To: The Commission

COMMENTS OF HUAWEI TECHNOLOGIES, INC. (USA) and HUAWEI TECHNOLOGIES, LTD.

Huawei Technologies, Inc. (USA) and Huawei Technologies Co., Ltd. (collectively “Huawei”)¹ appreciate the opportunity to submit these comments in response to the Notice of Inquiry ("notice" or "NOI") issued by the Federal Communications Commission ("Commission" or "FCC") on technologies underlying the development of millimeter wave ("mmW") mobile services in frequency bands above 24 GHz.² Huawei commends the Commission for initiating

¹ Huawei Technologies, Inc. (USA) is a subsidiary of Huawei Technologies Co., Ltd.

² See In the Matter of Use of Spectrum Above 24 GHz for Mobile Radio Services, Amendment of the Commission’s Rules Regarding the 37.0-38.6 GHz and 38.6-40.0 GHz Bands; Implementation of Section 309(j) of the Communications Act – Competitive Bidding, 37.0-38.6 GHz and 38.6-40.0 GHz Bands; Petition for Rulemaking of the Fixed Wireless Communications Coalition to Create Service Rules for the 42-43.5 GHz Band, Notice of Inquiry, 29 FCC Rcd. 13020 (2014) ("NOI"); see also Wireless Telecommunications Bureau and Office of Engineering and Technology Extend Period to File Comments and Reply Comments in Response to Notice of Inquiry on Use of Spectrum Bands Above 24 GHz for Mobile Radio Services, Public Notice, DA 14-1703, GN Docket No. 14-177 (rel. Nov. 25, 2014) (extending filing deadlines).
this examination of possible uses of the higher-frequency mmW bands for Fifth Generation ("5G") mobile services at this early stage in the development of 5G technologies. While the current generation of mobile technologies has transformed the way people communicate and access information, Huawei believes the advent of 5G will revolutionize end user mobility along with the entire landscape of the global information and communications technology (ICT) industry.

With future mobile access networks capable of supporting massive increases in data volume, connections and speed, 5G technologies will be the ultimate platform for a connected world. Huawei believes that 5G technologies will facilitate a truly converged network, supporting a variety of seamless new network deployments including ultra-high density wireless networks; backhaul; devices and communications equipment; dynamic spectrum integration; and wireless access infrastructure sharing.

I. Huawei’s Contributions to 5G R&D and Commercialization

Huawei is a leading, global provider of ICT solutions with a comprehensive set of advanced products and services that span wireline, wireless and IP technologies. Through our dedication to customer-centric innovation and strong partnerships, we have established end-to-end capabilities and strengths across the carrier network, enterprise, smart mobile device and cloud-computing sectors. We are committed to creating maximum value for telecommunications carriers, enterprises and consumers by providing competitive ICT solutions and services. Our

--

3 Huawei is a global leader of information and communications technology ("ICT") solutions. Continuous innovating based on customer needs drives our more than 150,000 employees globally in order to enhance customer experiences and create maximum value for telecommunications carriers, enterprises, and consumers. The company’s vision is to enrich life and improve efficiency through a better connected world. By leveraging our experience and expertise in the ICT sector, we help bridge the digital divide by providing to those not yet connected the opportunity to enjoy broadband services, regardless of geographical location. See http://www.huawei.com/en/ and Annual Report 2013, Huawei Investment and Holding Co., Ltd., available at http://www.huawei.com/en/about-huawei/corporate-info/annual-report/2013/index.htm.
products and solutions have been deployed in the United States and over 170 other countries, serving nearly three billion people or more than one-third of the world’s population.

Every Huawei innovation stems from close interactions with customers to understand their needs and market demands. Huawei annually invests an average of 10 percent of its revenues into research and development (“R&D”) and employs approximately 70,000 product and solutions R&D employees that comprise 45 percent of our global workforce. Currently, Huawei has 16 R&D centers, 28 joint innovation centers and 45 training centers worldwide. Huawei is passionate about supporting international standards and actively contributes to the formulation of such standards. Huawei is a member of more than 170 industry standards organizations and open source bodies and has actively contributed to driving consensus on international standards both in terms of positions held in such organizations and the submission of standards proposals.

