June 2014

1000x: More small cells

Hyper-dense small cell deployments

QUALCOMM®

Mobile data traffic growth—industry preparing for 1000x

Industry preparing for

1000x

data traffic growth*

Richer Content

more video

~2/3 of mobile traffic will be video by 2017[3]

Bestseller example, richer content:

- **5.93 GB** Movie (High Definition)
- **2.49 GB** Movie (Standard Definition)
- **1.8 GB** Game for Android
- **0.14 GB** Soundtrack
- **0.00091 GB** Book

More devices

everything connected

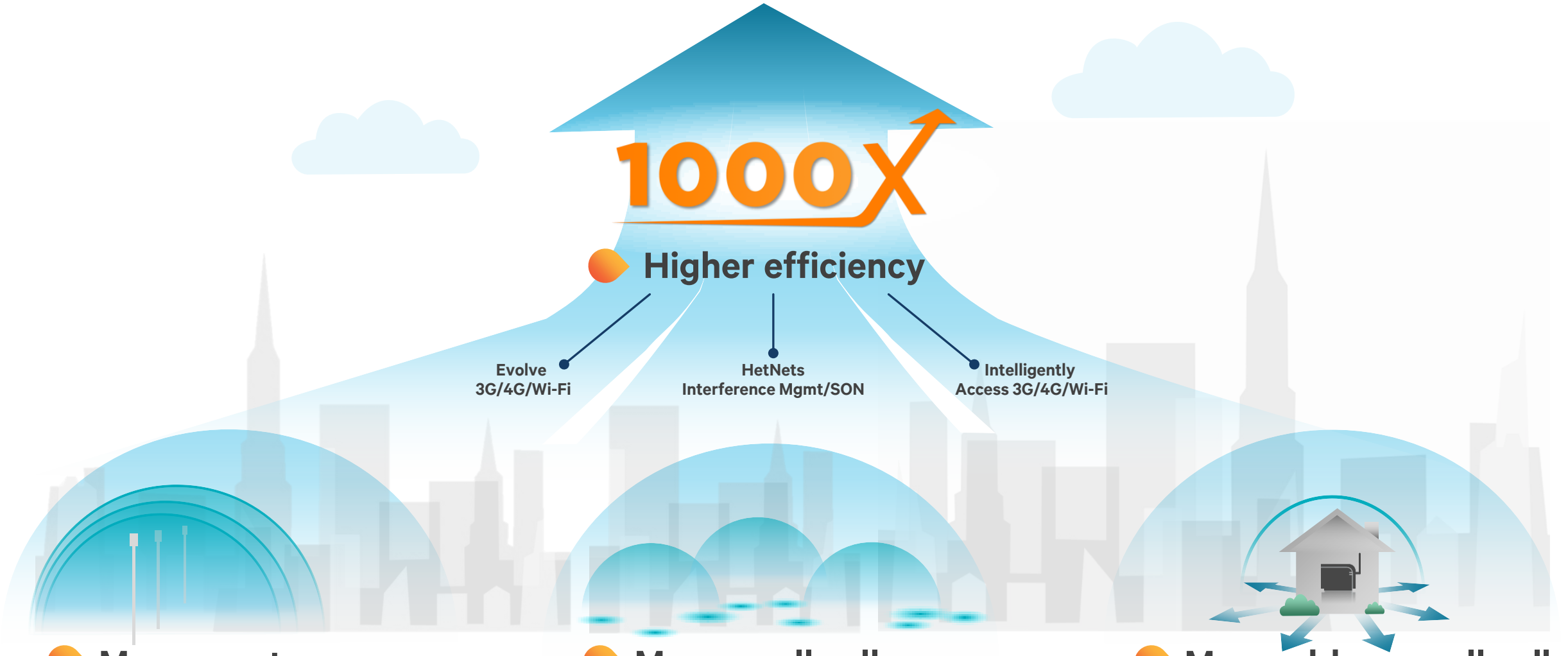
~25 Billion Interconnected device forecast in 2020[2]

~8 Billion Cumulative smartphone forecast between 2014-2018[1]

[1]Gartner,; Mar'14 [2]Machina Research/GSMA, Dec. '12. [3]Cisco, Feb. '13

*1000x would be e.g. reached if mobile data traffic doubled ten times, but Qualcomm does not make predictions when 1000x will happen, Qualcomm and its subsidiaries work on the solutions to enable 1000x

Rising to meet the 1000x mobile data challenge



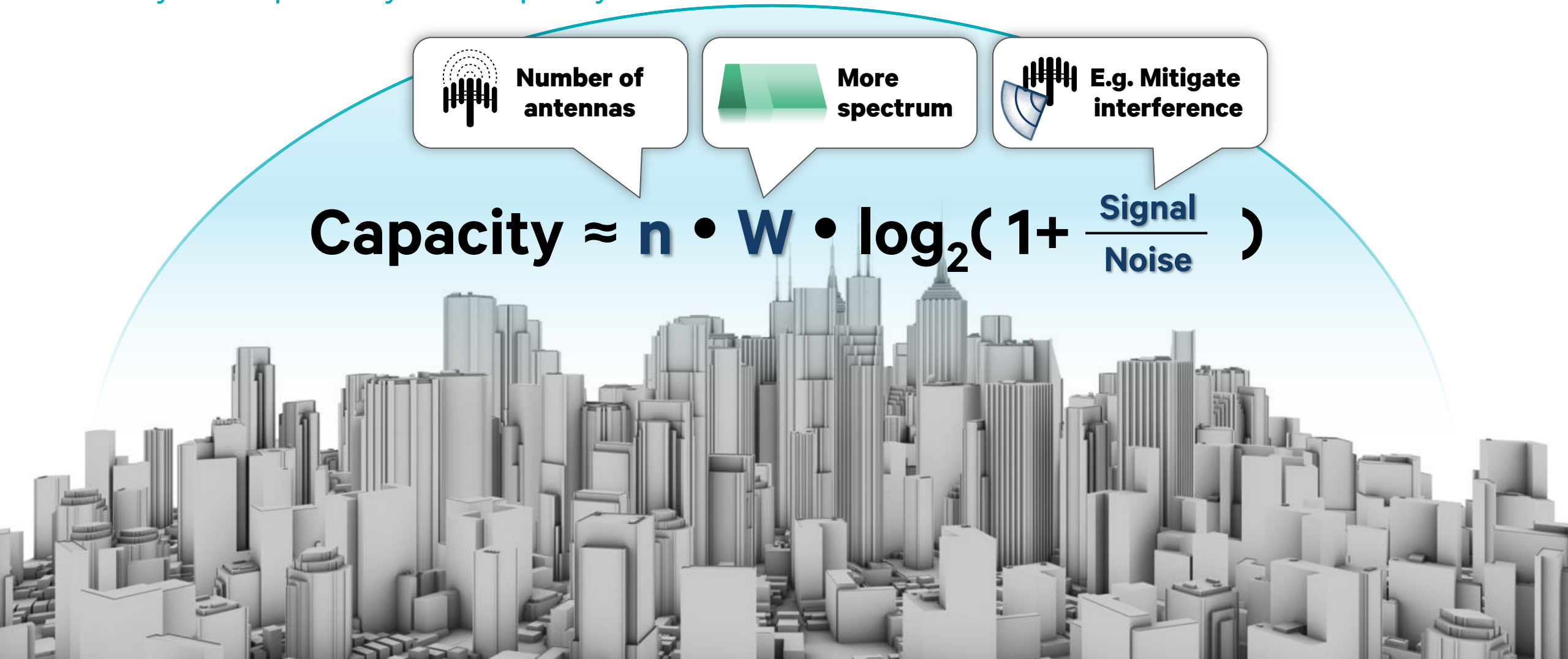
More spectrum
In low *and* higher bands

More small cells
Everywhere!

