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

In the Matter of	)	
	)	
Use of Spectrum Bands Above 24 GHz for Mobile Radio Services	)	GN Docket No. 14–177
	)	
Petition for Rulemaking of the Fixed Wireless Communications Coalition to Create Service Rules for the 42–43.5 GHz Band	)	RM–11664

To: The Commission

COMMENTS OF ERICSSON INC.

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Ericsson supports the Commission's Notice of Inquiry ("NOI") which launches an examination of technical and spectrum issues related to fifth-generation ("5G") mobile services.[1] As the NOI recognizes, Ericsson is a leader in research and development for 5G, spearheading the European Union's Mobile and Wireless Communications Enablers for the Twenty-Twenty Information Society ("METIS") project to study the technical capabilities and challenges ahead in 5G.[2] Ericsson herein identifies several important themes for the Commission to consider as it prepares for 5G, including:

- 5G will include evolved LTE technologies and additional component air interfaces that will support many new and evolving use cases.
- The search for higher frequency bands available for mobile broadband must not derail ongoing efforts to gain access to additional spectrum below 6 GHz.
- Higher frequency bands offer real promise for the provision of very high peak data rates in high demand areas—in the nearer term, the Commission should focus on spectrum above 10 GHz (rather than above 24 GHz) as today's evolving technology can more easily transition to these frequencies. The radio environment at higher frequencies is simply very different, and it gets more "different" as the frequency

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1 *Use of Spectrum Bands above 24 GHz for Mobile Radio Services*, Notice of Inquiry, 29 FCC Rcd 13020 (2014).

2 NOI, 29 FCC Rcd at 13023-24 ¶ 9 n.20 & ¶ 10.

increases. As a consequence, in the short term, the FCC needs to focus primarily on lower frequencies, especially on those below 24 GHz, also including bands at the lower end of those under consideration here, namely those below 30 GHz.

- There are many challenging technical issues that need to be examined closely before higher frequency bands can be integrated into 5G mobile networks that evolve from 4G LTE networks, as discussed more fully below.
- Global harmonization of spectrum resources and technical regulation is essential. Ericsson strongly urges the Commission to work with other regulators around the world to build consensus, especially in anticipation of WRC–2019.

I. INTRODUCTION AND SUMMARY

Ericsson commends the FCC for beginning the process of identifying spectrum opportunities for 5G. As the NOI acknowledges, the global mobile industry and technical standards organizations are in the early stages of assessing what 5G should encompass, and that analysis includes millimeter wave ("mmW") spectrum covering above 24 GHz.[3] This will be a long and complex process but an essential one given the skyrocketing demand for mobile data *and* the promising new technologies that offer mobile broadband opportunity in higher frequency bands. This NOI wisely begins the Commission's process to prepare for 5G. Ericsson urges the agency to join with other regulators across the globe to ensure a harmonized approach to the next generation of mobile broadband.

As the Commission is well aware, mobile broadband has experienced unparalleled demand and growth in the last five years. And the United States has been a leader in deployment, subscriptions, and usage. LTE has grown from zero in the North American market in 2010 to 25% of all mobile subscriptions in 2013 and 40% in 2014—the highest share of LTE

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[3] *Id.* at 13021 ¶ 1. While millimeter wave spectrum is usually defined as the frequencies from 30–300 GHz, *see, e.g.*, FCC Office of Engineering and Technology Bulletin No. 70, *Millimeter Wave Propagation: Spectrum Management Implications*, at 1 (July 1997), http://transition.fcc.gov/Bureaus/Engineering_Technology/Documents/bulletins/oet70/oet70a.pdf, the NOI broadens this definition slightly to include the bands above 24 GHz. *E.g.*, NOI ¶ 17. These comments will use the NOI's definition.

in the world.[4] The average household has over five wireless-connected devices.[5] In 2014, mobile data traffic grew to three-fifths of an ExaByte per month—equivalent to about two hundred million downloads of a full-length movie per month.[6] By the end of 2014, major wireless carriers in the U.S. had invested in network facilities to provide 4G service essentially throughout their entire networks.[7]

And mobile broadband traffic is projected to continue growing exponentially, with North American data usage growing at a compound annual growth rate of more than 30% from 2014 to 2020, reaching over 3 ExaBytes per month by 2020.[8] Data usage per smartphone is expected to quadruple, from 1.6 GB to 6.0 GB by 2020, and tablets will contribute an increasing proportion of data traffic, with the total mobile data traffic reaching 5 times its 2014 level by 2020.[9]

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4 ERICSSON MOBILITY REPORT, NORTH AMERICAN APPENDIX, at 4 (Nov. 2014) ("Ericsson Mobility Report-North America"), http://www.ericsson.com/res/docs/2014/emr-november2014-regional-appendices-rnam.pdf (accompanying ERICSSON MOBILITY REPORT ON THE PULSE OF THE NETWORKED SOCIETY (Nov. 2014) ("Ericsson Mobility Report"), http://www.ericsson.com/res/docs/2014/ericsson-mobility-report-november-2014.pdf).

5 Ericsson Mobility Report-North America at 4.

6 *See id.* at 5.

7 *Implementation of Section 6002(b) of the Omnibus Budget Reconciliation Act of 1993*, Seventeenth Report, DA 14–1862 at 92 (WTB Dec. 18, 2014) (Table VI.B.1, 3G/4G/LTE Deployment Reported by Selected Mobile Wireless Providers as of December 2014).

8 Ericsson Mobility Report-North America at 5.

9 *Id.* at 5.

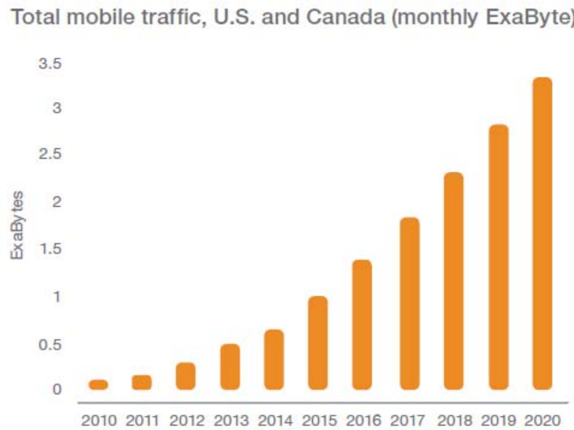

Figure 1. Mobile data traffic growth[10]

Network capacity is thus expected to fall short of market needs both in the United States and elsewhere as we approach 2020. New technologies—the next generation of mobile broadband—and additional spectrum will be needed to handle the mobile network traffic demands of the future.

As an initial matter, as the FCC approaches 5G, it should do so with restraint and flexibility, to avoid chilling the exploration and innovation that are essential to unlocking the full potential of the next generation of wireless communications. This includes understanding the evolving nature of technologies, the needs of the mobile industry, and how mobile broadband can further the Networked Society of 2020 and beyond—where "everyone, everything and everywhere will be connected in real time."[11]

Importantly, the Commission should not lose focus on ensuring the availability of additional mobile broadband spectrum at lower frequencies—below 6 GHz—for expanded 4G services and the evolution to 5G. The emphasis in this proceeding for the next generation of mobile technology addresses but one aspect of the needs of industry, but does not encompass the

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10 *Id.*

11 Ericsson, NETWORKED SOCIETY ESSENTIALS, at 2 (2013), http://www.ericsson.com/res/docs/2013/networked-society-essentials-booklet.pdf.

entirety of spectrum needs for 5G, as the NOI recognizes.[12] Further, the FCC should explore potential wireless broadband spectrum options below 6 GHz and at frequencies above 10 GHz.

Ericsson's response to the detailed technical questions posed in the NOI demonstrates that there are many important areas that need to be studied before mmW bands can practicably be integrated into 5G mobile networks evolving out of 4G LTE networks.

Systems using mmW bands will need to use high-gain narrow-beam antennas to overcome path loss and compensate for small antenna aperture size, which requires a different approach to coverage from 4G—such as creating independent high-gain, directional beams for each active user, and employing dynamic beam tracking. A much denser site grid may be needed, limiting the economic benefits of deployment within areas that are capable of generating traffic.

Base station receivers will need to compensate for limitations on mobile transmissions due to factors such as RF exposure limits, handset orientation, and blockage of the signal by the human body, and RF exposure limits at frequencies above 6 GHz may also pose challenges to the development of mobile communications.

A mmW system should not be fully dependent on lower-frequency systems for operation; it should be able to operate autonomously, although systems may be able to rely on lower-frequency systems to enhance performance.

