Before the
FEDERAL COMMUNICATIONS COMMISSION
Washington, DC 20554

In the Matter of	)	
	)	
Use of Spectrum Bands Above 24GHz For Mobile Radio Services	)	GN Docket No. 14-177
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	)	

COMMENTS OF NOKIA (D/B/A NOKIA SOLUTIONS AND NETWORKS US LLC)

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Contents

I. INTRODUCTION

The United States has been an early adopter in each generation of wireless technology, a major driver of innovation, and remains among the most vibrant wireless markets in the world. In the current generation of technology, called 4th Generation (4G) based on the Long-Term Evolution (LTE), the U.S. benefits from substantial investment by each of the four large national wireless carriers. We agree with the Commission that there seems to be an industry consensus for the need of next generation of mobile networks called "Fifth Generation" (5G) which will arrive after 2020. The U.S. can be a driving force in 5G. Indeed, 5G will be a key technology for many growing U.S. business sectors including software, video, gaming, data analytics, Device-to-Device (D2D) and Machine Type Communications (MTC). Significant early investment in 5G would help close the gap in ultrafast mobile broadband between the U.S. and other countries. Sustained investment in 5G research would begin to address limitations in mobile broadband availability in rural areas.

5G matters to the citizens because:

- Consumers generate an increasing amount of mobile traffic, which necessitates more capacity, better user experience and lower latency. 5G will offer an expected peak data rate higher than 10 Gbit/s compared to the 1Gbps LTE can offer today and cell edge rates higher than 100 Mbps combined with virtually zero latency, i.e. less than 1 ms, meaning that the radio interface will not be the bottleneck even for the most challenging use cases. 5G will support applications and industries of the future such as innovative health care services that provide real time monitoring capabilities, self-driving cars, and deliver the next generation of industry automation. 5G will mean stepping away from a best effort approach and towards truly reliable communication. Flexible integration of existing access technologies such as LTE and Wi-Fi with new technologies creates a design that is future proof. 5G will be designed for use cases expanding from humans to machines requiring more of networks. 5G supports the huge growth of Machine Type Communications (MTC), also called Internet of Things, through flexibility, low costs and low consumption of energy. At the same time, 5G will be reliable and quick enough for even mission-critical wireless control and automation tasks such as self-driving cars.

- 5G will lower costs and consumption of energy. Energy efficiency is an integral part of the design paradigm of 5G, not an afterthought. Virtualized and scalable technologies will further facilitate global adoption. Taking all of these factors together, 5G could bring Internet access to a larger group of people and things.

Nokia is a leader in the fields of network infrastructure, location-based technologies and advanced technologies. With operations around the world, Nokia invests in the technologies of the future. Nokia has three strong businesses: Nokia Networks, our network infrastructure business; HERE, our location intelligence business; and Nokia Technologies, which is focused on technology development and intellectual property rights activities. Through these businesses, we have a truly global presence. We are also a major investor in R&D, with investment through the three businesses amounting to several billion dollars annually.

Our network infrastructure business, Nokia Networks, is the world's specialist in mobile broadband. Innovating at the forefront of each generation of mobile technology, Nokia provides the world's most efficient mobile networks, the intelligence to maximize the performance of these networks, and the services to make it all work seamlessly. Nokia is leading the commercialization of 4G LTE, both its Frequency Division Duplex (FDD) and Time Division Duplex (TDD) versions, in terms of commercial references and live network performance. This includes pioneering efforts in reducing the footprint of mobile base station infrastructure, from compact yet full power macro sites down to the full range of "small cell" solutions. Nokia also offers the industry's most comprehensive portfolio of services for integrating heterogeneous networks ("HetNets"), encompassing analysis, optimization, deployment and management.

Nokia's expertise in mobile broadband is being leveraged to the fullest extent as it researches 5G technologies. Indeed, as mentioned in the *5G mmW NOI*, Nokia is also investing substantial resources in the development of 5G[1] and respectfully submits these comments to the Commission's *Notice of Inquiry* ("*5G mmW NOI*")[2] examining the potential of bands above 24 GHz, also referred to as millimeter wave (mmW)[3] in the *5G mmW NOI*, for the provision of 5G mobile radio services.

We also note that in early 2012, ITU Radiocommunication Sector (ITU-R) embarked on a program to develop "IMT for 2020 and beyond", setting the stage for "5G" research activities

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[1] *See NOI ¶ 10.*
[2] Commission Seeks Comment on "In the Matter of Use of Spectrum Bands Above 24 GHz For Mobile Radio Services", GN Docket No. 14-177, Released: October 17, 2014
[3] *See NOI ¶ 7.*

that are emerging around the world.[4] As part of this work, exploring spectrum above 6GHz and not just above 24GHz was deemed important as demonstrated in the work going on in International Telecommunications Union (ITU)[5] to study the technical feasibility of International Mobile Telecommunications (IMT) systems in bands above 6GHz. Nokia views that spectrum below 6GHz will continue to play an important role in the next generation of mobile radio services and that above 24GHz, there maybe be other good candidate bands for 5G in addition to the ones the Commission is studying in this *5G mmW NOI*. Nokia views that 5G will indeed use existing and new IMT spectrum below 6 GHz as well as from 6-100 GHz.

Therefore, while we applaud the Commission for exploring new spectrum above 24GHz to expand mobile broadband connectivity to consumers across the nation, we urge the Commission not to exclude other bands, below 6GHz and from 6-100GHz, that may become relevant for 5G, especially if there is potential for harmonization with other parts of the world and ITU.

II. NOKIA'S ON-GOING 5G RESEARCH SUGGESTS THAT BANDS ABOVE 24GHZ LOOK PROMISING FOR MOBILE SERVICES AND WARRANT FURTHER INVESTIGATIONS

In the following sections, we provide some preliminary answers to the Commission's specific questions about technology enablers of mobile services in bands above 24GHz. 5G research is on-going and we recommend that the Commission does not set hard rules yet but instead put in place an iterative process that will provide opportunities for the industry and academia to provide refined data on a regular basis to the Commission to help finalize the rules.

[4] See http://www.itu.int/en/ITU-R/study-groups/rsg5/rwp5d/imt-2020/Pages/default.aspx

[5] *See* ITU-R Working Party 5D Preliminary Draft New Report ITU-R M.[IMT.ABOVE 6 GHz] to provide "information on the technical feasibility of IMT in the bands above 6 GHz."

1.1. Antenna Technology

The Commission sought comment on the antenna technologies that will be feasible in the mmW bands and in what timeframe. We note that phased arrays are favored in most 5G system proposals as they offer the needed Equivalent Isotropic Radiated Power (EIRP) for the system gain and ability to steer dispersed users in the cells. Commercialization will take a number of years since the standards must first be defined and then semiconductor vendors will need to develop Monolithic Microwave Integrated Circuits (MMICs) and Systems on a Chip (SoCs) before finally equipment from cellular vendors are developed and deployed commercially.