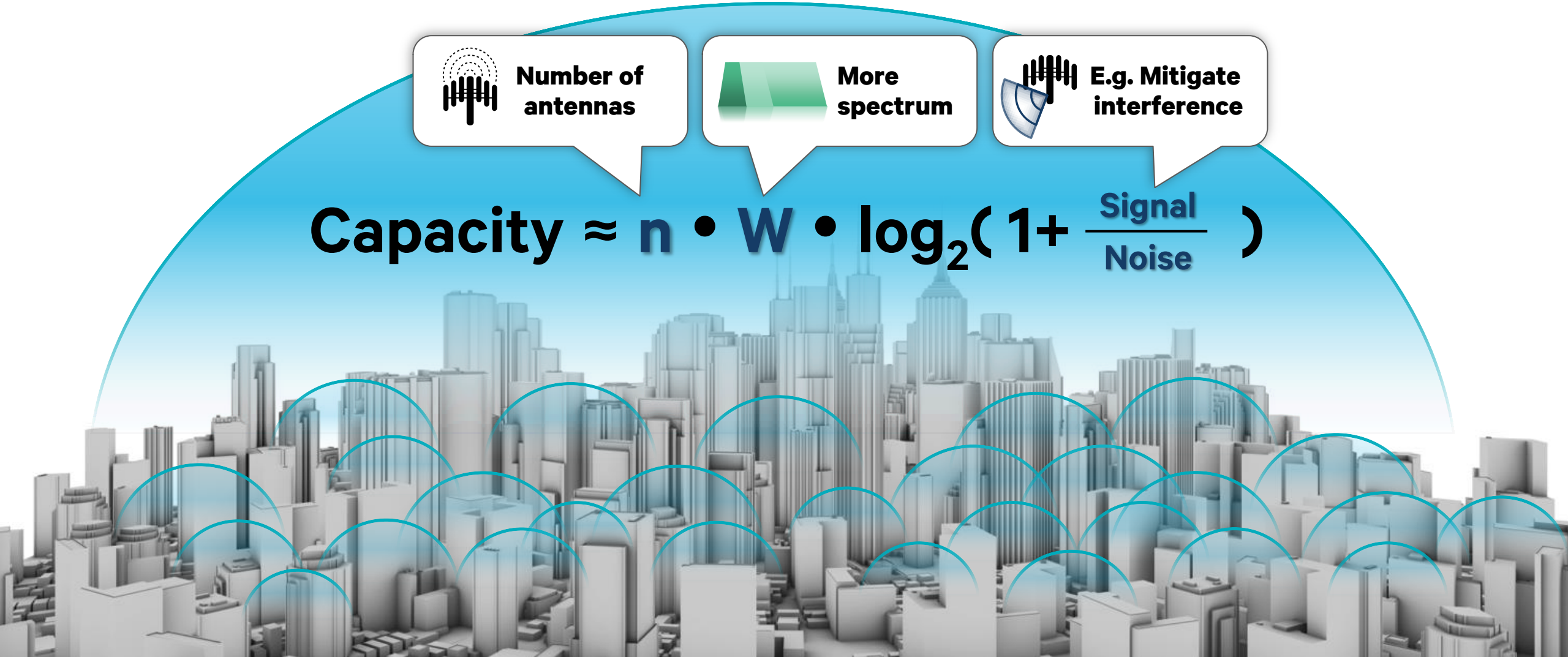
More ad-hoc small cells
And inside-out deployment

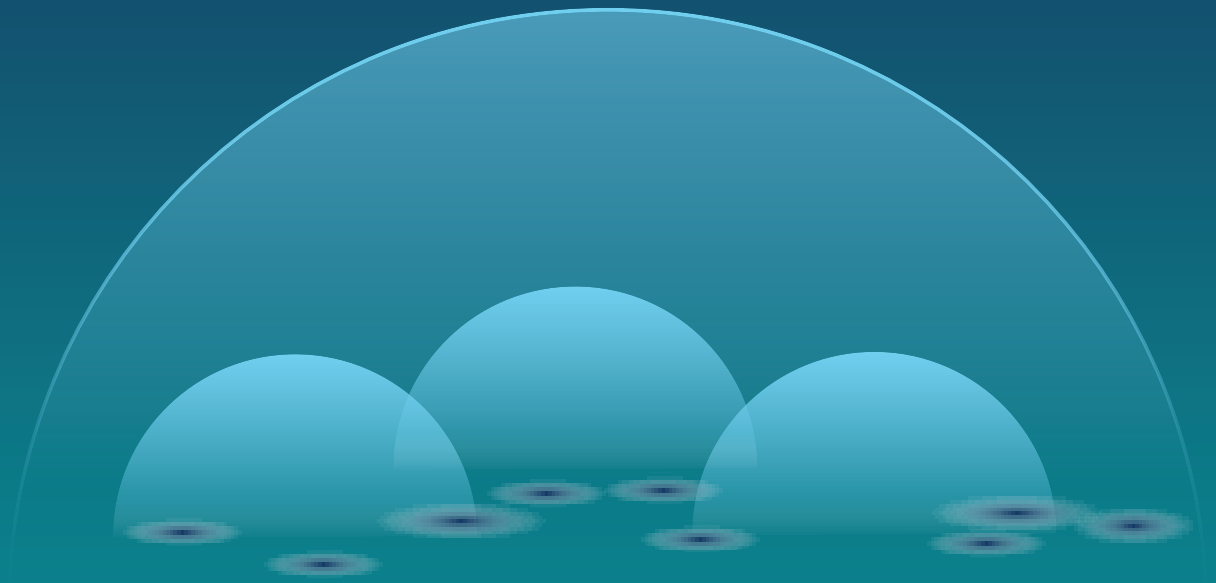
We can reach the air link limit—Shannon's Law

Still ways to improve system capacity



The biggest gain—re-use Shannon's Law everywhere!





Enabling hyper-dense small cells

Technology enablers to small cells everywhere

All venues; residential, enterprise, metro, indoor, outdoor and multiple deployment models

Highly compact, low-cost Small Cells

To enable densification & ease of deployment

Self-organizing networks (UltraSONN™)

To enable low cost hyper-dense deployments

Interference Management

So that capacity scales with small cells added

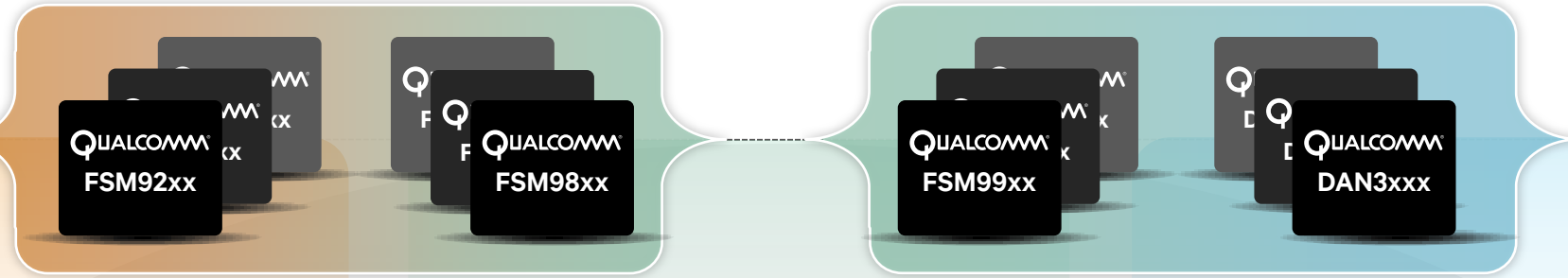
Backhaul Solutions

Fixed, wireless, relays
User provided

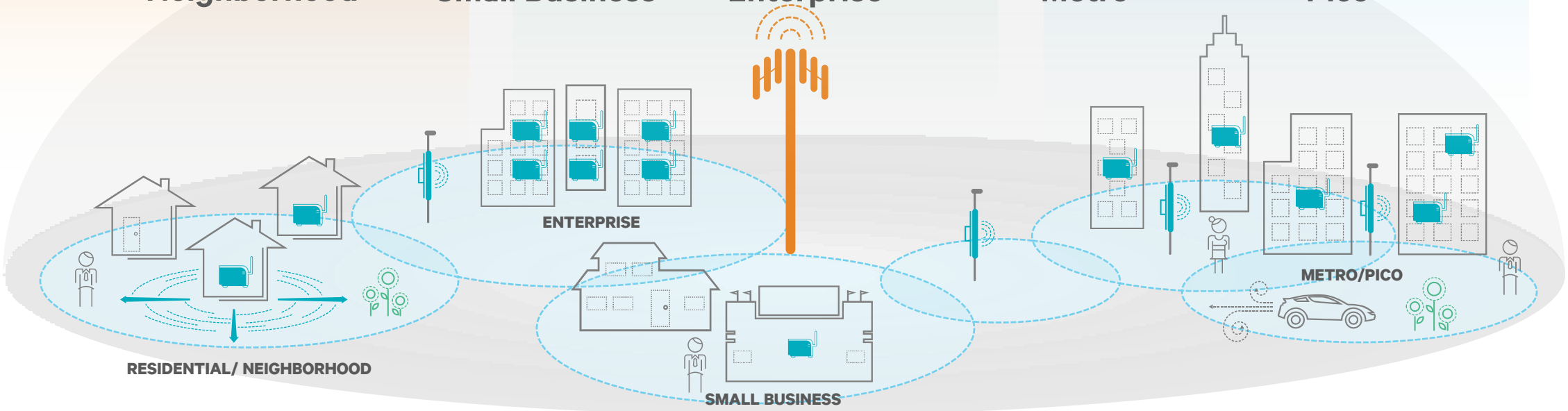
UltraSON, a suite of Self Organizing features for small cells, is a product of Qualcomm Technologies, Inc.;.