Ericsson advises against reliance on carrier aggregation between non-contiguous bands, which poses major challenges.

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[12] NOI, 29 FCC Rcd at 13021 ¶ 2.

There appear to be advantages in using time-division duplex ("TDD") for beamforming, and frequency-division duplex ("FDD") appears to be impractical due to the lack of duplex mobile filter technologies at higher frequencies.

Wider bandwidth signals enable high data rates and shorter transmission intervals, permitting new applications that can provide, *e.g.*, very low latency access. While 5G mmW networks may sometimes address 4G network congestion through opportunistic capture of mobile traffic, they are also likely to increase traffic growth by spawning new services. This may indeed place a burden on operators to improve the performance of traditional coverage networks so that quality of user experience can be maintained.

Propagation limitations will greatly limit non-line-of-sight ("NLOS") coverage, especially between indoor and outdoor locations and in rural and suburban areas where line of sight ("LOS") is not augmented by reflective paths. LOS coverage will be possible, but obstructions and vegetation will pose difficulties to reception. Diffraction loss will be higher than in traditional cellular bands and will limit coverage over hills.

Current out-of-band emission ("OOBE") rules discriminate against wideband technologies. Ericsson urges the FCC to adopt OOBE rules that do not require bandwidth-based attenuation, which would make mobile service deployment difficult. Current RF exposure rules impose significantly greater restrictions on mobile device power levels in bands above 6 GHz, and may need reexamination. Emission limits should be specified in an aggregated fashion for antenna arrays and may need new methodologies for measurement, *e.g.*, based on power flux measurements.

Access and transport should be allowed in the same bands, permitting the use of 5G spectrum for backhaul.

The LMDS band will be of interest for mobile service because there is sufficient spectrum that would allow multiple blocks of 100–200 MHz. The 24 GHz bands could be suitable for backhaul and, if larger blocks were available, may be suitable for mobile services, but they are not uniformly designated for mobile service globally. Bands above 30 GHz are more challenging. Industry has an incentive to innovate and employ the 39 GHz band productively, especially if the rules for 37–38.6 GHz and 28.6–40 GHz were made uniform. The 42–42.5 GHz band will not be of interest unless it is combined with the 42.5–43.5 GHz band, which is currently under consideration for other purposes. The 60 GHz band should be considered for mobile services at an appropriate time, and the 70 and 80 GHz bands are also similarly attractive, especially for backhaul and for short-range applications.

It is premature to address licensing and regulatory mechanisms for 5G systems, especially those employing mmW spectrum, given the substantial technical development that needs to be accomplished. Ericsson reiterates that greater guarantees on spectrum quality provide greater levels of economic certainty to operators who will be investing in infrastructure. Consequently licensing arrangements should be discussed on a band-by-band basis.

II. ERICSSON'S VIEW OF 5G

Ericsson's vision of 5G entails the next generation of mobile technology that will allow for massively increased connectivity for the Networked Society, enhanced mobile broadband, and the introduction of new modes of communication for very high reliability and service guarantee. It will be a very flexible, heterogeneous system employing numerous technological enhancements that can be configured to provide connectivity simultaneously to a wide range of application types with differing characteristics and requirements.[13] This will include massive

[13] *See* Ericsson Mobility Report at 20-21.

connectivity between machine devices, for provisioning of real-time low-latency communications for critical needs (*e.g.*, industrial applications such as manufacturing), as well as capacity and bandwidth expansion for communication in urban city centers, campuses, and indoor locations. Separate systems cannot and should not be built for each potential use case for wireless connectivity.

There is a broad consensus to this effect among the global mobile industry, which has identified various ways of expressing this consensus view. As noted above, Ericsson leads the European METIS project, which characterizes 5G as supporting the following capabilities:

- 1,000 times higher mobile data volume per area;
- 10–100 times higher number of connected devices;
- 10–100 times higher user data rate;
- 10 times longer battery life; and
- 5 times reduced latency.[14]

Along the same lines, the GSM Association ("GSMA") describes a 5G system aspiring to provide: 1–10 Gbps connections; 1 millisecond latency; 1,000 times higher bandwidth per unit area; 10–100 times higher number of connected devices; 99.999% availability; 100% coverage; 90% reduced network energy usage; and up to 10 year battery life for low power devices.[15]

Ericsson concurs with METIS' overall 5G characterization from the user perspective: amazingly fast; works in a crowd; best experience follows you; super real-time, and reliable

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[14] METIS, *Mobile and Wireless Communication Enablers for the 2020 Information Society*, at 5 (Mar. 2013), https://www.metis2020.com/wp-content/uploads/deliverables/METIS_project_presentation_public.pdf.

[15] GSMA Intelligence, *Analysis, Understanding 5G: Perspectives on Future Technological Advancements in Mobile*, at 6-8 (Dec. 2014), https://gsmaintelligence.com/files/analysis/?file=141208-5g.pdf.

connections; and ubiquitous things communicating.[16] These factors, in various combinations, will fulfill a wide variety of use cases that have varying requirements, such as expanded machine-to-machine ("M2M") connectivity, greater autonomy in vehicles, wireless cloud-based videoconferencing, and virtual reality.[17] And the use cases are limitless in the Networked Society. The Commission's focus in terms of regulation should be to ensure the smooth evolution of 4G LTE systems into 5G systems providing the high data rates and other characteristics needed to meet these visions.

5G will include evolved LTE technologies and additional component air interfaces that will support many new and evolving use cases, such as those mentioned above. This is true in existing cellular bands and will be the case in new bands that become available for mobile broadband in the region below 6 GHz, as well as in higher bands made available for 5G. For example, industry is exploring a range of evolutionary developments that can facilitate growth in existing and forthcoming bands employing cellular technology below 6 GHz, as well as higher bands. Beamforming via phased-array antennas has long been used for specialized applications, and is under consideration for use at LTE base stations in existing bands and near-term future expansion bands. But beamforming is especially likely to play a prominent role in 5G networks at higher frequencies, where it may be employed at both ends of the transmission path.[18] Ericsson is currently working with IBM on phased-array antenna solutions that would put a

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16 METIS, *Challenges and Scenarios of the Fifth Generation (5G) Wireless Communications System*, at 11-16 (Nov. 2013), https://www.metis2020.com/wp-content/uploads/presentations/W@kth_METIS_overview_scenarios_20131115_web.pdf.

17 *Id.* at 8-10.

18 *See, e.g.*, Ariel Bleicher, *Millimeter Waves May Be the Future of 5G Phones*, IEEE Spectrum (June 2013), http://spectrum.ieee.org/telecom/wireless/millimeter-waves-may-be-the-future-of-5g-phones; Stefan Schwarz & Markus Rupp, *Exploring Coordinated Multipoint Beamforming Strategies for 5G Cellular*, IEEE Access (Sept. 9, 2014), http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=6888496.

hundred or more antennas and radios on a single chip smaller than a credit card for use in high-capacity small cells in 5G networks.[19] Similarly, research is ongoing into Large Scale Antenna Systems, also known as Massive MIMO, which takes beamforming to the next level, using hundreds to thousands of antennas operated together to focus signals into ever-smaller spaces, thereby permitting increased throughput and efficiency.[20] Carrier aggregation is being introduced into 4G networks, and recently reached data rates of 300 Mbps in a trial aggregating two bands.[21] Development continues, and a 3-carrier downlink aggregation was recently tested in a Release 9 (LTE-Advanced) system, achieving download speeds of up to 410 Mbps using 55 MHz of spectrum.[22] Indeed, the ability of LTE to aggregate carriers is only limited by the radio front-end and the current imposition to operate over multiple disparate bands. A single wide band that is handled by a single front-end could aggregate many more carriers, limited only by filter technology. Technical developments being introduced in today's LTE systems will be the foundation for higher-capacity 5G networks of the future, starting with 5G networks in existing and nearby spectrum, and moving into higher frequency spectrum over time.

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[19] Dan Jones, *Ericsson & IBM: The Many Phases of 5G*, Light Reading (Nov. 24, 2014), http://www.lightreading.com/mobile/5g/ericsson-and-ibm-the-many-phases-of-5g/d/d-id/712230.

[20] *See, e.g.*, Massive MIMO Info Point, http://www.massivemimo.eu; Erik G. Larsson *et al.*, *Massive MIMO for Next Generation Wireless Systems*, IEEE Communications Magazine 186 (Feb. 2014), available at http://www.dcc.fc.up.pt/~slc/aulas/RCM/1415/Trabalho/papers/edfors.pdf.

