Steve Perlman
President & CEO
Artemis Networks LLC
355 Bryant Street Suite 110
San Francisco, CA 94107

December 4, 2014

***Via Electronic Filing***

Marlene H. Dortch, Secretary
Federal Communications Commission
445 12th Street, S.W., Room TW-A325
Washington, D.C. 20554

Re: ***Notice of Ex Parte Presentation:*** *Expanding the Economic and Innovation Opportunities of Spectrum Through Incentive Auctions*, GN Docket No. 12-268

Dear Ms. Dortch:

On December 2, 2014, individuals from Artemis Networks LLC ("Artemis" or "we" or "our") presented to individuals at Commission offices at 445 12st SW, Washington, DC, regarding the Artemis Networks LLC ("Artemis") Petition for Reconsideration[1] ("Artemis Petition") of the Commission's Expanding the Economic and Innovation Opportunities of Spectrum Through Incentive Auctions, Report and Order" ("Report and Order") [2]

The following individuals from Artemis presented:

Steve Perlman, Artemis President & CEO
Antonio Forenza, Ph.D, Principal Scientist
Mario Di Dio, Ph.D, Senior System Engineer
Cindy Ievers, Vice President, Finance

First, Artemis met with David Goldman, Senior Legal Advisor, Office of Commissioner Jessica Rosenworcel.

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[1] *Expanding the Economic and Innovation Opportunities of Spectrum Through Incentive Auctions*, *Petition for Reconsideration*, GN Docket No. 12-268, Artemis Networks, LLC (filed September 15, 2014)
[2] *Expanding the Economic and Innovation Opportunities of Spectrum Through Incentive Auctions*, GN Docket No. 12-268, Report and Order, FCC 14-50 (2014)



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Second, Artemis met with the following individuals from the Commission:

Bahman Badipour, Engineer
Martin Doczkat, Chief, Tech. Analysis Br., OET
Gary Epstein, Chair-IA Task Force
Michael Ha, Deputy Chief, Policies & Rules Division, OGT
Chris Helzer, Chief Engineer WTB
Pramesh Jobanputra, Economist/WTB
Walter Johnston, Chief-EMCD
Julius Knapp, Chief, OET
John Leibovitz, Special Advisor to Chairman for Spectrum Policy, Dep Chief WTB
Ziad Sleem, Associate Deputy Chief – Policy – WFB
Tom Tran, Engineer/WTB
Aleks Yankelevich, Economist
Weiren Wang, Ph.D., Senior Economist/WTB

Artemis presented the slide deck, attached below as Appendix A. During and after the presentation, there was extensive discussion on a technical, economic and public policy level.

The Commission engineering staff noted that Artemis was not the only party urging the Commission to accommodate future high spectral efficiency technology or convey the importance of TDD; they said they had just received a presentation on an alternative approach to achieve high spectral efficiency, Massive MIMO, by Thomas Marzetta, PhD, Group Leader, Bell Labs Alcatel-Lucent. Dr. Marzetta also gave a presentation on Massive MIMO on October 2014 to the Marconi Society in the video "MIMO 2025: A 10x or 100x Capacity Multiplier?" http://new.livestream.com/internetsociety/2014MarconiSocietySymposium/videos/63753060. At minute 1:13:36, note that Dr. Marzetta makes the same argument regarding TDD vs. FDD and high spectral efficiency that we made in our presentation on pCell, that TDD not only performs better for mobile users, but it is *essential* for enabling unlimited scalability of users. FDD not only performs worse at small scale, but has a hard upper limit in scalability.

Artemis' conclusions were presented on slide 54. Although there was strong consensus that, to the extent practical, the 600 MHz band should be "future-proofed" to enable future high spectral efficiency technology, everyone we spoke to at the Commission stated that it is extremely unlikely at this point that 600 MHz duplex scheme could be changed from FDD to TDD, unless we could convince the major U.S. wireless operators to agree to TDD.

We heard several proposed alternatives where TDD operation might be possible (our responses are in *italics*):



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1. We could participate in the rules regarding the 11 MHz unlicensed 600 MHz duplex gap. *Our concern was that high spectral efficiency technology would likely require real-time centralized control for shared spectrum, which may be difficult for all parties to agree to. But, we said we would be happy to propose suggestions on how that might work.*

2. If a television station that has a right to stay in the 600 MHz band declines to move, there would be a corresponding pair of spectrum in the uplink or downlink band that could be potentially used for TDD operation if power levels were low enough/guard bands wide enough to not interfere with adjacent FDD use. *Our concern was that such opportunistic spectrum would not be available in all markets, and that it would be limited to low power operation.*

3. There may be some small guard band gaps that could be aggregated for TDD use. *Our concern is that the overhead in very narrow bands would limit efficient use, and because of adjacency, they would be limited to low power operation.*

4. There are no restrictions on operating in TDD mode in the 700 MHz band, provided permission is obtained by the licensees of that spectrum. *Given how 100s of millions of FDD mobile devices rely on connectivity in the 700 MHz band, we believe it is impractical for current licensees to completely switch over to TDD and "orphan" those devices.*

5. We can propose TDD in future auctions of lower frequencies. *We certainly will, but it is unclear when, and if, such lower frequencies will be auctioned.*

6. There were new rules being considered for the 3.5 GHz band and TDD certainly could be proposed as well as other sharing schemes. *Although we certainly are open to participation in the 3.5 GHz band, it will have very poor propagation characteristics compared to 600 MHz. Our point in filing the Artemis Petition was that 600 MHz has exceptional propagation characteristics that the U.S. cannot afford to waste on low spectral efficiency technology.*

On slide 51, we presented our understanding of the trade-offs between FDD and TDD. First, we pointed out how TDD was essential for all known high spectral efficiency applications (e.g. pCell, "Full Dimension MIMO" proposed in the 3GPP Rel. 13 Study Group, and Massive MIMO). Second, we showed how TDD achieves much higher spectral efficiency given the 10:1 downlink:uplink traffic asymmetry in conventional LTE networks, with minimal technical obstacles compared to FDD. We pointed out that current U.S. mobile devices already have TDD capability to be compatible with Sprint's Band 41 (e.g. iPhone 6, iPad Air 2, Nexus 6).



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Further, we pointed out other major global economies, such as China, are deploying TDD in low band spectrum (e.g. Band 44 700 MHz), which will give them an enormous economic advantage over the U.S. in mobile connectivity since they will be able to deploy high spectral efficiency wireless in both 700 MHz and eventually 600 MHz, whereas the US will be limited to low spectral efficiency because of FDD in both 700 and 600 MHz bands. As our economies become increasingly reliant on mobile connectivity, China and other countries will ultimately have 100s of times more capacity in low-band spectrum than the U.S.

On slide 52, we showed a typical day time capture of AT&T 700 MHz FDD spectrum in San Francisco, showing the downlink band was utterly saturated (downlink blocks are green) and the uplink band was almost unused (uplink blocks are blue), resulting in almost half of the spectrum being unutilized (unused spectrum is black). We pointed out that captures of other carriers' FDD spectrum showed the same overwhelmed downlink spectrum and almost unutilized uplink spectrum. This is consistent with the 10:1 downlink to uplink ratio cited from Nokia Siemens research on Slide 51, and shows that, if TDD were utilized with the asymmetric downlink and uplink that exists in the real world, spectrum would be utilized far more efficiently.

Given that:

1. TDD is needed to future-proof for high spectral efficiency technology (for which at least pCell is a existence proof working today)

2. Both peer-reviewed and industry literature as well as actual measured results show that FDD is extremely wasteful of real-world use of spectrum, with uplink almost unutilized.

3. Current U.S. LTE devices already support TDD.

4. pCell is an existence proof that using TDD, off-the-shelf unmodified LTE devices can be used to achieve high spectral efficiency with no modifications. If FDD were to be used to achieve high spectral efficiency through next generation technologies at the cost of high overhead and limited scalability, modifications to the existing LTE standard would be required to support CSI feedback for a large number of users. As such, no existing LTE devices would be compatible with high spectral-efficiency FDD LTE.

5. Other major global economies such as China are adopting low-band TDD in 700 MHz, and likely will in 600 MHz as well, enabling >100X the capacity of U.S. low-band spectrum if 600 MHz remains FDD, placing the U.S. at an enormous economic disadvantage in an increasingly mobile future.



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6. If a TV station declines to move out of the 600 MHz band, FDD results in the loss of blocks paired with the blocks overlapping the TV station, whereas TDD results in only the loss of the blocks overlapping the TV station: one-half of the spectrum loss.

7. The only slight advantage of FDD over TDD is it is slightly (a few percent) more spectrally efficient in perfectly symmetric traffic, such as voice-only traffic. Date traffic is highly asymmetric, so this advantage is irrelevant. And, even that minor advantage is lost when high-spectral efficiency techniques are to be used even with perfectly symmetric traffic.

As we brought up these points, there were no counter-arguments voiced to any. At various points in the meeting we asked what were the supporting technical, economic, deployment or public policy arguments to support of FDD over TDD for 600 MHz. Again, none were stated. We were consistently told that the only practical way to change 600 MHz from FDD to TDD would be to convince the major U.S. wireless operators to support TDD.

We presented our conclusions on slide 54. The Commission asked if, other than changing from FDD to TDD, whether there is anything we could suggest to help future-proof 600 MHz. We replied that, although it is a distant second to switching from FDD to TDD, at the very least the Commission could mandate that mobile devices support both FDD and TDD in 600 MHz so that if 600 MHz is switched to TDD in the future to achieve high spectral efficiency, it would not orphan devices using that band. Mobile devices already support FDD and TDD at the same frequency (e.g. the iPad Air 2 supports both Band 7 FDD and Band 41 TDD at the same frequency) and it would not be difficult or expensive. The Commission responded that in general it is difficult to mandate non-essential design requirements for devices because manufacturers may argue it adds even minor cost in a highly cost-sensitive market.

We ended the meetings offering to provide high spectral efficiency demos of pCell technology operating on unmodified LTE devices to the Commission either in DC or at another location at their convenience, and further to avail ourselves to extent they would like to verify results. We made it clear our purpose is simply to provide an existence proof that very high spectral efficiency is practical using TDD on off-the-shelf unmodified LTE devices, regardless of what high spectral technology is ultimately used by 600 MHz licensees in the future.

We strongly believe that, as the custodians of the very scarce natural resource of low-band spectrum, the Commission should base its decision on FDD or TDD primarily on a technical, economic, deployment and public policy basis. While the recommendations of large incumbent companies should certainly be given a great deal of weight, given that virtually every factual consideration weighs against the large incumbents' recommendations, then we believe it is the Commission's responsibility to consider the strong public policy benefit of high spectral



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efficiency as carrying more weight than the recommendations of large incumbents advocating a technology that relegates low-band spectrum to low spectral efficiency.

We respectfully request the Commission specify the 600 MHz band to be a TDD band, or at least partially TDD (in licensed spectrum). We further respectfully request the Commission to require minimum reasonable spectral efficiency requirements for licensees of the 600 MHz utilizing any technology they choose that is available at the time of deployment and economically viable (similar to CAFE standards specifying minimum MPG requirements for automobile manufacturers).

Pursuant to section 1.1206(b) of the Commission's rules, this letter is being submitted for inclusion in the public record of the above-referenced proceeding. Please let me know if you have any questions.

Respectfully submitted

/Stephen G. Perlman/

Steve Perlman
President & CEO
Artemis Networks LLC

cc: Bahman Badipour, Martin Doczkat, Gary Epstein, David Goldman, Michael Ha, Chris Helzer, Pramesh Jobanputra, Walter Johnston, Julius Knapp, John Leibovitz, Ziad Sleem, Tom Tran, Aleks Yankelevich, Weiren Wang, Ph.D.



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Appendix A: Artemis Presentation to the Commission on December 2, 2014



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# High Spectral Efficiency in 600 MHz

## Protecting a scarce natural resource

Steve Perlman
Founder & CEO, Artemis Networks

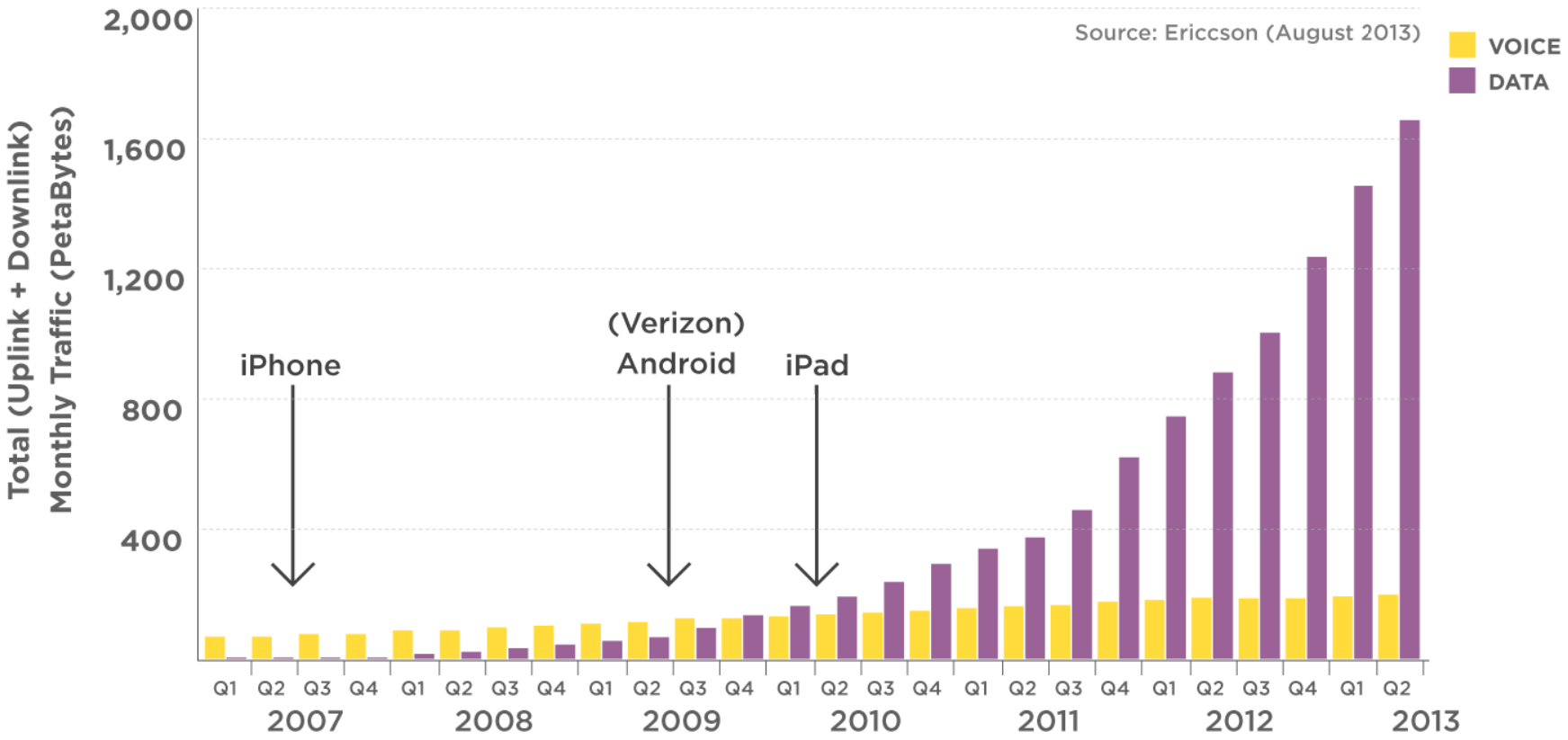
# Artemis Presenters

- Steve Perlman, Founder/CEO
  - **Companies:** Rearden, OnLive, WebTV/Microsoft, Apple, MOVA, Moxi, etc.
  - **Tech:** QuickTime, WebTV, Color Macintosh, Cloud Gaming, etc.
- Antonio Forenza, Ph.D, Co-founder/Principal Scientist
  - **Degree:** University of Texas at Austin
  - **Companies:** Rearden, Freescale, Samsung SAIT, ArrayComm, Iospan Wireless
- Mario Di Dio, Ph.D, Senior Systems Engineer
  - **Degree:** University of Pisa
  - **Companies:** Rearden, Italian Dept. of Defense, European Space Agency, Wiser
- Cindy Ievers, VP Finance
  - **Companies:** Rearden, OnLive, MOVA, Ice Blink, Talarian