Qualcomm Technologies Inc.'s small cell solutions for all venues

- Complete 3G/4G chipsets (multimode baseband, RF, power)
- Wi-Fi hosting
- Software solutions enabling UltraSON™, eICIC and HotSpot™ 2.0
- Wireless backhaul
- HomePlug®, PLC,PON, Ethernet backhaul



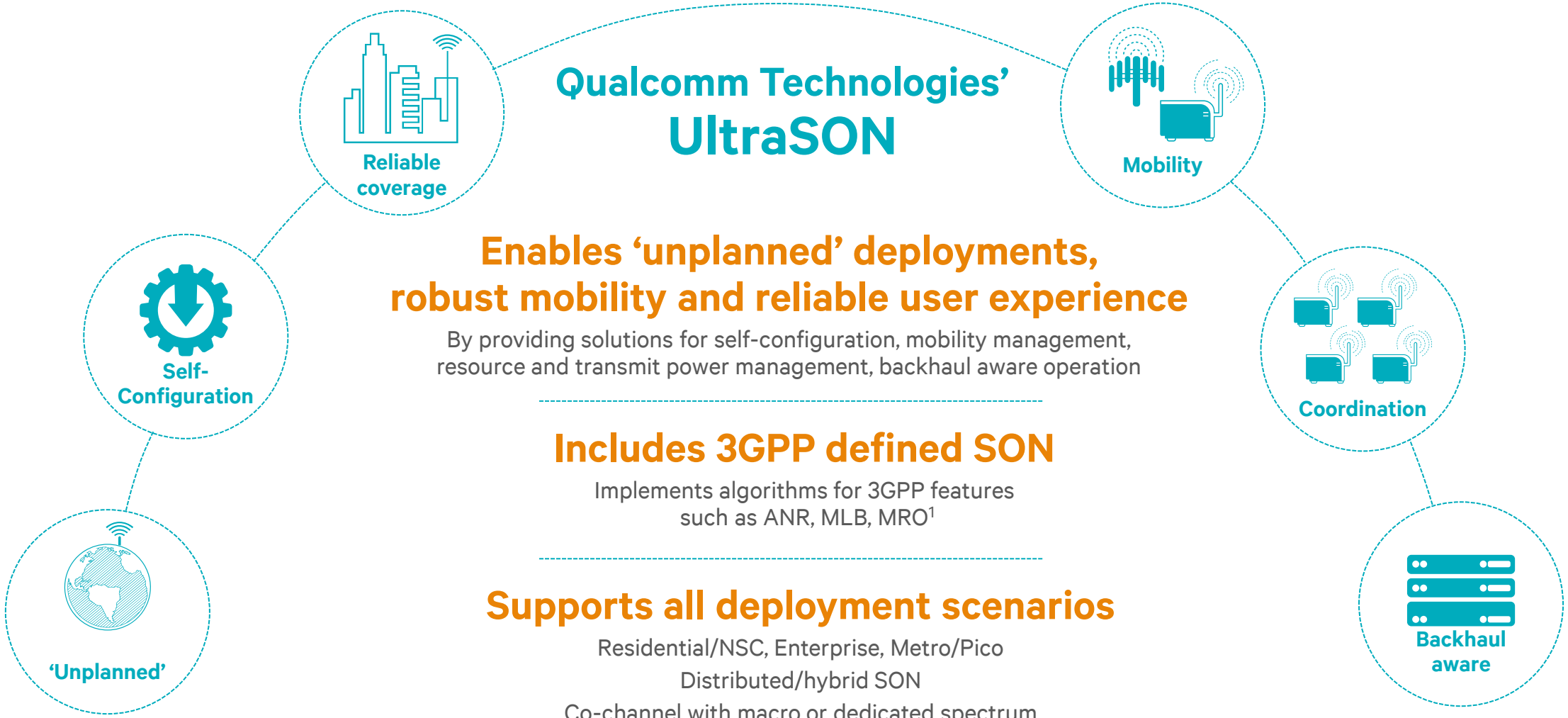
Neighborhood **Small Business** **Enterprise** **Metro** **Pico**



UltraSON, FSM and DAN are products of Qualcomm Technologies, Inc.

eICIC=enhanced Inter Cell Interference Coordination PLC=Power-line communications, PON=Passive Optical Networks.

UltraSON enables hyper-dense small cell deployments



Qualcomm Technologies' UltraSON

Enables 'unplanned' deployments, robust mobility and reliable user experience

By providing solutions for self-configuration, mobility management, resource and transmit power management, backhaul aware operation

Includes 3GPP defined SON

Implements algorithms for 3GPP features such as ANR, MLB, MRO[1]

Supports all deployment scenarios

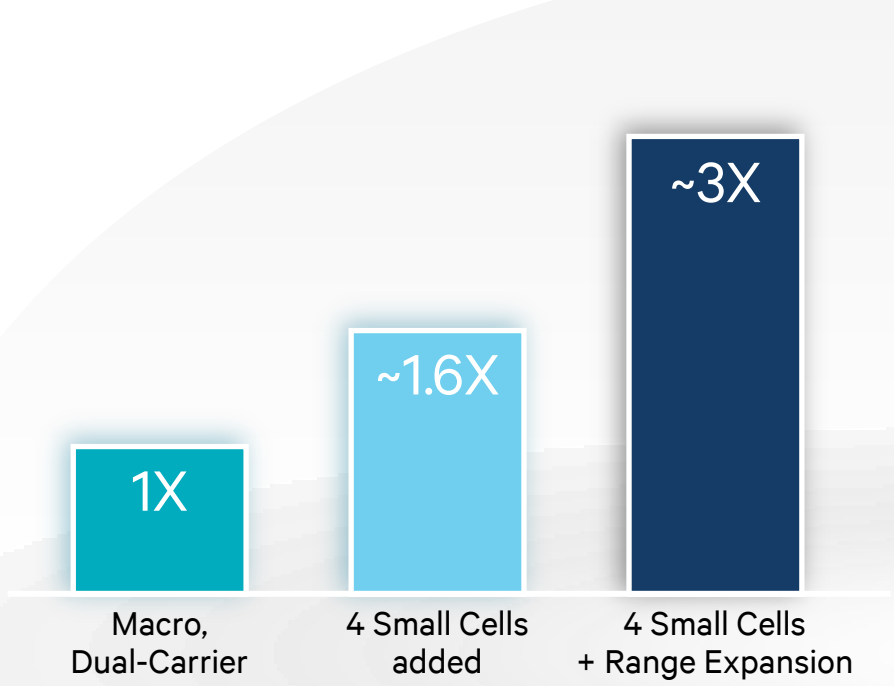
Residential/NSC, Enterprise, Metro/Pico

Distributed/hybrid SON

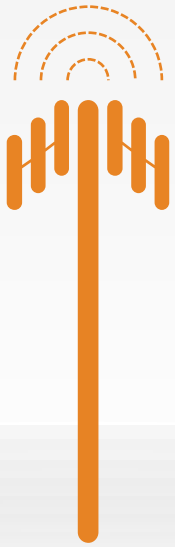
Co-channel with macro or dedicated spectrum

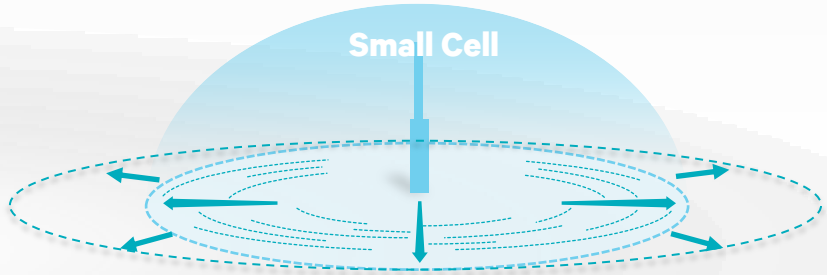
UltraSON is a product of Qualcomm Technologies, Inc. [1] ANR - Automatic Neighbor Relations, MLB - Mobility Load Balancing, MRO - Mobility Robustness Optimization

1000x begins with existing spectrum and available techniques
—small cell range expansion further increase capacity



Median Gain[1]
For same amount of Spectrum
HSPA+ example, similar gain for LTE Advanced

