Lower density deployment

Airport

~161.5k square feet

10 small cells

~16.1k square feet per small cell



1 Can include AP: Access Point and DAS: Distributed Antenna System

5G NR mmWave for underground subway stations

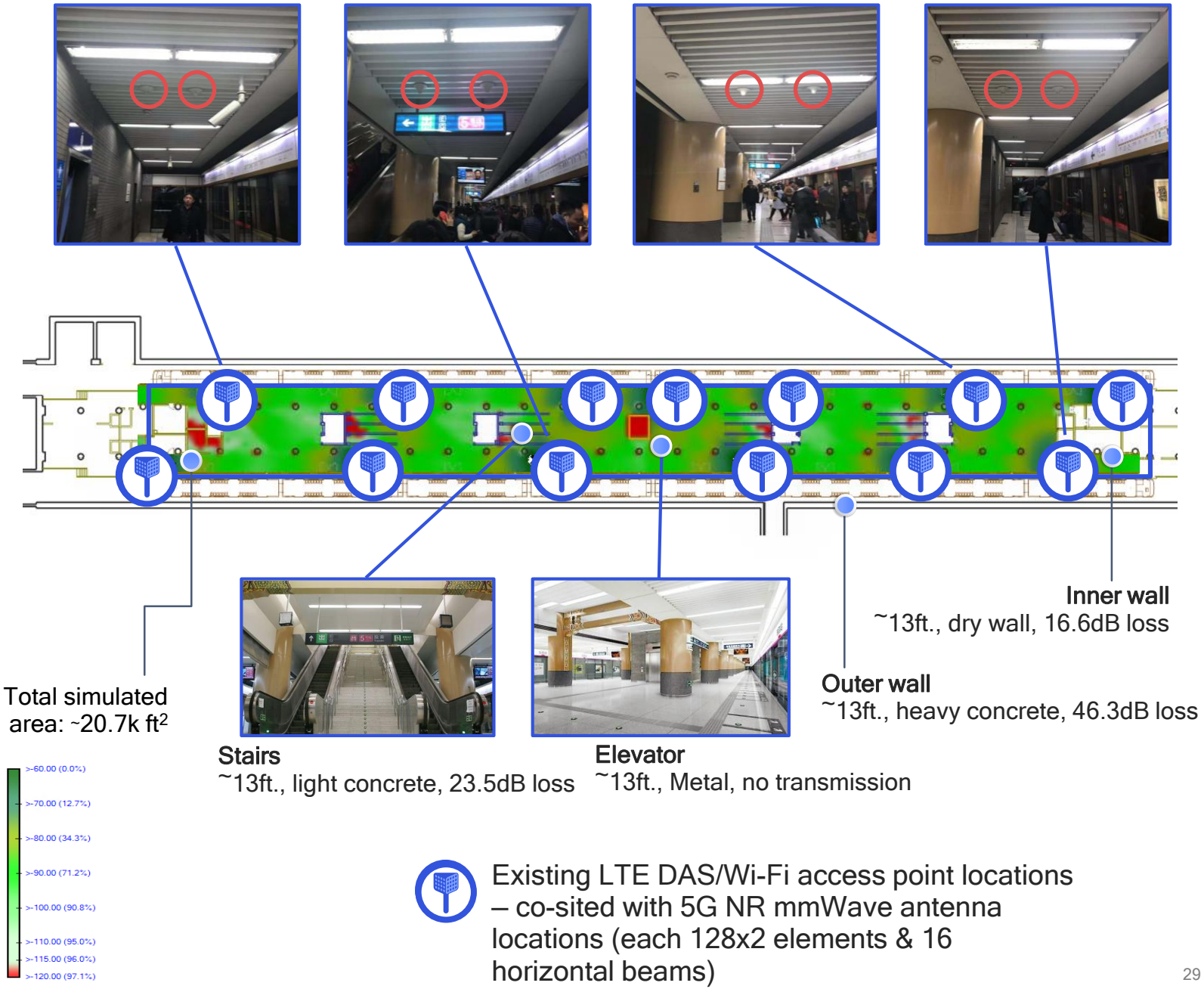
Co-siting 5G NR mmWave gNodeB antennas with existing LTE DAS or Wi-Fi access points