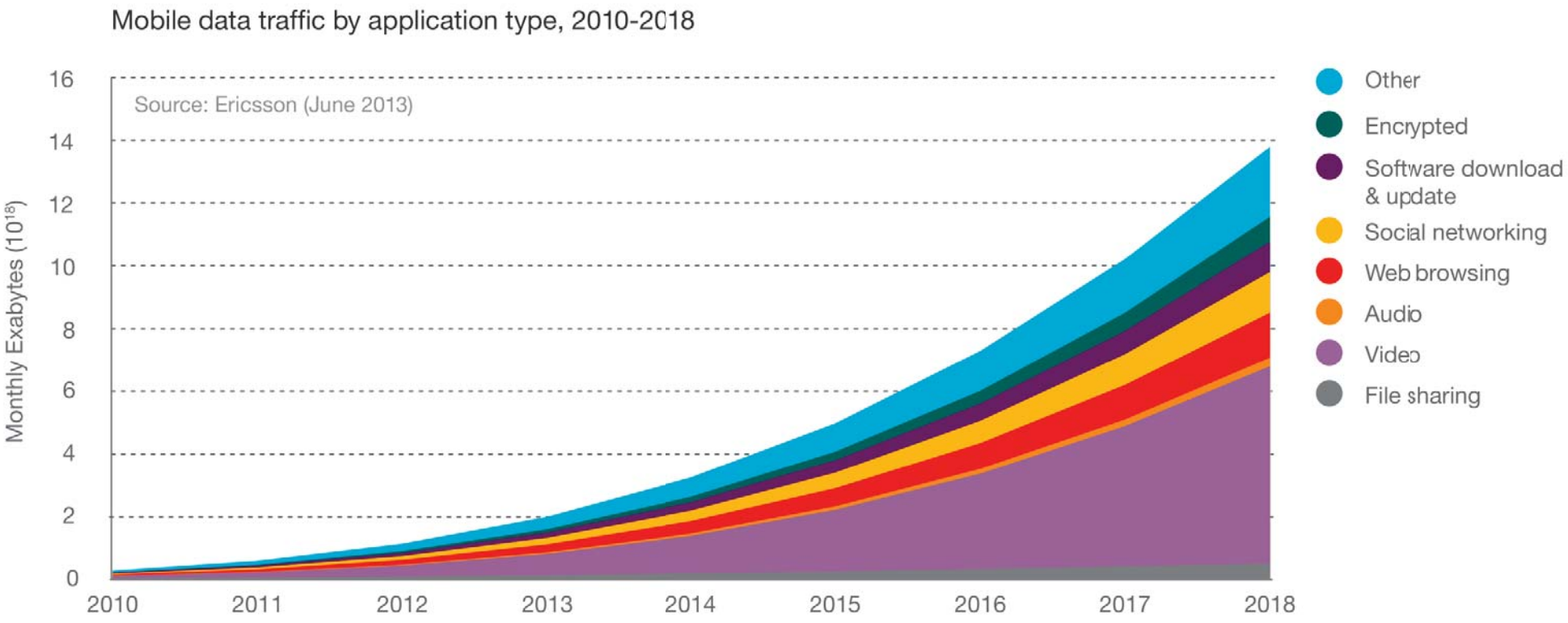
# Artemis team and pCell development

- Decade of development within Rearden incubator
  - Complete rethink of wireless waveforms, radios, system architecture
- Current dev team
  - 7 engineers (3 PhD's)

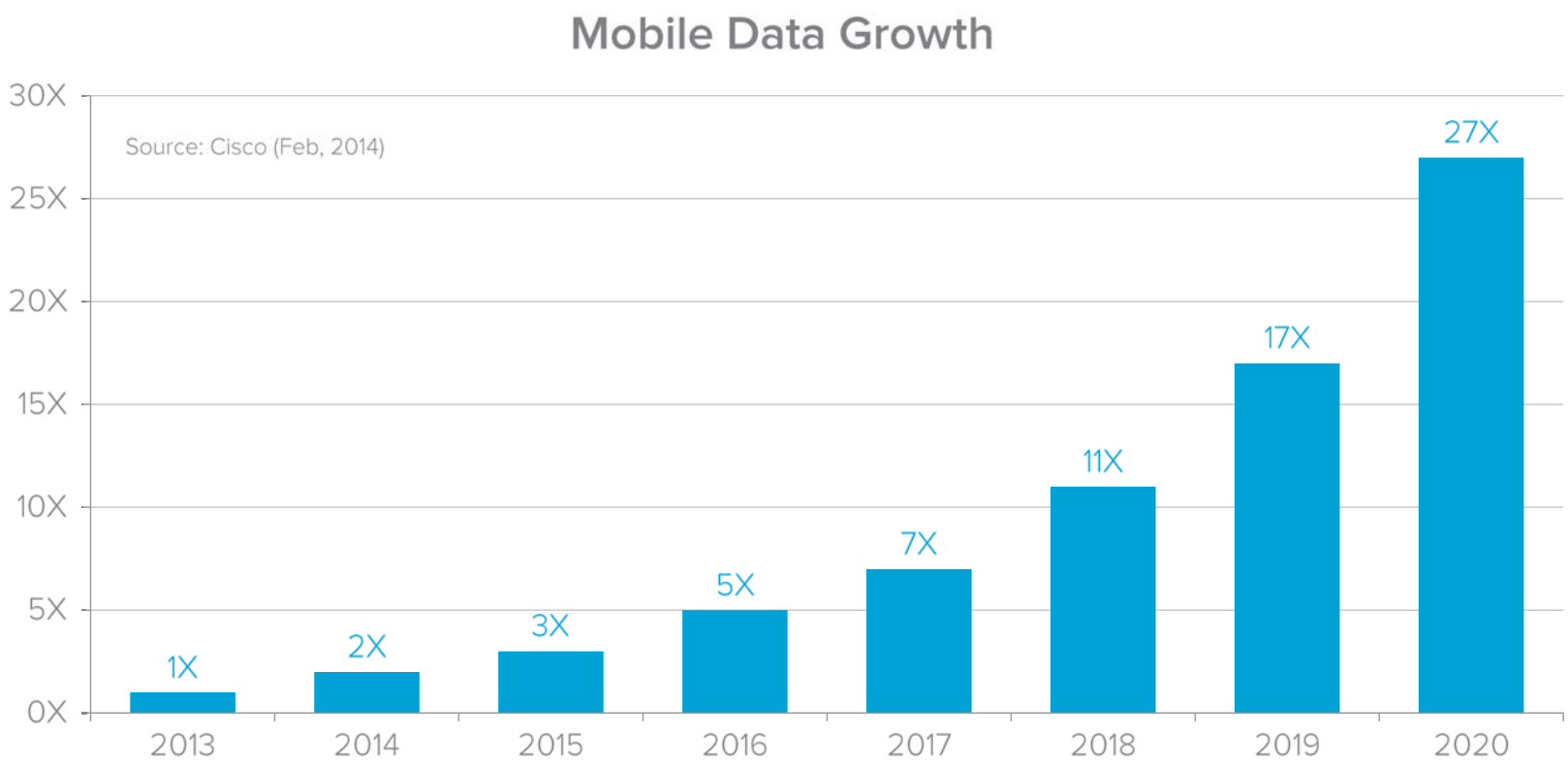
# Mobile Revenue is Fueled by Data



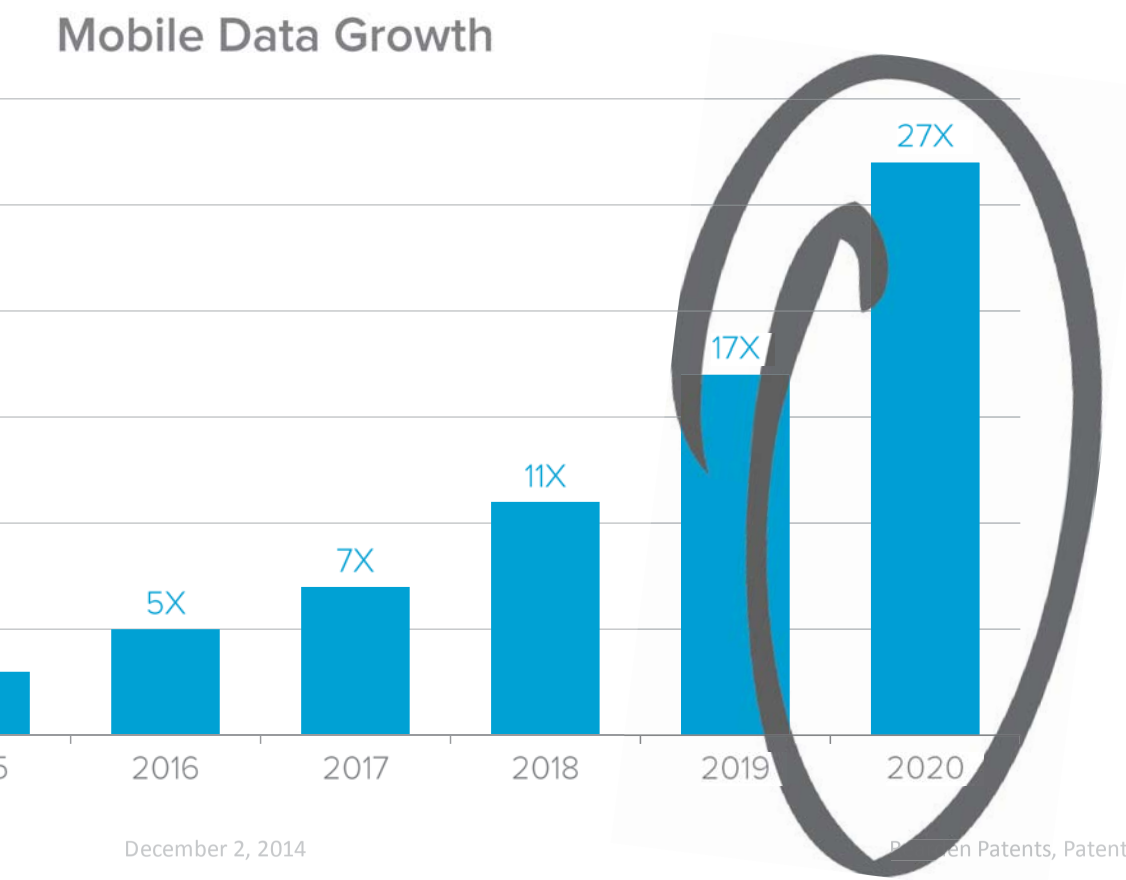
# Exponential Data Growth is Projected…



# ...to 27X Current Data Capacity by 2020



# What's Wrong with this Picture?




## 27X today's capacity? Seriously?

Cellular is already overloaded in major markets. 27X more?

Even 10X is far beyond the ***Physics*** limit of cellular.

***Yet, the entire $2.9 Trillion 2020 mobile market hinges on achieving 27X***

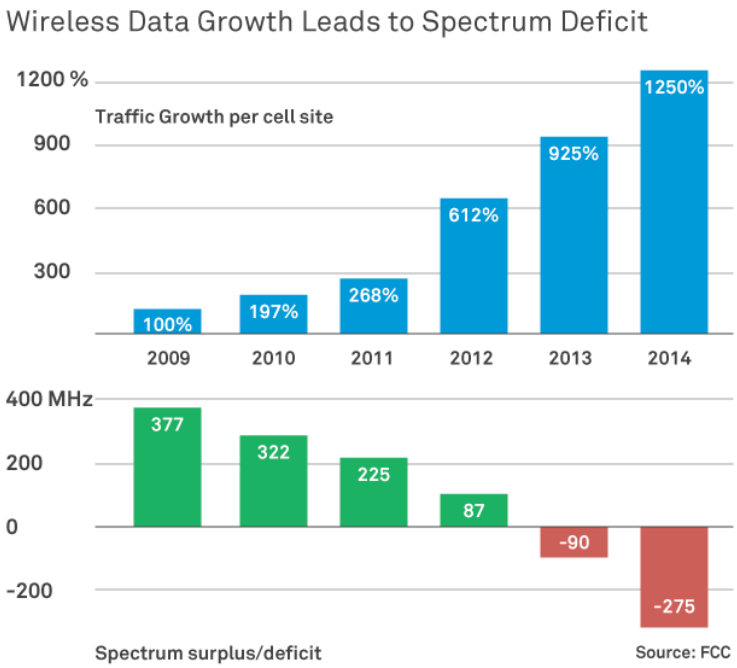
# The Problem:
# We're out of Spectrum

# Worldwide Spectrum Deficit

- US Mobile spectrum was "full" in 2013[1,2]
  - US LTE data rates declined from 2013-2014
- Overall demand exceeds capacity
  - Current networks already overloaded
  - 5G tech in early R&D stages
    - Wide deployment not expected till 2025

**"… it's the *physics* that breaks it …you just run out of gas."**

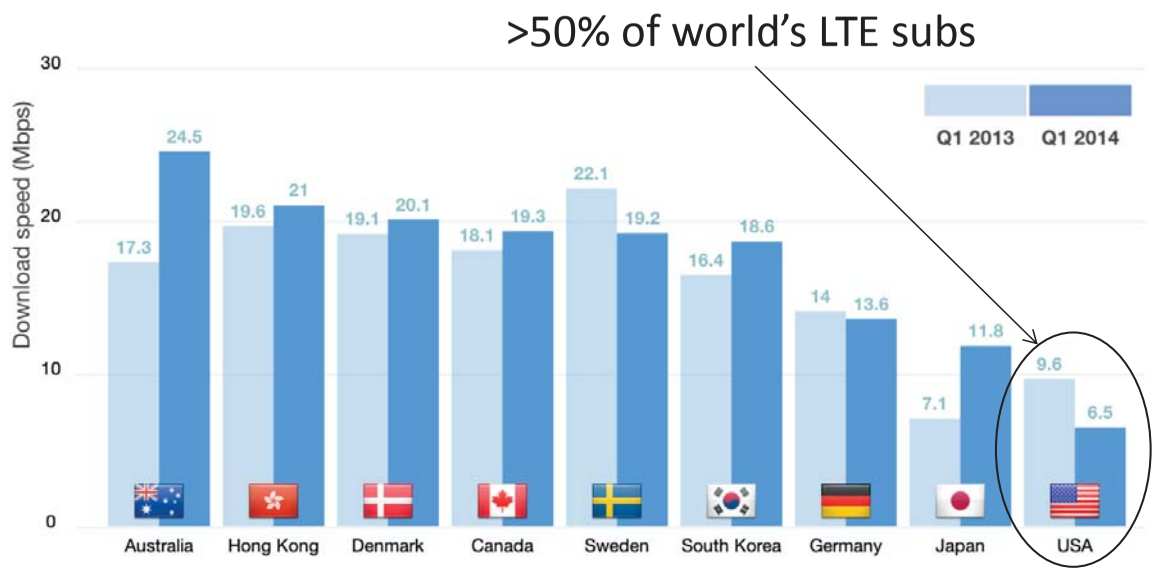
Verizon CEO, Lowell McAdam, Sep 2013




[1]FCC, 2010
[2]"Mobile Data Wave" blue paper, Morgan Stanley, 6/13/12

# LTE Hitting Ceiling

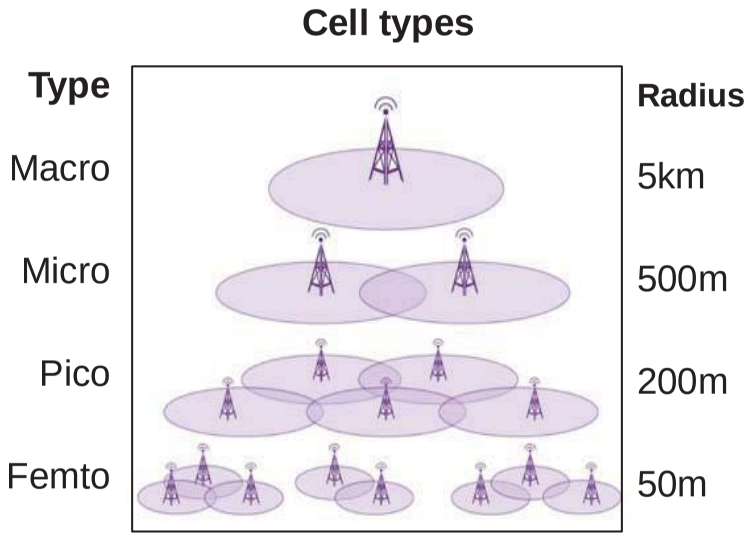
- LTE "success" results in slow service
  - US has more LTE subscribers than rest of world combined
    - >50% smartphones
  - NTT is Japan LTE leader
    - 2-year lead on rivals