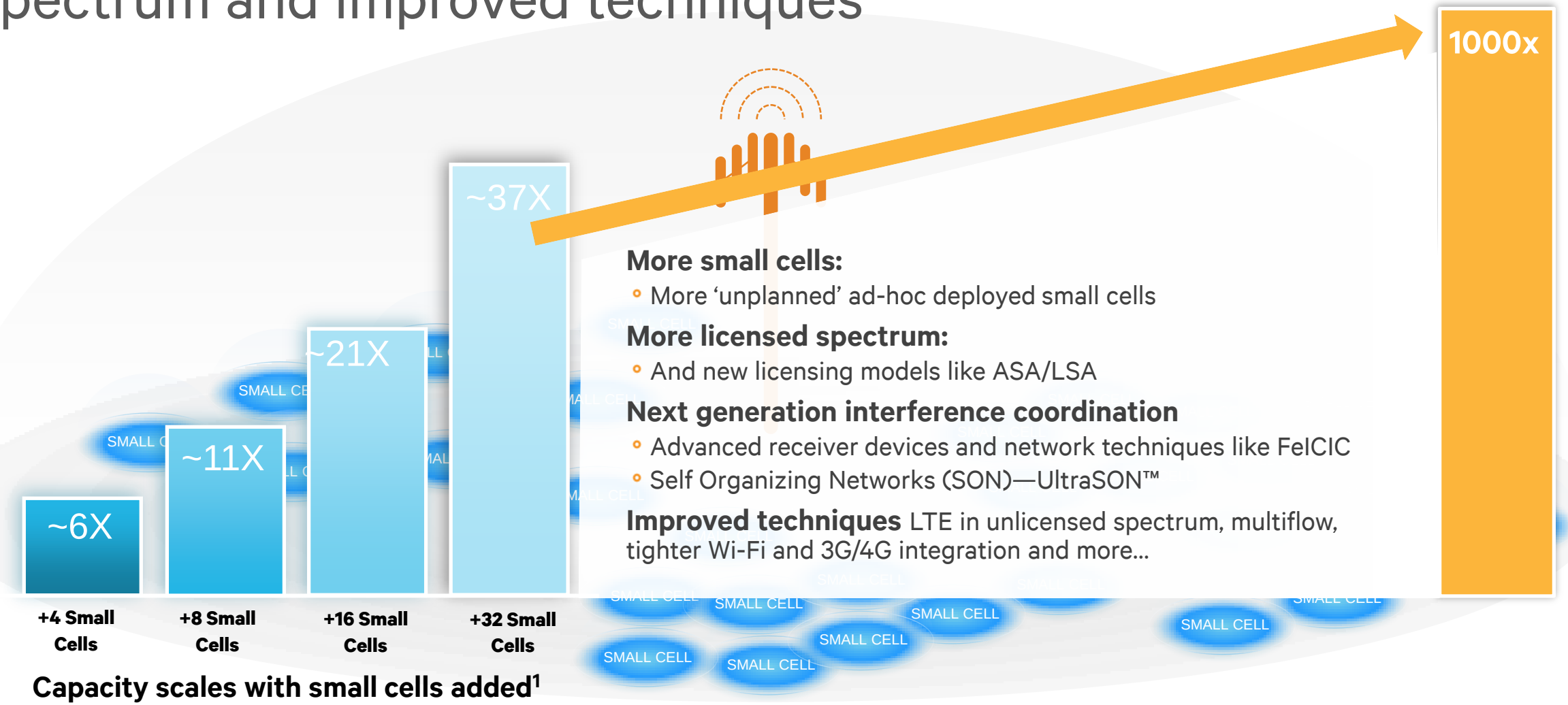




Possible With HSPA+ Today
and with LTE Advanced (FeICIC/IC)

[1] Gain in median downlink data rate, 4 small cells of pico type added per macro and 50 % of users dropped in clusters closer to picos (within 40m), Model PA3 full buffer ISD 500m. Enabling range expansion features: reduced power on second macro carrier, Dual-Carrier devices and mitigating uplink and downlink imbalance (3dB Cell-individual offset (CIO) and pico noise-figure pad)

The roadmap to **1000x**: hyper-dense small cells, more licensed spectrum and improved techniques



More small cells:
- More 'unplanned' ad-hoc deployed small cells

More licensed spectrum:
- And new licensing models like ASA/LSA

Next generation interference coordination
- Advanced receiver devices and network techniques like FeICIC
- Self Organizing Networks (SON)—UltraSON™

Improved techniques LTE in unlicensed spectrum, multiflow, tighter Wi-Fi and 3G/4G integration and more...

Capacity scales with small cells added[1]

LTE Advanced FeICIC with 2x Spectrum added

[1] Assumptions: Pico type of small cell, 10MHz@2GHz + 10MHz@3.6GHz,D1 scenario macro 500m ISD, uniform user distribution scenario. Gain is median throughput improvement, from baseline with macro only on 10MHz@2GH, part of gain is addition of 10MHz spectrum. Users uniformly distributed—a hotspot scenario could provide higher gains. Macro and outdoor small cells sharing spectrum (co-channel)

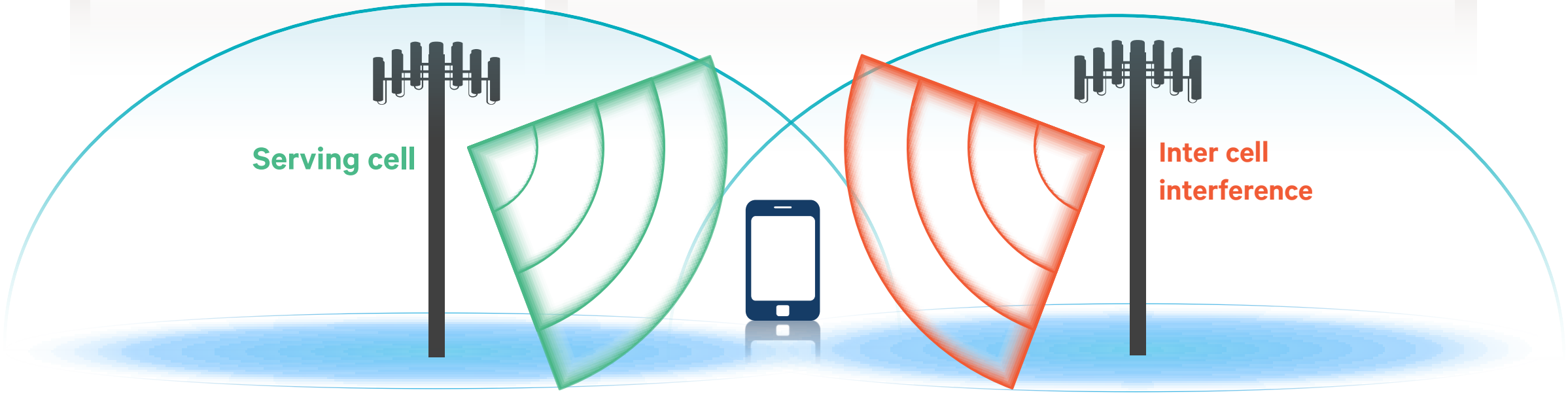
Leveraging next generation advanced receivers

To mitigate interference—even more beneficial in dense small cell deployments

HSPA+ cancels inter-cell common and traffic channels[1]

LTE advanced can cancel common signaling[2]

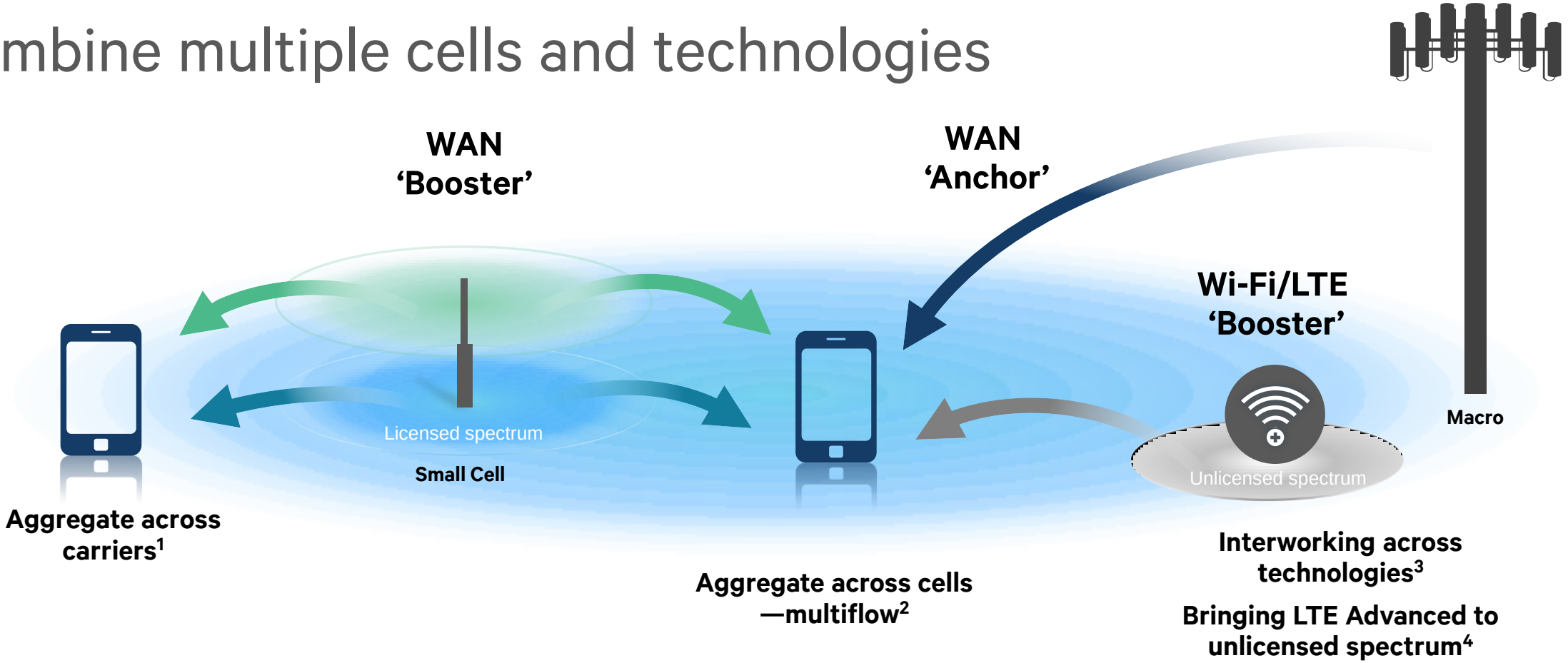
Next step for LTE advanced: further enhanced LTE receivers



Interference Cancellation

[1] Qualcomm's commercial Q-ICE supports equalization and inter-cell interference cancellation. [2]Performance requirement added to 3GPP for cancellation of common signaling (PSS/SSS/PBCH/CRS) in Rel 10/11.