Huawei believes that the success of 5G depends on a thriving ecosystem made possible by open innovation and collaborative research. Huawei launched its 5G R&D program in 2009 and is a key player in the establishment of essential 5G technologies and innovations. In November 2013, Huawei announced it would invest $600 million USD in 5G wireless technologies through 2018.\(^4\) These investments will cover a broad range of key enabling technologies, including research on air interface technologies, with a view of achieving the commercialization of the 5G network by 2020. Over 300 Huawei experts are currently dedicated to 5G research and innovation across nine R&D centers worldwide, and company experts collaborate extensively with stakeholders in industry, consortia, universities and leading

innovation vertical platforms around the world. Here in the United States, Huawei experts located at our R&D centers in Illinois, New Jersey and Texas are dedicated to the development of 5G technology standards. Further, Huawei announced in February 2014 its sponsorship of the New York University Polytechnic School of Engineering’s NYU WIRELESS Research Center. The Center is dedicated to the exploration of advanced wireless technologies, computing and medical applications. Among other collaborative 5G projects in which we participate, Huawei is a founding member and serves on the board of the 5G Innovation Centre in the United Kingdom; Huawei holds a board position and participates in the European Commission’s 5GPPP (5G Public-Private Partnership) Association; and Huawei joined forces with academic and industry partners to form the Mobile and Wireless Communications Enablers for the Twenty-twenty Information Society (“METIS”) project. As a core member of METIS, which was launched in 2012 to develop 5G system concepts and related key technology components, Huawei leads METIS research on the wireless air interface for 5G.

II. Objectives of 5G Mobile Services

Huawei believes the next generation of mobile networks will be infused with capabilities to flexibly deliver services at unprecedented speeds while meeting forecasts for tremendous growth in mobile data traffic, diversification of mobile app innovation, Internet of Things

---

5 See NOI at ¶ 9 (note 20), 10, 12.
6 See “NYU Wireless, Huawei Technologies Cooperate on Research for High-Speed Transfer of Mobile Data,” release of NYU Polytechnic School of Engineering, Feb. 14, 2014, available at http://engineering.nyu.edu/press-release/2014/02/14/nyu-wireless-huawei-technologies-cooperate-research-high-speed-transfer-mob. As an affiliate sponsor, Huawei assigns two members to the research center’s industrial affiliates’ board. Board members keep faculty and students informed about industry needs and provide employment opportunities for students, while faculty and students present new ideas to the affiliate companies. Affiliate sponsors gain early access to NYU WIRELESS research and often work with students and faculty on directed research projects. See www.nyuwireless.com.
7 See NOI at ¶ 9.
(“IoT”) connectivity, and security. To achieve these objectives, developments will primarily focus on two fundamental aspects of technology for eliminating infrastructure bottlenecks: massive capacity and massive connectivity. “Massive capacity” implies the delivery of services allowing connections between users and the network at “faster than thought” speeds (i.e., with sub-millisecond latency). In other words, the apparent distance between connected people and connected machines will shrink to virtually zero. “Massive connectivity” signifies the enabling of widespread adoption of mobile-to-mobile services and interactions, and facilitating innovation in localized mobile service delivery—service immediacy and on-demand adaptability.⁸

Huawei believes that mobile networks will increasingly become the primary means of network access for person-to-person and person-to-machine connectivity. This means that wireless networks will need to match advances in fixed networking in terms of delivered quality of service, reliability and security. To do so, 5G technologies will need to be capable of delivering fiber-like (e.g., 10 Gbit/s) speed to support ultra-high definition visual communications, immersive multimedia interactions, and other applications across ultra-wide bandwidth connectivity with extremely low latency.

III. mmW Mobile Service Technology Developments

While previous generations of wireless networks were characterized by fixed radio parameters and spectrum blocks, future systems will allow for the utilization of a range of spectrum and access technologies for the best delivery of services. 5G will feature native support for new kinds of network deployments, including ultra-dense radio networking with self-

backhauling, device-to-device communication, dynamic spectrum refarming and radio infrastructure sharing.