Source: OpenSignal 2014

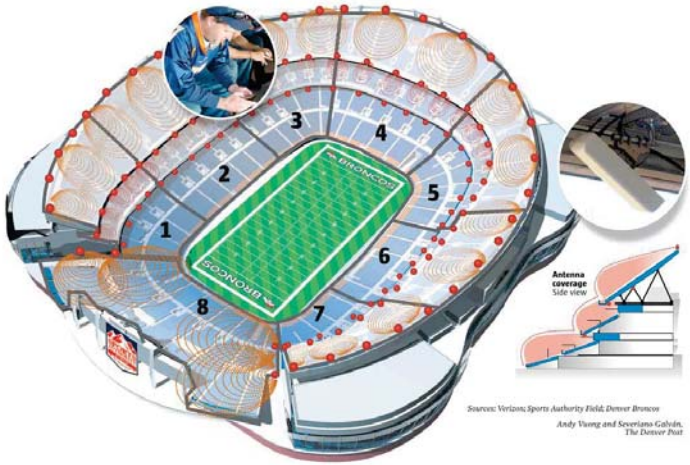
# Small Cells Only Known Capacity Option

- Smaller cells only significant capacity option
  - Looks great in theory, but not in practice
- Cellular overhead soon exceeds capacity gain
  - Intercell interference
  - Handoff overhead
- High cost, difficult deployment
  - Zoning permits
  - Backhaul
  - Power
  - Cost



# Wi-Fi Unpredictable, Overloaded

- Wi-Fi similar to very fragile small cells
  - Highly variable service: from good to zero
  - Easily interfered
  - Limited throughput
    - Legacy devices (a,b,g) slow down new devices (n,ac)
- Stadiums forced to control WiFi usage
  - Blocking streaming video (e.g. nfl.com)
  - Inspecting entering attendees for interference
    - Any interference can wipe out a section



Super Bowl 2014 sign

# Mobile Spectrum a Finite Natural Resource

- AWS-3 Spectrum auction has topped $40B. For perspective:
  - >4X reserve price
  - >2X 2008 700 MHz auction
  - >80% the value of all spectrum sold by FCC in past 20 years
- Spectrum arguably is the most valuable natural resource on Earth
  - Within 3 years, demand will exceed all mobile spectrum there is
  - Soon there will be no mobile spectrum left to auction
  - Mobile networks will become increasingly congested

**We must use remaining mobile spectrum far more efficiently**

# 600 MHz: **Must** be used as efficiently as possible

- 5+5 MHz FDD cellular LTE averages <**10** Mbps DL
  - 10 Mbps shared among all LTE devices in a cell
    - 10 Mbps is barely adequate for 1 user today, let alone in 2016
- 10 MHz TDD cellular LTE averages >**15** Mbps DL
  - Improvement, but far short of need
  - TDD enables new high-spectral efficiency technologies
- 10 MHz TDD pCell LTE averages >**400** Mbps DL today
  - Every LTE device can get >**25** Mbps concurrently
  - Can't be achieved with FDD
  - **Existence proof that high spectral efficiency is achievable**

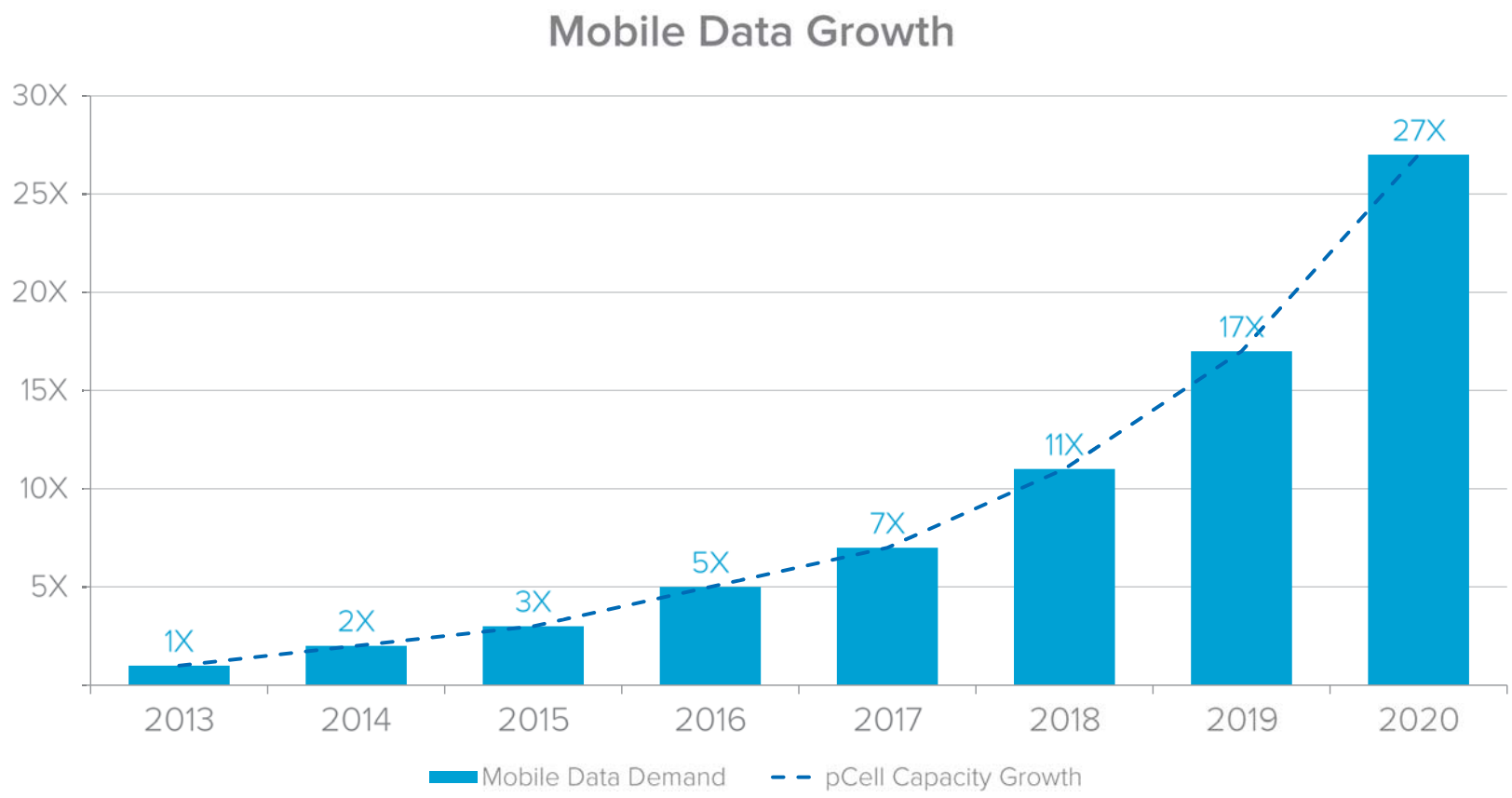
# pCell. User-centric Synthetic Cells

Existence proof high-spectral efficiency is practical

# Introducing pCell™

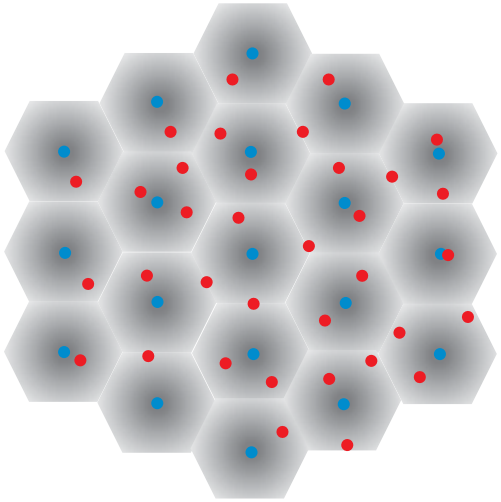
Mobile in the fast lane.
Everyone. All the time.

# pCell Scales with Data Demand

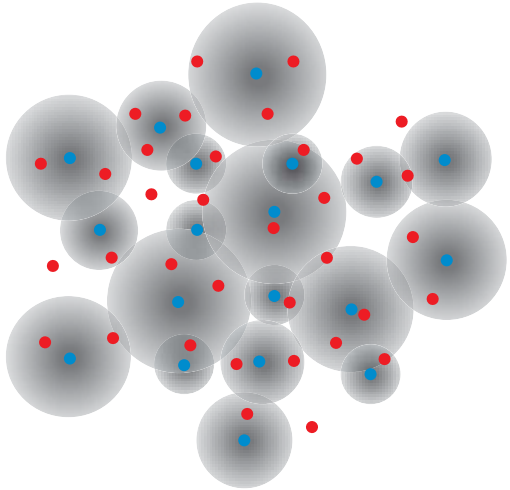



Source: 2/2014, Cisco VNI Global Mobile Data Traffic Forecast Update 2013-2018

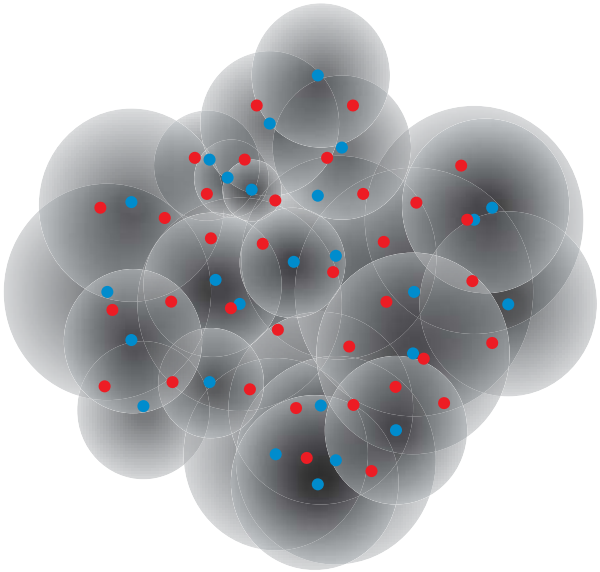
# LTE/WiFi vs. pCell Coverage



Idealized LTE/WiFi Coverage



Real-world LTE/WiFi Coverage

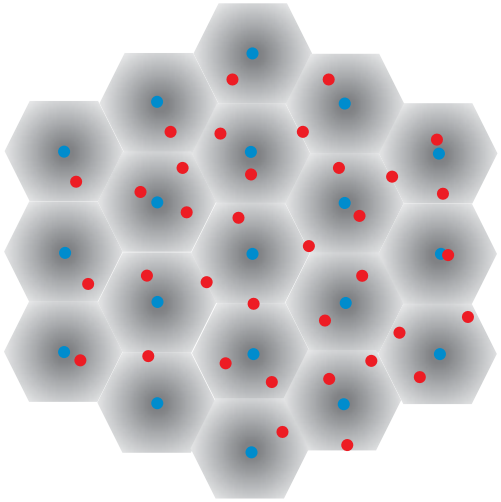


Real-world pCell Coverage

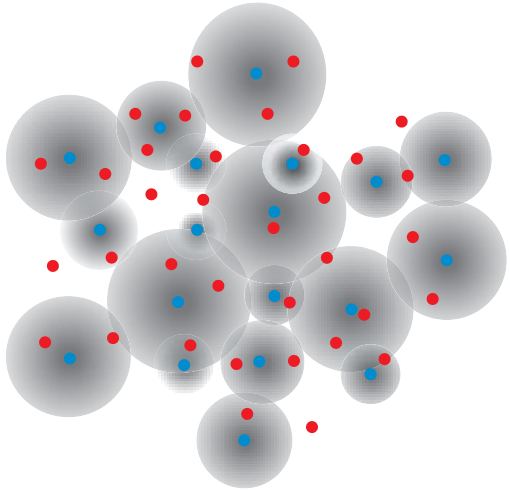
- Base Station
- User Equipment

Coverage

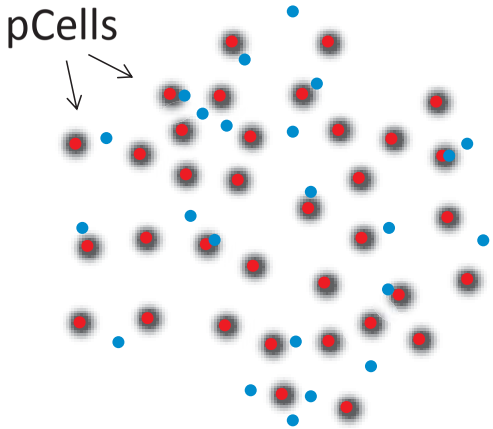
# User Signal Quality



Idealized LTE/WiFi SINR



Real-world LTE/WiFi SINR

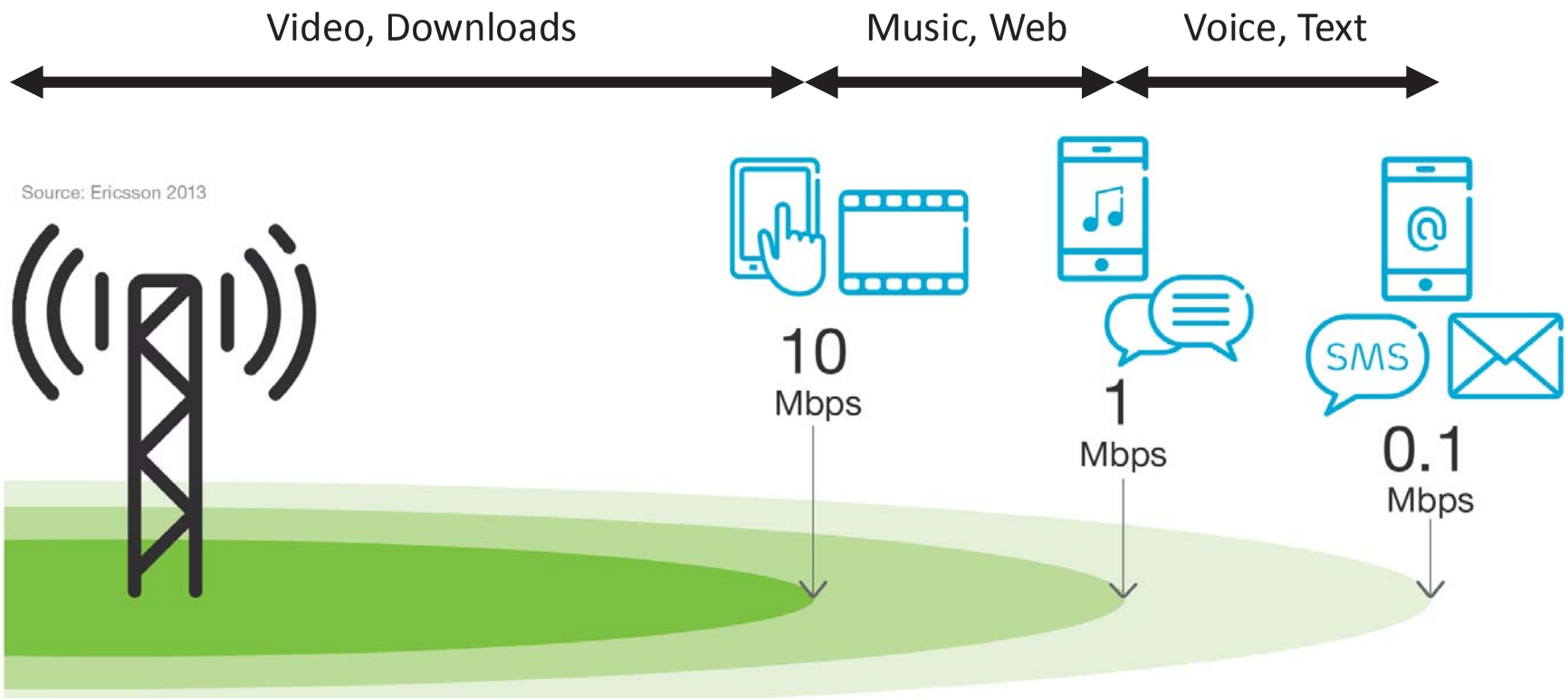



Real-world pCell SINR

- Base Station
- User Equipment

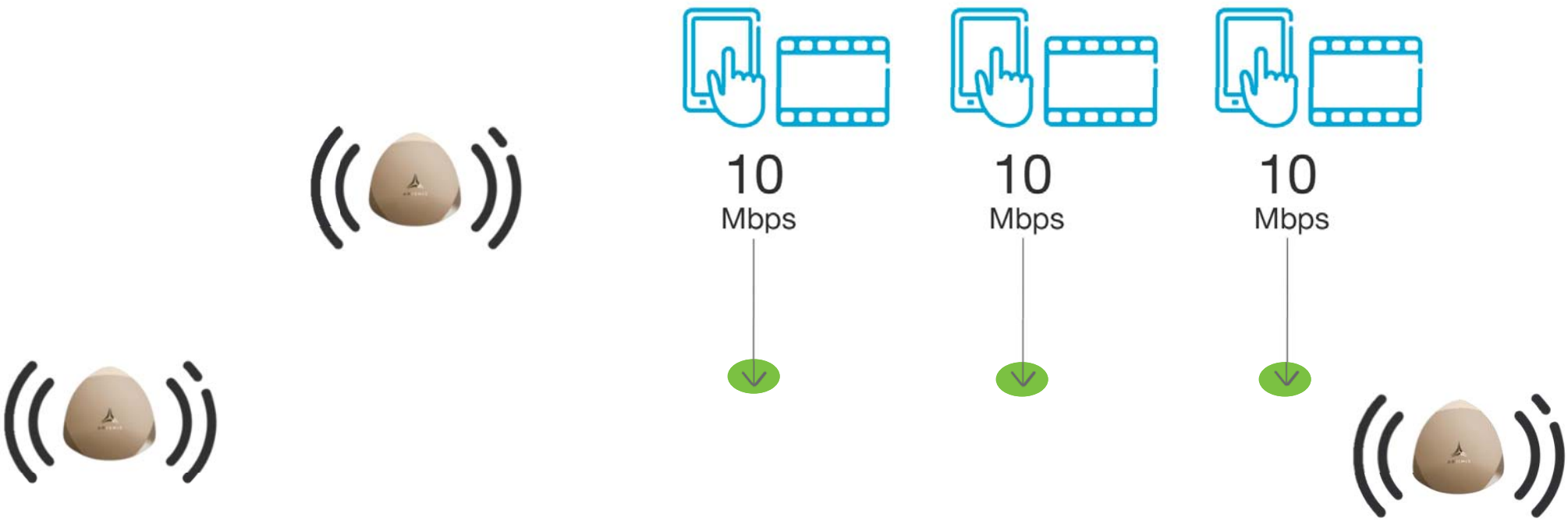
SINR (darker is higher)