Combine multiple cells and technologies



Improved offload to small cells

Efficient network load balancing

Improved mobility

[1] Carrier aggregation from 3GPP R8 HSPA+, and from R10 LTE . [2] Multiflow is part of 3GPP R11 HSPA+ and R12 LTE candidate. [3] RAN interworking across LTE, HSPA+ and Wi-Fi is an 3GPP R13 candidate. [3] Bringing LTE Advanced to unlicensed spectrum is an 3GPP R13 candidate

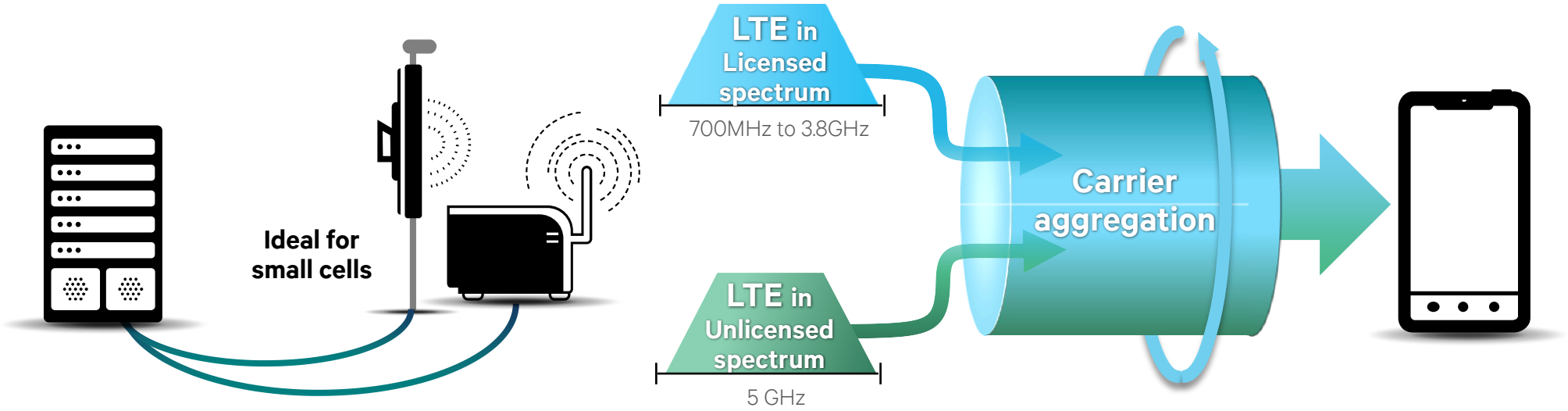
Extending the benefits of LTE Advanced to unlicensed spectrum

Better network performance

Longer range and increased capacity[1]

Enhanced user experience

Thanks to LTE Advanced anchor in licensed spectrum with robust mobility



Unified LTE Network

Common LTE network with common authentication, security and management.

Coexists with Wi-Fi

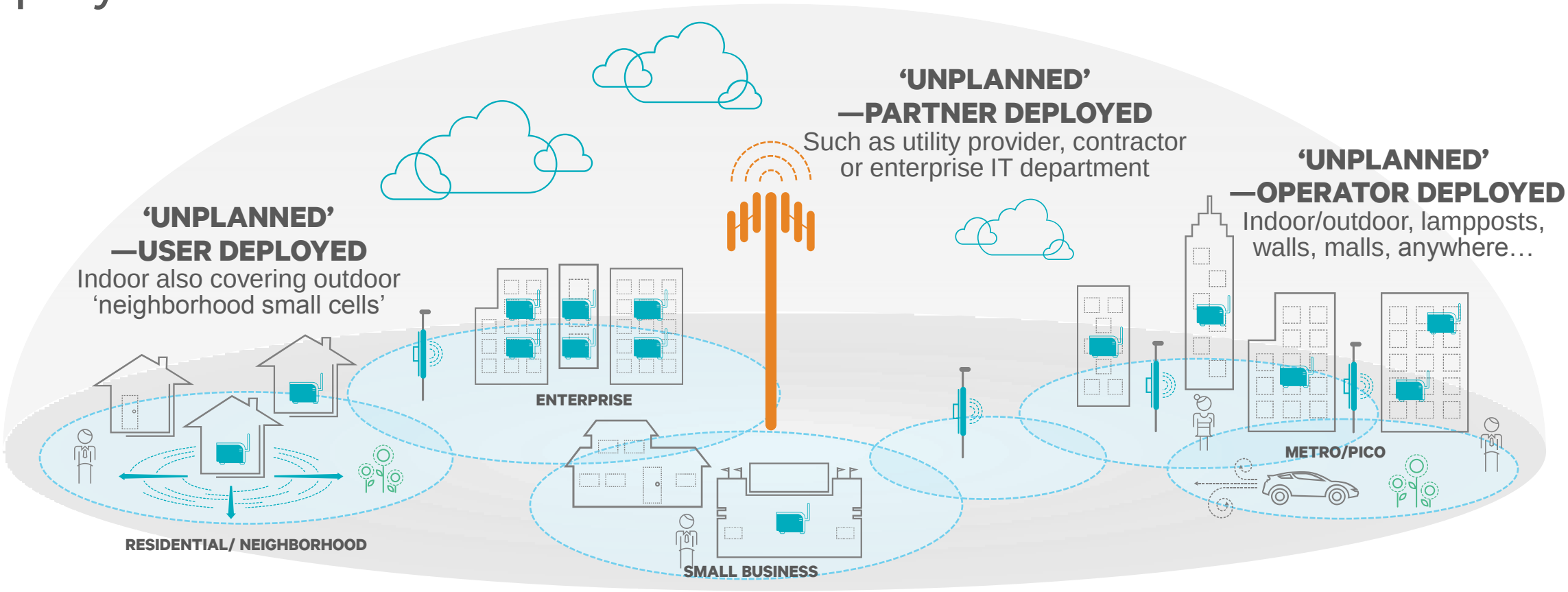
Features to protect Wi-Fi neighbors

[1] Compared to carrier Wi-Fi

More ‘unplanned ’ad-hoc small cells

Lower cost deployments in licensed spectrum, coordinated and managed by the operator

Small cell hyper densification requires more unplanned, ad-hoc deployments



Viral, ad-hoc, ’unplanned’, e.g. where backhaul exists—more like Wi-Fi

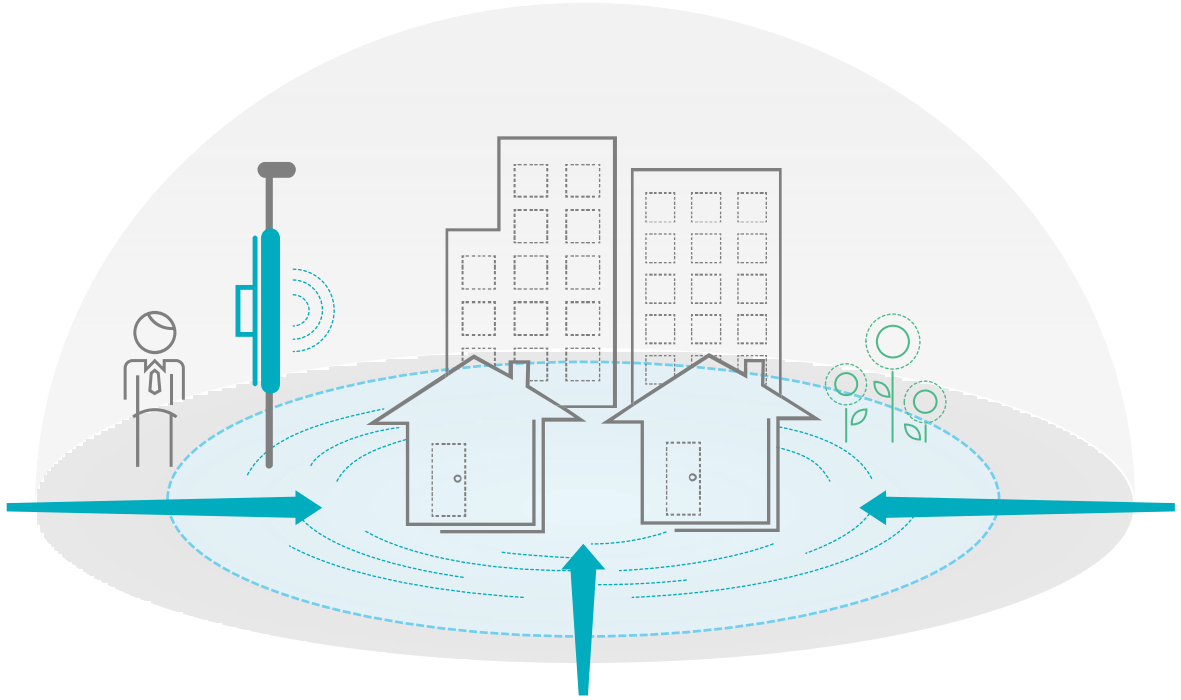
Plug & play, self organizing, coordinated small cells

Managed by operator in licensed spectrum

Note: Unplanned from an RF perspective, there may still be other planning aspects (like permits etc.)

