Before the
FEDERAL COMMUNICATIONS COMMISSION
Washington, D.C. 20554

In the Matter of		
	)	
Expanding the Economic and Innovation	)	
Opportunities of Spectrum Through	)	GN Docket No. 12-268
Incentive Auctions	)	
	)	

PETITION FOR RECONSIDERATION

Stephen G. Perlman
Antonio Forenza, PhD
Artemis Networks LLC
355 Bryant Street, Suite 110
San Francisco, CA 94107
(415) 947-5540

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Pursuant to Section 1.429 of the Federal Communications Commission's ("Commission's" or "FCC's") Rules, Artemis Networks LLC ("Artemis"), respectfully submits this Petition for Reconsideration of the Commission's Report and Order in the above-captioned proceeding ("Expanding the Economic and Innovation Opportunities of Spectrum Through Incentive Auctions, Report and Order").[1]

I. SUMMARY

Artemis is a San Francisco-based privately-held startup that, after over a decade of R&D, has developed a new approach to wireless, named "pCell™," that increases the spectral efficiency (SE) of LTE to >50 bps/Hz consistently throughout the coverage area (vs. <3 bps/Hz average for LTE-A) while remaining compatible with off-the-shelf LTE devices. pCell serves as an existence proof that LTE-compatible high SE is achievable today. In light of the enormous public interest benefit of congestion-free 600 MHz

[1] *Expanding the Economic and Innovation Opportunities of Spectrum Through Incentive Auctions*, GN Docket No. 12-268, Report and Order, FCC 14-50 (2014) *("Report and Order")*

spectrum, Artemis respectfully requests the Commission establish minimum SE requirements for 600 MHz licensees.

The Commission has recognized that due to "skyrocketing consumer demand for high-speed data … service providers need access to more spectrum."[2] The Commission also has recognized that "…the 600 MHz Incentive Auction … is a once-in-a-generation opportunity to auction significant amounts of greenfield low-band spectrum."[3]

Artemis agrees with the Commission's decision to promptly make 600 MHz spectrum available for mobile broadband. But Artemis is concerned that, given the U.S. spectrum deficit is far outpacing spectrum allocation in the U.S. (see Fig. 1, below), that the 600 MHz band will be utterly congested soon after it is deployed, and will remain congested for a "generation". Given the unique propagation characteristics of 600 MHz, it is strongly contrary to public interest to make a technical ruling which will relegate 600 MHz to a generation of congestion when a practical technical alternative exists that will eliminate congestion and still remain LTE device compatible.

Artemis has developed a practical technical alternative, an entirely new approach to wireless called pCell™ technology that, instead of avoiding interference like cellular, deliberately exploits interference throughout the coverage area to synthesize a tiny personal cell (a "pCell") for each user, enabling each user to concurrently experience the full capacity of the spectrum. pCell exceeds most projected performance goals for 5G, in particular the target SE of 45 bps/Hz (see Table 1, below). pCell achieves these results with unmodified, off-the-shelf

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[2] *Policies Regarding Mobile Spectrum Holdings: Expanding the Economic and Innovation Opportunities of Spectrum Through Incentive Auctions*, WT Docket No. 12-269, Report and Order, FCC 14-63 (2014). *("MSH Report and Order")* ¶ 2.
[3] *Ib.*

standard LTE devices today, such as the iPhone 5S/5C, iPad Air and Google Nexus 5, by synthesizing an LTE waveform in each pCell.

pCell has been extensively tested indoors and outdoors with unmodified commercial LTE devices in bands 38, 39, 40 and 41, and with custom LTE UEs at 400 and 900 MHz. pCell's over-the-air waveforms fit precisely within standard LTE power and spectral envelopes. pCell will be commencing large-scale trials later this year, for commercial deployment in 2015.

If pCell technology was used in the 600 MHz band for deployment, even at an SE of 45 bps/Hz, 600 MHz capacity would exceed that of *all mobile bands*. Beyond eliminating the spectrum deficit, the public interest benefit of so much capacity with the propagation characteristics of low-band spectrum would be enormous. Also, uncongested low-band spectrum is vital for public safety. Without a dramatic increase in SE, congestion will render 600 MHz increasingly unusable for all applications, including public safety.

Low-band spectrum is a scarce and irreplaceable natural resource that is, in fact, often referred to a "beachfront spectrum". The Commission, as the custodians of this natural resource, is mandated both by mission and statute to encourage "the highest and best use of spectrum"[4]. The Commission has recognized the U.S. is in a spectrum crunch[5], it has recognized the unique propagation characteristics of 600 MHz spectrum[6], it is seeking to promote competition and innovation for current and future wireless

[4] FCC "What We Do" web page. http://www.fcc.gov/what-we-do
[5] http://www.fcc.gov/encyclopedia/spectrum-crunch. ("*Spectrum Crunch*")
[6] *Report and Order*, footnote 92.

technologies[7] and, with this Petition, the Commission is now aware of at least one technology, pCell, that achieves orders of magnitude improvement in 600 MHz SE, while off-the-shelf LTE device-compatible.

Artemis respectfully requests the Commission establish minimum SE requirements for licensees of the 600 MHz band that scale in accordance with projected traffic demands, while remaining compatible with LTE devices and waveform envelopes, using any technology that meets those requirements without delaying the 600 MHz auction or deployment.