1.1 Base Station Antennas

Nokia hereby provides information about Base Station antennas. The MIMO methodologies in 4G systems cannot simply be reused in the mmWbands given the need for larger numbers of antennas to overcome the poor link budget. Also, with tens or hundreds of antenna elements, the use of a transceiver behind every antenna element coupled with wide bandwidth necessary to meet the 5G requirements necessitates very high speed Analog to Digital (A/D) and Digital to Analog (D/A) processors. These Analog to Digital Converters (ADC's) and Digital to Analog Converters (DAC's) will consume unacceptable amounts of power and will also likely be cost prohibitive, which means RF-oriented or hybrid approaches (both RF and baseband) may be more attractive. As a result, two alternative classes of transmit and receive architectures are being considered for 5G systems: an all-RF architecture needing only one ADC and DAC, where control of the MIMO and beamforming is performed at RF, and a hybrid architecture, where control of the MIMO and beamforming is split between RF and baseband. For the hybrid array where the number of active beams for an array, B, is much smaller than the number of elements in the array, M (B<<M, in this case there are B ADCs and B DACs). The bandwidth may dictate which approach is desirable. For example a 2.0 GHz bandwidth may use

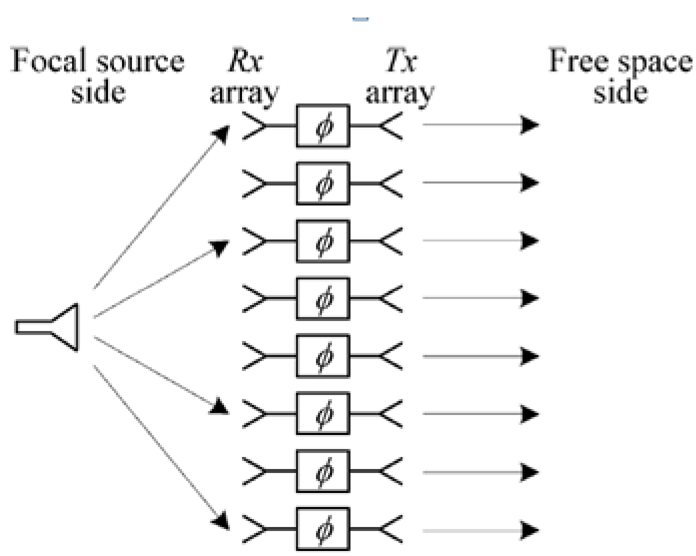
the single RF beamforming approach since the bandwidth itself will provide the desired high data rate and the power consumption of the DACs and ADCs will be extremely high. A 500 MHz bandwidth may use the hybrid approach since it can employ DACs and ADCs that consume less power than the 2.0 GHz bandwidth case and because multiple data streams within an array will likely be needed to meet peak data rates (i.e., bandwidth alone cannot deliver the desired data rate). The array itself is likely to be made up of patch antennas, which are directional in nature (e.g., a 65 degree 3 dB beamwidth in both azimuth and elevation). Therefore, if a base station desires 360 degree coverage, multiple patch antennas will need to be deployed around the base station. The different patch antennas could act as separate sectors to further enhance system capacity or one of the patches could be selected for transmission to or reception from a user device at a given time.

For any bandwidth, polarization will play an important role and is a reliable mechanism for delivering multiple data streams to a single user even in line-of-sight (LOS) conditions. Therefore, it is likely that there will be two arrays employed in each sector at the base station where each array has an orthogonal polarization (e.g., vertical and horizontal or right-hand circular and left-hand circular).

Array sizes will vary with the use case but one likely size of the array is between 4x4 and 8x8 with an equal number of elements in both azimuth and elevation. The size may depend on the carrier frequency as it is easier to fit more antennas in the same area at higher frequencies. Including the dual polarization concept, that would mean two 4x4 or two 8x8 arrays in each sector (for a total of M=32 or M=128 in both cases). Fitting either size array at a base station is relatively easy since at 28 GHz a 4x4 array (with 0.5 lambda spacing) fits within a 2 cm x 2 cm area and at 72 GHz a 8x8 array (with 0.5 lambda) easily fits within the same area. The likely limiting factors for the array are the technical challenges of creating the array of the given size at the desired carrier frequency and also if the antenna has to be aesthetically pleasing for the given area it is deployed (which can be of particular importance to the ultra-dense deployments envisioned for mmW).

Just like the array sizes, the power of Power Amplifiers (PAs) will also vary widely, particularly with frequency. For example, above 60GHz small scale arrays are likely with some approaching Integrated Circuit (IC) package size. In these cases a common PA out may be approximately +20dBm but more can be generated with more advanced topologies. At the high frequencies, PA/antenna separation usually induces excess loss and will be less commonly deployed. One possible exception is use of transmit-array antennas shown below.

Figure 1: Transmit-array antennas



Furthermore, to generate the desired gain, a beam selection procedure is likely to be deployed between the Base Station and the User Equipment (UE) where the UE will feedback the best beam to that base station.

Antennas are likely to be patch antennas with an element gain of around 4.0-8.0 dB. Uniform power is usually preferred for each element in the antenna array but when steering beams, there can be beam distortion as the beam moves from boresight and having the ability to control array element power will be a means to manage this. Some scenarios may also desire multiple beams and controlling array weights will be necessary.

As more elements of the array are used for operation, the Effective Isotropic Radiated Power (EIRP) will certainly increase as that is the reason for the larger arrays. The aggregate transmitter power may increase depending upon the specific implementation. The vertical and horizontal beamwidths could be as low as 13 degrees for a 8x8 array and around 26 degrees for a 4x4 array.

With the use of patch arrays for base station antennas, the individual elements would only have between a 65 and 90 degree 3 dB beamwidth. Hence, the base station would need at least three sectors but more likely four to ensure 360 degree coverage.

Nokia also believes that the antenna arrays used in these advanced mobile service base stations will use adaptive beamforming in all expected deployment scenarios and hence should be able to reasonably operate in a plethora of environments. Assuming that high speed deployments will not be a priority scenario for mmW, similar beam tracking procedures should be applicable to a wide range of deployment scenarios. Since it is reasonable to assume that mmW outdoor deployments will be targeted towards small cells and pedestrian speeds, the antenna arrays would likely be similar for both indoor and outdoor. This is not to say that the propagation conditions are identical, but the arrays and beam alignment strategies should be able to cope with both environments. One potential problem which outdoor environments would see and not indoor environments could be reflections off fast moving objects, but at this time, this effect is not expected to dominate performance.

On the handset front, it is expected that multiple patch arrays would be deployed over the handset to provide omni-like coverage and hence orientation of the handset should not be an issue with connectivity. However, factors such as head and body losses may block the direct link to the base station and affect connectivity. In these cases to maintain the mmW link, either a reflective path will be needed or the link will need to be handed off to another base station which is not shadowed. If neither is available, it is expected that any mmW system will be operating with an overlay system at a lower frequency which can maintain connectivity with the user. It should be noted that given the expected high loss through the human body that the mobile unit will likely direct the energy away from the person to a reflective path or a non-shadowed base station since the mobile unit will likely also have patch arrays to direct the energy in a desired direction.

b. Mobile Station Antennas

Nokia believes that because of power consumption and size limitations on mobile stations, at least initially, a small sized array (perhaps just 2x2) would be used at the mobile station. However, like the base station, two of these small arrays may be available for use where each employ orthogonal polarizations thus enabling multi-stream transmission even in LOS conditions. Patch arrays may be deployed in the mobile unit meaning that multiple patch arrays would be needed in the mobile unit to provide 360 degree coverage. However, we do not anticipate that the limited number of elements within an array will present connectivity issues because of the small cell size expected (e.g., Inter-Site Distance (ISD) of no more than 200 m) and that any loss due to the size of the array at the mobile device can be made up for by increasing the array size at the base station. Given that planar arrays have a limited field of view, typically less than +/-60 deg, a potential architecture to achieve omni coverage and overcome body blockage is the use of multiple arrays in the user device. A distributed antenna system may also be feasible but there are coupling loss issues in the higher mmW bands. It is expected that the mobile station array will be a phased array similar to the base station array. This means that most any beam can be synthesized. However, it is expected that the mobile array only needs to point its beam towards the base station so that standard beam patterns (selection from a grid of beams or Eigen beamforming) would be used. Handsets can be designed to overcome obstacles in two ways. The first would be beam alignment at both the base and mobile. The second would be protocols for handing off and detecting better base stations. Furthermore, to maintain the latency targets suggested for 5G (1 msec), the handset would need to recognize connectivity impairments and switch connections within the 1 msec window.