Achieving significant coverage at 28 GHz[1]

- Downlink coverage of **~96%** with 115 dB MAPL[2]
- Uplink coverage of **~97%** with 117 dB MAPL

Realizing multi-gigabit user experience[3]

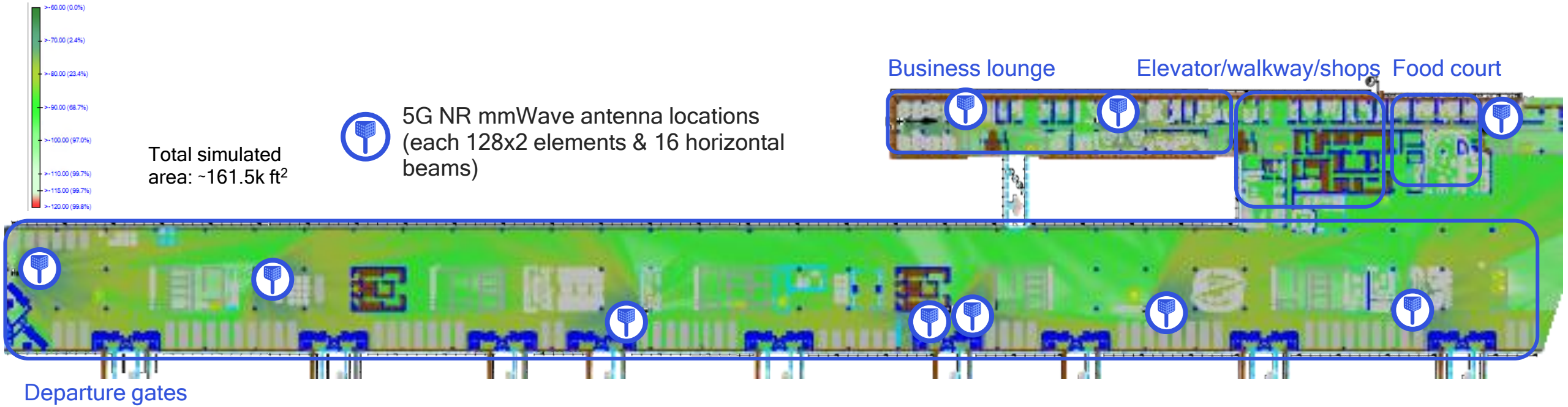
- Downlink median burst rate of **~4.6 Gbps**



1 Coverage simulation based on MAPL (maximum allowable path loss) analysis with ray tracer propagation model and measured material and propagation loss; minimum 0.4/0.1 bps/Hz for downlink/uplink data and control; 2 Maximum Allowable Path Loss; 3 Using 800 MHz DL bandwidth and 100 MHz uplink bandwidth with 7:1 DL:UL TDD

Deploying indoor mmWave for an airport concourse

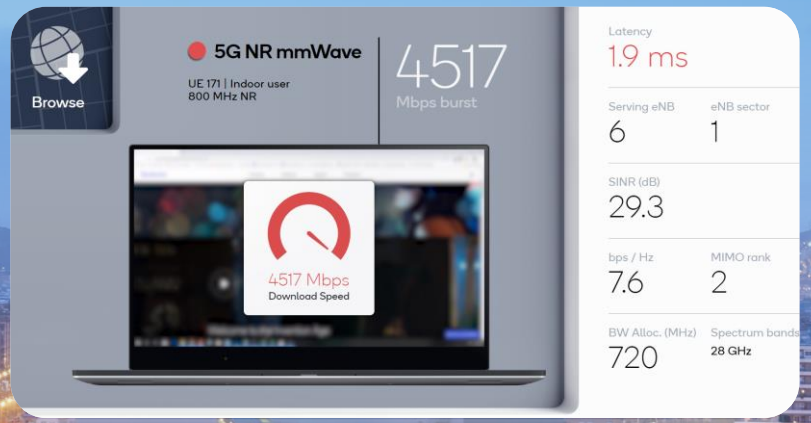
Simulating 5G NR mmWave operating at 26 GHz