[21] Michael Carroll, *Ericsson, Orange Hit 300 Mbps in French Trials of FDD LTE Carrier Aggregation*, FierceWireless Europe (Dec. 17, 2014), http://www.fiercewireless.com/europe/story/ericsson-orange-hit-300-mbps-french-trials-fdd-lte-carrier-aggregation/2014-12-17.

[22] Light Reading, *EE Tests 3-Carrier LTE-Advanced* (Dec. 22, 2014), http://www.lightreading.com/mobile/4g-lte/ee-tests-3-carrier-lte-advanced/d/d-id/712714.

III. THE COMMISSION SHOULD MAINTAIN FOCUS ON BANDS BELOW 24 GHZ, AS WELL AS CONSIDERING BANDS ABOVE 24 GHZ, FOR 5G

Ericsson commends the Commission for bringing new spectrum to market in the AWS-3 auction and, more broadly, is eager to consider new frequency bands for mobile broadband. New spectrum for 5G should be phased into the marketplace in different ranges of frequencies, but only as the challenges associated with those higher frequencies are better understood. At first, development should focus on bands below 6 GHz, which can leverage existing technologies and facilities. Longer term, the focus can shift to spectrum assignments in the bands from 10–30 GHz and the mmW bands above 30 GHz.

A phased-in approach allows providers to address a variety of use cases with differing latency, bandwidth, and other requirements. While some use cases, such as M2M connectivity, can be delivered either by legacy networks or 5G, other use cases, such as performing surgery remotely, or augmented or virtual reality applications, may require a combination of high bandwidth and low latency that are beyond the capabilities of existing releases of LTE. These more demanding use cases will require the introduction of new 5G technologies, either in existing spectrum (or new bands nearby), where they can be combined with existing infrastructure in relatively short order, or at higher frequencies, which will take more time because of the need to address new technical challenges.

A. In the Near Term, as Mobile Broadband Evolves toward 5G, It Will Be Deployed in Spectrum Below 6 GHz

The FCC should continue to make available additional spectrum below 6 GHz for wireless broadband as demand continues to grow and the technology evolves from 4G to 5G over the near term. The NOI observes this important principle in stating at the outset: "[t]his proceeding is not a substitute for our efforts to make additional lower frequency spectrum available for mobile services, but rather is a supplement to those efforts."[23] Ericsson firmly supports this ongoing commitment and calls for continued efforts and resources to identify additional spectrum below 6 GHz for mobile broadband.

Additional spectrum below 6 GHz is critical to obtaining the full benefits of the evolution of LTE toward 5G. As time progresses, there will be a continued evolution of LTE for mobile broadband using tested techniques such as higher-order modulations and carrier aggregation to expand bandwidth capabilities beyond current limitations. Three-carrier aggregation has already been successfully tested in a Release 9 (LTE-Advanced) system,[24] and LTE Releases 12 and 13 will introduce a new LTE-compatible air interface capable of low complexity, low energy variants of LTE for Machine Type Communications ("MTC"), for delay-tolerant sensor networks.

These new features can be implemented in current mobile bands with minimal delay and no need for major rule changes, because the FCC has wisely chosen to employ flexible technical regulations that give mobile broadband operators the ability to employ a range of technologies, instead of mandating the use of particular technologies in specific bands. As a result, the mobile broadband industry can phase in 5G technologies within existing allocations as well as in new bands as spectrum is allocated and licensed.

But the need for new bands below 6 GHz is critical. The continuous increase in data traffic makes it essential to increase the amount of spectrum within which these technologies can be deployed in a way that is compatible with existing bands, so that old and new bands can be used in a complementary manner and in the same devices with comparable technology. New mobile broadband spectrum below 6 GHz can be used together with existing mobile broadband

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23 NOI, 29 FCC Rcd at 13021 ¶ 2.

24 *See* note 22 above.

spectrum in a well-understood manner. In short, spectrum below 6 GHz can be put to use in the short term to expand the capacity and availability of existing wireless broadband networks. The Commission must not allow its inquiry about higher-frequency spectrum to stand in the way of continued provisioning of spectrum in the region below 6 GHz for mobile broadband.

B. SPECTRUM BANDS FROM 10 TO 30 GHZ WOULD BE MORE APPROPRIATE FOR THE INITIAL EXPANSION OF 5G BEYOND 6 GHZ

Ericsson believes that the mobile industry is capable of extending mobile services into spectrum bands in the range 10–100 GHz. We believe however that the lower end of this range is more appealing for the immediate policy decisions that will follow this NOI, specifically the range 10–30 GHz.

Eventually, new generations of LTE will need to grow into spectrum higher than 6 GHz to gain additional bandwidth. The 10 to 30 GHz range would be the most natural initial location for this growth, given that the technology used below 6 GHz can be adapted to this frequency range, with lower degrees of difficulty towards the lower end of the range.

This region is very attractive for the evolution of existing technologies to 5G, even though all spectrum above 6 GHz presents challenges for use in mobile devices due to the applicability of more restrictive RF exposure rules above that threshold.[25] Although path loss is itself independent of frequency, individual antenna element pairs will suffer a loss proportional to the square of the frequency due to a reduction of aperture. This must be compensated by significant increases in antenna gain (at the transmitter or receiver) as the frequency is increased, and the increases in gain needed to move significantly above 10 GHz will result in directional antenna patterns that pose significant challenges for use in mobile networks, as discussed in Section V.

[25] *See* 47 C.F.R. §§ 1.1310(d), 2.1093(d).

Bands closer to 10 GHz pose fewer challenges in these respects as compared to higher bands. Accordingly, bands below 24 GHz should be vigorously pursued. And the 24 GHz and LMDS bands are inherently less difficult to employ in a mobile broadband network, from a technical perspective, than the mmW bands above 30 GHz. Accordingly, the FCC should place its highest priority on bands below 30 GHz, with the focus on the lowest-frequency potential mobile bands in that region, starting below 6 GHz, then exploring spectrum between 10 and 30 GHz, with a preference for allocations at the lower end of that range.

C. Research Is Underway to Develop 5G Technology for Millimeter Wave Bands, but Much Work Remains to be Done

The mmW bands above 30 GHz hold promise for providing very high peak data rates in specific areas where traffic demands are very high at relatively short range, such as high-definition video communications. As discussed further below, however, these bands pose complex issues for mobile broadband multiple-access networks. A great deal of promising research has been done, and more is ongoing, but, as we discuss below, there is a great deal of work left to consolidate the state of the art into integrated system concepts.

IV. THE COMMISSION SHOULD KEEP PACE WITH GLOBALIZED 5G STANDARDS, WHICH ARE IN AN EARLY STAGE OF DEVELOPMENT, AND AVOID STEPS THAT MAY REDUCE INNOVATION

The United States has been a leader in mobile broadband—North America has the highest share of LTE in the world, 40% in 2014—but the rest of the world is rapidly catching up and is already planning for tomorrow with 5G. While the FCC was instrumental in making LTE a national success story by insightful forward-thinking, the next generation of mobile broadband technologies needs to be globally developed and deployed. Ericsson urges the Commission to work with other regulators around the world to build consensus for 5G. Global harmonization of spectrum resources and technical regulation is essential.

The Commission should work to further the development of global standards for 5G and, at the same time, to minimize the fragmentation of spectrum in the furtherance of globally harmonized spectrum usage. The ITU–R World Radio Conference of 2015 is expected to begin consideration of IMT–2020,[26] with 5G spectrum allocations to be negotiated in the following years for consideration on the agenda of the World Radio Conference of 2019. Global harmonization of technical and regulatory requirements is necessary for the success of advanced services in bands above 10 GHz. Ericsson urges the FCC to take steps to support ITU–R movement toward similar rules in all three regions.

It is indeed important for the Commission to seek to identify spectrum between 10 and 100 GHz that may be suitable for 5G networks in a globally harmonized manner, avoiding or minimizing the future fragmentation of mobile spectrum around the world. Ericsson urges the Commission to engage other regulators around the world to build consensus, so that treaties negotiated during WRC–19 may be less contentious in regard to sharing common bandplans.

The United States' success with LTE is also the result of a careful and considered path of flexible rules that have enabled mobile systems to evolve from analog cellular telephones to digital devices that bring the Internet to the palm of the user's hand. Any successful transition to new generations of mobile technology must undergo a similar evolution from previous technology, enabling similar economies of scale to 4G. Continuation of a robust, flexible policy for mobile broadband expansion will be good for America.