To support the beamforming techniques in the mmW bands, the development of phased array MMICs with integrated antennas, either chip scale or via an interposer board is an essential requirement for mmW bands at 60GHz and above. A reference point would be the Silicon Image 60GHz phased arrays[6]. In mmW bands development of small, low cost Transmit/Receive modules will be needed. Both metal-oxide-semiconductor (CMOS) and silicon-germanium (SiGe) chips are expected to be viable integrated circuit (IC) technologies for mmW mobile systems with SiGe offering higher transmit power and CMOS offering lower cost and power consumption.

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[6] *See* http://ir.siliconimage.com/releasedetail.cfm?ReleaseID=827550

c. Antenna Operation

Given the high bandwidths of mmW systems and the use of highly directional beams, it is observed that mmW systems, especially operating with a 2.0 GHz bandwidth, are likely noise limited, not interference limited. The higher path loss and high directionality of the arrays mean that there is less chance for harmful interference among licensees. Therefore, it is anticipated that complicated interference management schemes may not be needed. In case of moderate bandwidth mmW systems and for extremely dense deployments with high bandwidth systems interference management schemes may still be needed.

1.2. Bandwidth, Duplexing, Modulation, and Multiple Access

There are different ways to support the peak data rate in excess of 10 gigabits per second (10 Gbs) mentioned in the *5G mmW NOI*.[7] These approaches have their pros and cons. One way would be to use 400MHz of contiguous spectrum or more with optimized higher order MIMO schemes. The other approach consists in using much larger bandwidth (e.g., 2GHz) of contiguous spectrum to achieve maximum data throughputs of 10 Gbps without the need for higher order MIMO schemes. Carrier Aggregation technology could allow licensees to aggregate smaller, non-contiguous blocks of spectrum for use in providing mobile services, but would be more complex to implement and needs further study.

The Commission is correct to state that most current 5G proposals or demonstrations using spectrum above 24 GHz are based on Time-Division Duplexing (TDD) and not Frequency-Division Duplexing (FDD)[8]. Some inherent advantages of TDD are less complex radios, the

[7] *See NOI* ¶ *7.*
[8] *See NOI* ¶ *31.*

ability to use dynamic TDD, and obtaining more accurate channel state information (CSI) for transmit beamforming with lower overhead. Dynamic TDD means that each different base station can optimize its uplink/downlink split for the traffic in its cell and not coordinate across base stations. In addition, it is possible also to share the dynamic TDD link between access and backhaul traffic to allow for efficient in-band backhaul links. The more noise-limited behavior of mmW systems enables dynamic TDD since little interference is seen between cells. The use of dynamic TDD enables a more efficient use of the spectrum (e.g., unused uplink resources can be reused for the downlink) than both FDD and "normal" TDD. More accurate CSI is possible through channel reciprocity (i.e., the uplink RF channel is the same as the downlink RF channel) and appropriate array calibration. For example, to obtain CSI for downlink beamforming the mobile station only needs to sound its antennas on the uplink. However, while TDD is a good candidate for 5G mmW systems, at this early stage of 5G research, the Commission should not mandate TDD for mmW systems but should leave the door open to FDD and other new types of duplexing that may be available in the future.

We further agree with the Commission that in system development there are tradeoffs between using complex coding and modulation schemes that promote spectral efficiency versus simpler schemes which may not be as spectrally efficient but can still deliver the data rates targeted for 5G. It is anticipated that systems incorporating mmW bands for mobile use will initially use simpler modulation and coding schemes, especially since the peak rates can be met by exploiting bandwidth more than spectral efficiency. Also lower complexity modulation and coding schemes should minimize power consumption in the radios especially with the extremely high data rates expected in 5G (e.g., 10 Gbps or more).

Multiple Access schemes would allow simultaneous connections of many users to the network. Time-Division-Multiple-Access (TDMA), Frequency-Division-Multiple-Access (FDMA), Code-Division-Multiple-Access (CDMA), and Orthogonal-Frequency-Division-Multiple-Access (OFDMA) have been implemented in 2G/3G/4G systems. When it comes to which multiple access schemes to use for mmW mobile systems, TDMA seems to be a preferred option for the following reasons:

- Given the high bandwidths, the symbol time and block-processing time will be very small (by block processing it is meant the group of symbols which are jointly processed for equalization and in particular, for frequency-domain equalization). For example a block of 1024 symbols in a 2.0 GHz bandwidth may only span around 0.667 usec. Coupled with a relatively low number of active users which are likely at a given time since mmW will be deployed in small cells, multiplexing users in time (TDMA) is about as efficient as in frequency.
- A major factor that may favor the use of TDMA for mmW 5G systems is the use of RF beamforming, especially when only one RF beam can be active at a given time in a single array. The use of RF beamforming drives down power consumption by limiting the number of digital to analog and analog to digital converters needed, but it also means that only one user can be served at a given time since an optimal beam for one user is very unlikely to be the same optimal beam for another user (particularly because the geographical separation between users).

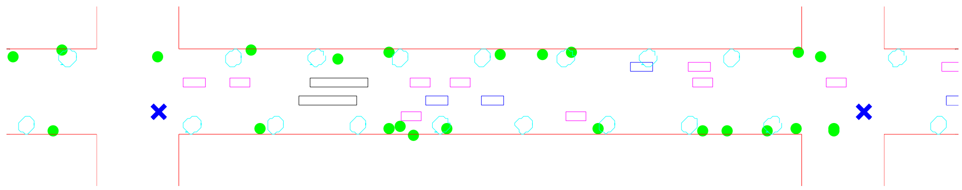
However, it should be noted that if higher multiplexing is needed in the future then Spatial Division Multiple Access (SDMA, also known as multi-user MIMO) may be deployed to improve the spectral efficiency.

Based on the discussion in this section, we recommend that the Commission tries to make large blocks of contiguous spectrum (e.g., at least 400MHz) available to the extent possible.

1.3. Performance and Coverage

In this section, we present simulation details of performance of outdoor local area access systems employing mmW frequencies and deployed in a dense urban environment with different base station densities [3]. Line of Sight (LOS) blocking probability models were developed from a ray-tracing environment which can be used to add more realism to system-level simulations. System-level simulation results were presented using a newly developed mmW channel model. The full details of the channel can be found in [2]. At mmW frequencies objects such as vehicles, trees, and people, will block the LOS signal from the radio node to the mobile if they are between the radio node and mobile. This blockage was modeled in [3] to reasonably assess the capacity gains as well as outage probabilities. Figure 2 shows one block of the simulated environment which includes cars, trucks, sport-utility vehicles (SUVs), trees, people, and radio nodes. One hundred users are dropped along 3 m wide sidewalks which are on both the north and south sides of the street and the users are assumed to be walking east or west (randomly determined). The users hold the mobile 0.4 m in front of them and 1.5 m above the ground at shoulder height. The user is modeled as a 1.5 m high and 0.5 m wide cylinder topped with a head which is a 0.3 m high and 0.3 m wide cylinder.

Figure 2: Example ray-tracing environment for determining LOS probability. Green dots are users, cyan circles are trees, blue x's are radio nodes, magenta rectangles are cars, blue rectangles are SUVs, and black rectangles are trucks.



Four different radio nodes layouts are considered as shown in Figure 3 and Figure 4 where all radio nodes are 5 m above the ground. In all cases the radio nodes have four sectors pointing north, east, south, and west. In layout A, there are radio nodes located at the southeast building corner in every intersection. Layout B has the same radio nodes locations as layout A but with an additional radio node in each intersection located at the northwest building corner in an intersection. The additional radio nodes give a second chance for a user to have a LOS link if the user is blocked to one of the radio nodes. In layout C an additional set of radio nodes over layout A are added in the middle of the blocks of the north-south running streets. In layout D, an additional set of radio nodes over layout C are added in the middle of the blocks of the east-west running streets. The radio nodes density is 75/km2 for layout A, 150/km2 for layouts B and C, and 187/km2 for layout D.