# Cellular Service Highly Variable

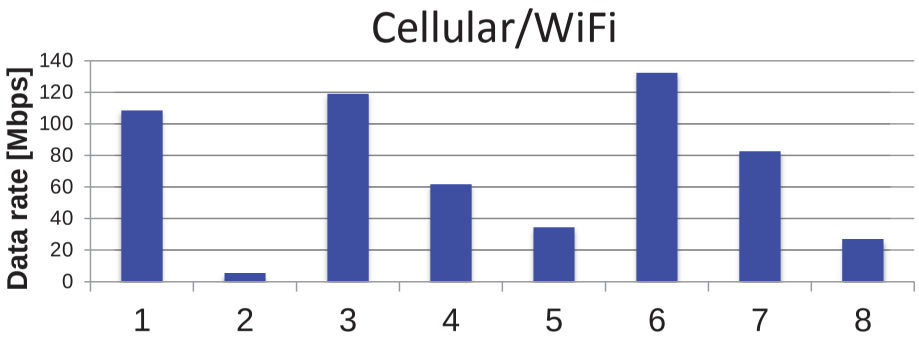


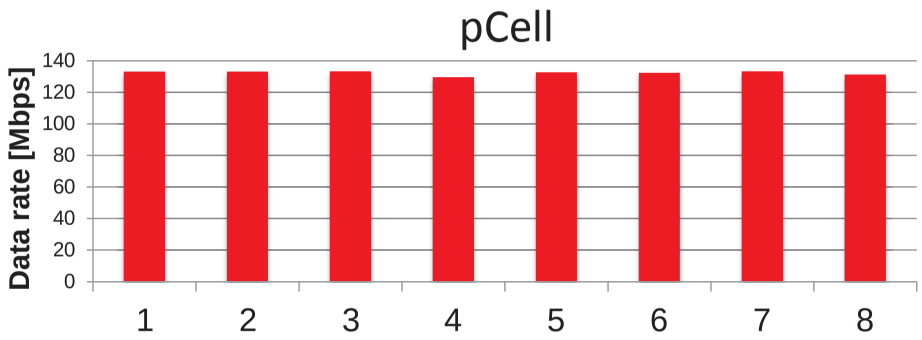
# pCell Service Highly consistent

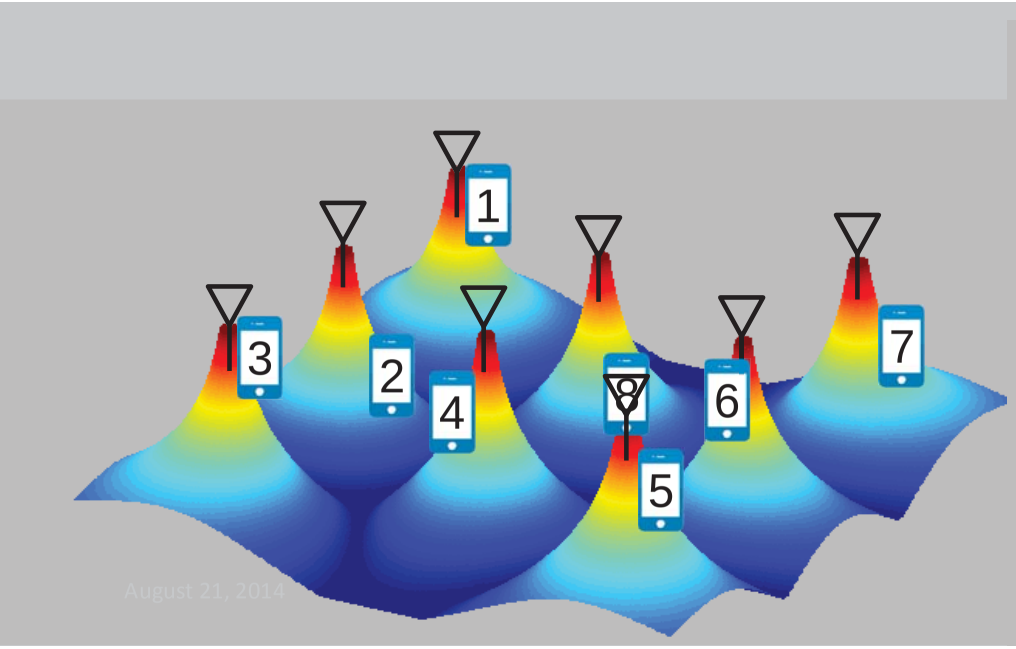
Video, Downloads, Music, Web, Voice, Text ***EVERYWHERE***