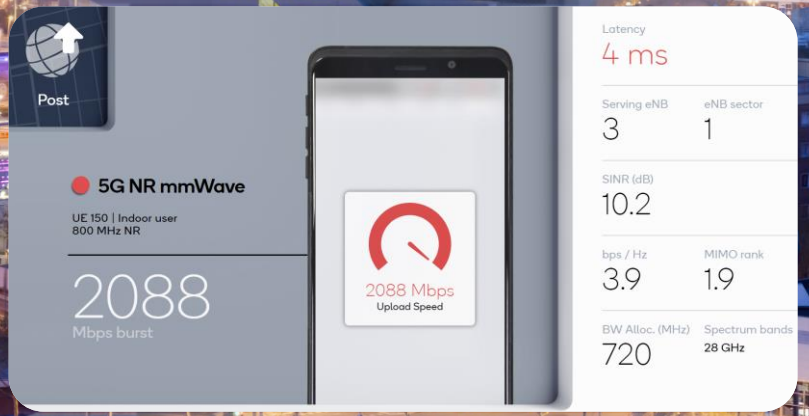


1 Coverage simulation based on MAPL (maximum allowable path loss) analysis with ray tracer propagation model and measured material and propagation loss; minimum 0.4/0.1 bps/Hz for downlink/uplink data and control; 2 110 dB Maximum Allowable Path Loss (MAPL); 3 Using 800 MHz DL bandwidth with 7:1 DL:UL TDD

Achieving ~100% downlink coverage[1,2] and ~4.2 Gbps median burst rate[3]

Showcasing enhanced mobile mmWave user experiences





Simulation assumes 5G NR mmWave co-siting at actual LTE DAS locations in Fira Gran Via Hall 3, uses 800 MHz spectrum in 28 GHz, and is based on Qualcomm engineering simulation tools

Advanced Network Simulations

Deploying 28 GHz 5G NR mobile mmWave at Mobile World Congress venue

Ubiquitous coverage via co-siting

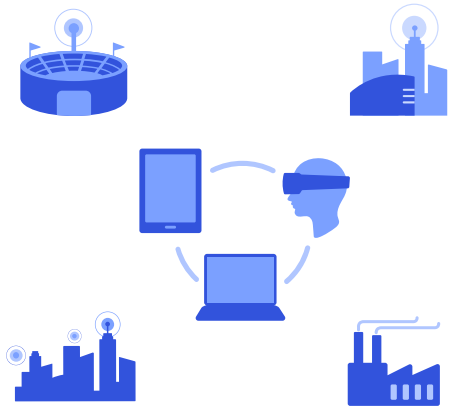
Virtually unlimited capacity

Multi-Gbps speed & low latency

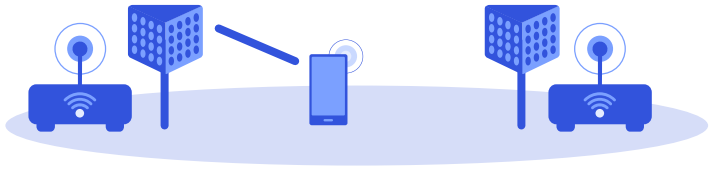
More uniform user experience

For a wide range of mobile devices:

Delivering new experiences with 5G NR mmWave



5G NR mmWave is bringing new waves of opportunities



Co-siting 5G NR mmWave with Wi-Fi can provide enhanced user experiences

We are making 5G NR mmWave a commercial reality in 2019

Qualcomm

Thank you!

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