Figure 3: Radio node layouts A with a density of 75/km2 (left) and B with a density of 150/km2 (right). Radio nodes locations are marked with an x and the red area demarcates the data collection area.

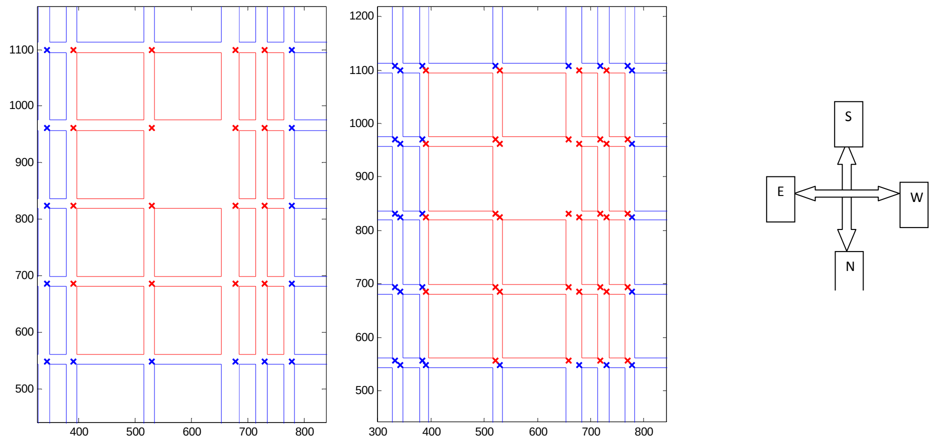
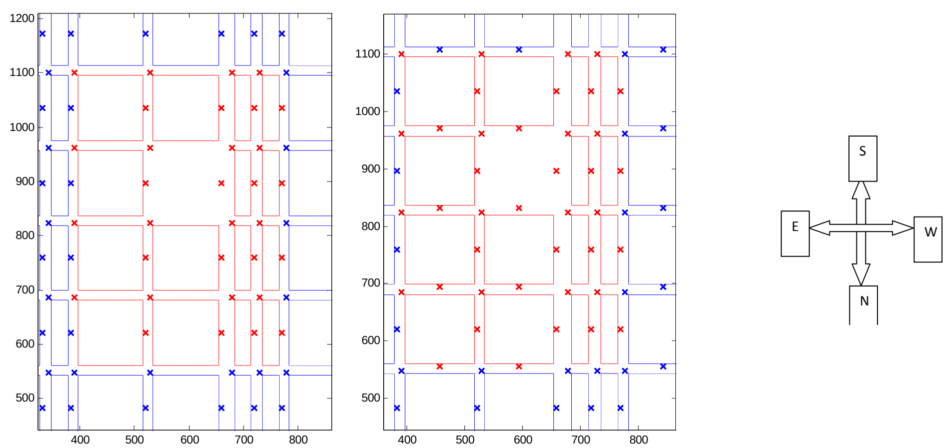


Figure 4: Radio nodes layouts C with a density of 150/km2 (left) and D with a density of 187/km2 (right). Radio nodes locations are marked with an x and the red area demarcates the data collection area.



The general system-level parameters are given in Table 1.

Table 1: System simulation parameters

Parameter	Value
Carrier frequency	72 GHz
Bandwidth	2.0 GHz
Traffic type	Full buffer
Radio node array	4 sectors, each sector has two 4x4 RF arrays (one vertically polarized, one horizontally polarized) with 0.5λ spacing in both dimensions
Mobile antennas	2 omni-directional antennas, one with vertical polarization, one with horizontal polarization
Radio Node Tx power	30.8 dBm/sector (split between the two arrays in each sector)
Maximum rank	2 (single-user MIMO only)
Beamforming	Eigen beamforming using the uplink signal to point Radio Node RF beams
Modulation levels	LTE MCS levels
Channel estimation	Ideal
Scheduler	Proportional fair
HARQ	None, but retransmissions are allowed

The overall system-level results including average user throughput, cell-edge throughput (i.e., the 5% throughput point), and outage probability (as determined as the percent of users which do not obtain 100 Mbps) is shown in Table 2.

Table 2: Summary of system-level results (w/F indicates with foliage and w/o F indicates without foliage)

Layout	Radio Node density	Average user Throughput	Cell edge Throughput	Outage Probability
A w/F	$75/km^2$	2.07 Gbps	0 Mbps	16.4%
B w/F	$150/km^2$	4.06 Gbps	222 Mbps	3.2%
C w/F	$150/km^2$	4.15 Gbps	173 Mbps	4.4%
D w/F	$187/km^2$	5.12 Gbps	552 Mbps	1.0%
A w/o F	$75/km^2$	2.10 Gbps	18.3 Mbps	6.6%
B w/o F	$150/km^2$	3.80 Gbps	456 Mbps	1.0%
C w/o F	$150/km^2$	3.93 Gbps	375 Mbps	1.75%
D w/o F	$187/km^2$	4.82 Gbps	707 Mbps	0.33%

As can be seen, very high average user throughputs of between 2.07 Gbps to 5.12 Gbps are obtained in all layouts. The cell-edge throughput of layout A is a disappointing 0 Mbps (with foliage) and 18.3 Mbps (without foliage) due to the inadequate radio node density, but when the radio node density is increased as in layouts B-D then the cell-edge throughputs are an impressive 173 to 707 Mbps.

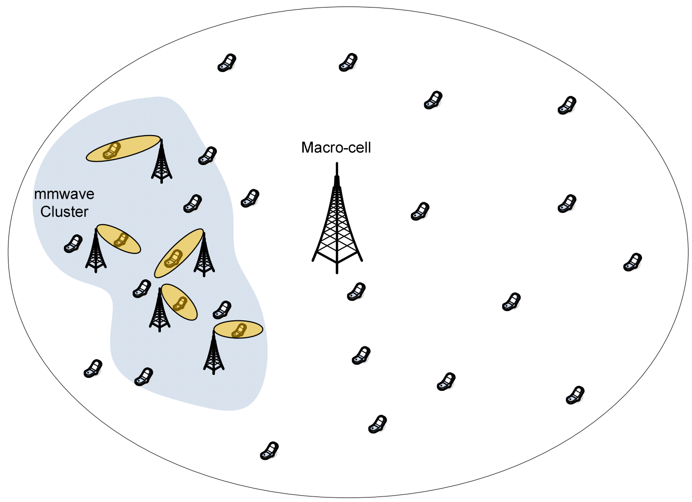
The system simulation results show that low outage probability is possible with a high enough radio nodes density and that average mobile throughputs of up to 5.12 Gbps and cell edge rates of up to 707 Mbps are possible. Also the results showed the impact of foliage on the system capacity where foliage helps average user throughput by decreasing the interference seen by strong links but hurts cell-edge throughput and coverage by creating more non-LOS links.

1.4. Deployment schemes and Network Architectures

Figure 5 illustrates mmW access point deployment with an LTE overlay. The LTE in macro-cell type deployment can also be used to provide coverage outside the area covered bymmW access. With an LTE overlay, the user can be connected to both the LTE overlay and one or more mmW access points. In this way, the radio link can always be maintained should access to mmW clusters become unavailable. To maximize the user experience, tighter integration between LTE and 5G system can be investigated. This approach can also be used to maximize the user experience by combining the high data rate of the mmW system with the reliability of the LTE overlay. For instance, control-plane transmission can be sent via LTE to ensure continuous radio link while user-plane transmission can be sent on either LTE or mmW. User-plane data may be selected for transmission on LTE or mmW using criteria such packet size (e.g small packets are sent via LTE), service (e.g. VoIP is sent via LTE), priority, and link state.