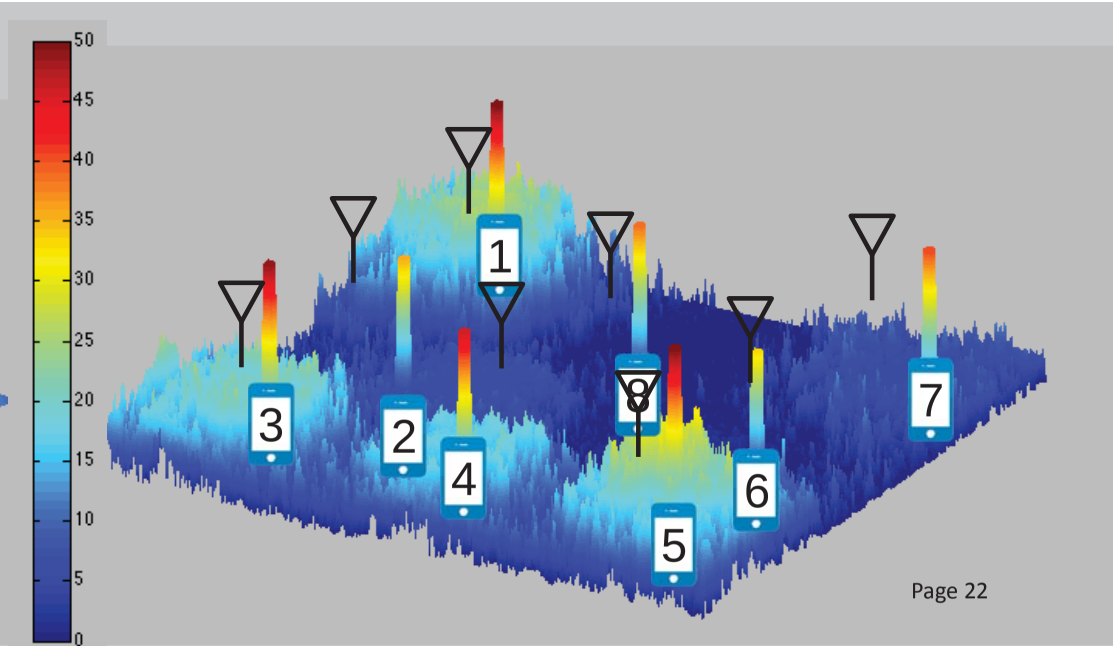


# Cellular Layout, Sparse Users

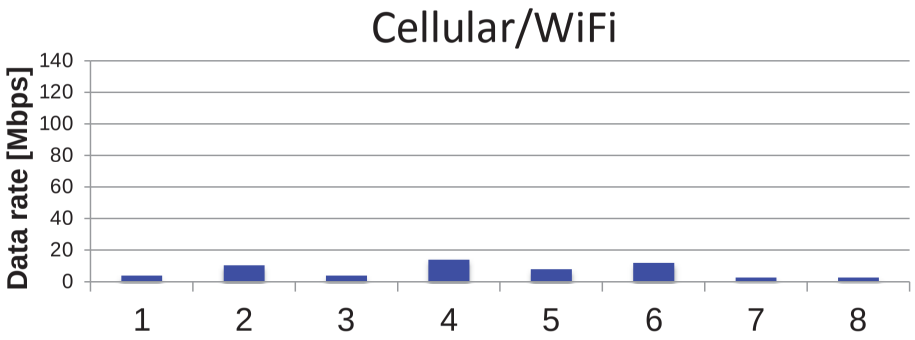


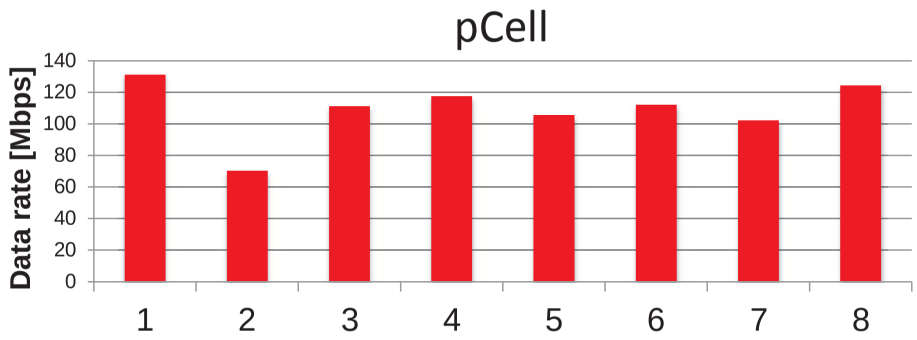



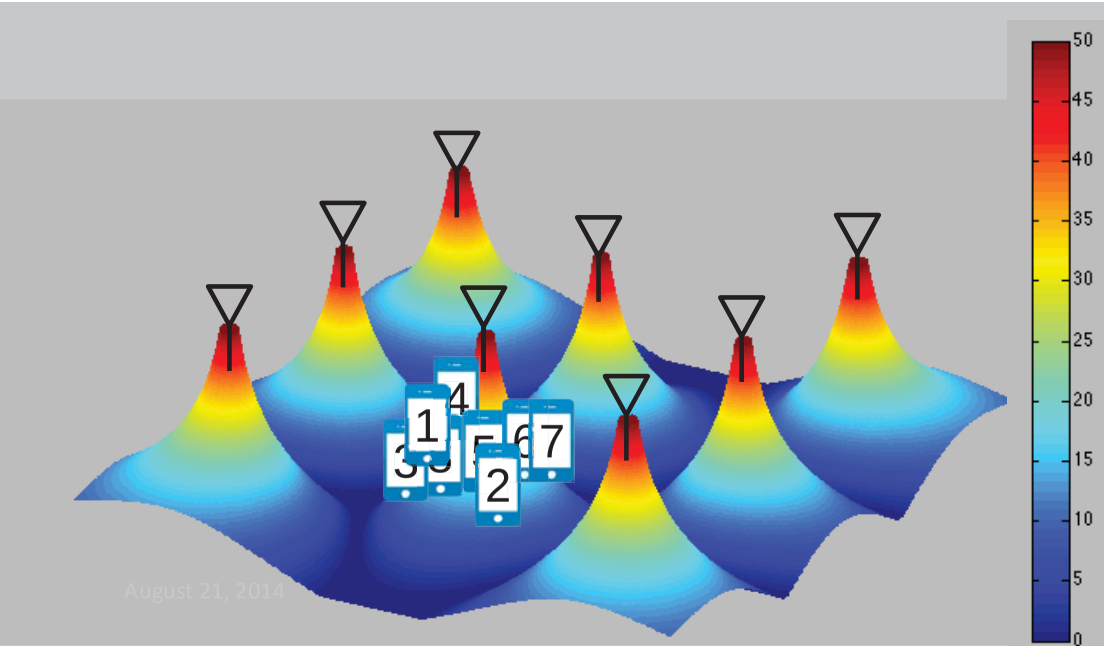



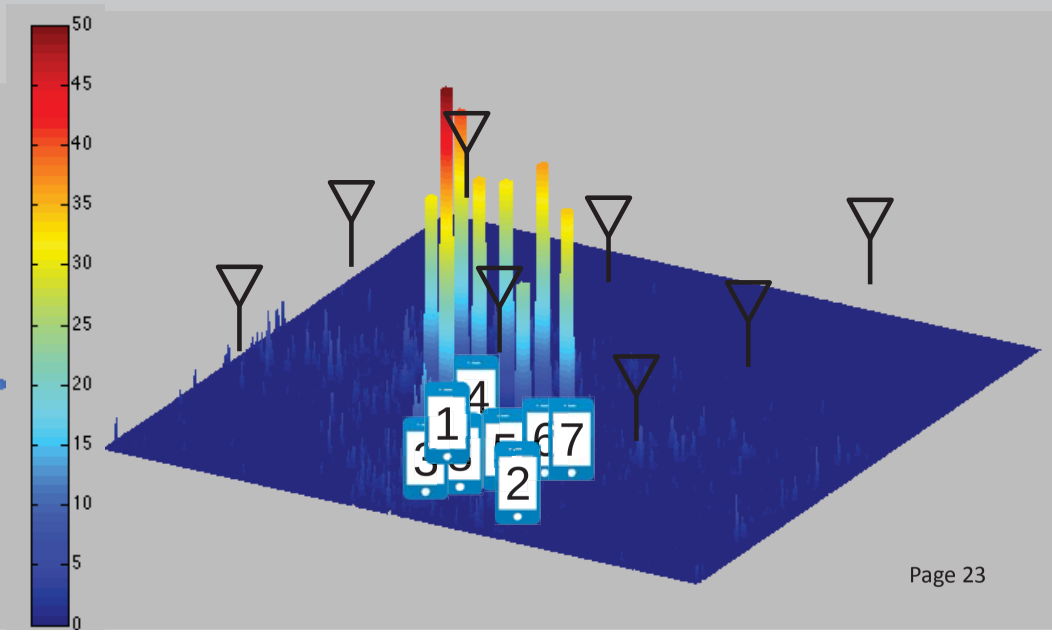



# Cellular Layout, Clustered Users

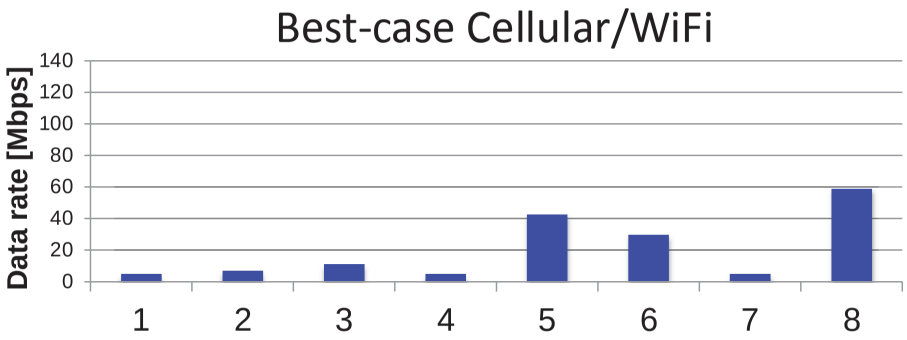


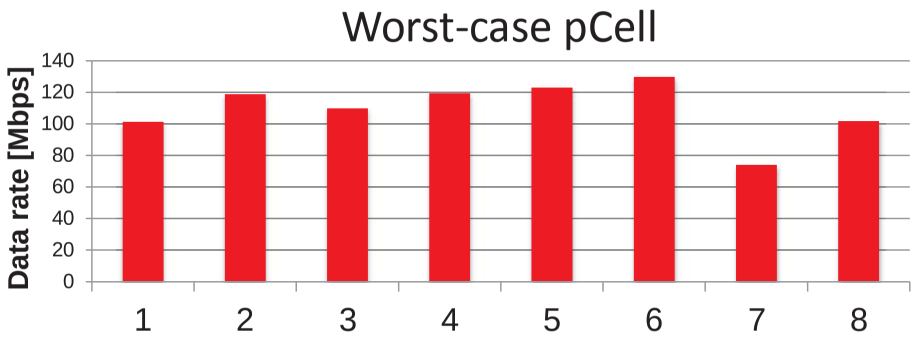



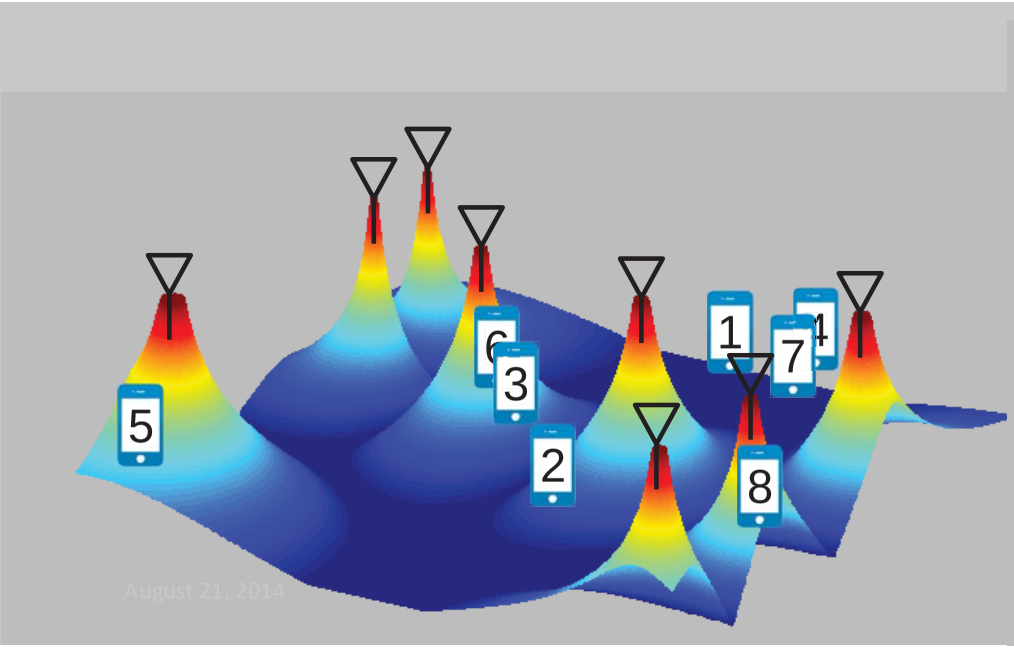



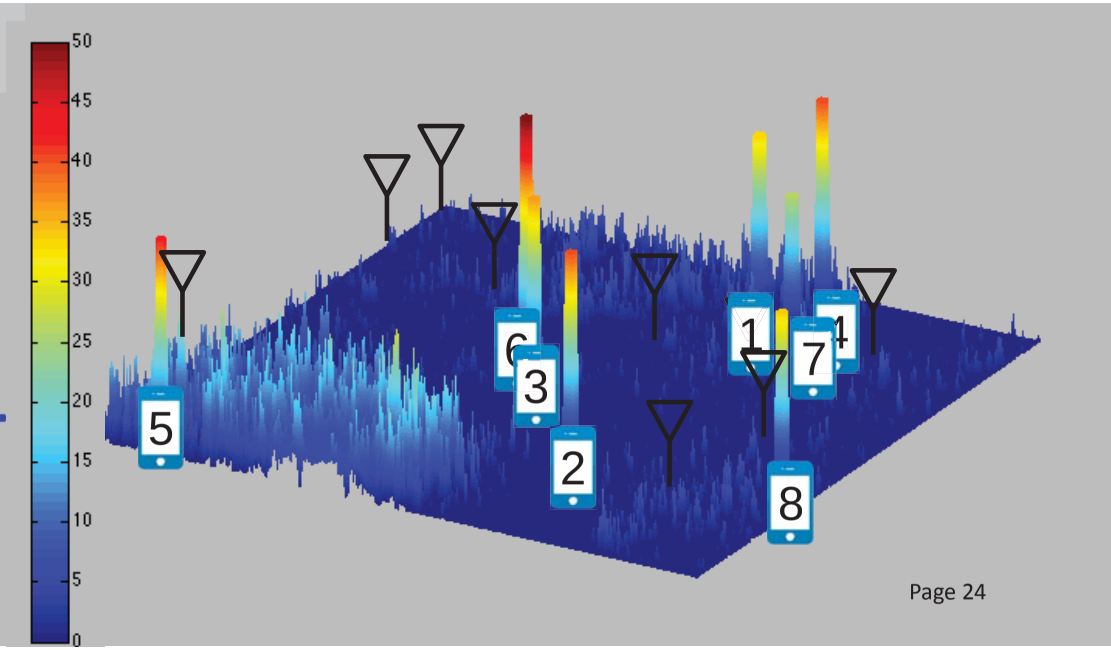



# Serendipitous Layout, Sparse Users



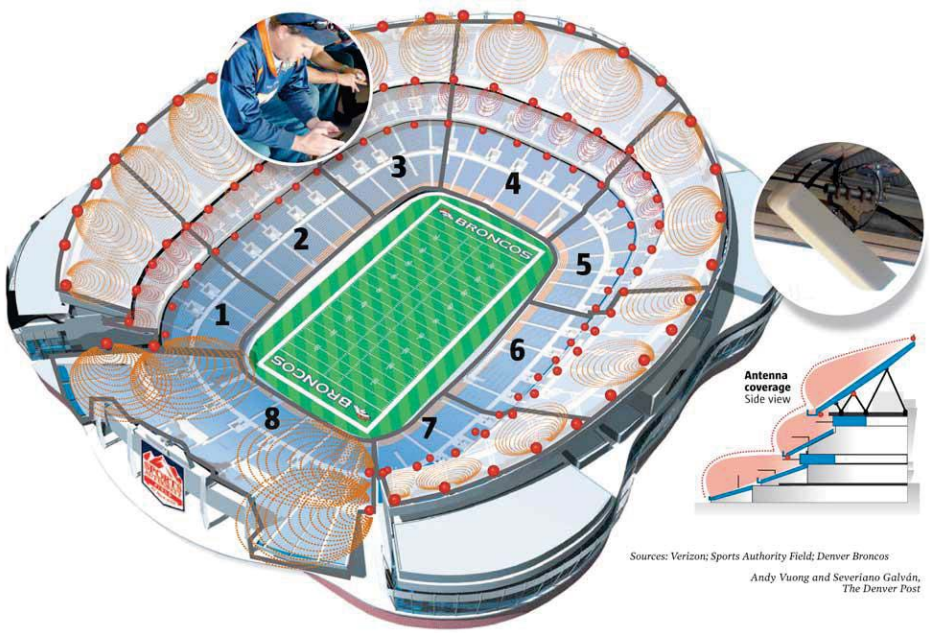



# Venue Coverage: Cellular/WiFi vs. pCell

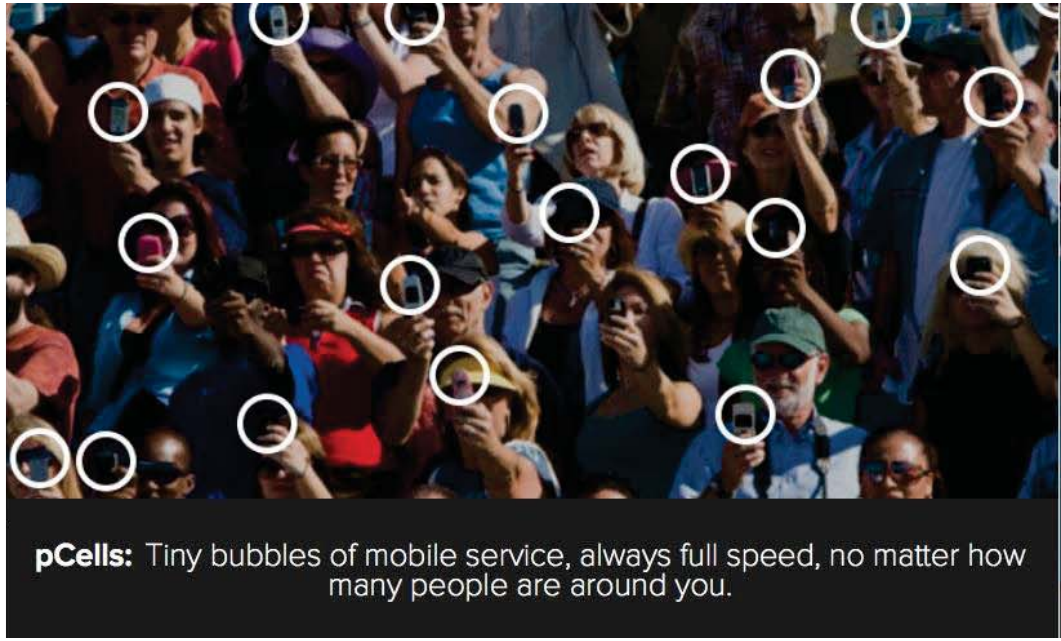
## Best-case Cellular/WiFi Coverage

From good to zero service, restricted video




## Worst-case pCell Coverage

Always great service, unlimited HD video



# Practical pCell Results

LTE, Wi-Fi compatibility and spectral efficiency

# pCell Compatibility

- Compatible with unmodified LTE, WiFi devices
  - Licensed or unlicensed spectrum
  - Operates within FCC LTE and Wi-Fi spectral masks
- Seamless integration with legacy networks
  - Gradually deployed, likely in high-density areas
  - Hands off to LTE, 3G or Wi-Fi
- Supports FCC Goals
  - First responder
    - Precise indoor/outdoor 3D positioning
    - Maintains service despite failed base stations, sudden peaks
  - Supports schools
    - Low-cost, easily-supported broadband
    - High-density concurrent usage

# pCell vs. Cellular Spectral Efficiency

## Downlink spectral efficiency and data rate

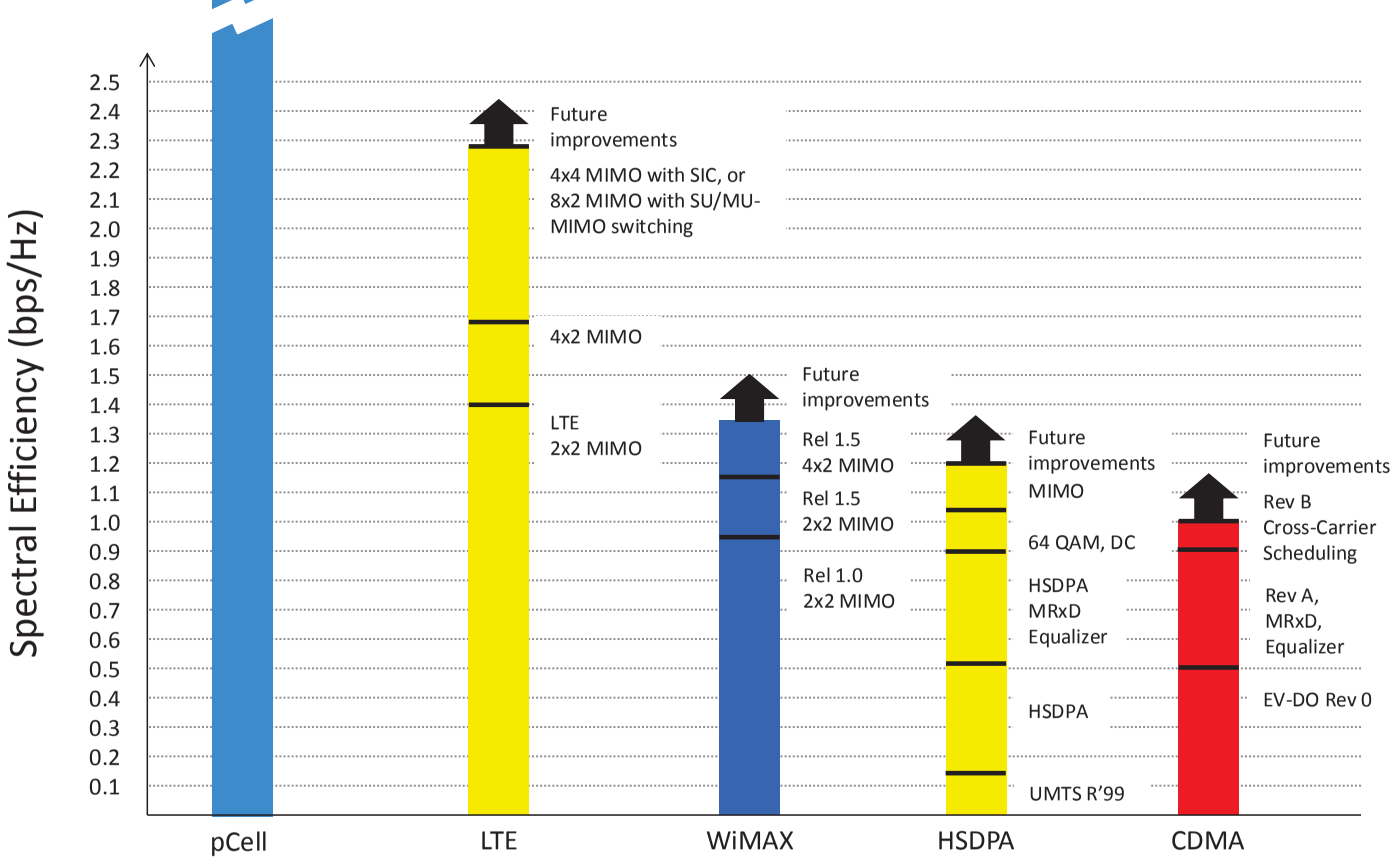
### 20 MHz, 2-antenna LTE device

| Network Antennas | Cellular LTE DL | | | pCell LTE DL | | pCell vs. Cellular bps/Hz |
|---|---|---|---|---|---|---|
| | Average bps/Hz[1] | 10+10 MHz FDD Mbps[2] | 20 MHz TDD Mbps[3] | Average bps/Hz | 20 MHz TDD Mbps[3] | |
| 4 | 1.7 | 15 | 23 | 17 | 224 | 10x |
| 8 | 2.3 | 21 | 31 | 34 | 447 | 15x |
| 16 | 2.3 | 21 | 31 | 67 | 894 | 29x |
| 32 | 2.3 | 21 | 31 | 134 | 1,789 | 58x |
| 64 | 2.3 | 21 | 31 | 267 | 3,578 | 116x |

← pCell Today

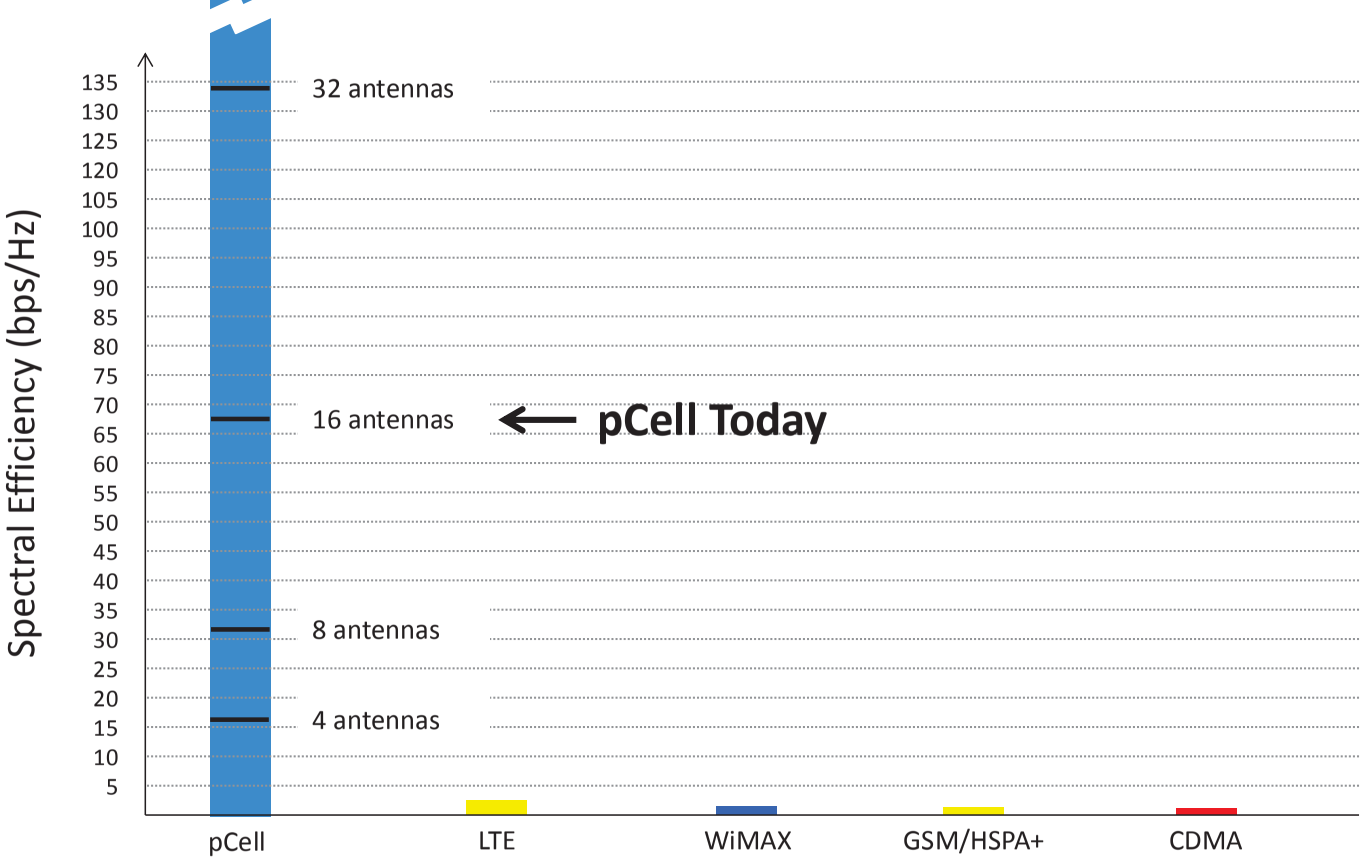
[1]Rysavy Research/4G Americas, August 2013
[2]LTE FDD 10+10 MHz
[3]LTE TDD 20 MHz, DL:UL 3:1, S-subframe config. 7