The NOI also makes the important point that any revision of the rules for higher frequency bands needs to ensure flexible rules that accommodate a wide variety of services.[27]

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26 *See*ITU, ITU Towards "IMT for 2020 and Beyond," http://www.itu.int/en/ITU-R/study-groups/rsg5/rwp5d/imt-2020/Pages/default.aspx

27 NOI, 29 FCC Rcd at 13026 ¶ 15.

This approach will avoid the premature cabining of this spectrum for particular uses, especially at a very early stage, which would chill innovation. Rules that facilitate flexible and innovative commercial use of this spectrum will serve the public interest.

V. DISCUSSION IN RESPONSE TO SPECIFIC INQUIRY ITEMS

A. TECHNOLOGY DEVELOPMENTS

Response to NOI ¶ 17: Ericsson believes it is possible to provide mobile services in bands above 24 GHz, subject to limits that the NOI appears to recognize exist. The mobile service in current bands cannot simply be extended into much higher bands, which are very different in their technical characteristics. Instead, there is an opportunity for developing mobile broadband systems at higher frequency bands that can provide very high peak data rates in specific areas where traffic demands are very high and exceed the capacity available at lower cellular bands. Ericsson is optimistic about the technological and commercial aspects of new air interfaces that may be developed in newer bands to augment the future revisions of 4G.

Rather than focusing principally on the mmW bands above 30 GHz, the Commission would be better served by a focus on bands below 6 GHz and subsequently 10–30 GHz, with bands above 30 GHz being phased in over time. Ericsson's current plans for a new 5G air interface are focused on bands below 30 MHz. Operational capacity is within reach in the LMDS bands, which are above 24 GHz but below 30 GHz, but that represents the limits of the planned technology. In general, complexity increases with operation in bands above 30 GHz. Above 30 GHz, significant innovation may therefore be required. In what follows, Ericsson offers information of the technology choices that will guide the development of services in bands above 10 GHz and extending operation towards 100 GHz. This response then proceeds with specific information about the suggested bands and concludes thereafter.

1. ANTENNA TECHNOLOGY

(a) Base Station Antennas

Response to NOI ¶ 19: Systems using bands above 24 GHz that use narrow adaptive beams will likely have to achieve this dynamically for initial system access and for tracking of mobile users. High directivity for mobile antenna systems will have to be achieved by arrays of many elements. This is by no means a trivial task, and current research and development efforts are just beginning. Systems will need to be engineered for the mass market, and the state of the art is yet to make significant headway beyond laboratory prototypes.

Several factors will determine the size of base station antennas and the size of the arrays. One advantage of mmW is the smaller size of antenna elements; this allows a large number of antenna elements to be packed into a given area in relation to similar antenna areas for lower frequencies. However, getting adequate power conducted into a larger number of antenna elements is not trivial.

Issues concerning the number of transmit chains, the number of power amplifiers needed, *etc.*, are complex and may have different answers depending on the scenario. It is indeed possible to integrate a power amplifier for each element in an array. With such a design, it is a challenge to maximize the aggregate conducted power into the array, so that element phasing can provide the right beam shape and orientation for a desired EIRP. Beamformers can be completely digital, completely analog, or partially digital, and various tradeoffs determine the right design for the scenario. Since the digital interface often limits complexity, a few independent signals corresponding to the spatial multiplexing ability of the transmitter will feed into the array.

Response to NOI ¶ 20: Existing 3G and 4G base stations sites would only be able to support a mmW system with identical coverage by creating as many independent beams as actual users, with sufficiently high gain to compensate for the higher path loss. This would not be practical in most mmW bands. Instead, a mmW technology would likely try to support a limited number of users simultaneously, by focusing narrow beams toward the served users (and then refocusing them toward other users in the coverage area in successive transmission intervals), and most deployments would likely use lower inter-site distances than today.

The number of power amplifiers does not have to be the same as the number of antenna elements, although there is much promise in considering power amplifier designs that are integrated with the antenna element. The minimum number of power amplifiers is typically dictated by the technological limits of maximum average power per power amplifier, the angular span of users that the base station will serve, and the desired aggregate conducted power into the antenna system. The maximum number of power amplifiers is likely to be the number of antenna elements.

In a truly adaptive beamformer, it may be possible to "connect" to many users simultaneously when those users have low EIRP requirements. As the link quality to users gets compromised, higher EIRP may be needed (but with narrower beams), and the diversity in the channel cannot be exploited as much. At the edge of coverage, it may not be possible to connect to more than one user simultaneously. Thus, in mmW bands, it may be possible to support urban microcells with maximum range equivalent or comparable to 4G microcells, but the area coverage would not be equivalent.

An additional dimension of configurability is offered by the rate of transmission. In general, the maximum number of users that can be connected to simultaneously is identical to the number of independent streams that can be transmitted from the adaptive array. In a time-division multiple access ("TDMA") system, it is of course additionally possible to support many more users by changing the antenna configuration in successive transmission time intervals (“TTIs”).

Response to NOI ¶ 21: All mmW access systems will likely depend on high antenna gain to increase EIRP towards a receiver. This is necessary because the typical gain of an antenna element of a particular type is not frequency dependent—it will be the same at 30 GHz as a similar element tuned to 3 GHz. It must also be emphasized that the path loss between two antennas that have similar apertures or effective areas is independent of frequency. However, the path loss between the transmitter and receiver as referred to an isotropic antenna pair at either end of the link is proportional to the square of the frequency, which means that there will be 20 dB less power transferred between a single antenna element at transmitter and receiver at 30 GHz versus 3 GHz. Typically, the gain needed to overcome this increased path loss will be achieved by phasing antenna elements so that signal energy adds constructively towards the receiver. The physical aperture of the antenna increases during the process of using multiple elements.

It may not be possible for each antenna element in the array to have independent control of amplitude; it is more likely that antenna elements will have phase shifters. If an antenna array is designed to have separate power amplifiers feeding different sets of array elements, the aggregate power of the array can increase as more elements are added. Beam widths depend on coverage and capacity needs and can vary from wide beams to narrow pencil beams, but at wider beamwidths there will be lower power transfer efficiency between the transmitter and individual receivers.

As more antenna elements are involved in reaching an individual receiver, it is possible to increase the EIRP; the base station conducted power can be controlled independently from the

EIRP. In the mmW bands above 30 GHz, a dynamic beam tracking a user is a likely solution. A deployment where three antenna panels are mounted edge-to-edge will resemble today's three-sector deployments.

Response to NOI ¶ 22: While human-related factors are more directly associated with mobile device characteristics, they also affect base station environments, because the base station may need to compensate for weaker mobile transmissions by employing enhanced reception capabilities. For example, the random orientation of handheld user equipment, limits on EIRP in proximity to the human body, and blockage of the signal by parts of the human body require compensation at the base station's receive antenna. As a result, further work needs to be done to understand the various ways in which antenna arrays can be tailored to specific environments.

In outdoor environments, the system is unlikely to provide ubiquitous coverage—for example, it will be difficult to account for losses through vehicles, and even in the presence of reduced multipath, Doppler tracking for high speed mobility presents a challenge, and connectivity may have to be more opportunistic. Further, it is extremely difficult for an outdoor base station to provide significant indoor coverage for frequencies as high as 60 GHz, while it might still be feasible at the frequencies below 30 GHz. Even communications through a window may require higher power than an outdoor-to-outdoor link because of high attenuation through windows as well as walls.[28] In addition, commercial buildings often have windows that are metallized, which will further attenuate signals.

(b) Mobile Station Antennas

Response to NOI ¶ 23: Several possibilities present themselves for the design of antennas for mobile stations. One option is to use antenna diversity on the receiver with many

[28] *See, e.g.*, *Revision of Part 15 of the Commission's Rules Regarding Operation in the 57–64 GHz Band*, Report and Order, 28 FCC Rcd 12517, 12528 n.73 (2013).

individual antenna elements, while another is to use multiple antenna arrays. Either option presents challenges and must be studied for the frequency bands of interest. In addition, the form factor of many mobile devices will limit the number of arrays or antenna elements and will test the creativity of designers.

Generally, increased transmit beamforming (more antenna elements at transmitter) can compensate for less receive beamforming (fewer antenna elements at receiver) and *vice versa*. When both transmitter and receiver use narrow beams for connectivity, changes in the channel can be abrupt. System procedures for beam tracking will then have to be designed to allow for mobility tracking. Alternatively, the coverage of the base station can be reduced so that adequate connectivity can be maintained without beamforming. Such architecture would require a much denser site grid than used for 4G systems deployed below 3 GHz.