In mmW access, a set of co-operating access points or a “cluster” of access points, could be deployed to cover an area, for example, a 100 meter radius. A cluster can be used because mmW may be subject to high shadowing loss and low diffraction, such that each individual coverage area contains multiple shadow regions where radio communication is not supported. Cooperating cluster nodes can be arranged such that these shadowed regions are covered from a unique propagation direction. As a result, a user may be covered by multiple access points within the cluster.

Figure 5: mmW Access Point Deployment Architecture



Nokia views that the Mobile Network Operators (MNOs) deployment model, usually with licensed spectrum, where a single operator deploys and manages a network would still remain a preferred network topology by the MNOs. In this model, service providers deploy a network composed of a radio access network and core network to provide wireless coverage and capacity to subscribers of the service. Service provider deployments increasingly support various levels of heterogeneity among kinds of base stations, allowing the operators to manage their resources effectively and maintain service quality.

However, some parts of the mmW like 57-64GHz could play the same role as WiFi play in the bands below 6GHz. For these unlicensed 5G bands, a decentralized Wi-Fi-like deployment, in which network elements are mostly deployed by end users, could be used. This model offers service with limited coverage utilizing low-power access points. Just like bands below 6GHz, there could be different models supporting various types of deployment depending on the different licensing mechanisms which could guide the architectural decisions.

Recent wideband measurement campaigns in New York City and Brooklyn, NY at 28 GHz and 73 GHz [4], [5] have verified that large contiguous bandwidths in the mmW bands are viable for both backhaul and access for 5G. The mobile backhaul networking can have inherent self-healing, self-optimization and self-configuration capabilities based on mesh topology utilizing mmW radio links. The WMN (Wireless Mesh Network) backhaul solution is a novel concept solution targeted for next generations' small cell, ultra high capacity mobile base station first mile access backhaul. Essentially the WMN system is a highly transparent subnetwork offering connectivity between desired end points (e.g. a set of base stations and an aggregation transport network gateway) with advanced and smart self-optimization, self-healing and self-configuration capabilities offering traffic engineering and configuration features but requiring little or no OAM intervention.

It is possible to use "in band" service in which backhaul reuses frequencies that are also used for access. In one example of a 5G system design, Nokia envisions that the 5G system is TDD, and each subframe could either be uplink, downlink, or backhaul, and can be configured differently from access point to access point (this technique is referred to as "dynamic TDD").[9]

1.5. Technical Rules

In this Section, we provide Nokia's views on some of the technical questions asked by the Commission. We agree with the Commission that for access system base stations, small cell deployment in mmW bands will be dominate, and a lower level that the Commission's proposed +55dBW may be appropriate but we cannot preclude larger cell applications. Therefore, at this stage of the inquiry, we agree with the Commission's proposed +55 dBW EIRP limit. As a reference point, we are assuming a maximum of about +55dBm EIRP per polarization or MIMO

[9] See A. Ghosh, et al., "Millimeter wave enhanced local area systems: A high data rate approach for future wireless networks," *IEEE Journal on Selected Areas in Communications, vol*. 32, no. 6, pp. 1152-1163, June, 2014.

stream. We also view that mobile units' transmit power will be much lower and additional studies on Specific Absorption Rate (SAR) and coexistence with other systems in and outside the bands being considered are needed but at this time we are assuming approximately a maximum +30dBm EIRP for mobile units which can serve as an initial guidance to the Commission. Phased array solutions with integral antennas are likely in mmW bands. Therefore, it would be appropriate to define EIRP limits but also allow them to be not only measured but also calculated based on independent measurements of Transmit Output Power and antenna gain. Both spectral density and aggregate channel power values are pertinent to the assessment of incumbent service protection.

The Commission's proposed attenuation of 43+10log(P) for out-of-band emissions (OOBE) should be appropriate since it should be feasible to obtain such levels without filtering and filtering on small chip scale phased arrays is quite difficult. However, we assume that this is the emission at the transmitter output and not EIRP with antenna gain. These OOBE limits could be specified on a per beam basis, at the boresight of the beam but side lobes also need to be considered.

Phased array systems with beams steered to each user on a TDMA basis will help mitigate overall harmful interference between licensees in adjacent geographic areas using the same frequency bands. Therefore, we believe that at this stage there is no need to establish Power Flux Density (PDF) limits at the boundaries of license areas prevent harmful interference. The coexistence between licensees could be managed by coordination and technology without the Commission regulating PFD or other types of limits. If this does not work, then the Commission could introduce some hard PFD limits in the rules.

Spectral efficiency is a measure of how efficiently the spectrum can be used during data transmission – how many bits per Hz per second the system is able to deliver over the air. By increasing the spectral efficiency, the capacity of the network increases without the need to add more cell sites or taking more spectrum in use. Multiple components affect the spectral efficiency of the radio link (modulation, multi-antenna operation, signal waveform) and whole system (coordination between nodes, interference suppression, collaborative radio resource management). Out of these two the spectral efficiency of the link has been pushed quite close to the theoretical limits, while the spectral efficiency of the system (or area) still allows improvements that are less expensive in terms of cost but also energy and overall complexity.

III. NOKIA FULLY SUPPORTS THE INITIAL SET OF BANDS IDENTIFIED IN THE NOI WHILE RECOGNIZING THAT OTHER BANDS, BOTH BELOW AND ABOVE 6GHZ, CAN ALSO BE GOOD CANDIDATES

Nokia commends the Commission for the work they already did in identifying the initial set of bands in the *5G mmW NOI*, namely:

1. LMDS Band (27.5-28.35 GHz, 29.1-29.25 GHz, and 31-31.3 GHz)
2. 39 GHz Band (38.6-40 GHz)
3. 37/42 GHz Bands (37.0-38.6 GHz and 42.0-42.5 GHz)
4. 60 GHz Band (57-64 GHz and 64-71 GHz)
5. 70/80 GHz Bands (71-76 GHz, 81-86 GHz)
6. 24 GHz Band (24.25-24.45 GHz and 25.05-25.25 GHz)

Nokia views all of these bands as being potentially suitable for the next generation of Mobile Services and warrant further study, namely in terms of coexistence with the existing and future services in the bands being considered and also in the adjacent bands. We think that a mobile allocation is one of the most important criteria for the identification of bands for advanced mobile wireless services and all but the 24GHz band in the *5G mmW NOI* have existing mobile allocations. The main reason why we think the 24GHz band is still a viable band is because they are available in other countries as can be seen in Figure 7 below and we could see the development of a global 5G ecosystem around 24GHz extending into the adjacent LMDS 28GHz bands also identified by the Commission. We fully support the Commission's desire to consider international allocations and service rules in other countries in order to foster global harmonization.[10] We therefore recommend that the Commission adds a mobile allocation in the 24GHz band and develops mobile service rules for all of the bands identified in the *5G mmW NOI*. We also support other bands below 6GHz and from 6-100GHz.