II. RECONSIDERATION IS WARRANTED

Reconsideration is warranted when the facts or arguments relied on relate to events which have occurred or circumstances which have changed since the last opportunity to present such matters to the Commission, the facts or arguments relied on were unknown to petitioner until after petitioner's last opportunity to present them to the Commission, and petitioner could not through the exercise of ordinary diligence have learned of the facts or arguments in question prior to such opportunity; or the Commission determines that consideration of the facts or arguments relied on is required in the public interest[8]. pCell technology was still in development until after the 600 MHz auction comment and reply deadlines, and Artemis was still in the process of testing commercial LTE devices until after the *Report and Order* was issued. Artemis could not anticipate the final technical details of the 600 MHz plan until the *Report and Order* was published. Further, Artemis believes it is strongly in the public interest for the Commission to accommodate technologies that significantly increase 600 MHz band SE.

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[7] *Report and Order* ¶ 5.
[8] *See, e.g.,* 47 C.F.R. § 1.429

III. The 600 MHz BAND AS PLANNED WILL BECOME RAPIDLY CONGESTED

The Commission has recognized that:

> "Skyrocketing consumer demand for high-speed data is increasing providers' need for spectrum at an unprecedented rate. Consumers today expect mobile broadband at home, at work, and while on the go. To meet this increasing consumer demand, service providers need access to more spectrum."[9]

And further, it has recognized that, "The most important dimension of wireless network performance is spectral efficiency."[10] The Commission also has recognized the exceptional and unique value of 600 MHz spectrum, stating "…the 600 MHz Incentive Auction … is a once-in-a-generation opportunity to auction significant amounts of greenfield low-band spectrum."[11]

Artemis strongly agrees with the Commission decision to promptly make 600 MHz spectrum available for mobile broadband. Artemis' concern is that given the exceptional propagation characteristics of the 600 MHz band, and the fact its allocation will be a "once-in-a-generation" opportunity, it is strongly in the public interest that licensees of the 600 MHz band deploy technology that not only achieves the highest practical SE available at the time of deployment, but the technology is able to scale SE to keep pace with demand, and further enables use of future protocols concurrently with legacy LTE and LTE-A devices, such that 5G, 6G, etc. technology will be able to use the unique low-band characteristics of the 600 MHz band without having to "wind down" 4G users.

In 2010 the Commission projected that U.S. mobile carriers would be operating at a spectrum deficit as of 2013, with the deficit rapidly getting worse thereafter (Fig. 1).

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[9] *MSH Report and Order* ¶ 2.

[10] FCC, "Mobile Broadband: The Benefits of Additional Spectrum", Oct. 2010 ("*Benefits of Spectrum*"), IV.c. http://transition.fcc.gov/national-broadband-plan/mobile-broadband-paper.pdf

[11] *Ib.*

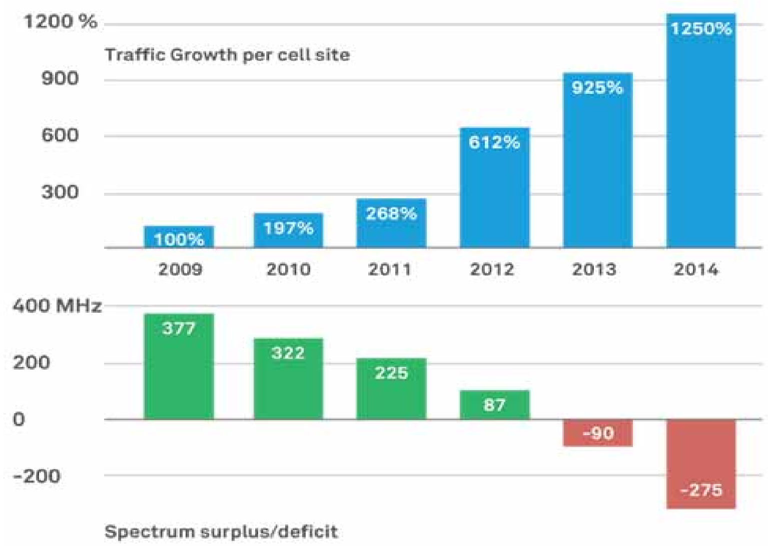

Figure 1: U.S. Mobile data demand vs. spectrum capacity[12]

The Commission's 2010 projection was accurate. 2013 U.S. mobile statistics should have been enviable…

a. The U.S. had more LTE subscribers than all other countries combined.[13]

b. 24.5% of U.S. mobile connections were LTE, versus 2.9% globally.[14]

c. At 65% penetration, the U.S. was the only region of the world with mostly smart devices. Smart devices devour mobile data, accounting for 88% of global traffic.[15]

d. Most U.S. mobile traffic was video[16], enabled by LTE and smart devices.

…but instead of enviable performance, U.S. mobile demand far exceeded spectrum capacity, causing US average LTE download speed to plummet in 2013 by 32% to 6.5Mbps by 2014, by far the slowest LTE speed in the world (Fig. 2).

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[12] *Benefits of Spectrum*, Exhibit 10
[13] Statista 2014. http://www.statista.com/statistics/309599/lte-mobile-subscribers-by-country/
[14] Cisco Virtual Network Index 2014, February 2014. ("*Cisco VNI*" 2014)
[15] *Ib.*
[16] Verizon reported in April 2013 that 50% of mobile traffic was video, growing to 67% by 2017. http://www.fiercewireless.com/story/verizon-ceo-50-our-wireless-traffic-video/2013-04-10

Figure 2: Average LTE download speed by country (2013 vs. 2014)[17]

Ironically, slow U.S. LTE data rates are a consequence of LTE's U.S. market success. The same result is seen worldwide: Japan's NTT DOCOMO launched LTE two years before competitors and holds a wide market lead. The consequence of its "success" is an average download speed half that of later Japan LTE-market entrants with far smaller subscriber bases[18], almost as slow as U.S. LTE. The unfortunate reality of cellular technology today is *market success results in declining service quality*, eventually rendering mobile service to become almost unusable. Such results are already seen in dense cities like New York and Chicago[19]. New spectrum deployments may briefly mitigate congestion[20], but given the inexorable growth of mobile data demand,[21] data rates ultimately decline with market success[22].