Huawei believes that future mobile services can operate in bands above 24 GHz under several different scenarios. These include independent operations (i.e., exclusive use of mmW spectrum assignments) and/or in-concert (“complementary”) with other wide-area mobile network frequency spectrum (e.g., as a “supplementary component carrier” in lower 6 GHz wide-area networks). As a practical matter, due to the small size of the mmW cell coverage in comparison to the lower-frequency wide-area coverage mobile systems, in some cases it may be advantageous for user devices to receive information via the wide-area mobile system to avoid the need for device scanning of multiple wide bands to determine if mmW service capability is available at their current location. Huawei also believes that mobile system backhaul links and broadcast services-to-mobile devices may be self-contained utilizing mmW frequencies.

A. Base Station Antennas

As to the development of antenna technologies to support mobile services in the mmW bands, Huawei believes they will include (directive) array antennas and perhaps also forms of traveling wave antennas. The directive array antennas will have many elements (i.e., >64 at the access node and ~10-20 at the mobile device, initially). These antenna arrays may eventually be operated in beamforming, multiple-input and multiple-output (MIMO), and possibly other modes to help concentrate radio signals at the desired device and reduce interference with other nearby mobile system operations. Further research and experimentation on such technologies is ongoing. While antenna technology and design will continue, some mobile equipment operating

\[9 \text{ See NOI at ¶¶ 19-22.}\]
in the 60 GHz bands is becoming available and will likely form the basis for future mmW systems in the short term and beyond.

The antennas used at the mmW base stations for mobile services will develop over future years and their configuration may vary depending on the actual frequency band(s) of operation. While various base stations may be used indoors or outdoors, it is likely that in both cases the expected cell sizes will be small (i.e., > in the order of 100 m maximum range). Also, given the temporal variation in propagation due to obstructions and environmental reflections, terminal motion, foliage, snow coverage, etc., operating very small beams may be challenging due to difficulties in site acquisition and dynamic tracking in the mobile environment. While large arrays that have potentially small beamwidths may be developed, alternatively, they may be configured for multiple wider beams (i.e., broad beam for acquisition and signalling, and a small beam for tracking and high-rate throughput).

For mobile services, limits of propagation and obstruction at these mmW frequencies will diminish the practicality of mmW systems to low level small cells, both indoors and outdoors. Therefore it is less likely that there will be a range of low and high power base stations used for mobile system access in the mmW bands. The smaller overall size of both the mmW base station and antennas will lead to a more practical arrangement in which the power amplifier (“PA”) is coupled either directly to the antenna or is integrated with the antenna mounts.

Huawei believes that future systems will make use of variable transmit power, both for individual elements and collectively, as a means of managing interference among groups of co-located or adjacent cells. Dynamically reducing the transmitter power to a level that is sufficient to reach the directed mobile device may be beneficial in reducing co-channel (or adjacent channel) interference within the cell and neighboring cells. If more elements of the array are
used for operation, the additional elements may increase the aggregate transmitter power in some scenarios but not in all scenarios. The multi-element array antennas may be operated in modes in which the elements are used to increase the directionality of the antenna in some cases (but with constant power), and in other cases the multiple elements may act to increase the radiated power.

B. Mobile Station Antennas

Huawei believes that antennas in mobile stations (“handsets”) will occupy as much space (“volume”) as can be found in the interior of users’ handsets. This constraint is common with current handsets. These considerations are primarily influenced by overall size and the relative volumes occupied by batteries, displays and keyboards—the largest items in the device. While the antenna size is preferably chosen based on the wavelength (i.e., with lower frequencies/longer wavelengths utilizing larger antennas), in practice the antenna or antenna array is usually made as large as possible to fit in the handset for any frequency. Generally, as handsets must operate within multiple frequency bands, they already include multiple antennas ranging in frequency from 600 MHz to 5.8 GHz.11

The practicality of the antenna(s) in the device is, and will be, one of the limiting elements in the performance of handsets in the mmW bands (as it is in all bands). While the number of elements in an array in the handset may be one design element, in practice it is the

---

10 See NOI at ¶¶ 23-26.
11 As has been noted in other discussions (see In the Matter of Expanding the Economic and Innovation Opportunities of Spectrum Through Incentive Auctions, GN Docket No. 12-268, Report and Order, 29 FCC Rcd. ¶¶ 22-39 (2014)—the 600 MHz band plan for mobile services), antennas are limited in the percentage bandwidth for which they are effective. A single antenna spanning 600 MHz to 5.8 GHz is not practical and hence, handsets generally include an antenna for each band of operation (although in some cases it is possible to “double tune” an antenna structure to cover two bands). Similarly, a single tuned antenna or antenna array to span all the bands above 24 GHz is not currently practical.
coupling of the antenna with other parts of the handset, including other antennas, and the interaction with the user’s hands, body and the environment that actually determine real world performance. These design issues will become better understood and addressed through continuing design and research. These developments, including adaptive features and protocols, will ensure that both the antenna and the associated radio air interface include adaptive features and protocols that enable mobile handset connectivity to be maintained throughout normal handset use.