Response to NOI ¶ 24: The FCC's RF exposure rules currently impose significantly greater restrictions on mobile device power levels above a threshold of 6 GHz.[29] As a result, the development of mobile communications at frequencies above 6 GHz presents greater design challenges than at lower frequencies. This will necessarily have to be factored in when considering the viability of bands above 24 GHz for mobile communications, and in developing effective equipment and system designs, and may be a reason for the Commission to focus on the near term on spectrum at lower frequencies.

Larger array sizes can trade conducted power off against antenna gain, and may have some advantages. Handsets are of course limited in the maximum array size, but there is an opportunity to use higher receive-side antenna gains at the base station as an offset. It is desirable that antenna configurations in handsets be flexible and not mandated by regulation. It is

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[29] *See* 47 C.F.R. §§ 1.1310(d), 2.1093(d).

unlikely that handsets will have a digital interface for each antenna element of an array.[30] The number of independent feeds to and from the array will have to be reconciled with the power budget for the analog-digital interface, given that wideband converters are power-hungry.

The gain of individual array elements in a handset may be higher than cellular handset antennas in use today, mainly due to a larger effective ground plane. However, the effect of body loss becomes more significant for internal antennas.

Handsets, to some degree, can overcome obstacles in their path by finding other signal paths to close the link; however, outage probabilities for high data rates will likely be significant, because buildings, foliage and atmospheric conditions can affect propagation characteristics with significant attenuation in comparison to bands below 3 GHz. The ability for handsets to correct connectivity impairments depends on factors such as mobility and the spatial environment.

The IEEE 802.11ad amendment has defined beam finding and tracking procedures for very short range links; such techniques do work but have to be made robust for more dynamic mobile NLOS scenarios. This is not trivial. On the other hand, the TTI in a wide bandwidth mmW system will be extremely short, on the order of several microseconds or so—far shorter than the time needed to find and track a signal.

Hybrid beamforming will be the preferred choice for handsets for two reasons—to ensure optimal power efficiency, and to allow handsets to be designed with multiple arrays that are

[30] The limitation here is probably due to hardware limitations and analog-to-digital conversion power efficiency. On the downlink, there is no spatial selectivity before the analog-digital converter ("ADC") and thus no headroom for interferers. In a noise-limited environment this may not be significant, but low interference levels cannot always be assumed.

strategically distributed to minimize blockage, each array having its own RF transceiver. The RF transceivers need to be comparable with present 4G modems in cost structure.[31]

Response to NOI ¶ 25: An advanced wireless network at mmW will require different handset architectures from those used in an LTE handset. It is too early to determine the extent to which MIMO (multiple input, multiple output) techniques will be similar between 4G and 5G technologies, but beamforming is likely to have a more prominent role in mmW 5G. In 4G systems the number of baseband ports is similar or equal to the number of antenna elements, while for 5G systems there are expected to be many more antenna elements than baseband ports.

Integration between the LTE network and a new 5G network would be easier between 5G systems deployed closer to 10 GHz and systems based on future releases of the 3GPP specifications. The integration will depend on factors such as signal bandwidth, control plane compatibility, power levels, and other factors that suggest that integration would be more difficult at mmW frequencies than at lower frequencies more comparable to those already in use for LTE. There are fundamental physical differences that require completely different approaches rather than tweaks, such as the path loss, which is proportional to the square of the frequency.[32] As a result, when the frequency is increased by a factor of ten or more, the design of the circuitry and antennas is not simply scaled up or down a bit, as may be the case when there is a more moderate increase in frequency; the design needs to be fundamentally reexamined.

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[31] This implies a dependence on complementary metal-oxide-semiconductor ("CMOS"), and perhaps on Silicon-Germanium ("Si-Ge") bipolar CMOS ("BiCMOS") technology. Further research is necessary to reduce power consumption and improve accuracy of various components including phase shifters, ADCs, and local oscillator ("LO") synthesizers. LO synthesizer design will be benefited by a substantial increase in reference crystal oscillator frequency. Crystal resonator frequencies up to 0.5 GHz are feasible already today. This is roughly ten times the most commonly used frequency in handsets.

[32] *See* page 19 above.

Integration of 5G and LTE designs is crucial to the success of 5G. A close relationship between new and old generations of mobile technology has been a recipe for the success of mobile development in the past, and the challenges in creating standalone networks in mmW bands make it even more important.

Response to NOI ¶ 26: There is great potential for a wide variety of technologies for mmW bands ranging from the so-called "III–V" semiconductor technologies (*e.g.*, Gallium Arsenide ("GaAs"), Gallium Nitride ("GaN"), and Indium Phosphide ("InP")), to Si-Ge and CMOS. Several results showing viable CMOS designs have been published for 60 GHz, and those for frequency bands as high as 70 GHz are unlikely to differ significantly. Any of these approaches have differing characteristics in terms of ease of manufacturing, noise characteristics and power capabilities. The continuing scaling of CMOS technology will primarily pave the way for improved analog and digital baseband blocks whereas new technology features such as fully-depleted silicon-on-insulator ("FD-SOI") will improve the design headroom for RF parts. Further, heterogeneous integration (mixed process technologies on same substrate) and through-silicon-via ("TSV") are examples of techniques supporting new building practices and are expected to mature within a 5 year time frame.

(c) Operation

Response to NOI ¶ 27: Ericsson believes that 5G systems must be capable of autonomous operation in local deployments, and should not be dependent on systems at lower frequencies. The ability of a 5G radio access component to independently handle local synchronization and mobility tracking may be important for low latency access and high capacity. Accordingly, while assistance from lower frequency signals may be a means of enhancing performance of the mmW system, it should not be required by design for its operation.

Connectivity to lower frequency radio systems can improve performance at higher frequency bands, such as by increasing mobility performance. Lower frequencies, if present, can also be used to distribute system information, assist the terminal at initial access, and advertise the presence of mmW systems. At the same time, wide area access conducted predominantly at lower frequency bands will benefit from the capacity increase offered by mmW offloading at very high traffic locations, even though capacity offload is not the main reason for 5G mmW deployment.

The need for autonomous operation creates significant challenges. Handovers will have to be coordinated within considerations of coverage and expediency. Connectivity between indoor and outdoor environments is very difficult, especially if mobility is anticipated between indoor and outdoor environments, or within many indoor environments.

Multipath and diffraction are very useful sources of diversity in 4G systems, but they are also sources of interference. To varying degrees, the same will be true of 5G systems above 24 GHz. Interference due to diffraction will be less severe at higher frequencies because the diffraction loss increases with frequency. Interference due to multipath may also be less problematic at higher frequencies because beamwidths will be very narrow, so that the illuminated area will be smaller and the reflected rays will emanate from a smaller part of the environment. Indeed, in many situations, interference can be mitigated by moving the beam or changing the antenna pattern.

Response to NOI ¶ 29: At the higher frequencies, initial access, adaptive beamforming, handover, and beam tracking for mobility are ongoing research problems that have barely been understood. Ericsson expects that both the network and the user equipment will have to participate in these processes, such as by having the user receiver looking to discover linear beam scans from base stations. Much remains to be done to move from theoretical research to practical solutions.[33]

2. BANDWIDTH, DUPLEXING, MODULATION, AND MULTIPLE ACCESS

Response to NOI ¶ 30: Ericsson advises against depending on carrier aggregation between non-contiguous frequency bands to boost bandwidth. It is a significant challenge to develop the electronics, the radio systems, and the operational methods for the higher frequency bands in the NOI without being burdened with aggregating spectrum over multiple bands. For example, user equipment manufacturers will need to design adaptive antennas that will simultaneously cover multiple, widely separated frequency bands; this may not be feasible for bands that are significantly removed from one another. The support of aggregated use of non-contiguous blocks of spectrum is costly and power consuming, especially in handsets. While such a feature may arguably be justified for LTE in the fragmented spectrum below 3GHz, there is no reason to create a similar scenario at higher frequencies where large contiguous arrangements may be available.

There appears to be a rough relationship between bandwidth and frequency range based on data rate capability. Accordingly, Ericsson proposes additional information pertinent to Nokia's suggestion of 2 GHz of contiguous spectrum, as discussed in the NOI:[34]

- Between 6 and 30 GHz, Ericsson proposes single bands of 400–800 MHz each that can be divided into 4–8 carriers of 100 MHz each.

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[33] For example, Ericsson's current studies on indoor networks at mmW frequencies are based on a highly dense architecture with inter-site distances of tens of meters. However, such inter-site distances may not be practical for outdoor networks, especially if the footprint for such networks must extend over significant parts of high-traffic neighborhoods. In a real-world network, it would be more practical to have outdoor inter-site distances on the order of 100 m.