The Radiocommunication Sector of the International Telecommunication Union (ITU-R) working on the global management of the radio spectrum has recognized the relationship between IMT (International Mobile Telecommunication system) and "5G" and is working towards realizing the future "IMT2020" vision of mobile broadband communications. Currently, Working Party 5D, an ITU-R sub group is working on various reports providing guidance on what may be expected in the future development of IMT for year 2020 and beyond, including systems operating above 6 GHz. The World Radio Conference (WRC) scheduled for November 2015 is expected to set the stage for the next WRC early 2019 to be able to identify frequency bands from the range of 6 to 100 GHz for mobile use and facilitate global harmonization of the spectrum. WRC 2019 will be a unique opportunity to identify spectrum for mobile broadband (5G) above and also below 6 GHz, and it is therefore important that the WRC 2015 will decide on the respective agenda item for the WRC 2019. To maximize the positive outcome of

[10] See *NOI* ¶ *47*.

identification of the right bands at the WRC 2019 several aspects related to new frequency bands need to be assessed and studied, including but not limited to:

1. Frequency ranges that contain bands which already have **worldwide primary allocation to Mobile Service** should be considered as more likely options for possible spectrum designation and need to be further studied. However, bands which do not have a mobile allocation can still be valid, especially if they are lightly used currently and/or are global bands. The US 24GHz band is a good example of a band that currently has no mobile allocation but has the potential of becoming a global band.

2. Spectrum bands that are **harmonized** at least regionally should be given high priority.

3. Availability of **contiguous spectrum** (e.g. at least 300MHz) should be taken into account.

4. **Current use** of these frequency ranges should be further investigated.

5. **Minimum bandwidth requirement** should also be considered as a criterion for the selection of frequency ranges. **Coexistence** with systems in the bands under consideration and in adjacent bands.

6. **Channels in 6-100 GHz need to be characterized since channel properties change with frequency.** What range of bands is a given channel/path loss model reasonably good for needs to be studied?

Figures 6 to 9 below give **examples of bands from 6 to 100GHz which satisfy criteria 1-3** for USA (using FCC's non Federal Table of Regulations), China, Japan, S. Korea, and Europe. The goal of this exercise is to show that there can be more potential 5G bands in addition to what the Commission has initially identified in the *5G mmW NOI*. Therefore, while we support the initial set of bands in the *5G mmW NOI*, we also urge the Commission to keep all the options open to allow for identification of other bands, especially if they can be harmonized globally.

Figure 6: 6-16GHz, Co-Primary Mobile Allocation, At least 300MHz Contiguous Spectrum

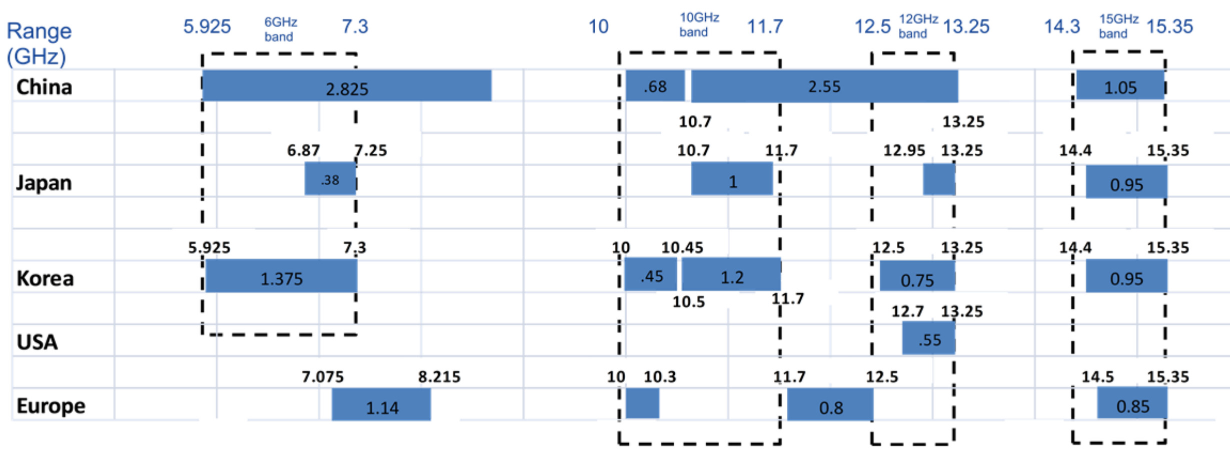


Figure 7: 16-30GHz, Co-Primary Mobile Allocation, At least 300MHz Contiguous Spectrum

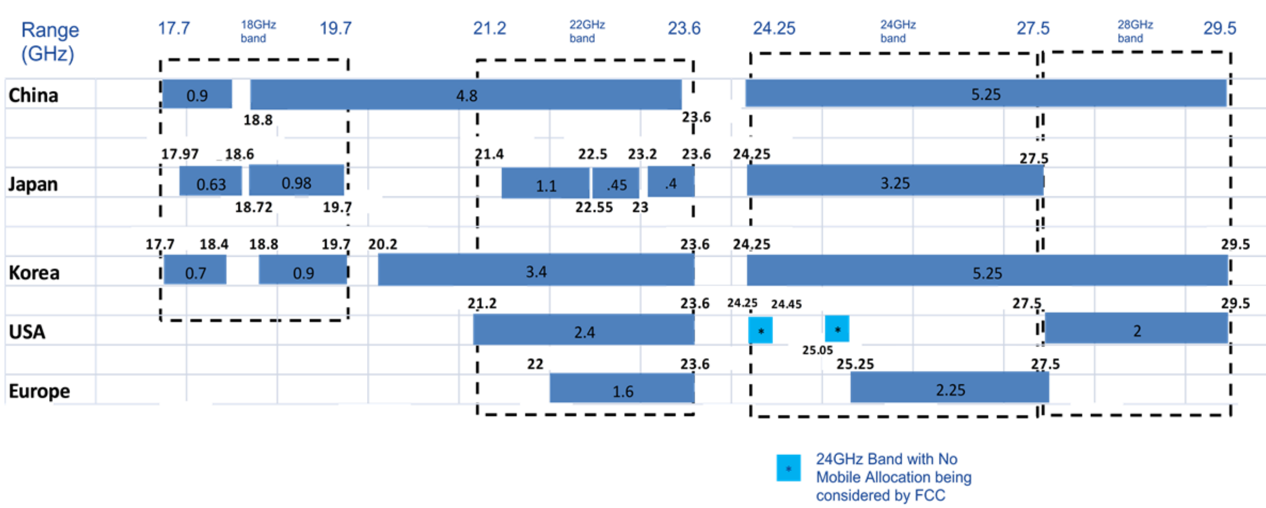


Figure 8: 30-54GHz, Co-Primary Mobile Allocation, At least 300MHz Contiguous Spectrum