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[17] "Global state of LTE report", Feb. 2014. OpenSignal. http://opensignal.com/reports/state-of-lte/usa-q1-2014/ ("*Open Signal*")
[18] A.C. Nichols, "We anticipate the iPhone will slow DoCoMo's subscriber losses", Jun. 2014 http://analysisreport.morningstar.com/stock/research?t=DCM&region=usa&culture=en-US&productcode=MLE, *OpenSignal.*
[19] Cheng, Roger, "Verizon admits network faces traffic pressure in big cities," CNET, November 12, 2013. http://www.cnet.com/news/verizon-admits-network-faces-traffic-pressure-in-big-cities/
[20] Fitchard, Kevin, "Verizon quietly unleashes its LTE monster, tripling 4G capacity in major cities," Gigaom, December 5, 2013. https://gigaom.com/2013/12/05/verizon-quietly-unleashes-its-lte-monster-tripling-4g-capacity-in-major-cities/

Costly efforts to increase cell density with small cells have been unable to mitigate the performance decline. Small cells suffer from increased inter-cell interference and handoff overhead[23], ultimately exceeding capacity gains which, even disregarding the economic considerations of backhaul, power, physical access, etc.[24], establishes a practical upper limit for cell density. Thus, as observed by the Commission, the only known option to significantly increase U.S. mobile broadband capacity is to allocate more spectrum for mobile use.

Unfortunately, the U.S. is almost out of mobile spectrum. Only a narrow range of frequencies that can efficiently penetrate obstacles are suitable for mobile[25]. Even if all practical spectrum were allocated for mobile, it would only accommodate 3 years of mobile data growth[26]. And, after that, all mobile spectrum would be gone *for decades*, with mobile congestion getting worse every year. As noted in an October 2013 Wall Street Journal op-ed commemorating the 30th anniversary of commercial cellular, "…wireless engineers will have to come up with a

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[21] *Cisco VNI* 2014, *Benefits of Spectrum*.
[22] Verizon average LTE speed fell from 9.5 Mbps to 8.1 Mbps from 1Q13 to 1Q14. "The State of US LTE", OpenSignal, March 2014. http://opensignal.com/reports/state-of-lte/usa-q1-2014/
[23] *Mobile Broadband Explosion—The 3GPP Wireless Evolution*, Rysavy Research, August 2013. http://www.4gamericas.org/UserFiles/file/White%20Papers/4G%20Americas%20Mobile%20Broadband%20Explosion%20August%202013%209%205%2013%20R1.pdf, Fig. 15. ("*Rysavy*")
[24] *Ib.*
[25] Current mobile spectrum ranges between 700 MHz and 3800 MHz, of which about 2000 MHz is mapped for LTE deployments worldwide (3GPP TS 36.101, "E-UTRA: UE radio transmission and reception", Release 11, Oct. 2013, http://www.3gpp.org/DynaReport/36101.htm, version 12.4.0, document 36101-c40_s00-07.
[26] 3200 MHz of spectrum (~600-3800MHz) is suitable for mobile (*see Ib.)* of which 574 MHz was available for cellular as of 2010 (see "Connecting America: The National Broadband Plan." http://download.broadband.gov/plan/national-broadband-plan.pdf *, p.84).* Assuming all other spectrum users are displaced, at most 4.9X the 547 MHz remains in the 3200 MHz, i.e. (3200-547)/547 = 4.9). Since wireless traffic is projected to grow by 5.2X in the three-year period from 2013-2016 (*Cisco VNI* 2014), this is insufficient to cover 3 years of traffic growth.

better way to use the finite amount of spectrum they already have. If they don't, soon enough your smartphone will remind you of the dial-up speeds of the 1990s."[27]

While the additional spectrum in the 600 MHz band will alleviate the spectrum won't come close to solving it. The *entire bandwidth* of the 600 MHz band accounts for half the projected 275 MHz spectrum deficit for 2014 (Fig. 1), and will account for an smaller fraction of the much larger deficit by the time 600 MHz is actually deployed. *As the 600 MHz band may well be utterly congested shortly after it is deployed.* Given the (plus 10-year renewals) term[28] of the 600 MHz licenses and the need to remain devices introduced when 600 MHz is deployed, the band may be rendered effectively for a generation.

Losing the 600 MHz band to congestion is not just a matter of inconvenience; it's a serious issue of both economics and public safety. Because of the unique propagation characteristics of the 600 MHz band there are usage scenarios where it is the only option for communications, such as penetrating large buildings and heavy foliage, or enabling distant transmissions from new classes of low-power devices, such as the Apple Watch or Android Wear. Having a usable 600 MHz band is also a matter of public safety, for example, enabling communications for someone needing help in a heavily wooded area, or trapped within a large building or a basement.

The Commission has already specified that LTE user devices shall be supported in the 600 MHz band[29], and Artemis agrees that this is a good choice. The LTE standard

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[27] Townsend, "Smartphones to Monitor Insulin and Smell Flowers: The wireless industry will be transformed by 2023—if it can overcome a lack of spectrum", The Wall Street Journal, Oct. 28, 2013, http://online.wsj.com/news/articles/SB10001424052702304520704579129730041631274
[28] *Report and Order*, ¶ 37, 759.
[29] *Report and Order*, Appendix C, ¶ 55.

has the highest SE of any mobile standard[30] with the most flexibility. But, even with the highest projected target SE of 3 bps/Hz for IMT-Advanced[31], the total capacity of the 600 MHz band falls far short of the 2014 capacity demand, let alone meeting demand in the 2020s, which may well be 100X higher than today.