[34] *See* NOI, 29 FCC Rcd at 13030 ¶ 30 & n.40 (citing Amitabha Ghosh, *Can Mwave Wireless Technology Meet the Future Capacity Crunch*, Nokia Siemens Networks, Inc. (June 2013), http://icc2013.ieee-icc.org/Mmwave_Spring_ICC2013_Ghosh.pdf).

- Above 30 GHz, Ericsson proposes carrier bandwidths of at least 500 MHz and preferably as much as 2 GHz, with the same stipulation of a minimum of 3–4 independent non-interfering carriers per band.

The 60 GHz ISM band meets this basic requirement for the near future, but the Commission may want to monitor the development of radios for this band to expand telecommunications industry reach into other mmW bands later.

Response to NOI ¶ 31: At this time, Ericsson does not anticipate the use of full-duplex approaches ("any division duplexing" or "ADD," as used in the NOI) in mmW bands. These approaches typically use a combination of analog and digital self-interference cancellation techniques and are less applicable in a networked environment even for single antenna communication.

There are some advantages in using TDD for beamforming, specifically pertaining to reciprocity between uplink and downlink directions to improve channel estimation. However, theoretical notions of channel reciprocity are rather difficult to translate into real-world gains due to differences between the transmit and receive paths through the radio and the need for complex calibration circuitry in antenna arrays that rely on beamforming.[35]

It is anticipated that mmW systems will largely be used in environments that allow very localized and dense deployment, making TDD more viable. Additionally TDD enables flexible resource allocation which is important in fluctuating traffic conditions observed in small cell networks. Moreover, FDD appears to be impractical, given that there are no feasible duplex filter technologies for mobile units at tens of GHz, and, even if there were, it would be

[35] In general, there is an expectation that directionality of propagation is approximately reciprocal for either duplexing method, but multipath channel characteristics are not necessarily so.

undesirable to have tens or hundreds of duplex filters in a single antenna array in a handset or access node.

Ericsson accepts the Commission's suggestion that duplexing direction can be flexible and need not be regulated by policy. At the same time, it is desirable that clear guidance be given regarding allowable transmitter characteristics. Mixing FDD/TDD etc. in the same geographical area or neighboring area should in all cases be avoided.

Response to NOI ¶ 32: While the FCC should generally seek to foster efficient use of spectrum, simpler coding and modulation does not guarantee high spectral efficiency. Nonetheless, if current 5G demonstrations at higher frequency bands use simple modulation and coding, it is because of the nascent nature of the technology.

Ericsson does not believe that complexity is out of reach for mmW systems. The IEEE 802.11ad protocol used by wireless gigabit ("WiGig") devices enables short-range communication with higher order modulations, LDPC coding and complex beamforming.[36] Commercial viability has also been demonstrated.[37] While WiGig systems are not yet common, it is expected that they will form a complement to future Wi-Fi devices that communicate with remote displays or storage units. Cost is indeed related to complexity, but the world has seen the deployment of several generations of complex mobile networks that have progressed along a curve of greater efficiency and lower cost. Much of this improvement has been driven by greater operational efficiency and the ability to handle ever growing numbers of users. The Commission should consider the potential growth if new frequency bands are introduced.

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[36] *See generally* Wi-Fi Alliance, *WiGig and the Future of Seamless Connectivity* (Sept. 2013), http://www.wi-fi.org/download.php?file=/sites/default/files/private/WiGig_White_Paper_20130909.pdf.

[37] *See, e.g.*, David Shamah, *Qualcomm's Wilocity move shows momentum building around WiGig*, ZDNet (July 7, 2014), http://www.zdnet.com/article/qualcomms-wilocity-move-shows-momentum-building-around-wigig/.

Response to NOI ¶ 33: It is likely that systems in higher frequency bands will continue to use time, frequency, and space division for multiple access. Modern systems typically implement frequency domain equalization with the aid of a cyclic prefix. While METIS and other research projects are actively investigating non-orthogonal multiple access schemes such as filter bank modulation and coding, it is not readily apparent that it will be necessary to depart significantly from the principles around the LTE approach of single carrier or orthogonal frequency-division multiple access ("OFDMA")-based multiple access.

A base station that is processing aggregate data rates of the order of 10 Gbps will need to expend significant power in the radio and baseband hardware is needed merely to keep bits moving through the protocol stack. The complexity of the air interface and the burden on advanced signal processing will no doubt have to be reconciled with the state of the art.

3. PERFORMANCE AND COVERAGE

Response to NOI ¶34: Wider bandwidth signals are a prerequisite for high data rates and for shorter transmission intervals. In this sense, a signal at 10 GHz with 2 GHz bandwidth has as much potential to meet requirements such as peak rates of the order of 10 Gbps, with typical average rates of 1 Gbps and 100 Mbps at the cell edge, as does a similar bandwidth signal at 30 GHz or even 60 GHz. The ability to provide longer range and uniform coverage improves as frequency bands get lower. In general, commercial mobile systems should aim for bands where coverage is not severely compromised.

5G systems with adequate bandwidth can provide effective last mile connectivity to fiber networks, and will allow mobile broadband systems to transition from their current capabilities to new application areas, including:

- Virtual and augmented reality;
- Easy access to interactive and streaming video services;

- New paradigms in immersive gaming;
- High bandwidth access networks for data centers that will improve connectivity between components of a computing cluster and provide quick access to storage networks; and
- Low latency communications for industrial applications such as flexible manufacturing and robotics, as well as other critical services such as vehicular communications or safety systems for utilities.

While 5G networks at mmW bands will offload some data traffic from 4G networks, any amelioration of network congestion is secondary to the primary benefit of 5G: to spawn new services and increase the movement of data in the Internet. The mmW technologies have the potential to increase traffic growth beyond what is observed in 4G networks.

Response to NOI ¶ 35: With adequate EIRP (*i.e.*, a large enough antenna aperture), a mmW signal can theoretically be designed to have very long range, but there are several caveats that limit this general principle:

- One limitation is that a long range does not translate to wide coverage.[38] Typical mobile deployments may not serve more than a fraction of the maximum possible range for each base station deployment.
- Another limitation is the upper limit on allowed RF power density in areas where people are located, and therefore it may not always possible to offset the increased path losses at higher frequencies with higher antenna gain.
- For energy efficient buildings, especially in combination with energy efficient windows, outdoor to indoor coverage can be very difficult, and even impossible, to achieve in the entire frequency range from UHF to mmW.[39]

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[38] Although atmospheric losses generally show an upward trend with increasing frequency, the effect is more noticeable at 60 GHz, where oxygen absorption increases path loss by around 15 dB/km. In fact, frequency bands above 70 GHz may have advantages over 60 GHz for long range transmission.

[39] Path loss through building materials such as concrete and brick increases considerably at increasing frequency and will be very large above 24 GHz. In buildings that are not constructed of wood one has to rely on the waves that propagate through non-energy efficient windows (and even these have considerable attenuation at higher frequencies).

NLOS outdoor to indoor coverage cannot be obtained in a satisfactory manner at frequency bands above 24 GHz. On the other hand, LOS outdoor to indoor coverage is possible to obtain, especially when the waves propagate perpendicularly through the wall (or window). If a building is wide, outdoor antennas will need to be located at all relevant sides. A high gain antenna would need to be used, at least at one end of the link.

Obstructions can cause problems with coverage, for example down side streets, behind large trees, inside a car, or behind a large truck or bus. Nomadic obstructions such as a parked truck will cause sporadic dropouts unless another strong reflected ray can be found and used. Thus, the outdoor coverage area in an urban area can become spotty if there is not LOS, or near-LOS, to at least one base station antenna at all locations, but NLOS outdoor coverage is possible in urban and dense urban areas if there is a dominating reflected path that can be used, which typically requires LOS from the two antennas to the common reflector. In suburban areas the probability of finding strong reflections from large buildings is quite small, and one has to rely on LOS paths.

At higher frequencies one has to rely on very strong LOS paths or strong reflections in combination with narrow antenna beams. This means that if there are a lot of trees or tall bushes in the area, these will significantly increase the path loss, especially in the summer, and coverage might not be possible if alternative strong paths cannot be found. In rural wooded areas, outdoor coverage will be very limited due to the high loss through the vegetation and the lack of strong reflections. In rural open areas, outdoor coverage can be larger than at UHF frequencies if there is LOS between the antennas because the first Fresnel zone is smaller at higher frequencies. However, a single building, some trees or a truck or bus obstructing the path might break the connection.