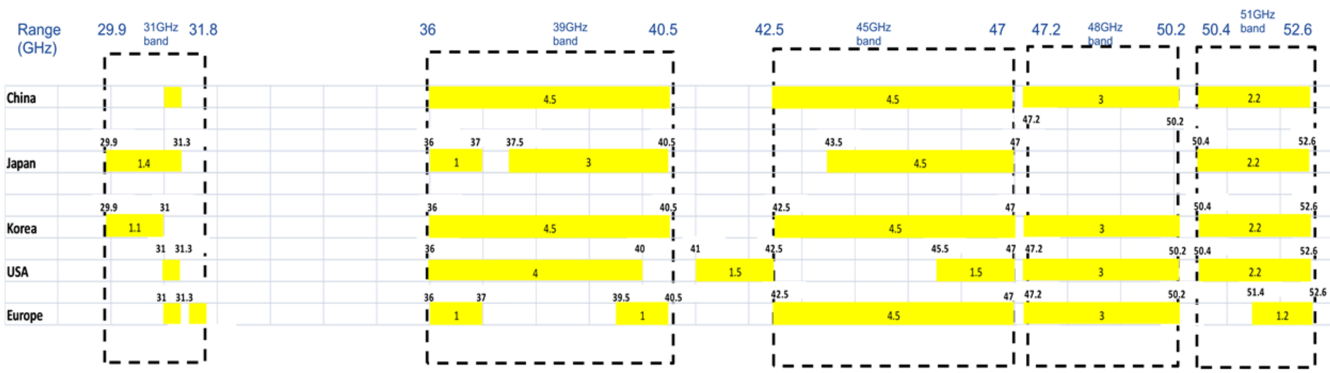
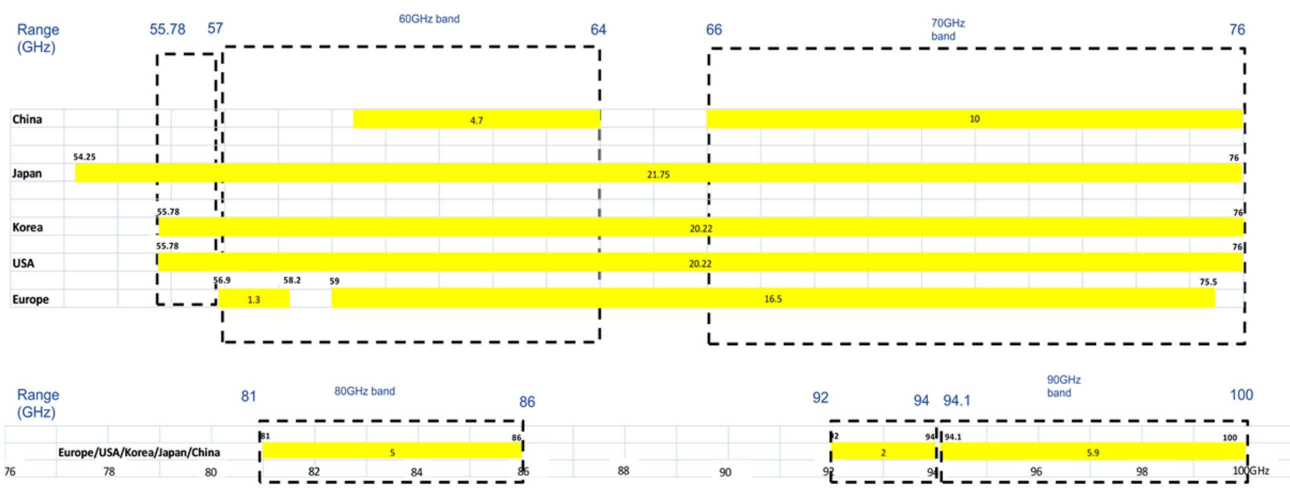


Figure 9: 54-100GHz, Co-Primary Mobile Allocation, At least 300MHz Contiguous Spectrum



IV. NOKIA WANTS TO REITERATE THE FACT THAT THE IMMEDIATE PRIORITY IS TO PROVE THE FEASIBILIY OF ADVANCED MOBILE SERVICES AT BANDS ABOVE 6GHZ BEFORE FINALIZING THE LICENSING REGIMES

Nokia fully appreciates the Commission's willingness to study the licensing regimes that would best apply to the bands identified in the *5G mmW NOI* and provides hereafter some initial thoughts to help with that task. At the same time, we want to emphasize the immediate priority should remain the technical feasibility of these Advanced Mobile Services at such high frequencies as we push back the "Spectrum Frontiers" to justify the fact that there is a need for more spectrum above 6GHz and we need an Agenda Item from World Radio Conference 2015 (WRC 2015) for WRC 2019 for 5G above 6GHz. Indeed, as the *5G mmW NOI* points out, the FCC Technological Advisory Council (TAC) recommended that the Commission issues "*a notice of inquiry to evaluate mobile broadband feasibility in bands above 30 GHz.*"[11]

The commercial mobile market has blossomed under a framework of access to exclusively licensed spectrum. This paradigm is driving the deployment of robust 4G broadband networks across the country and can continue to be the case for 5G. Therefore, identifying additional spectrum for exclusive licensing must remain the top objective for government spectrum decision makers, even for 5G.

While we urge the Commission to implement an exclusive licensing regime in all of the 5G bands to the extent possible, we also explore some alternative regimes in case exclusive licensing may not be possible. However, the licensing regimes will need to be studied in more details to "*ensure flexibility of technology and use as well as compatibility with incumbent*

[11] *See NOI* ¶ *14.*

federal and non-federal operations."[12] We further support protecting incumbent operations and considering them as part of any potential service rules.

Therefore, the discussion of licensing scenarios below is not meant to be exhaustive but should be viewed as initial inputs that can evolve.

4.1 24 GHz Band (24.25-24.45 GHz and 25.05-25.25 GHz), LMDS Band (27.5-28.35 GHz, 29.1-29.25 GHz, and 31-31.3 GHz) and 39 GHz Band (38.6-40 GHz)

These bands have several things in common:

- They have been licensed in geographic areas to fixed services;
- Not all of the licenses offered by the Commission were actually "grabbed" for use;
- Some licenses were voluntarily cancelled or terminated for failure to meet substantial service requirements.

Therefore, there is vacant spectrum available that could be licensed by auctioning exclusive rights to geographic service areas. The Commission rightfully discussed the upsides of such an approach, namely "*This option would extend to mobile services the status quo for the 24 GHz, LMDS, and 39 GHz bands, and it would be the most familiar option for carriers that are presently providing mobile wireless services in the bands below 3 GHz under similarly extensive geographic area licenses*".[13]

We view that secondary market leasing, establishing smaller licensing areas and adjusting performance requirements as mentioned by the Commission[14] are all promising approaches that can alleviate the potential concern that portions of license areas outside of high-traffic areas

[12] See *NOI* ¶ *88.*
[13] *See NOI* ¶ *92.*
[14] *See NOI* ¶ *92-95.*

could end up lying fallow. Another approach may consist in doing incentive auctions whereby the existing licensees return some or all of their spectrum usage rights in exchange for incentive payments but this entails additional complexity.[15]

However, these approaches need to be further studied. Nokia at this time is not proposing specific details about the licensing requirements.

4.2 37/42 GHz Bands (37.0-38.6 GHz and 42.0-42.5 GHz)

We support licensing on an exclusive use, geographic area basis for these bands, essentially since these bands represent "clean slates" when it comes to commercial use. We recommend that the Commission establishes terrestrial mobile service rules in the 37 GHz and 42 GHz bands. We also agree that the rules should protect federal operations via coordination or some other means while maximizing the use of these bands for commercial operations. In addition, we agree it would be appropriate to give NTIA and other federal agencies an opportunity to refresh the record on federal deployments and plans in the 37-38.6 GHz band.

4.3 57-64 GHz

As the Commission noted in the *5G mmW NOI*[16], Part 15 rules regarding unlicensed transmissions already apply to the 57-64 GHz band. This is a global band with the US, Canada, Europe, Japan, South Korea, Australia and China having an unlicensed spectrum allocation in the 60 GHz region as shown in Figure 9. The unlicensed frequency allocations at around 60 GHz in each region do not match exactly, but there is substantial overlap. At least 3.5 GHz of contiguous