In summary, under the current 600 MHz plan as specified in the *Report and Order*, Artemis believes that the 600 MHz band will be heavily congested shortly after initial deployments, and will remain heavily congested for a generation. When the Commission was considering the technology options that were available at the time the *Report and Order* was drafted, there were no options that would mitigate this outcome. There now is at least one option available that will eliminate 600 MHz congestion: pCell technology, as described below.

IV. 5G-CLASS SPECTRAL EFFICIENCY IS ESSENTIAL FOR 600 MHz

As industry and governments are coming to the inescapable conclusion that LTE 4G technology is unable to meet mobile data demands today, let alone catch up to growing demands in the future, they are urgently turning to new 5G technologies to overcome the spectrum crunch[32]. In the last year several heavily-funded 5G research efforts were initiated, with projected deployment dates ranging from the early- to mid-2020s[33]. All are basic R&D efforts, exploring a wide range of directions, with no practical prototypes operating today. So, it is

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[30] *Rysavy,* Fig. 24. *Benefits of Spectrum,* Exhibit 9.
[31] Report ITU-R M.2134, "Requirements related to technical performance for IMT-Advanced radio interface(s)", 2008, http://www.itu.int/dms_pub/itu-r/opb/rep/R-REP-M.2134-2008-PDF-E.pdf ("*IMT-Advanced")* Table 1.
[32] *Spectrum Crunch, Benefits of Spectrum.*
[33] E.g., the EU Commission has funded and co-funded a range of 5G research and development, such as €700M to the 5G Public and Private Partnership (http://5g-ppp.eu/contract/). In South Korea, the Ministry of Education, Science and Technology (MEST) will be investing $1.5B to fund 5G research and development (http://www.ibtimes.com/south-korea-will-invest-15b-building-5g-network-will-be-1k-times-faster-existing-speeds-allow-1). Huawei plans to invest €444M for a similar goal (http://www.huawei.eu/events/huaweis-5geurope-summit-2014).

uncertain that 5G—whatever it ends up being—will be deployable by the mid-2020s, let alone be capable of overcoming what will then be a massive spectrum deficit—particularly in desirable lower bands like 600 MHz, relative to mobile data demand. And, even if a viable 5G solution does arrive at some point in the 2020s, between now and then, mobile congestion may well become more than 100X worse than it is today.

Nonetheless, the performance specifications proposed by these 5G working establish an expert consensus on goals for the next generation of mobile services. In 2014 ITU's IMT-2020 (5G) Promotion Group presented a comprehensive vision for what 5G would look like in the 2020s[34] (*"IMT-2020"*), that is largely consistent with other recent 5G visions[35]. Table 1 lists some IMT-2020 requirements for 5G in the 2020s:

Target Spectral Efficiency	Traffic Density per km^2	Connection Density per km^2	User Density	QoS	Min Per-user Data Rate	Latency	Min Device Cost	Min Device Power
45 bps/Hz[36]	**100 Tbps**	**1 million devices**	**Subway, Stadium**	**Reliable, consistent**	**100 Mbps**	**< 1 ms**	**IoT[37] scale**	**IoT power**

Table 1: IMT-2020 proposed requirements for 5G[38]

At the heart of the proposed IMT-2020 goals is a huge leapfrog in average SE to 45 bps/Hz, 15X beyond the highest IMT-Advanced average spectral efficiency of 3.0 bps/Hz that LTE-A is targeting.[39]

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[34] *IMT Vision towards 2020 and Beyond.*IMT-2020 (5G) Promotion Group, February 2014, ITU. http://www.itu.int/dms_pub/itu-r/oth/0a/06/R0A0600005D0001PDFE.pdf ("*IMT 2020*")

[35] Other similar visions for 5G performance include "5G Use Case and Requirements", April 2014, Nokia Siemens Networks (http://nsn.com//file/31121/5g-requirements) and "Scenarios for the 5G Mobile and Wireless Communications: the Vision of the METIS Project", May 2014 (https://www.metis2020.com/wp-content/uploads/publications/IEEEComMag_Osseiran_et_al_METIS_overview_scenarios_201405.pdf)

[36] 15X *IMT-Advanced* highest target average spectral efficiency of 3 bps/Hz.

[37] "IoT" refers to "Internet of Things," meaning connected M2M devices, like wearables.

[38] *IMT-2020*

The IMT-2020 SE goals reflect the inescapable conclusion that the world's supply of practical mobile spectrum is almost exhausted, and that the only hope to achieve such a leapfrog would be a revolutionary approach to wireless. Related to SE are IMT-2020 goals for traffic-, connection- and user-density as well as reliable and consistent QoS to make such performance predictable. The minimum per-user data rate reflects the expectation of a cellular architecture with cell-edge performance of at least 100Mbps, so that at least 100Mbps is available consistently throughout the coverage area.