Diffraction loss increases with frequency, which means that the coverage area in rolling landscapes will be much more limited than at UHF frequencies. Coverage over and beyond a hill will likely not be possible. For functionality pertaining to synchronization, initial access and connection management, the network will have to rely on greater knowledge of user location and channel characterization at lower layers of the protocol stack.

4. Network Architecture

Response to NOI ¶ 39: One potential solution to the choice between the service provider model and the decentralized Wi-Fi-like deployment model would be to virtualize small cell networks deployed within buildings. In this model, future small-cell systems, especially when deployed indoors in premises with public access, may have to support multi-operator networks.

Ericsson mainly provides systems to telecommunication operators, and we are committed to sustaining and growing our customers' business. At the same time, new business models may arise due to the organic deployment of small cell networks by third parties. At this time, it seems that mmW systems will not replace commercial cellular systems and will have to "follow the traffic" as data rate demands increase and users expect to extend the range of fiber transport to the wireless domain. Use cases such as the delivery of ultra-high-definition 4k video, interconnects between racks in a data center, high bandwidth enterprise networks, *etc.*, will likely be the key to mmW system deployment. Both operator-deployed and private networks can be expected to drive the market, but the specific business models and commercial arrangements are still under study. There are some promising approaches for commercial deployment of mmW technologies. Antenna arrays located around all sides of multi-story buildings can provide indoor coverage through windows or through the use of repeaters across the walls. In suburban environments, high cell sites can provide access to rooftop antennas. In locations with many obstructions and foliage, it may be possible to create a mesh network of antenna arrays. All these models have to be considered in regard to economies of scale, with particular attention to the variety of deployment conditions and uniqueness of hardware.

5. Technical Rules

Response to NOI ¶ 41: Since mmW mobile services will most likely employ adaptive high gain beams for the communication, it would be beneficial to set the EIRP or power flux density requirements using a time averaging over a large number of data frames and not the instantaneous high gain beam.

Response to NOI ¶ 42: OOBE requirements which are based on carrier bandwidth by their very nature discriminate against wideband systems and should be avoided for 5G systems, which will operate at significantly higher carrier bandwidths. If regulations that make OOBE attenuation bandwidth-dependent are applied to mobile services, this would make deployment of mobile services particularly difficult. The current policy to require attenuation of OOBE by 43 + 10 log(P) dB has an outsized and discriminatory impact on broadband systems at the first MHz adjacent to the block edge, because the resolution bandwidth for the measurements is related to carrier bandwidth. For example, a 100 MHz 5G waveform has an OOBE requirement that is 13 dB more stringent than the corresponding such requirement for a 5 MHz LTE signal at the first MHz adjacent to the licensed block. Even as large antenna arrays and beam-forming are an enabler for deployment of 5G at higher frequencies, it would be onerous to specify OOBE limits for each antenna element for 5G.

Ericsson suggests that all emissions limits should be specified in an aggregate fashion. Assuming a tight integration of the radio front ends with the antenna array, there will most likely not be any physical test points available or even feasible for conducted testing of emissions, but it would need to be tested using over-the-air ("OTA") testing. It would therefore be beneficial to also have the emission requirements defined as a radiated requirement. Moreover, requiring a conducted test would require the introduction of physical test points or test connectors, which would be both costly and bulky.[40]

The validation and certification of products based on radiated power measurement is itself complex.[41] The Commission should seek further input from the mobile industry on the best approach to specifying OOBE and regulation on general emission requirements for multi-antenna systems.

Response to NOI ¶ 43: It is premature to address the potential use of database-aided spectrum allocation, given that the appropriate regulatory model cannot be meaningfully discussed at this early stage, as noted in Section V.C below.

6. Alternative Uses, Including Backhaul

Response to NOI ¶ 44: The FCC should seriously consider allowing joint deployment of access and transport in the same bands. It is not always convenient to deploy fiber to every site, nor is it convenient to deploy cell sites only where fiber deployments are available.

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[40] Also, the performance of RF connectors at frequencies above 24GHz is questionable unless very expensive connectors made for lab use are employed, leading to larger measurement errors for conducted tests than for OTA tests.

[41] There may be a need to introduce statistical requirements that averages over time and spatial domain, *etc.*, instead of a deterministic approach. 5G systems implemented above 10 GHz would possibly be based on large carrier bandwidths. For such wideband signals, there is a benefit in stating requirements for power spectral density instead of specifying them in terms of carrier power, which is less helpful in the 5G context. Current policy for multi-antenna transmission in some bands requires reduction of the conducted power by the number of dB of antenna gain above 6 dBi. So long as safety requirements are not violated, 5G systems will require some flexibility in the extent to which antenna gain can be used to extend coverage. Also, adaptive MIMO systems cannot be required to monitor the gain of the antenna configuration for every phasing of their antennas. Ericsson desires some rationalization of policy in this regard, especially because antennas for mmW bands could be composed of hundreds of individual elements. There should be a regulatory framework leading to simplified statistical requirements, and conformance testing for adaptive massive MIMO antenna systems, instead of case-by-case handling of different frequency blocks at higher frequencies.

Consequently, we expect that any mmW access technology will need to support transport as well, using self-backhauling.

Ericsson strongly believes in the value of establishing a single global band for mobile mmW systems at an appropriate time in the future. Whether the most convenient band is the LMDS band is a matter for further consideration. The size of the proposed band is more appropriate for 5G air interfaces that are evolved from LTE. The suggested frequencies are also acceptable, but lie at the outer edge of suitability.

Response to NOI ¶ 45: Some backhaul systems can coexist with access in the same band. Ericsson notes that certain wireless transport scenarios require very high reliability and should continue to be administered according to traditional approaches. For mobile broadband systems offering access in the mmW bands, sharing the same frequencies between access and backhaul appears attractive. Highly directive transmission at mmW frequencies provides good spatial separation between transmissions and can thus be seen as an enabler for access and backhauling sharing the same frequencies. Since link performance drops over NLOS paths, which have neither LOS nor specular reflections, mmW systems' inter-site distances may sometimes be short; a multi-hop backhaul may be an option to bridge larger distances. It remains to be seen whether this multi-hop backhaul will develop into a featured mesh network or will only be used for multi-hop transport.

B. Frequency Bands Above 24 GHz for Mobile Services

Response to NOI ¶ 48: Ericsson categorically emphasizes the need for global harmonization of technical and regulatory requirements to the success of advanced services in all bands above 10 GHz. Global harmonization will limit the number of models of equipment required to be developed, making each cheaper and more affordable for operators to deploy. A classic example where harmonization has not occurred is 60 GHz. In the U.S., the FCC adopted a distinct approach for unlicensed services in the 60 GHz band. The Commission has gone a long way in creating liberal rules for a variety of different scenarios in this band. Unfortunately, rules in other parts of the world are not so liberal. Some parts of the world allow higher power operation in the band for licensed operation, while other parts of the world do not permit high EIRP levels at all. Ericsson welcomes the influence of the FCC in moving the ITU–R towards similar rules in all the three regions for the 60 GHz band as well as new bands that will be designated for future mobile services.

Response to NOI ¶ 49: The NOI tends to mix varying concerns in the questions about software defined adaptive air interfaces and networking. Moreover, issues concerning non-contiguous bands or agile movement across multiple bands are premature in the context of mmW communication. The state of the art for radios at mmW bands is barely past the level of provable design for the mass market. Any extrapolation of technological ability to a frequency agile architecture would entail a significant increase in cost and complexity. It is true that 5G radio architectures in traditional mobile bands will evolve to greater software adaptable design. However, the large bandwidth needed in mmW systems will make software-defined air interfaces very difficult, since requirements on the analog-to-digital conversions—which are already very high due to large bandwidths—become even higher, since software defined radios typically require high bit resolution.[42]

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[42] All the frequency agile constraints that are currently imposed on 4G are a significant barrier to new entrants into the mobile chipset business, and significantly complicate work by infrastructure vendors due to the number of bands that need to be supported, the number of channel aggregation combinations to be implemented and the amount of customization of products for various markets around the world. In contrast, Wi-Fi has been able to live in two large bands, and is supported by intense competition among a large number of device manufacturers.

Complexity in technology must be used purposefully, and not be depended on as a crutch to compensate for insufficient diligence during policy decisions. All future mobile radio technologies, to varying degrees, will benefit from software defined networking ("SDN") and network function virtualization ("NFV"), to allow more flexible control and provisioning of resources needed for customized service classes, and for greater operational efficiency. Therefore, Ericsson urges the FCC to ensure contiguous allocations for 5G in the mmW bands.