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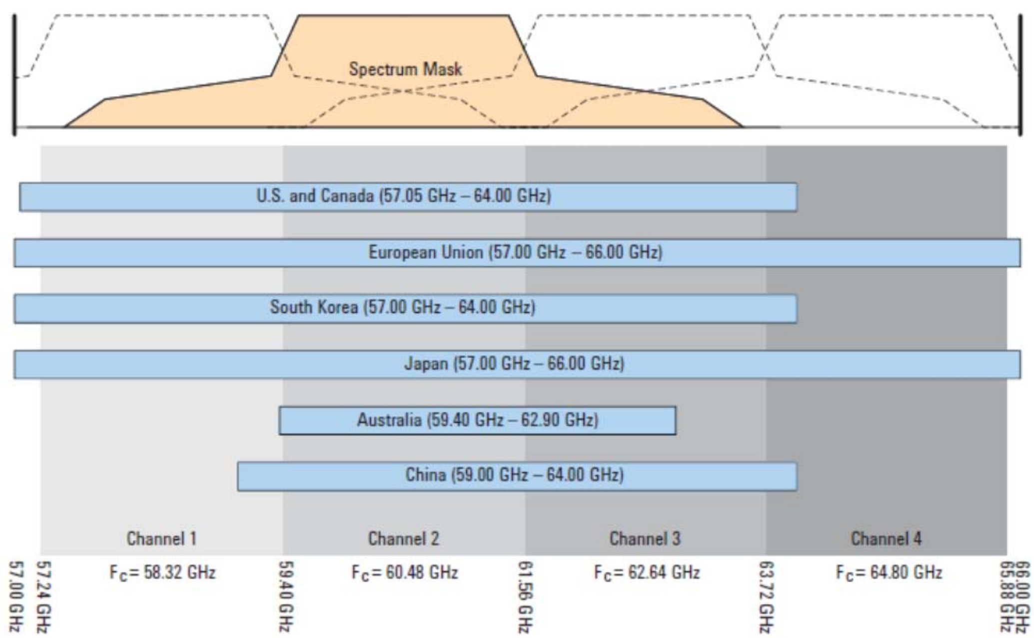
[15] *See* Expanding the Economic and Innovation Opportunities of Spectrum Through Incentive Auctions, GN Docket No. 12-268, *Report and Order*, FCC 14-50 (rel. June 2, 2014).
[16] See *NOI* ¶ *100.*

spectrum is available in all regions that have allocated spectrum. This band is relatively uncongested compared to the 2.4GHz and 5GHz bands. There is a substantial RF oxygen absorption peak in the 60GHz band, which gets more pronounced at ranges beyond 100 meters. High path loss can be mitigated by increasing antenna gain. The Commission's Part 15 rules seem to be enough to encourage innovation and could continue to apply. For example, IEEE Working Group TGad has published 802.11ad specifications, providing up to 6.75 Gbps throughput using approximately 2 GHz of spectrum at 60 GHz over a short range and products based on this technology are now commercially available.[17]

Figure 10: 60GHz Band Channel Plan and Frequency Allocations by Region



[17] See http://cp.literature.agilent.com/litweb/pdf/5990-9697EN.pdf

4.4 64-71 GHz

We believe that 64-71GHz will benefit from a licensing regime that makes spectrum available by auctioning exclusive rights to geographic service areas because[18]:

- there are no licensed operations in 64-71GHz.
- frequencies from 64-71GHz are not among those listed in the Commission's rules as available for licenses issued in the terrestrial Fixed Service or for any satellite services except for inter-satellite service.
- the Commission's rules list 65-71 GHz as available for Inter-Satellite (ISS) licenses, but there are no current ISS licenses.
- there are currently no active satellite licenses in that band.

Therefore, we support the possibility of authorizing licensed operations in 64-71GHz band instead of unlicensed Part 15 operations.

4.5 70/80 GHz Bands (71-76 GHz, 81-86 GHz)

If possible, exclusive licensing should be the preferred licensing regime for these bands. If not possible, then the automated registration system that applies currently to fixed stations in this band could further be enhanced into a system of dynamic access control using databases similar to Nokia's proposed Authorized/Licensed Shared Access (ASA/LSA) regime to protect Federal and radio astronomy sites.[19] We do not think that allowing unlicensed Part 15 operations segments would be the most appropriate licensing regime in the 70/80 GHz band.

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[18] See *NOI ¶ 70-74.*

[19] See Nokia Solutions and Networks comments in GN Docket No. 12-354 "Amendment of the Commission's Rules with Regard to Commercial Operations in the 3550- 3650 MHz Band."

V. CONCLUSION

Nokia welcomes this *5G mmW NOI* to explore the use of spectrum above 24GHz to develop the Fifth Generation of Mobile Services (5G) that can "*accommodate an eventual 1000-fold increase in traffic demand, supporting high-bandwidth content with speeds in excess of 10 gigabits per second (Gb/s); end-to-end transmission delays (latency) of less than one-thousandth of a second; and, in the same networks, sporadic, low-data-rate transmissions among an "Internet of things*"[20] The availability of huge bandwidth coupled with the use of large antenna arrays at both transmitter and receiver can make this spectrum attractive for deploying high capacity 5G networks.

We provided some inputs on technological developments relevant to the use of bands above 24 GHz for mobile services and shared our views of the service rules that would be necessary to facilitate mobile use of those bands. Our on-going research on related Antenna Technology, Bandwidth, Duplexing, Modulation, and Multiple Access, Performance, Coverage, Deployment schemes, Network Architectures and Emissions indicates bands above 24GHz look promising for the provision of 5G mobile services but that further investigations are needed. 5G research is on-going and we recommend that the Commission does not set hard rules yet but instead put in place an iterative process that will provide opportunities for the industry and academia to provide refined data on a regular basis to the Commission to help finalize the rules.

We also fully support the initial set of bands identified in the *5G mmW NOI* while recognizing that other bands, both below and above 6GHz, can also be good candidates. We noticed that all of the proposed bands, except 24GHz, have a mobile allocation in USA, which is

[20] See *NOI* ¶ *7*.

very important. We therefore recommend that the Commission adds a mobile allocation in the 24GHz band and develops mobile service rules for all of the bands identified in the *5G mmW NOI*. We also fully support the Commission's desire to consider international allocations and service rules in other countries in order to foster global harmonization. While we applaud the Commission for exploring new spectrum above 24GHz to expand mobile broadband connectivity to consumers across the nation, we urge the Commission not to exclude other bands, both below and from 6-100GHz that may become relevant for 5G, especially if there is potential for harmonization with other parts of the world and ITU. We also want to reinforce the need to study the coexistence issues with current and future systems in those bands and in adjacent bands. We further support protecting incumbent operations and considering them as part of any potential service rules.

Nokia fully appreciates the Commission's willingness to study the licensing regimes that would best apply to the bands identified in the *5G mmW NOI* and provided some initial thoughts to help with that task. At the same time, we want to emphasize the immediate priority should remain the technical feasibility of these Advanced Mobile Services at such high frequencies as we push back the "Spectrum Frontiers" to justify the fact that there is a need for more spectrum above 6GHz and we need an Agenda Item from World Radio Conference 2015 (WRC 2015) for WRC 2019 for 5G above 6GHz. Indeed, as the *5G mmW NOI* points out, the FCC Technological Advisory Council (TAC) recommended that the Commission issues "*a notice of inquiry to evaluate mobile broadband feasibility in bands above 30 GHz.*"[21]

The commercial mobile market has blossomed under a framework of access to exclusively licensed spectrum. This paradigm is driving the deployment of robust 4G broadband

[21] *See NOI ¶ 14.*

networks across the country and can continue to be the case for 5G. While we urge the Commission to implement an exclusive licensing regime in all of the 5G bands to the extent possible, we also explored some alternative regimes in case exclusive licensing may not be possible. The licensing regimes will need to be studied in more details to "*ensure flexibility of technology and use as well as compatibility with incumbent federal and non-federal operations.*"[22]

Nokia believes that to take full advantage of the mmW spectrum will require thinking through some novel technical and policy issues. This will take some time. Meanwhile, we urge the Commission to continue to make new spectrum below 6GHz available for commercial use. We also encourage the Commission to explore new spectrum from 6GHz to 24GHz and not just above 24GHz. Finally, we look forward to continuing to work with the Commission and our industry partners to make new spectrum available for Mobile Broadband.

Respectfully submitted,

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[22] See *NOI* ¶ *88.*

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