If the 600 MHz band were deployed from the outset with the performance capabilities in the previous paragraph (highlighted in *light* green in Table 1), while remaining compatible with standard LTE devices, it would not only address the spectrum crunch issues raised in Chapter III, but combined with 600 MHz's exceptional propagation characteristics[40], would enable a vast range of applications otherwise unachievable or impractical with current mobile technology. 600 MHz would provide both long-range and high-density service, whether in a rural area, in a dense urban area, in a stadium or an airport. 600 MHz would also be a viable broadband competitor to wireline broadband services, promoting competitive improvements and pricing. And, from a public safety perspective, not only would 600 MHz reach locations otherwise impenetrable to high-band wireless, but it would allow 600 MHz to be able to handle high-density crisis situations, such as the 2013 Boston Marathon bombing, where an enormous surge in mobile

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[39] 3 bps/Hz requires LTE-Advanced 8x8 MIMO capability, both in the network and devices. To the best of our knowledge, this has not yet been deployed. Current LTE average spectral efficiency is reported at 2.3 bps/Hz per *Rysavy*. IMT 2020's 45 bps/Hz spectral efficiency would be a 20X leapfrog beyond today's 2.3 bps/Hz.

[40] *Report and Order*, footnote 92.

demand from people seeking help overwhelmed all mobile networks in the crisis area, resulting in almost no service at all[41].

But, even with such extraordinary performance, we would still want a compatible that would enable 600 MHz to support future technologies as they are introduced, while concurrently supporting legacy LTE and LTE-A devices. For example, the remaining proposed capabilities (in *dark* green) in Table 1 of <1ms latency and Internet of Things (IoT) cost and power are not achievable within the LTE protocol[42]. Ideally, we would want the 600 MHz band to be future-proof, enabling yet unimagined wireless innovations to make use of its unique propagation characteristics, concurrently with legacy devices.

V. pCell ACHIEVES 5G GOALS TODAY WITH LTE DEVICES

pCell technology, under development by Artemis for over a decade, achieves all of the *light* green IMT-2020 targets in Table 1 using off-the-shelf LTE devices and is operational now. It is compatible with unmodified off-the-shelf LTE Release 8 and above devices such as iPhone 5S/5C, iPad Air, Nexus 5 and LTE dongles, it achieves consistent and reliable SE throughout the coverage area in excess of the 5G target SE in Table 1, and can maintain a consistent and reliable per-user data rate in excess of 100 Mbps with LTE devices capable of that speed. pCell far exceeds all of the Density requirements of Table 1, not only supporting devices at stadium/subway densities, but supporting densities of devices separated by only a few centimeters.

[41] Ungerleider, N.,"Why Your Phone Doesn't Work During Disasters—And How To Fix It", Fast Company. April 17, 2013. http://www.fastcompany.com/3008458/tech-forecast/why-your-phone-doesnt-work-during-disasters-and-how-fix-it
[42] E.g., the minimum LTE latency is several milliseconds and many aspects of the LTE standard (e.g. the requirement of 2 antennas) preclude minimal cost and power devices.

pCell has been extensively tested with unmodified LTE devices in bands 38, 39, 40 and 41 as well as with lab LTE devices in 900 MHz and 400 MHz bands, both indoor and suburban outdoor. Urban and stadium trials start later this year, with commercial deployments starting in 2015.

pCell will also support new protocols concurrently in the same spectrum as LTE and LTE-A devices such as protocols that would meet the *dark* green IMT-2020 targets in Table 1, which are not achievable within the LTE protocol. As such, pCell future-proofs spectrum to allow concurrent use with yet-to-be finalized (or yet-to-be-conceived) standards.

pCell is an entirely new approach to wireless. Unlike cellular which, *avoids* or suppresses interference, pCell *exploits* interference, deliberately overlapping interfering waveforms throughout the coverage area to concurrently synthesize a tiny personal cell (a "pCell") at the location of each user device antenna. Each pCell is an independent channel capable of delivering the entire capacity of the entire spectrum to each user at once. At 600 MHz, a pCell is a 3D spherical region a few centimeters in diameter with 3D polarization, resulting unprecedented spatial separation—literally allowing mobile devices to be stacked together and each have an independent channel in the same spectrum. pCell is Doppler-tolerant, supporting high-speed train speeds of >150 MPH, and it requires lower uplink power than cellular for a given distance, reducing device power consumption. pCell waveforms were designed to precisely conform to LTE spectral and power envelopes (albeit requiring less power for a given distance), meeting Commission specifications for commercial LTE transmissions.

A full description of how pCell works is beyond the scope of a filing of this nature, but the following is a brief explanation:

pCell is deployed in a C-RAN architecture using IP fronthaul to single-antenna pWave™ radio heads. All of the processing, down to the baseband physical layer, is implemented in Artemis-developed real-time Software-Defined Radio (SDR) within the C-RAN data center.

While cellular base station deployments follow a precise cell plan to avoid interference among base station transmissions, pWave deployments are quite the opposite: pWaves can be placed in any location that is inexpensive and convenient, and pWave radio transmissions deliberately overlap each other. Thus, pWave locations are typically chosen based on where pWaves are least expensive to deploy.

To understand how pCell works, it is helpful to compare pCell to conventional cellular architecture. Fig. 3 shows idealized cellular coverage in the left diagram, real-world cellular coverage in the center, and real-world pCell coverage on the right. Each blue dot is a base station (a pWave radio head, in the case of pCell), each red dot is a user device, and gray shading shows coverage (the transmission range of each base station or pWave).