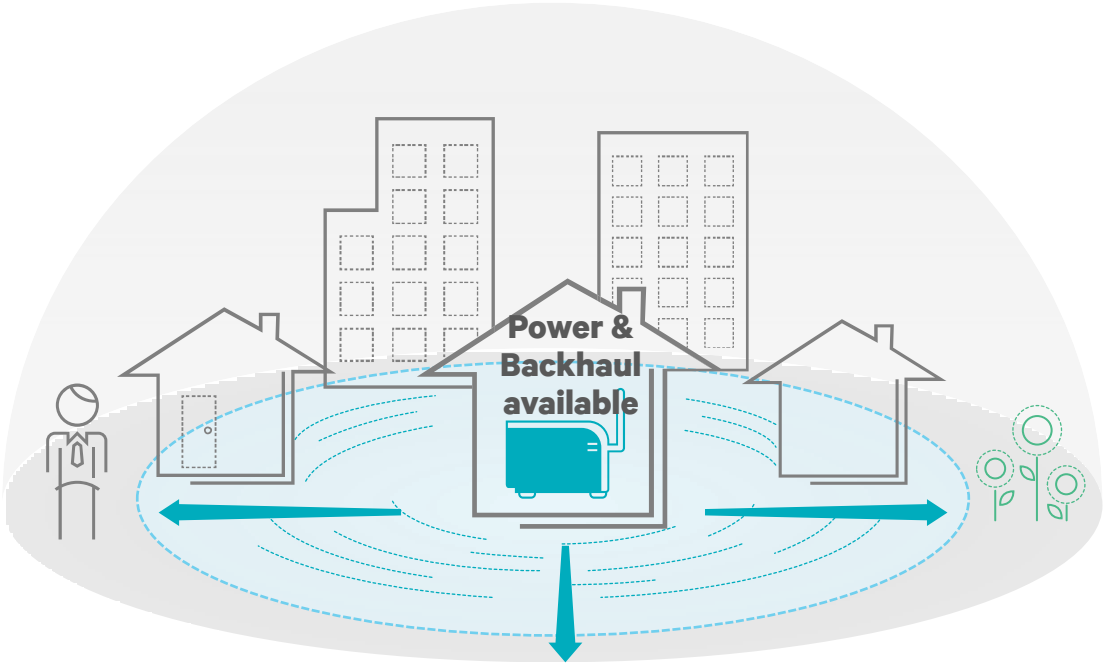
We need more indoor deployments—also covering the outside

Capacity from the outside —to outside/inside users



TRADITIONAL OUTSIDE-IN

Capacity from the inside – also serving outside users



INSIDE-OUT

And new deployment models like neighborhood small cells

>70% of mobile data traffic is consumed indoors and steadily increasing

More ‘unplanned’, ad-hoc deployed small cells to reach 1000x

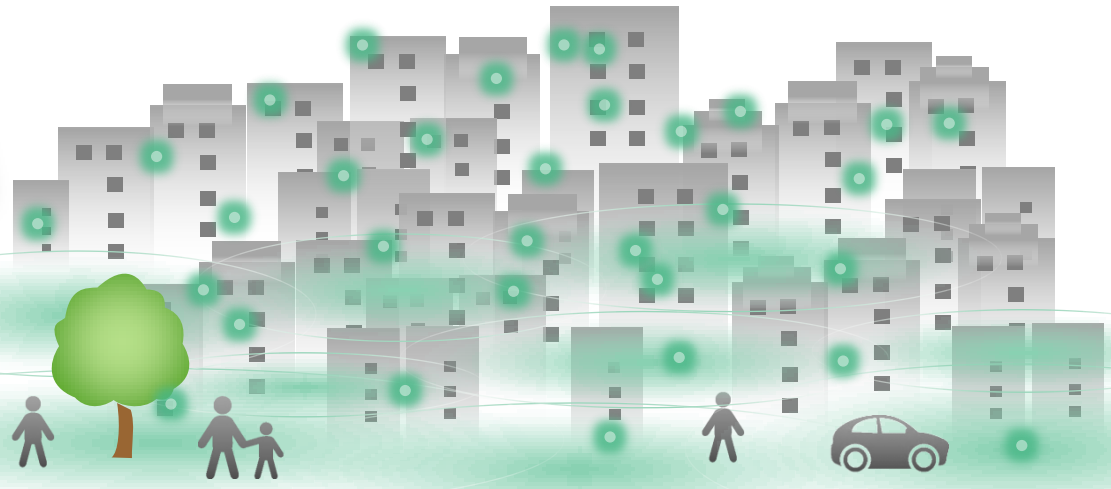
ADD 10x SPECTRUM

10Mhz for macros @ 2GHz

Example with higher band:
100MHz *dedicated* to small cells @ 3.6GHz[1]

Negligible loss in coverage and capacity at high small cell density

INSIDE-OUT DEPLOYMENT EXAMPLE
‘NEIGHBORHOOD SMALL CELLS’



ALSO SERVING OUTSIDE USERS

Median throughput gain versus Macro only baseline

1000x

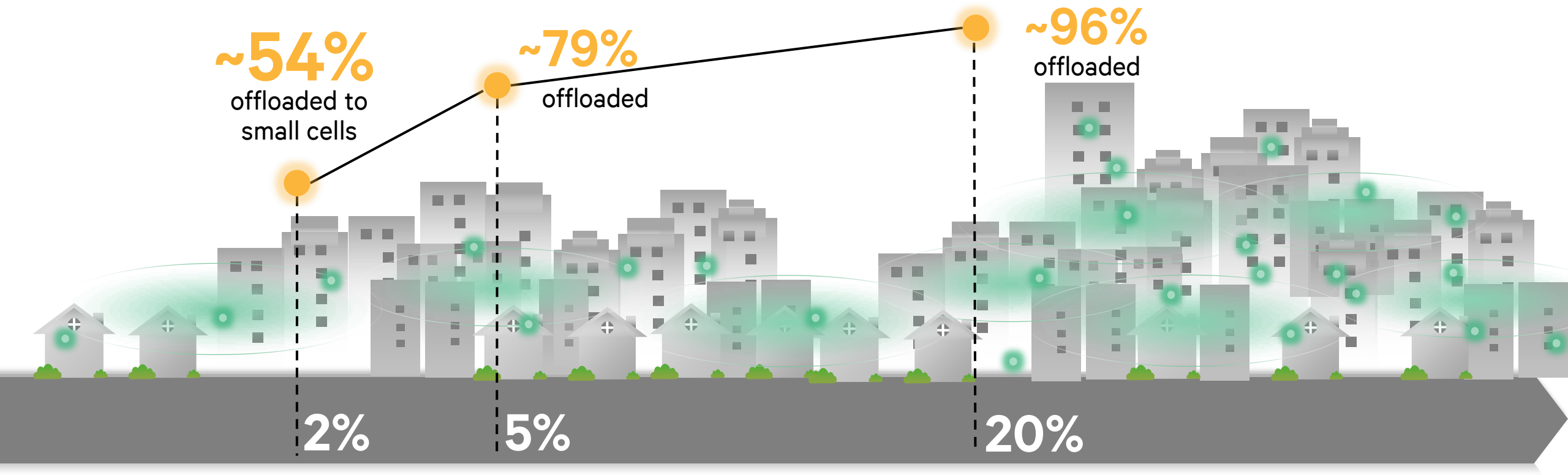
~ 20 % Household penetration

500x

~ 9% Household penetration

Example for LTE FDD, 2x2 MIMO. Assumptions: 70% indoor users, 200 Active users per macrocell, small cells randomly dropped in households in a mix of 2 to 6 story apartments.1Small cells on dedicated spectrum used in this example, but we envision future neighborhood small cells also sharing the spectrum with macro and other small cells. 20% household penetration equals ~ 144 small cells, and 9% penetration equals ~ 65 small cells.

Even low small cell penetration provides good performance



Household penetration, neighborhood small cells

Low transmit power sufficient[1]

Gain not sensitive to external wall loss

[1] Example for LTE FDD, 2x2 MIMO. Assumptions: 70% indoor users, 200 Active users per macrocell, small cells randomly dropped in households in a mix of 2 to 6 story apartments Macro uses 2GHz and small cells uses 3.5GHz. Shows the percentage of users offloaded to the small cells 1Interference limited, not coverage limited; 20mW or less is sufficient (we compared 20mW/13 dBm with a baseline of 100mW/20dBm).