# Mobile Spectral Efficiency




Source: Rysavy Research/4G Americas, August 2013

# Mobile Spectral Efficiency

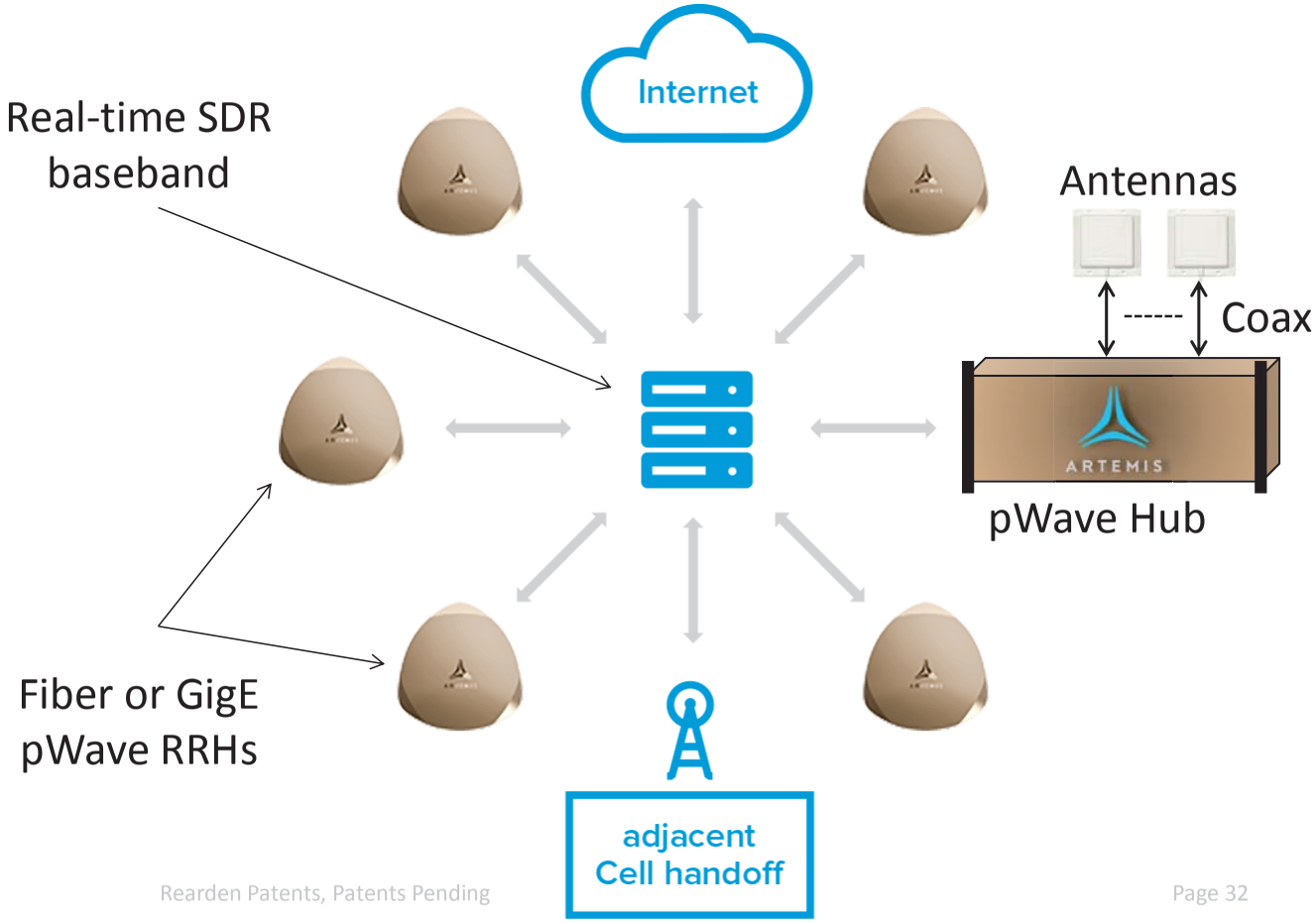



Source: Rysavy Research/4G Americas, August 2013

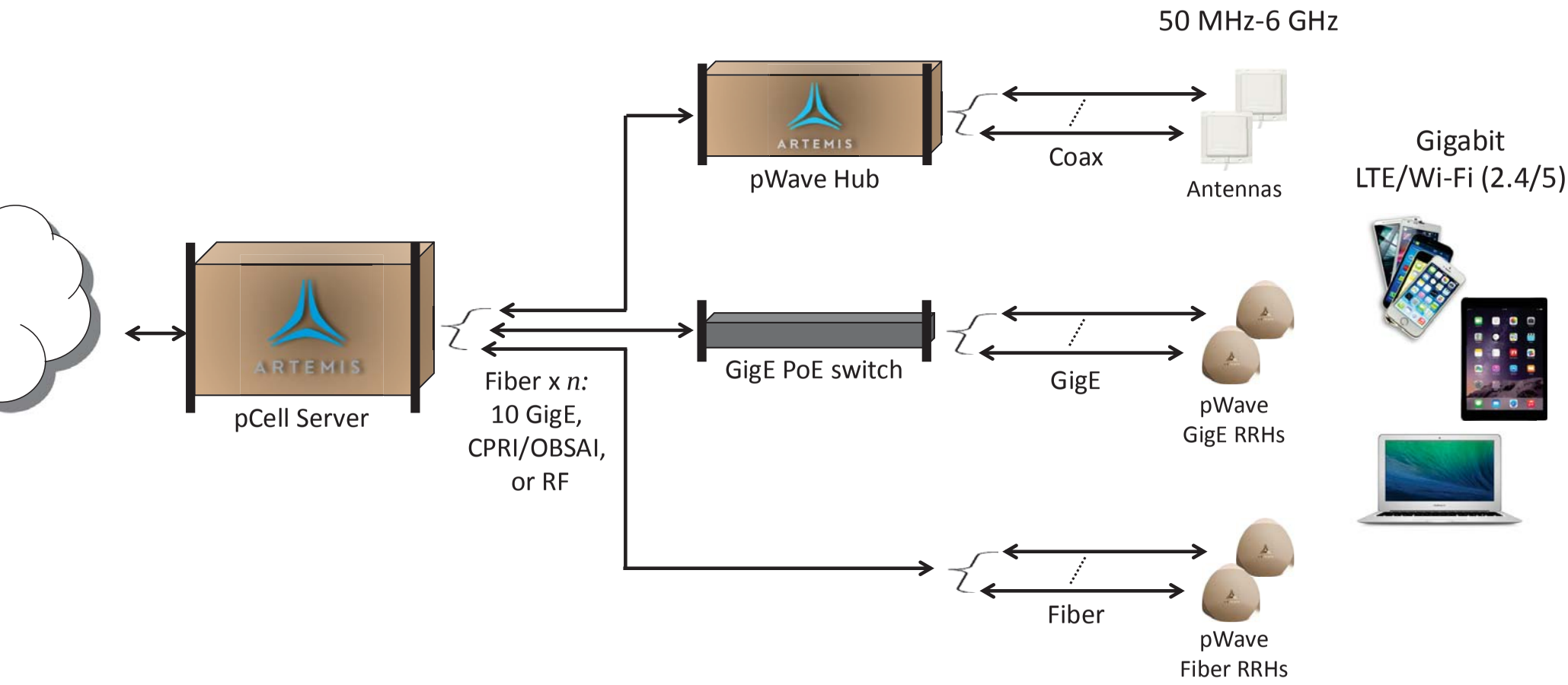
# pCell Product Configurations

Release 1.0 and future

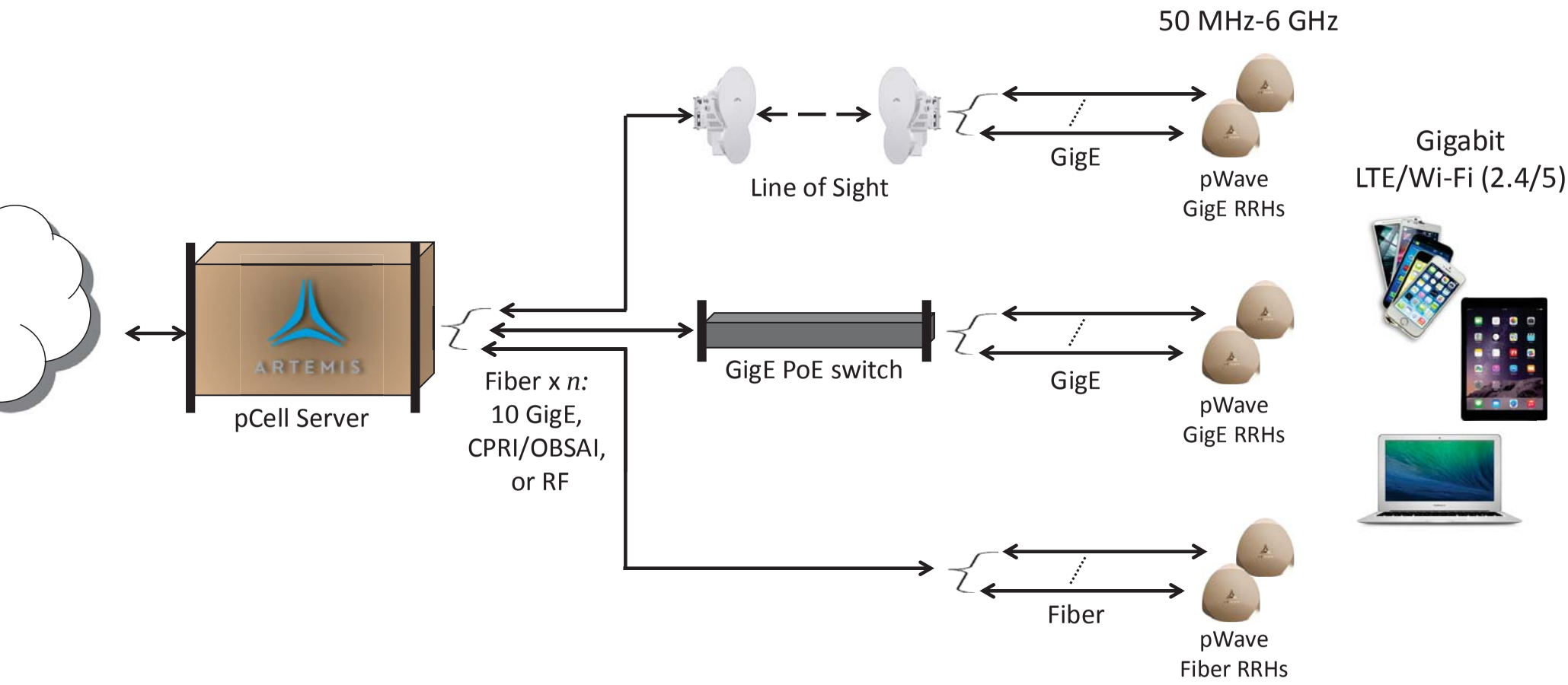
# SDR-based C-RAN Architecture



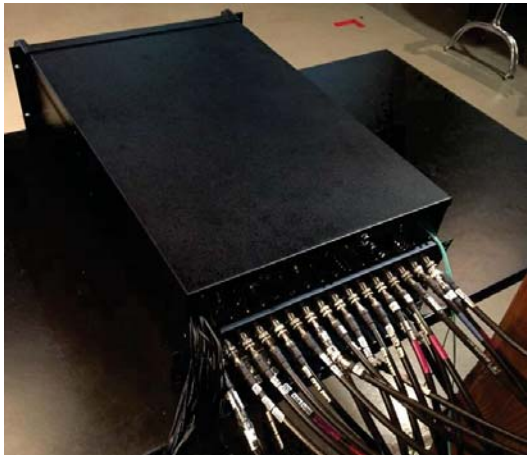
# pCell Indoor/Venue Options



# pCell Outdoor Options



# pWave Hub 1.0

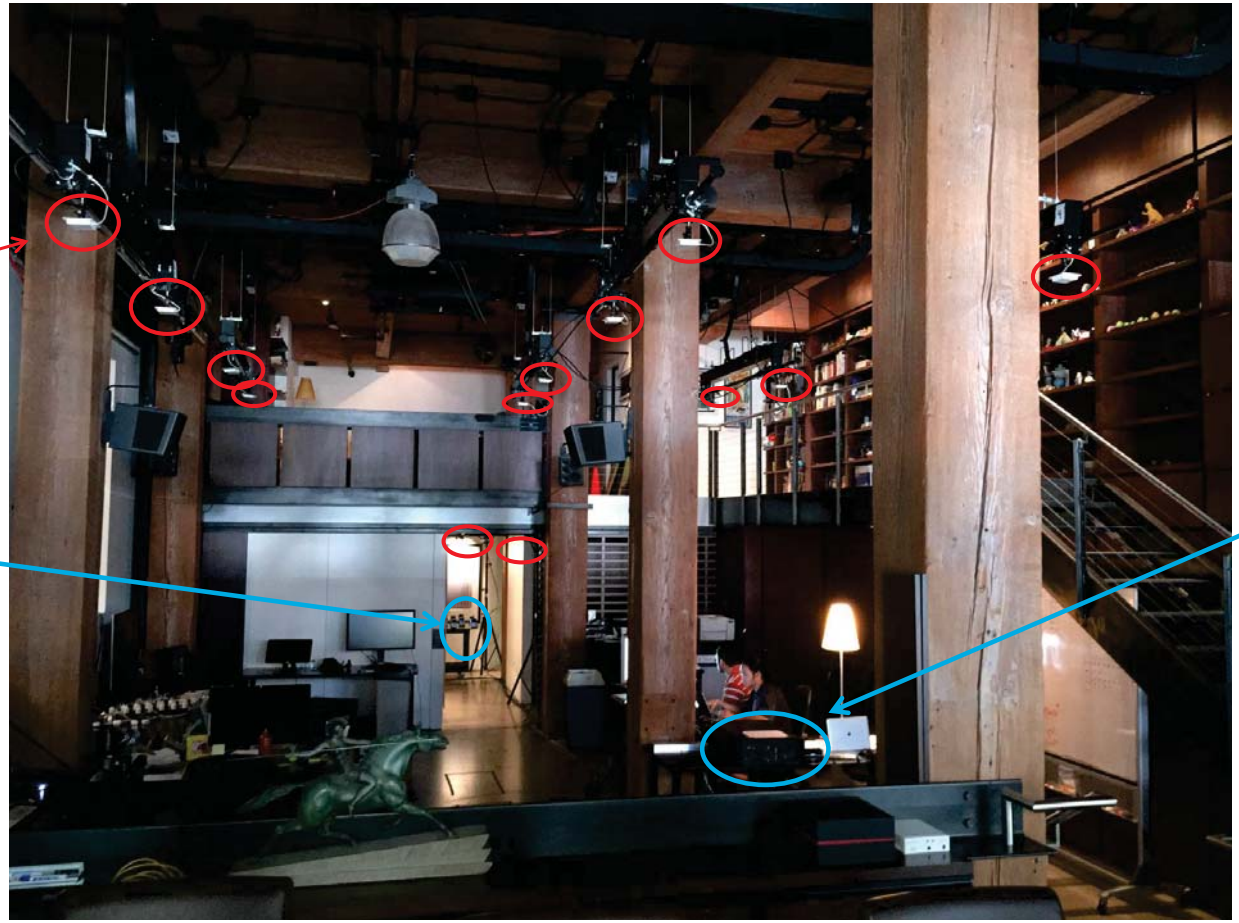


- 50 MHz – 6 GHz
- Up to 32 antennas
- 20 MHz bandwidth
- 1 mW RF output
- 50 ohm coax
- 10 GigE fronthaul to servers
- Gigabit LTE, Gigabit 2.4 Wi-Fi, Gigabit 5 Wi-Fi
- 4U