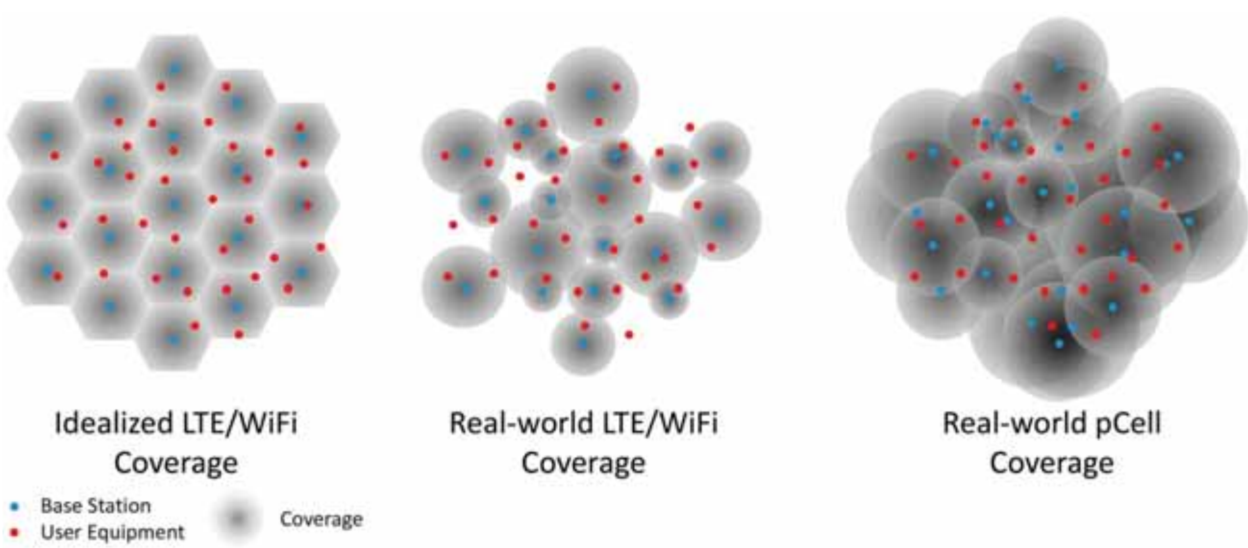

Figure 3: Cellular vs. pCell Coverage

In the idealized cell layout on the left of Fig. 3, the signal strength of each base station transmission drops off perfectly in a hexagonal grid with no intercell interference or dead zones. But, in a real-world cellular system, as shown in the center diagram, this isn't achievable. Obstacles and sub-optimal base station placement result in cells of varying size as well as dead zones and intercell interference.

In the real-world pCell diagram on the right side of Fig. 3 the pWave radio transmissions deliberately (and heavily) interfere. pWaves are in arbitrary locations with varying power output; the only requirement is that the pWave transmissions overlap (interfere) where there are users. This is again in contrast to real-world cellular, where the base station placement and transmission range must approximate an ideal hexagonal grid, requiring specific and often expensive real-estate locations, specific (only slightly varying) power output, and careful antenna aiming.

Since arbitrarily creating interference is far easier than precisely avoiding interference, pCell is much simpler and less expensive to deploy than cellular, and pCell can easily provide 100% coverage with no dead zones.

While the gray shading in Fig. 3, above, shows *coverage*, the gray shading in Fig. 4, below, shows *SINR* (i.e., Signal-to-Interference-plus-Noise Ratio, a measure of signal quality) for the exact same base station and user layout.

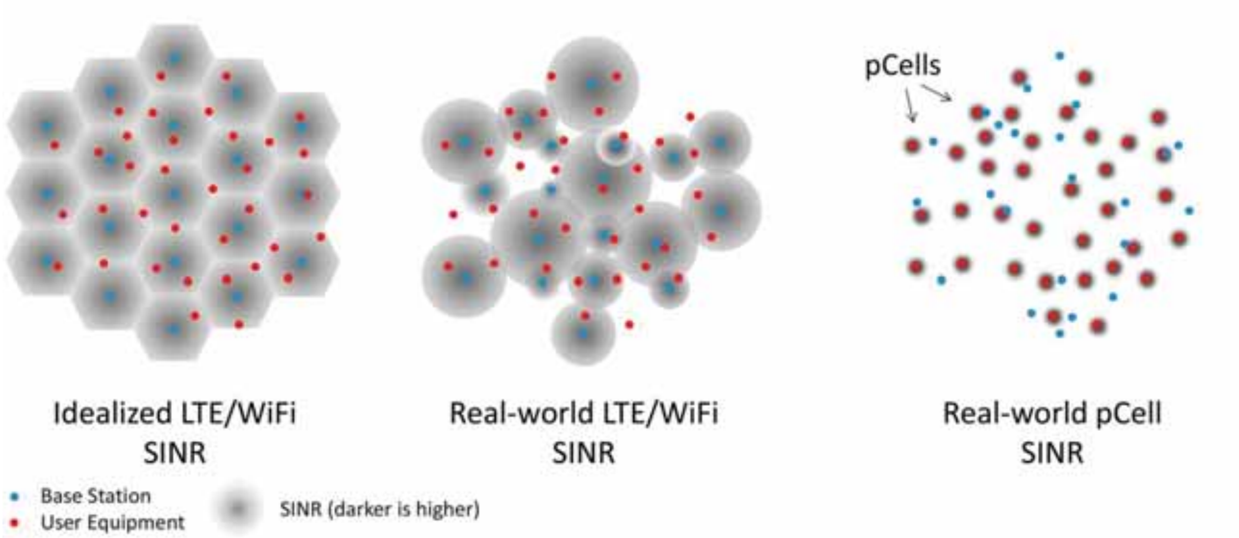

Figure 4: Cellular vs. pCell SINR

In the idealized cellular case, coverage and SINR are identical because there is zero intercell interference. In the real-world cellular case, coverage and SINR are nearly identical, because there is (hopefully) little intercell interference, but there typically is some (especially with small cells). In contrast, the pCell SINR in Fig. 4 is drastically different than the pCell coverage shown in Fig. 3. The interfering pWave transmissions create random waveform patterns throughout the coverage area *except* where there are user antennas (at the red dots). Rather, at the precise location of each user antenna, *the sum of all of the interfering signals add up to the exact waveform intended for that user (e.g. an eNodeB waveform) with extremely high SINR*. Each of these high SINR waveforms is a pCell, shown as a small gray circle around each red dot. All of the pCells can be synthesized at once and each is an independent channel, enabling every user to experience the full capacity of the channel at once.