Over-the-air hyper-dense network for all deployment scenarios

All deployment scenarios at our campus work as one seamless network with UltraSON

Outdoor metro/pico

- Only ~15m between small cells
- Primarily outdoor coverage

Indoor Neighborhood Small Cells

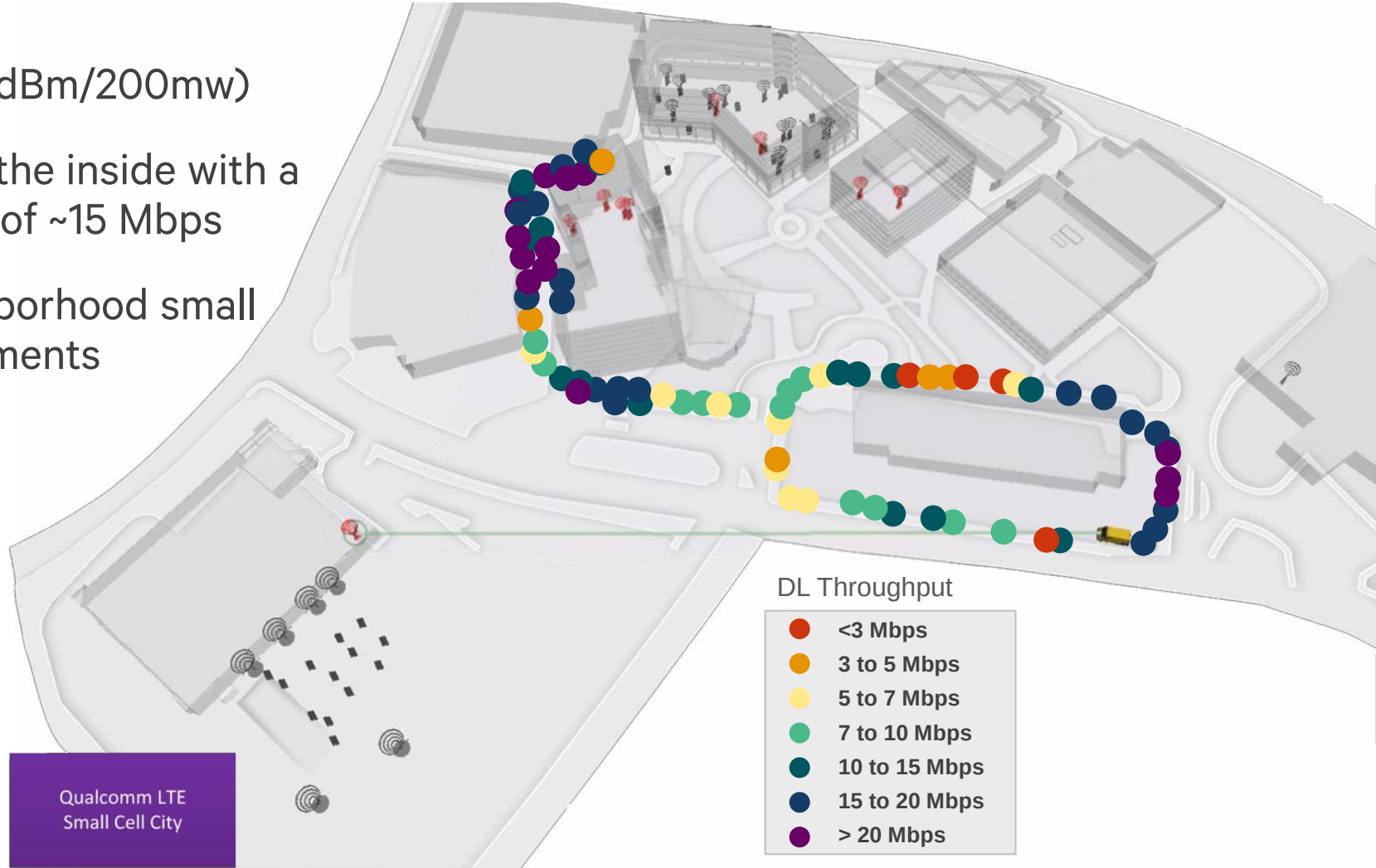
- Indoor deployed also for outdoor coverage
- Full campus coverage and mobility

Indoor enterprise

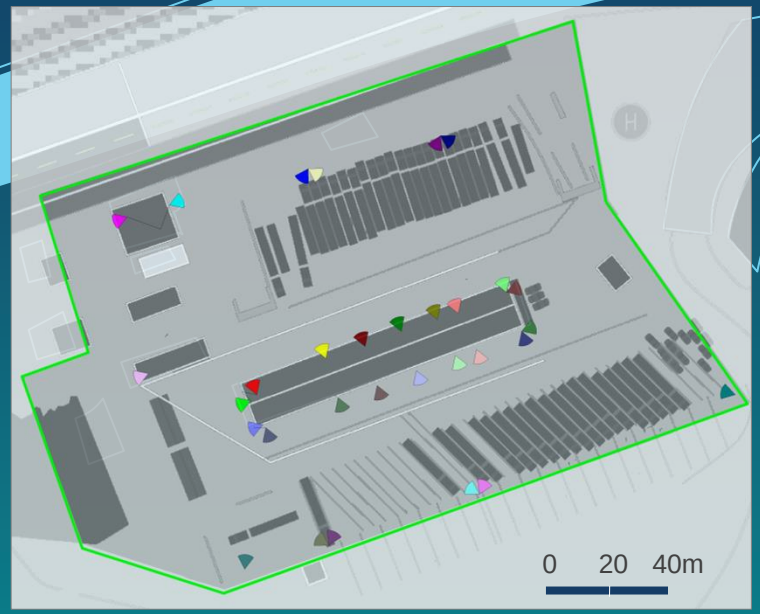
- Primarily for indoor coverage—typically limit coverage leakage to outdoor

Excellent outdoor performance with indoor small cell

- Low power indoor small cells (23dBm/200mw)
- Serving also outdoor users from the inside with a median outdoor user throughput of ~15 Mbps
- Shows the potential of the neighborhood small cell model and inside-out deployments



- All indoor NSCs, 23dBm each,
- LTE-TDD, 20 MHz @ 2.6 GHz, 60:40 DL:UL ratio



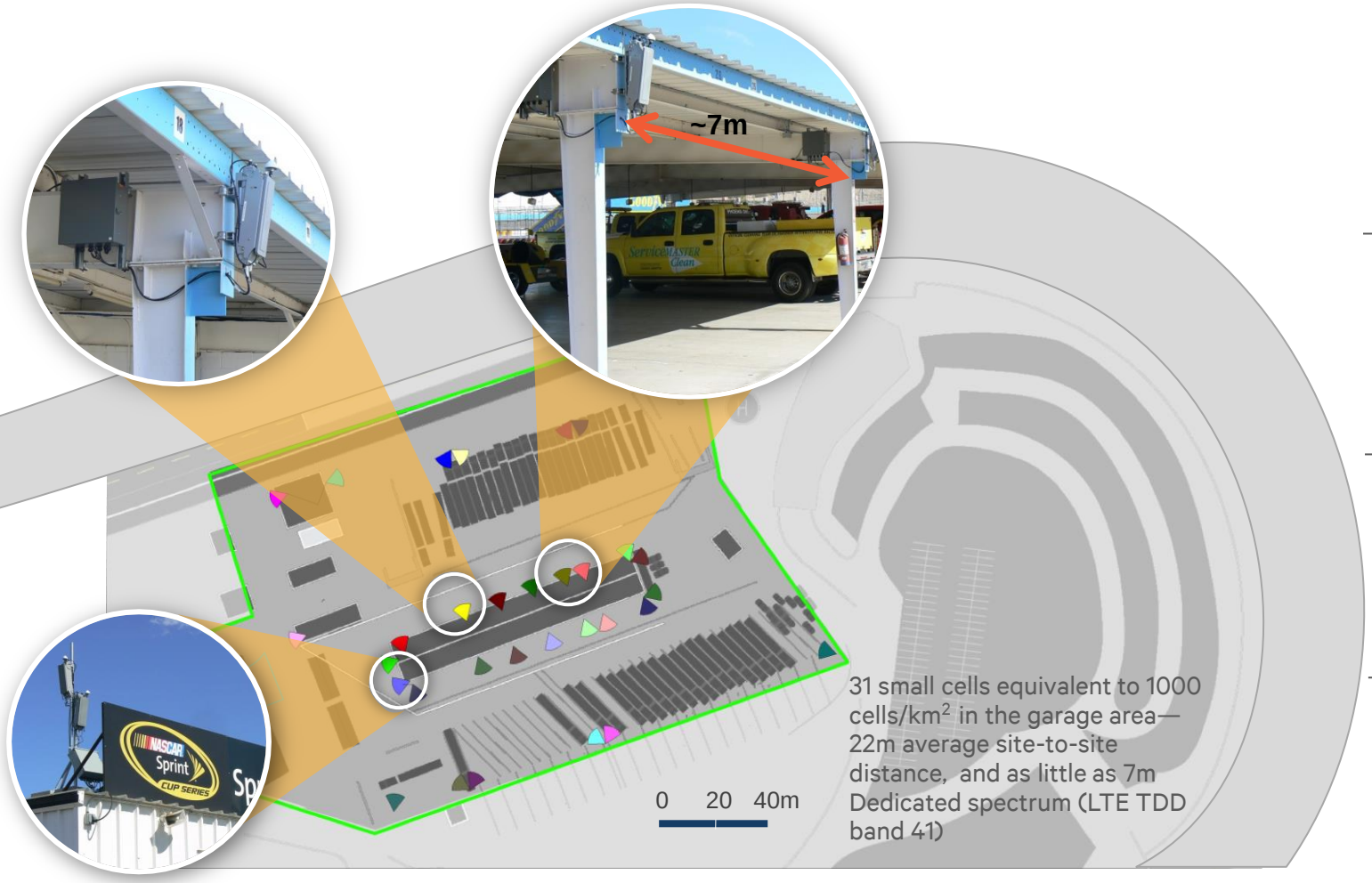
World's densest LTE small cells deployment brings 1000x closer to reality[1]