# Test Conditions

Patch antennas
8 dBi, HPBW=75°

Cart with 16
iPhone 6
Pluses in 1 $m^2$

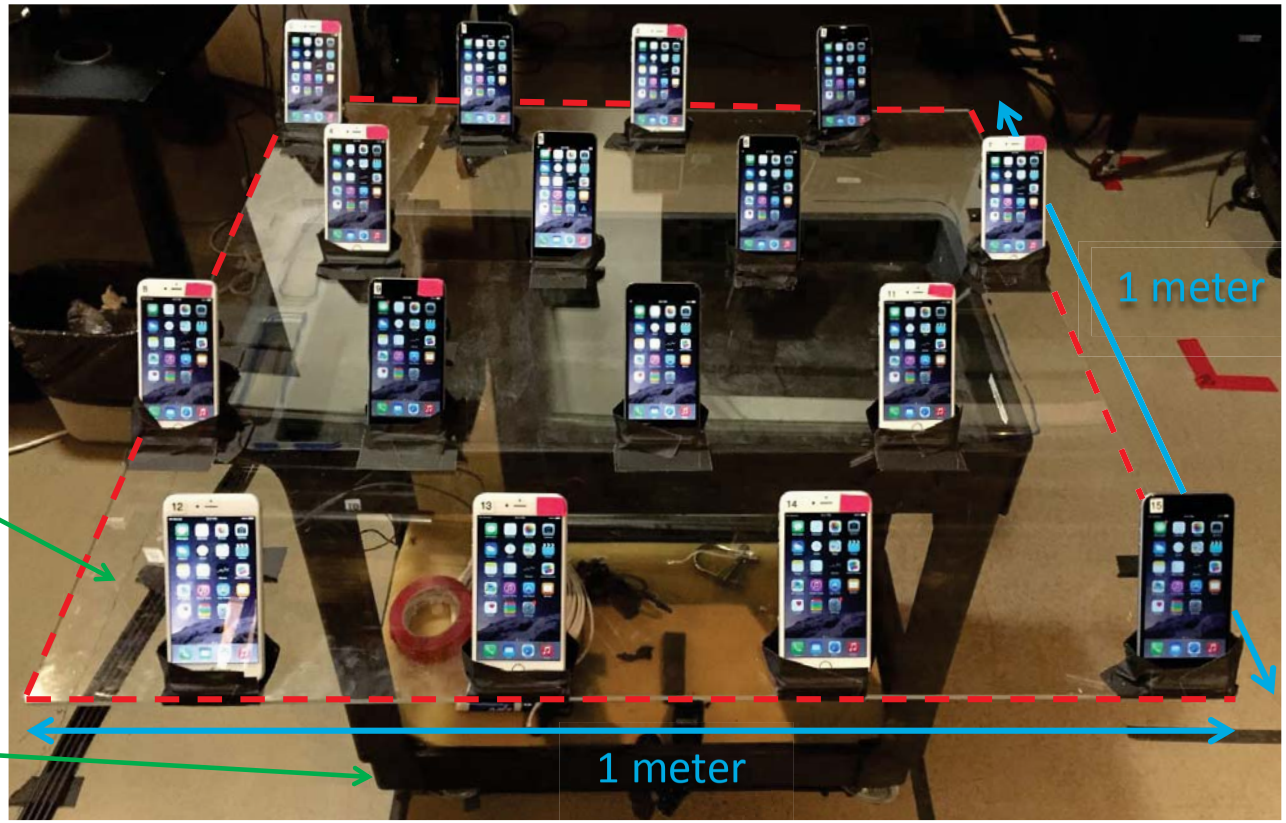


pWave Hub
1 mW RF output
at 1.9 GHz in 5MHz

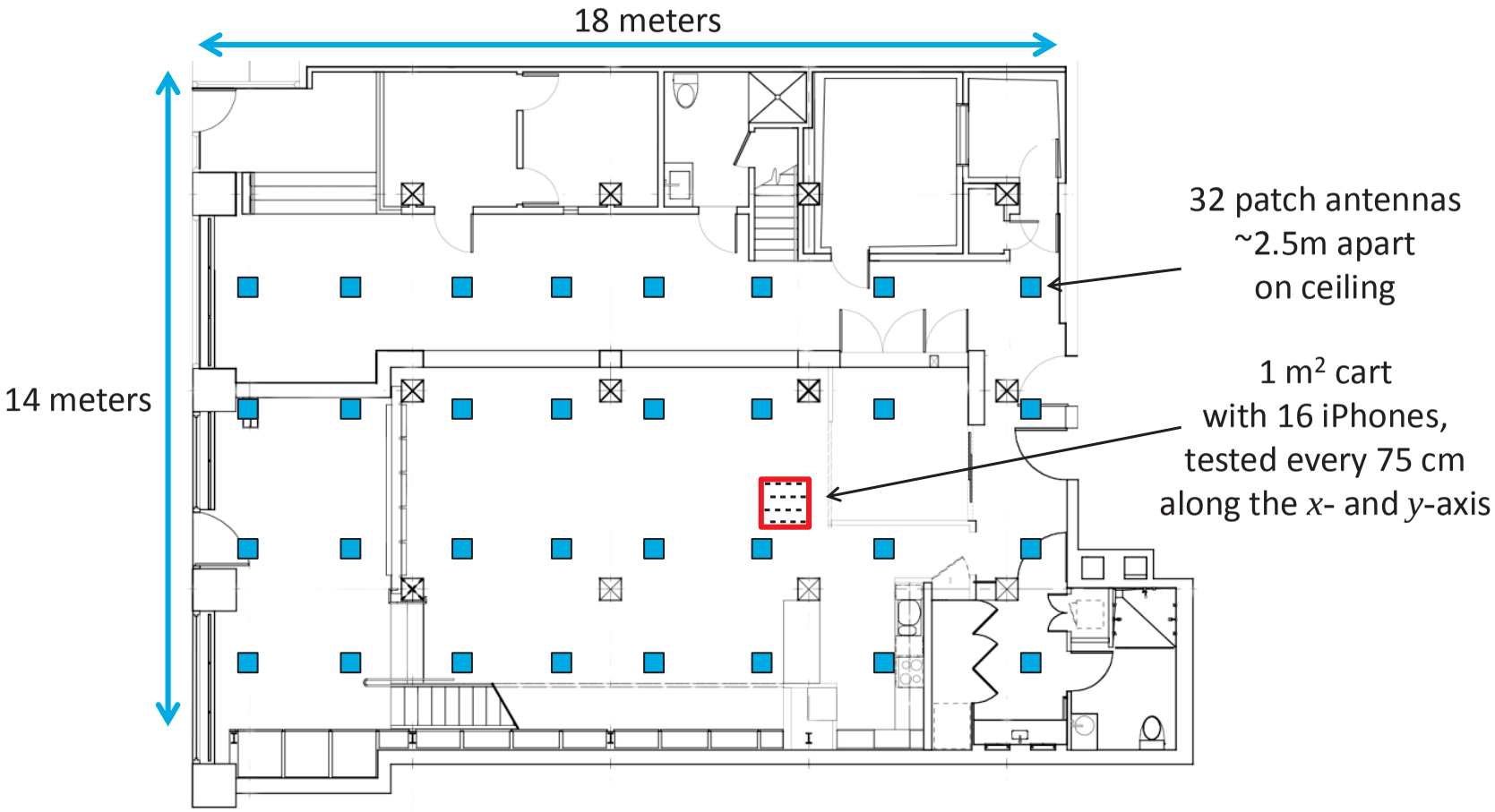
# 16 iPhone 6 Pluses in 1 Square Meter

1m x 1m
Plexiglass
surface

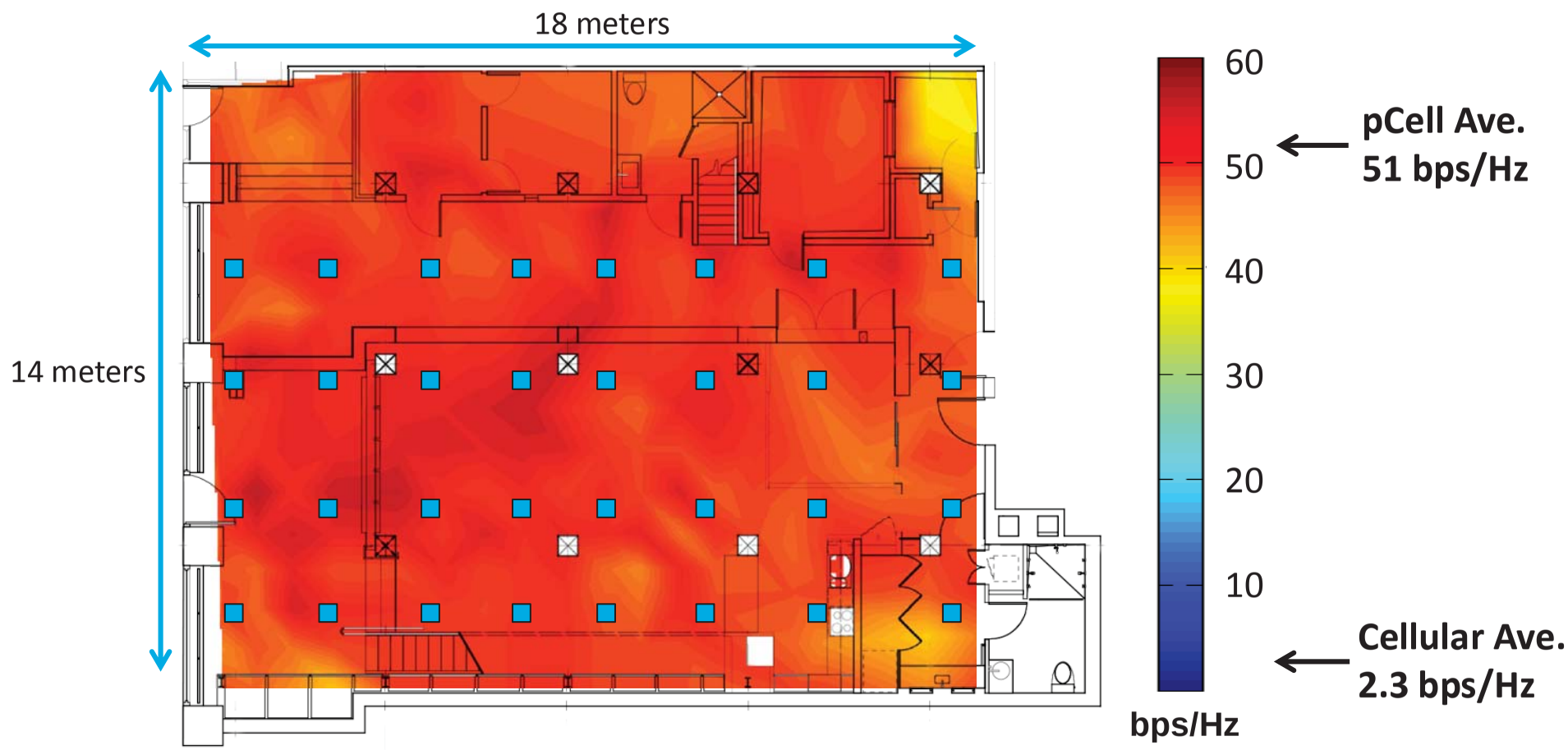
Cart



# Office Floor Plan

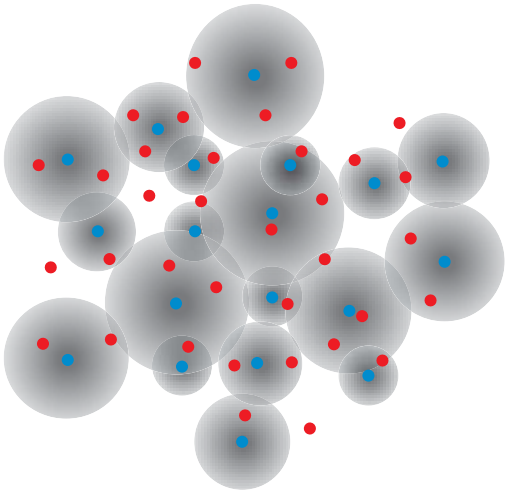


# Measured LTE MAC-layer Spectral Efficiency

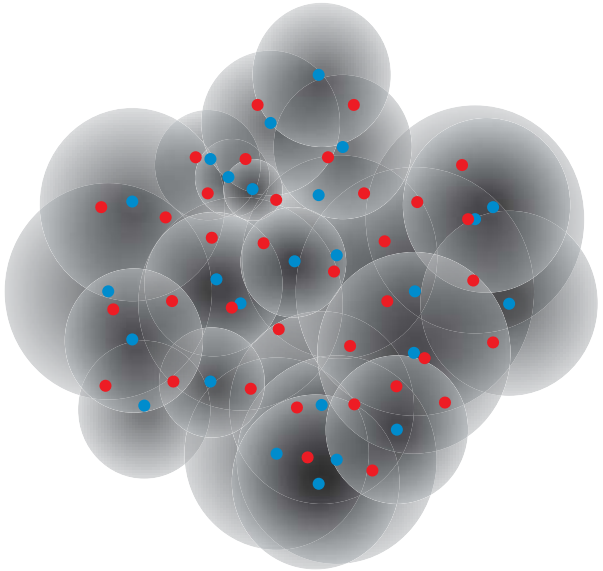


# pCell and First Responders

# LTE/WiFi vs. pCell Coverage



Real-world LTE/WiFi Coverage

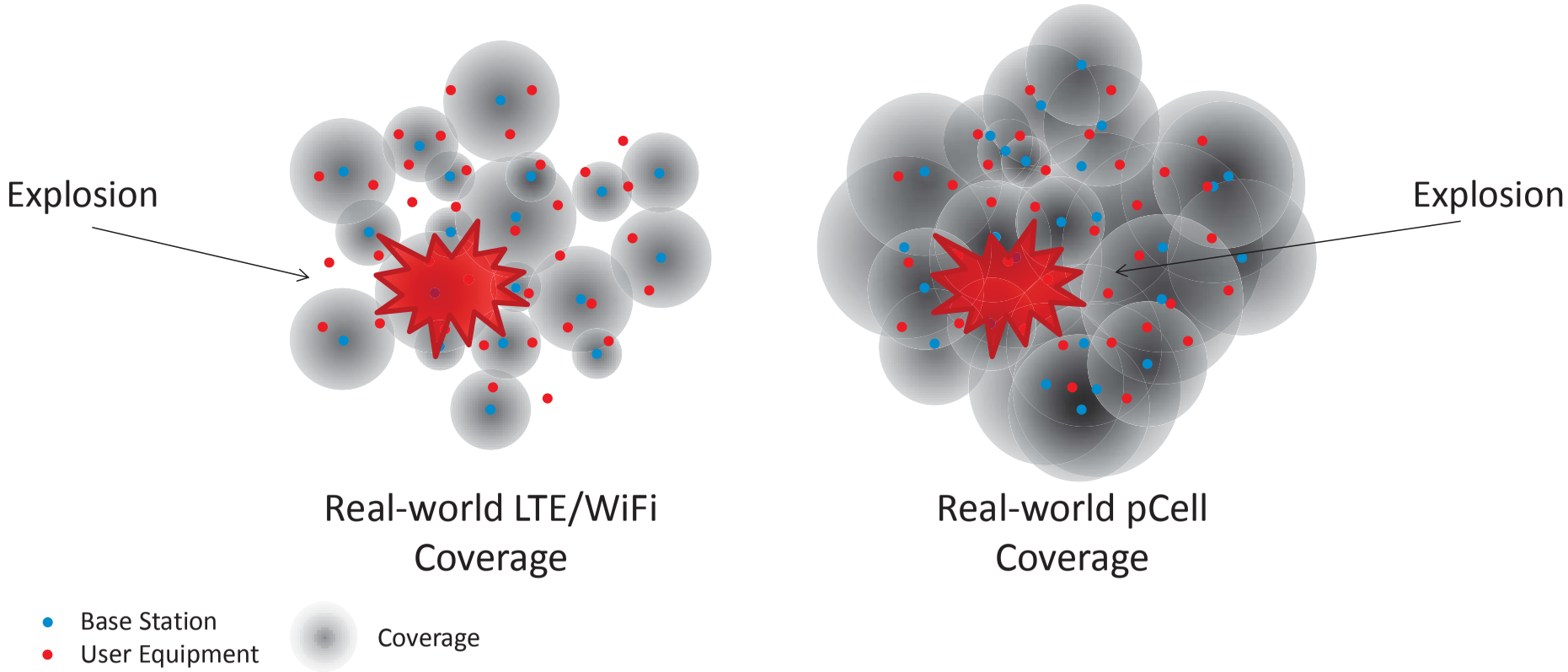


Real-world pCell Coverage

- Base Station
- User Equipment

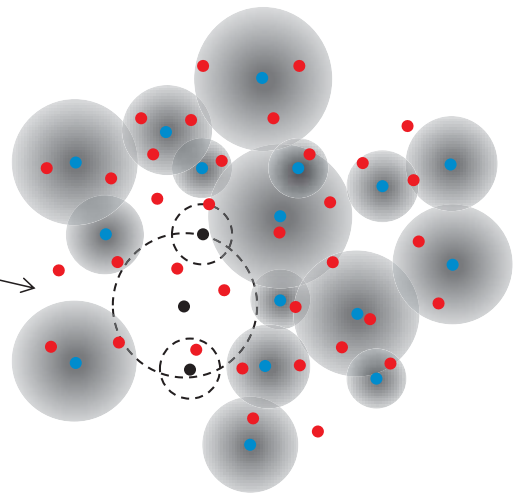
Coverage

# An incident occurs

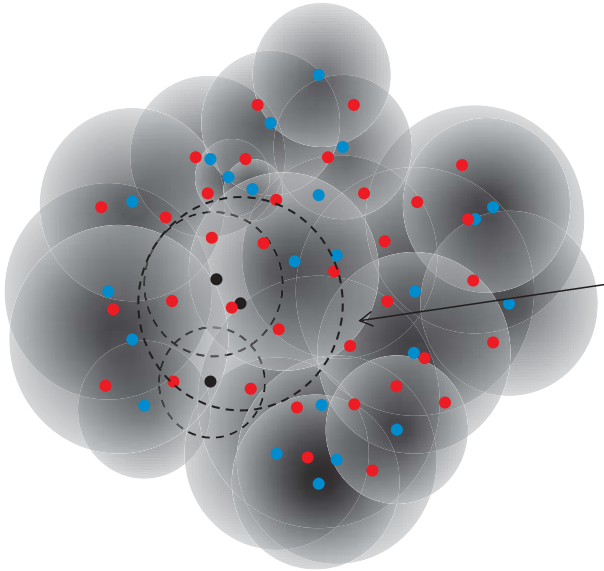


# Knocked out base stations

Knocked out base stations: **No** coverage



Real-world LTE/WiFi Coverage



Real-world pCell Coverage

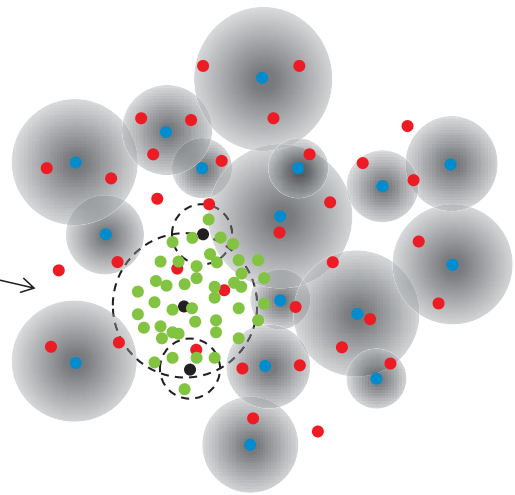
Knocked out base stations: **Full** coverage

- Base Station
- User Equipment

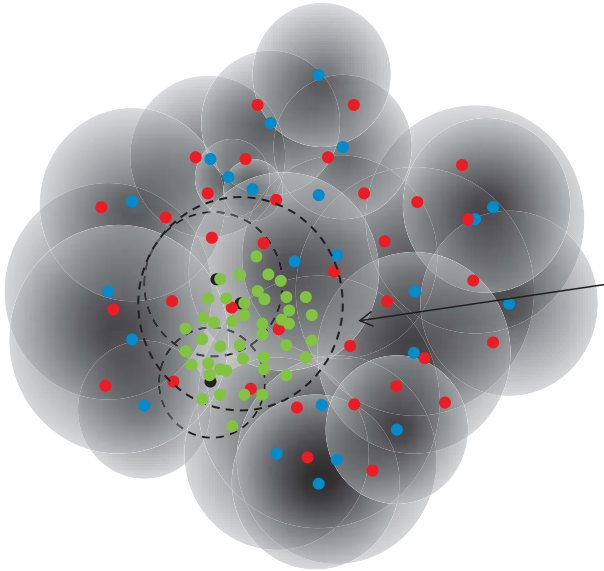
Coverage

# LTE/Wi-Fi overloaded/pCell handles load

Surge in demand:
No coverage and/or
Overloaded network



Real-world LTE/WiFi Coverage



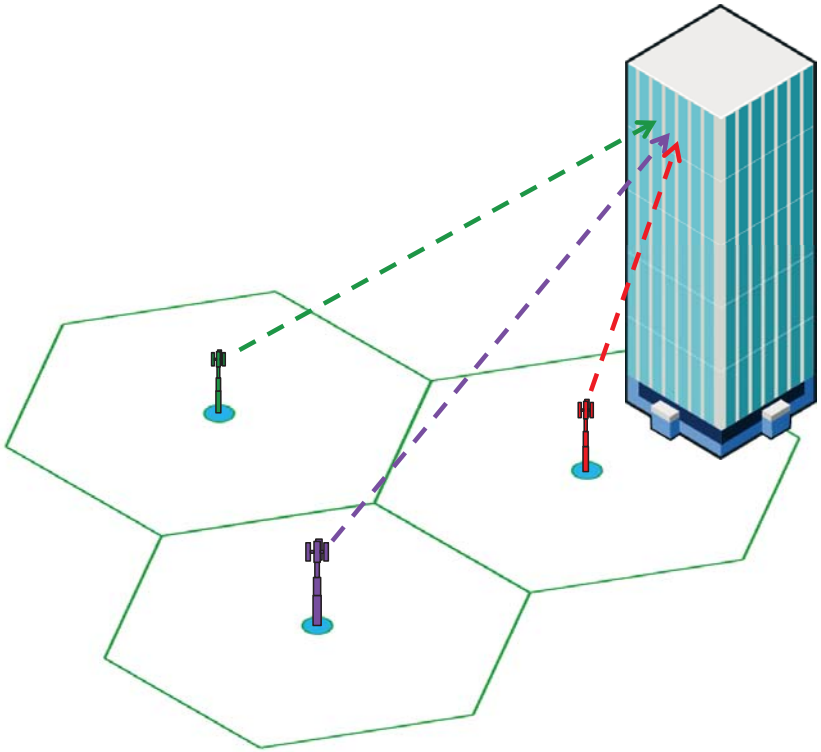
Real-world pCell Coverage

Surge in demand
Full coverage and
Handles load

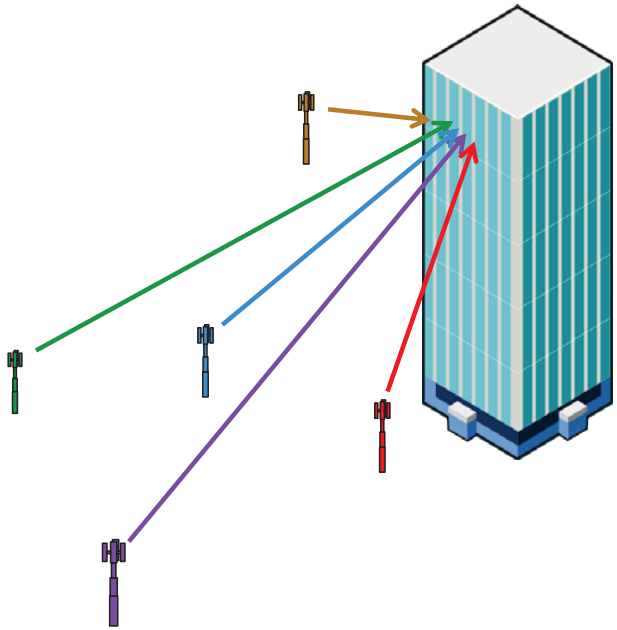
- Base Station
- User Equipment

Coverage

# 3D Indoor/Outdoor Positioning



Cellular performs poorly in 3D.
Imprecise locating ability.



Multiple indoor/outdoor pCell antennas attach to all users in 3D space.
Can locate users within meter in 3D.

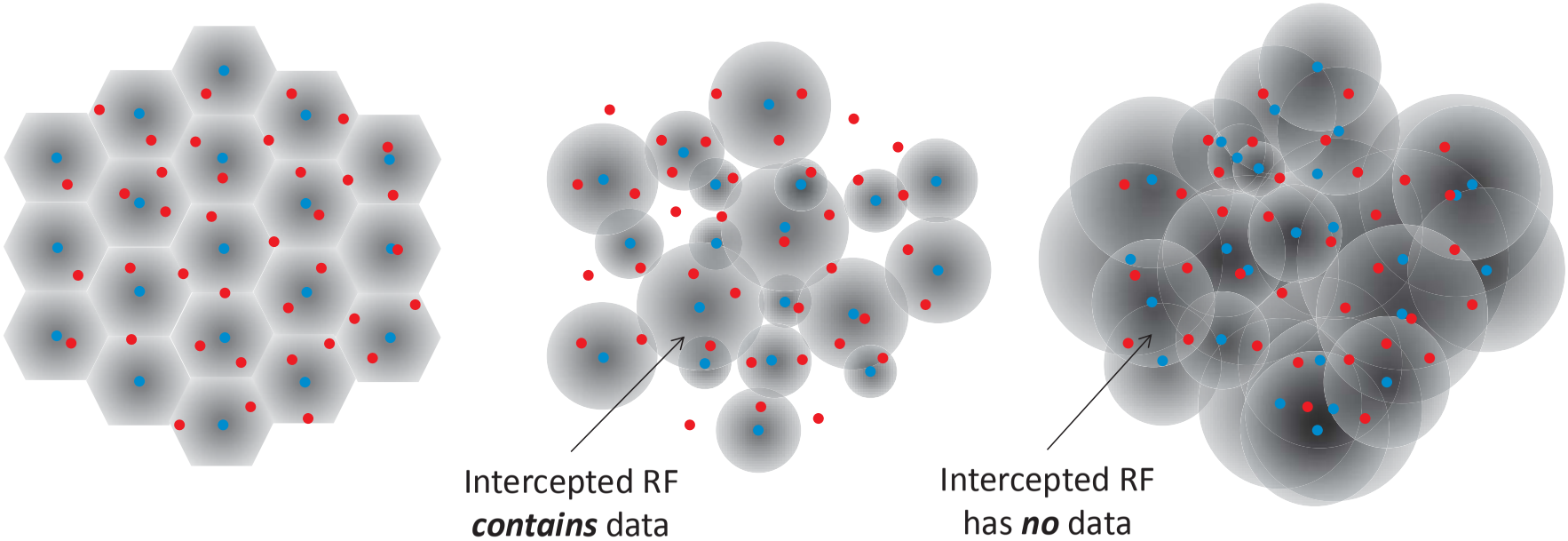
# pCell and Schools

# pCell and Schools

- U.S. schools have spotty connectivity
  - Need fast, low-cost connections
    - Rural schools need long-haul connections
  - Need solutions to Wi-Fi congestion within schools
    - Low-cost and minimal IT knowledge
- pCell very good solution for schools
  - Cost is far lower than cellular or even wired connectivity
    - Ionospheric radio can deliver pCell to even the most remote areas
  - Performance scales with need
  - Not affected by high student densities