Unlike cellular, which is base station-centric, where users are handed-off from one base station to another as they move through the coverage area, pCell is user-centric, synthesizing each pCell from whatever pWave antennas happen to be in range of a given user at a given moment. Consequently, each pCell user experiences a consistent, high-SINR throughout the coverage area with no hand-offs, very much in contrast to cellular where, users experience highly-variable SINR throughout the coverage area as they move from cell-center to cell-edge, and in and out of dead zone or interference zones, with hand-offs between each cell.

pCell capacity scales with the number of pWave radio heads placed in the coverage area. Each pWave adds to the aggregate capacity in the coverage area a data rate equal to the highest modulation order (e.g. 64 QAM for Release 8). In 20 MHz TDD, 3:1 ratio, each pWave adds about 70 Mbps to the aggregate capacity, so 10 pWaves would provide 700 Mbps of aggregate capacity, 20 pWaves would add 1.4 Gbps, and so on. User devices in the coverage area share that aggregate capacity per their data needs, whether 15 Mbps for 4K video, 10 Mbps for web surfing, 5 Mbps for HD video, 100 kbps for audio, etc. The aggregate capacity is divided up among the users, and users are scheduled if the capacity is exceeded. Since there is no "cell-center" or "cell-edge", there is no drop-off in SINR when users are between pWaves; all users experience near peak SINR wherever they are, resulting in reliable and consistent QoS. Also, because there is no "cell plan", pWaves can be placed wherever it is convenient and inexpensive, making it easy to increase aggregate capacity to match growing demand.

pCell works in the uplink as well as in the downlink. In the uplink, user devices transmit as they normally would, but with overlapping transmissions. The overlapping uplinks are received by pWave antennas within range of the users and the transmissions are separated by the pCell SDR in the C-RAN data center.

pCell C-RAN data centers can be built to whatever scale is appropriate, to within about a 10ms fronthaul latency, which means one pCell C-RAN could support a large metro area, a neighborhood, or a stadium. Adjacent pCell C-RANs cooperate, so users seamlessly continue to have an uninterrupted pCell as they move between C-RANs. Also, C-RANs can hand-off at the edge of their coverage area to cellular, as required.

pCell is very different than MIMO[43]. MIMO relies on rich multipath and high power, and even in a rich multipath environment, MIMO sees little SE gain above 4 antennas and no gain above 6 antennas[44,45]. MIMO throughput is highly inconsistent and unpredictable, performing poorly both in Line-of-Sight (LOS)/low-multipath conditions and in low-power cell-edge conditions.

In contrast, pCell does not rely upon multipath at all and works consistently whether in high-/low-power, LOS/NLOS or low-multipath/rich-multipath scenarios. pCell capacity scales linearly and consistently with the number of pWaves, far beyond MIMO's average 4X gain limit achievable in practice.

Unlike cellular eNodeBs that have an upper limit of concurrently-connected users, pCell has no inherent upper limit. Many thousands of users can be supported in the same dense area, such as a stadium or Times Square.

pCell achieves such high SE by exploiting very high order spatial multiplexing. Channel signaling from each user device is received by the pWaves and then processed by the Artemis SDR code in real-time to synthesize a pCell at the precise location of each

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[43] "MIMO" can be used to refer to any system with multiple transmit antennas and multiple receive antennas, but "…the most common use of the term 'MIMO' applies to spatial multiplexing." *Rysavy,* p. 81. We use the common meaning of "MIMO": spatial multiplexing.

[44] "Spatial Channel Model AHG (Combined ad-hoc from 3GPP and 3GPP2)", 3GPP, April 22, 2003. Figs 3-4.

[45] K. Werner, H. Asplund, D.V.P. Figueiredo, N. Jaldén, B. Halvarsson, "LTE-Advanced 8x8 MIMO Measurements in an Indoor Scenario", Ericsson AB, Stockholm, Sweden. April 16, 2013. http://www.ericsson.com/news/130416-lte-advanced-8x8-mimo-measurements-in-an-indoor-scenario_244129228_c?categoryFilter=conference_papers_1270673222_c

user device antenna. Because there are so many concurrent users, conventional channel state information (CSI) feedback techniques would quickly swamp the uplink channel. So, pCell can rely entirely on TDD channel reciprocity, resulting in minimal uplink signaling overhead. For example, using TDD the total overhead for 64 concurrent users in a 10ms frame time is only 2.9%.

While pCell can utilize FDD, the uplink overhead for CSI is very high. For example, using FDD the total uplink overhead for 64 concurrent users in a 10ms frame time would consume more than 80% of the uplink channel, plus there is signaling overhead in the downlink channel. This is not only a vast waste of spectrum, it does not scale. While 64 concurrent users may seem like exceptionally high order spatial multiplexing today, it will be considered low order in the future.

And, while pCell is the only existence proof of high-order spatial multiplexing today, all 5G technologies currently on the table are contemplating high-order spatial multiplexing and will likely require efficient channel feedback mechanisms to operate. TDD is extremely efficient for high order spatial multiplexing as we know it today. FDD is very inefficient and hits upper bounds.