1. LMDS BAND (27.5–28.35 GHZ, 29.1–29.25 GHZ, AND 31–31.3 GHZ)

Response to NOI ¶ 55: The LMDS bands at 28 GHz will be of particular interest to the mobile industry for systems that may follow 4G into higher frequency bands. As indicated earlier, Ericsson feels that the mobile industry may benefit more from frequency allocations closer to 10 GHz, but the LMDS band happens to be of a reasonable size. The entire band from 27.5 GHz to 31.3 GHz can probably be handled by an integrated radio depending on coexistence requirements for existing primary services. There are no known filter technologies for the band suitable for mobile products. However, the total band is capable of handling several signals of over 100 MHz each.

To address the requirements appropriate for 5G air interfaces, it may be optimal for the band to be divided into multiple 100 MHz or 200 MHz blocks with separate sets of rules for mobile access and for fixed point-to-multipoint service, including NLOS operation. To better accommodate these block sizes, the gap between the A1 and A2 sub-bands would need to be shifted by 50 MHz to allow the definition of contiguous 100 MHz blocks. Further considerations with the incumbents in the band will be necessary to establish harmonization for fixed and mobile access.

2. 39 GHz Band (38.6–40 GHz)

Response to NOI ¶ 56: The industry may have to develop a separate air interface that operates above 30 GHz. While there is no hard separation *per se* at 30 GHz, the building practices for infrastructure and devices, as well as the business models that drive mobile services in those bands, are likely to be different than below 30 GHz. Still, the possibility of gaining access to 1.4 GHz of contiguous spectrum that is already designated as co-primary for mobile services is not something the industry will likely ignore. If no other suitable spectrum were forthcoming, over time the 38.6–40 GHz band could likely be harnessed in a way that is useful to industry. The operational characteristics that would be needed are similar to what has been detailed for the LMDS band. Unpaired spectrum allocations would be preferred.

Response to NOI ¶ 61: The 38.6–40 GHz band may also be suitable for joining with the 37–38.6 GHz band, which would also be acceptable for 5G use over time. The total band is 3 GHz in width, and harmonized rules in this band could enable six signal carriers of 500 MHz each to be allocated on a shared basis for short range (5–100 m) service. Coexistence requirements with satellites have to be studied, and if mobile operation is permitted, it is preferable that they be unencumbered by incumbent services. For space-to-earth satellite operations, coordination of co-primary use can be arranged. Power spectral density rules can be used to limit aggregate interference for earth-to-space operations. Of course, the issue of global harmonization of the band has to be addressed.

3. 37/42 GHz Bands (37.0–38.6 GHz and 42.0–42.5 GHz)

Response to NOI ¶ 69: The 42–42.5 GHz band likely holds no current interest for mobile services unless the 42.5–43.5 GHz band is released from consideration by the FCC for the ongoing petition of the Fixed Wireless Communications Coalition, Inc. (“FWCC”), consideration of which has been incorporated into the NOI.[43] The 1500 MHz size of the larger allocation (*i.e.*, rolling 42.5–43.5 MHz in with 42-42.5 MHz) would potentially be useful for mobile services, but a single 500 MHz block is not appealing. To consider this band, it would need to accommodate several 500 MHz or greater bandwidth blocks.

4. 60 GHz Bands (57–64 GHz and 64–71 GHz)

Response to NOI ¶ 74: Ericsson urges the FCC to consider release of the 64–71 GHz band for mobile services at an appropriate time. The band offers a unique opportunity to accommodate both licensed and unlicensed operation using similar technology. Along with the 57–64 GHz band, the 14 GHz available will likely be a significant innovation band for a variety of use cases for short range access. Since the 57–64 GHz band is already available for unlicensed operation, licensing of 64–71 GHz band in non-exclusive arrangements has potential appeal. The proximity to vehicular radar bands also increases the appeal of this band and the 70 GHz band for vehicular communications.

5. 70/80 GHz Bands (71–76 GHz, 81–86 GHz)

Response to NOI ¶ 82: Database-aided spectrum allocation is acceptable for the 70/80 GHz bands to protect federal operations. This band is just as capable of supporting mobile services as the 60 GHz bands being proposed. In fact, the band does not suffer the additional oxygen absorption attenuation observed at 60 GHz, and may be particularly attractive for longer range transmission. Ericsson believes that the band is useful for LOS backhaul in some circumstances. The band also has appeal for indoor short range applications, vehicle-to-vehicle ("V2V") communications, data center communications (replacement of cabling for racks), *etc.*

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43 *See* Petition for Rulemaking, FWCC, RM-11664 (filed May 9, 2012), revised in Supplemental Petition for Rulemaking, FWCC, RM-11664 (filed Feb. 11, 2013), (filed as *ex parte* letter notice from Mitchell Lazarus, counsel for FWCC, to Secretary Dortch, RM-11664 (filed Feb. 11, 2013)); *see* NOI, 29 FCC Rcd at 13040 ¶ 64 n.101.

The band may in the future also be able to support outdoor mobile services, but would not be the industry's primary choice at the time of this NOI.

6. 24 GHz Bands (24.25–24.45 GHz and 25.05–25.25 GHz)

Response to NOI ¶ 86: The 24 GHz bands are suitable for NLOS backhaul for 4G small cells, provided contiguous multiple licenses can be obtained. If the rules were changed to allow for larger blocks, mobile services may be introduced within these bands. Unfortunately, the bands are not uniformly designated for mobile service in all three world Regions.

Additionally, the bands are paired, and rules regarding the direction of communication must be considered. NLOS communication can provide high spatial and spectral efficiency when there is accurate channel knowledge. In an FDD system, a significant amount of bandwidth on the reverse link must be dedicated to communicating channel knowledge to the transmitter. In the case of TDD systems, there is potential for the use of reciprocal estimation of channel knowledge. These problems are less significant for LOS communication, since directional communication in such environments is largely reciprocal.

It appears to be possible to protect Earth-to-space links in the band 25.05–25.25 GHz as well. Downtilt of base station antennas is one viable approach that enables control of the radiation in the spaceward direction, and power levels may be adjusted in a way that limits the aggregate interference from backlobes or specular reflections. Ericsson believes the introduction of exclusion zones to protect Earth-to-space link receivers would be unnecessary and inefficient, since the receiver is in space and such exclusion zones would be very large. It would be better to control the mobile system on earth so that it does not radiate energy towards space.

Response to NOI ¶ 87: Up through 4G, each generation of mobile technology has been able to balance subscriber growth against the shrinking of inter-site distances and, at the same time, provide increasing data rates to users both individually and in the aggregate. There are some advanced antenna technologies such as the development of MIMO, reconfigurable and adaptive antenna systems, coordinated multi-point ("CoMP") transmission, and very large arrays that show significant promise in being able to continue to improve cellular systems.

However, it is not clear that deployments in higher frequency bands, especially those above 24 GHz, can provide the same advantages of capturing ever increasing numbers of users while continuing to increase per user capacity. Indeed, it is expected that much of the growth in connectivity is going to occur by means of the massive introduction of connected devices such as wearables, sensors, process control systems for industrial environments, intelligent transportation systems, health care, and such. The air interfaces and transport paradigms that will enable this natural substitution of subscriber growth are not likely to occupy bands above 24 GHz. Bands above 24 GHz will largely serve high bandwidth data transfers for video services and large data transfers within and between data centers, and for high bandwidth virtual interactive communication between people.

For the mmW bands to transform mobile communications, there must be multiple types of benefits, given the complexity of the physics and the investment required: (1) There must be significant value to the end user in terms of bandwidth and capacity; (2) The new spectrum must not create oases of limited coverage with high bandwidth, outside which users are unable to expect uniform quality of experience as they move through the network; (3) The economies of scale for technologies deployed in these bands must provide operators the ability to grow their business, to justify their investment, and to have available multiple sources for devices, infrastructure and services; and (4) The bands must be harmonized all over the globe, so that the U.S. market is not isolated from policy decisions elsewhere in the world.

C. LICENSING MECHANISMS

Response to NOI ¶¶ 88–102: It is premature to address what licensing and regulatory mechanisms are most appropriate for 5G systems, especially mmW spectrum, given the substantial technical development that needs to be done. When the industry and regulators have a better understanding of how this spectrum can most beneficially be used, it will be possible to have an informed discussion about the appropriate mechanisms for authorization of the use of this spectrum—including issues such as whether it should be licensed exclusively, licensed and shared with supervisory database-aided authorization, or unlicensed. The appropriate licensing framework would also need to consider each frequency band individually, with regard to the incumbency and timeframe concerns.

Respectfully submitted,

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