If an 'unplanned' deployment works at a Nascar venue—it should work everywhere!

[1] World's densest LTE outdoor small cell network as of 4/2014, based on prior publicly announced deployments

Bringing 1000x closer to reality: hyper-dense small calls

If ‘unplanned’ hyper-dense deployments work at NASCAR venue—it should work everywhere



31 small cells equivalent to 1000 cells/km^2 in the garage area—22m average site-to-site distance, and as little as 7m Dedicated spectrum (LTE TDD band 41)

World’s densest LTE outdoor network[1]

Extreme localized data demand, challenging RF conditions

40x more capacity than alt. solutions

Compared to traditional portable macro solution[2]

Enabled by UltraSON™

Unplanned deployment, robust mobility, reliable user experience

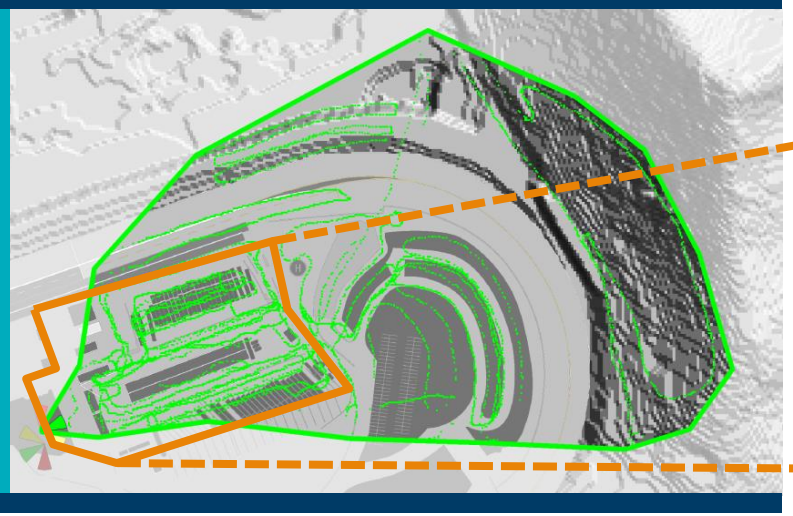
UltraSON is a product of Qualcomm Technologies, Inc.

[1] World’s densest LTE outdoor small cell network as of 4/2014, based on prior publicly announced deployments. [2] Compared to a Portable ‘cell on wheels’ site. Sprint/Nascar/Airspan/Qualcomm small cell demo took place March 2nd 2014 at the Phoenix international raceway

40x more capacity compared to traditional solutions

Combined with more spectrum, shows that 1000x is feasible in real world environments

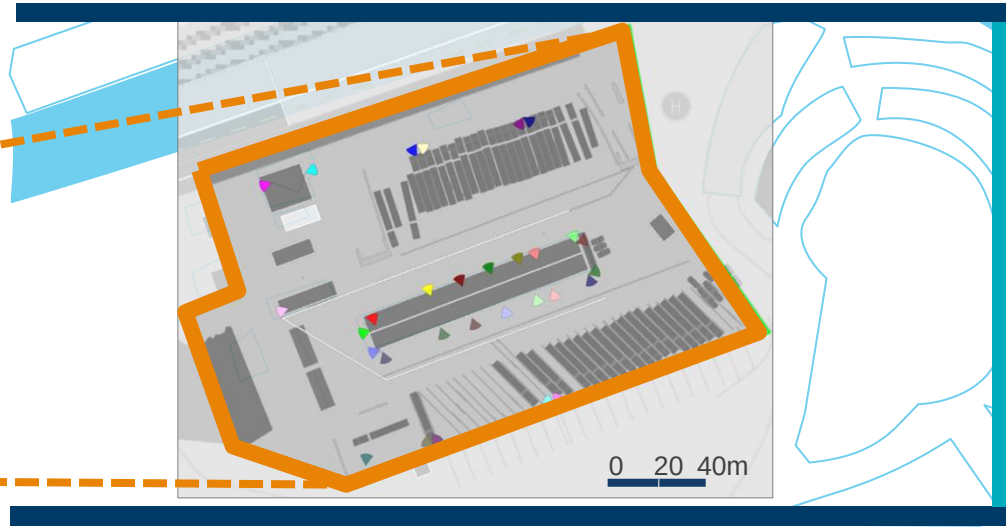
Traditional deployment 'Cell On Wheels'



Equivalent cell density: 9 cells/km^2
Average site-to-site: 519m
Spectrum: 5 + 5 MHz, LTE FDD
Coverage: 0.11 km^2

Measured Efficiency
~16 bps/Hz/km^2

More than 40x capacity



'Unplanned' small cell deployment

Equivalent cell density: 1107 cells/km^2
Average site-to-site: 22m
Spectrum: 20 MHz, LTE TDD (60%DL/40%UL)
Coverage: 0.028 km^2

Measured Efficiency
~660 bps/Hz/km^2

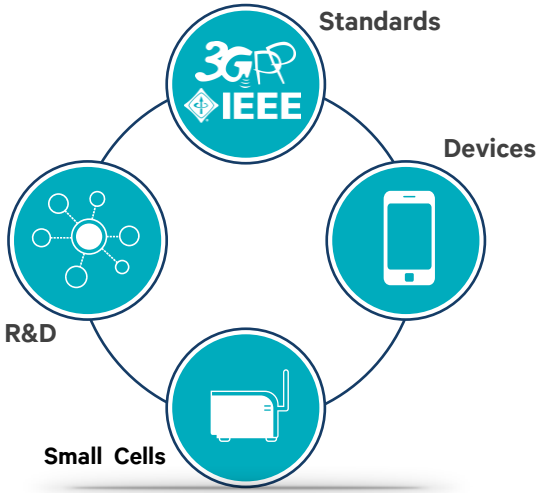
Sprint/Nascar/Airspan/Qualcomm small cell demo took place March 2nd 2014 at the Phoenix international raceway

Summary: Qualcomm enables small cell solutions for 1000x

Multiple paths to 1000x with different small cell types and sizes, indoor, outdoor, …

1000X

End-to-End Approach



Demonstrating hyper-dense small cells

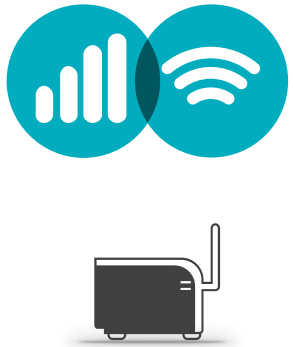
New small cells Deployment models

More ‘unplanned’ Ad-Hoc. And inside-out such as neighborhood small cells

Enabling Technologies

Interference management UltraSON

Enabling Small Cell Product Solutions



Small cell solutions for all venues

Will there be 1000x demand?
It's just a matter of time...

Pushing wireless boundaries

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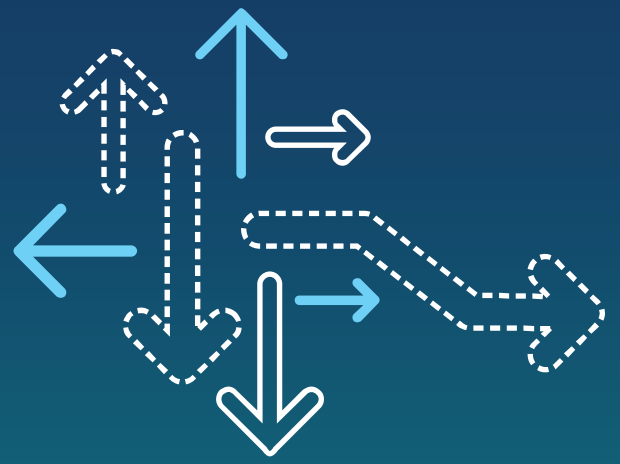

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