Without knowledge of pCell technology's existence or the fact that a technology with such high-order spatial multiplexing was possible, the Commission decided upon FDD for the 600 MHz band. In its report, the Commission outlined a series of arguments of why FDD should be used in the 600 MHz band. The final Report summarized several of the arguments for and against FDD and TDD, and ultimately concluded (emphasis added),

> Based on our examination of the record, FDD is better suited for the 600 MHz Band at the present time *in light of current technology*, the Band's propagation characteristics, and potential interference issues present in the Band. Therefore, we decline to adopt a TDD-based band plan.[46]

Thus, the Commission evaluated the FDD vs. TDD *"in light of current technology"*, and it chose FDD based on technologies that achieved 3 bps/Hz (i.e. LTE-A) and less. The Commission further recognizes that "…advances in technology, may make an unpaired, TDD-compatible framework appropriate in other circumstances"[47]. With high-SE technologies such as pCell (and most other 5G technologies likely to be used in the 600 MHz band), FDD is profoundly less efficient than TDD, to the point of being impractical for very high order spatial multiplexing.

In summary, to achieve high SE, high-order spatial multiplexing is required. High-order multiplexing requires channel state information feedback per user. TDD is highly efficient for per-user channel signaling and scales to very high numbers. FDD is extremely inefficient for per-user channel feedback and hits a ceiling. Consequently, if 600 MHz is to scale to high SE, whether using pCell or not, with the knowledge we have today, TDD is the only practical choice.

VI. REQUEST FOR RECONSIDERATION

Artemis respectfully requests the Commission establish minimum SE requirements for licensees of the 600 MHz band that scale in accordance with projected traffic demands, while remaining compatible with LTE devices and waveform envelopes and designed to be future-proof to concurrently support new technologies in same 600

[46] *Report and Order*. ¶ 51.
[47] *Report and Order*. ¶ 52.

MHz spectrum as legacy LTE and LTE-A devices. While pCell serves as an existence proof that these requirements are achievable by the first deployment in the 600 MHz band, of course, the requirements are technology-independent; licensees could use any technologies that meet these requirements.

Artemis respectfully requests the Commission to reconsider its decision to exclusively adopt FDD in the 600 MHz band in light of the new knowledge of pCell as an existence proof that LTE-compatible high SE is achievable for the first deployments in the 600 MHz band, and the new knowledge that high-order spatial multiplexing is far more efficient with TDD than FDD. Artemis respectfully request that at least part of 600 MHz spectrum is allocated to TDD instead of committing the entire 600 MHz band to FDD.

VII. pCell VALIDATION AND THE PUBLIC INTEREST

We recognize that pCell's claims go far beyond what is known in industry and academia as the current state of wireless technology. Such exceptional claims can and should be validated for the Commission to take this filing under consideration. pCell is readily verifiable, both rigorously with LTE test equipment, or simply inserting SIM cards into a large number off-the-shelf LTE devices with no modifications and seeing them all stream HD video concurrently. We would be happy to come to the Commission's test facilities and set up any demonstrations and testing the Commission (or any other stakeholder) requires.

Further, we recognize that we are a small startup proposing requirements (high SE and future-proofing) that strongly recommends TDD, despite the FDD consensus from all of the major carriers (except Sprint[48]), as well as that of other major corporations and industry groups.

[48] Sprint has maintained its preference for TDD, but ultimately agreed to support FDD because there was "…substantially more support for a 600 MHz FDD band plan than a TDD allocation"

We do not make this request lightly. We recognize the detailed and thorough work that went into the decision to choose FDD and, since no one had yet achieved a practical high-order multiplexing system, at the time no one could have known that TDD was so highly efficient for high-order multiplexing while FDD was not.

We also recognize that, in any light, this Petition is an unusual request, asking the Commission to recognize that the 600 MHz band is a very scarce and unique natural resource, and as its custodian, require that it is used efficiently. pCell is a completely verifiable existence proof that LTE-compatible high SE with concurrent support for future technologies in the same spectrum is achievable.

The advantages high SE brings (and the congestion pitfalls high SE eliminates) are so substantial to public interest and public safety we respectfully argue that the Commission is compelled both by mission and statute to seek to validate or invalidate pCell's claims, and if pCell's immense SE gains are confirmed, require 600 MHz licensees to meet minimum SE requirements in accordance with traffic projections. Also, given that TDD is far more efficient for high-order spatial multiplexing technologies such as pCell, allocate at least some of the 600 MHz band for TDD operation.

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and sought to "…facilitate broad consensus on 600 MHz band plan." Sprint Corporation, Letter to Marlene H. Dortch, Secretary, FCC. *"Notice of Ex Parte Presentation: Expanding the Economic and Innovation Opportunities of Spectrum Through Incentive Auctions, GN Docket No. 12-268"*, January 7, 2014.

VIII. UBIQUITOUS WIRELESS AS A 21st CENTURY UTILITY

While this Petition may be an usual request, the impact of high-SE low-band spectrum to U.S. mobile communications will have a transformative effect not only in economic and public safety terms, but it also opens the door for a wide range of innovation that we cannot begin to anticipate today. Effectively, with high-SE low-band spectrum, the U.S. will have a canopy of reliable, high-density, long-range, low-power connectivity. Just as water and electricity were established as always-available utilities in the 20th century, by reconsidering the *Report and Order* in accordance with this Petition, the Commission can establish ubiquitous broadband mobile connectivity in the 21st with the 600 MHz band.

Respectfully submitted,

/s/ Stephen G. Perlman	/s/ Antonio Forenza, PhD
Founder & CEO Artemis Networks LLC	Co-Founder & Principal Scientist Artemis Networks LLC

Stephen G. Perlman
Antonio Forenza, PhD
Artemis Networks LLC
355 Bryant Street, Suite 110
San Francisco, CA 94107
(415) 947-5555

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