# pCell and Security

# Non-interceptable, Physically Secure




Key-reliant encryption
(interceptable data)

Key-reliant encryption
(interceptable data)

pCell Physical Security
(***non***-interceptable data)

- Base station
- User equipment

# FDD vs. TDD

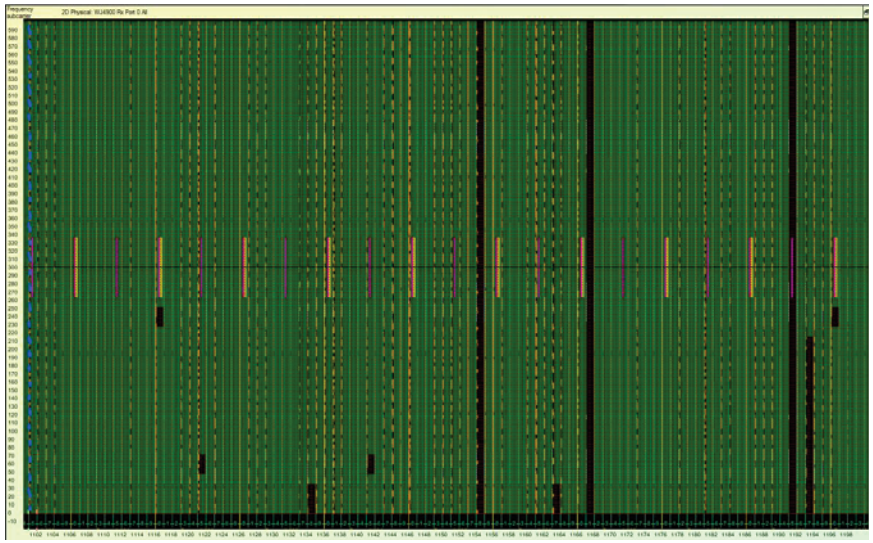
# TDD Needed for High Spectral Efficiency

- TDD essential for all known high spectral efficiency technologies
  - E.g., pCell, Full-Dimension MIMO (3GPP Rel. 13 Study Group)
  - All rely on per-user channel information
  - TDD can use reciprocity (e.g. 64 devices results in 2.9% overhead)
  - FDD cannot use reciprocity (e.g. 64 devices results in >80% overhead)
- TDD is justified by 10:1 asymmetry in current wireless traffic[1]
  - FDD only slightly more efficient in perfectly symmetric networks (e.g. voice-only)
  - TDD disadvantages not significant
    - Synchronization of adjacent bands easily achieved via, e.g., GPS
    - Only 2 relevant choices for DL:UL ratio: 3:1 (lower latency) or 8:1 (higher DL)
  - TDD being deployed by other countries (e.g. China in 700 MHz)

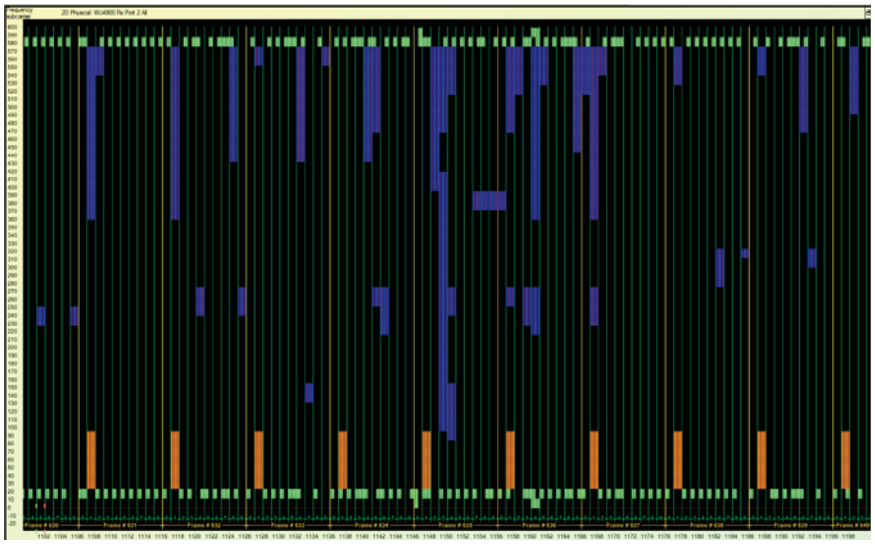
[1]http://networks.nokia.com/system/files/document/nokia_smartphone_traffic_white_paper.pdf

# Typical Daytime FDD Usage in San Francisco

Downlink (green): Saturated



Uplink (blue): Almost unused



(700 MHz AT&T spectrum usage shown. FDD bands from other carriers similar.)

# Conclusion

# Requests to Commission

- Enable high spectral efficiency technologies for 600 MHz band
  - 600 MHz Band too valuable to be wasted with low spectral efficiency
  - TDD only known duplexing structure that enables high spectral efficiency
  - **Please reconsider allowing TDD in at least part of 600 MHz band**
- Require minimum spectral efficiency in remaining mobile spectrum
  - Any technology that achieves high spectral efficiency would meet requirement
    - pCell is existence proof of one working technology
    - 3GPP Rel 13 study group shows other technologies being considered
  - No technology would be required that creates economic burden or delays deployment
    - CAFE standards requiring vehicles to meet minimum, but reasonable, MPG is good template

# Thank you.