The incorporation of the mmW bands into service will require additions and changes to the handsets. But these are not really “architecture” changes as handsets already accommodate multiple bands and radio systems ranging from Wi-Fi and 2G, to 3G and 4G systems. Adding 5G mmW capability is another incremental feature that will be justified by the improved performance (throughput) and system capacity offered by the 5G mmW channels. The LTE MIMO implementations and the 5G beamforming for mmW are not without their challenges and will require some additional arrangements. Generally, however, these will be confined to the RF processing sections and antennas used for each band. In our view, these modifications would not be considered a “new” architecture for handsets.

C. Operation

In an mmW multi-layer architecture, there are many ways that a user’s mobile device may detect and connect to a local base station or access point. Similar scenarios occur for initial contact in lower frequency mobile systems that make use of directional antennas. Typically, to acquire a supplementary component-carrier, the handset will receive information about the contacting protocol including appropriate frequencies, identification codes and time-
synchronization of contact from the wide-area network or a geographic database. The mmW network base station will be conditioned to have an acquisition phase during which it may utilize a wide beam, or perhaps a scanning beam, to acquire the new handset. When the initial contact is made, the base station (and perhaps the handset) can negotiate to focus and direct their beams to enable full communications. While this process may be facilitated by the information passed by the wide-area system, other protocols permit the direct detection of the mmW base station or access point through the periodic use of broad-beam paging and acquisition phases by the mmW systems.

There are several approaches for seamless handoff between cells. In some cases the data flow may be transferred to the wide-area network facilities while the handoff of the mmW channels is completed and the traffic moved back to the mmW channels when the handover is complete. In a multi-layer network, it would be advantageous also to make use of the wide-area network to communicate for assistance with the handoff. These techniques are sometimes used in existing networks at lower frequencies. However, handoff may be completed without such assistance given that for many data services, an interruption of a few milliseconds is considered acceptable (and still perceived by the user as “seamless”).

Handoffs between indoor and outdoor environments, which often involve multiple doors and corridors, are a challenge for any system. There may be interruptions in coverage as the user passes through these areas and sometimes the indoor and outdoor systems are attached to different networks (or sub-networks). Similar solutions that are used in the lower frequency bands will facilitate such handover for mmW systems. In some cases there may be user imperceptible interruption to data flows as the indoor and outdoor facilities orchestrate the service transfer.
Huawei believes the mmW networks will utilize similar techniques and RF/baseband signal processing as are used in lower frequency bands to address the multipath and diffraction interference (with suitable parameter amendments to account for the more rapid mmW time scales of fading and reflection). It is to be expected that as antenna beamforming techniques become more proficient, the beams may be directed adaptively to minimize the effects of multipath and reflection. In practice, some of the initial systems may make use of simpler modulation schemes that are more resistant to such (multipath) effects.

D. Bandwidth, Duplexing, Modulation, and Network Architecture\textsuperscript{13}

5G systems are being designed to achieve maximum data throughputs up to 10 Gbit/s and at least 100 Mbit/s performance at the cell edge with a maximum latency of no more than one millisecond. Achieving these performance goals, Huawei believes, will require contiguous channel bandwidths in excess of 1-2 GHz available within each access network. The mmW radio equipment should support operation over several GHz of contiguous bandwidth. The wide contiguous bandwidth needed to support very high user throughput up to 10 Gbit/s is the principal reason for developing the new systems to operate in the mmW bands; without the availability of sufficient contiguous bandwidth, the service goals of the 5G systems will not be achieved.

Huawei believes that aggregation of multiple separated smaller blocks of spectrum for 5G services will not be practical to achieve channel bandwidths in excess of 1-2 GHz. At least one of the major practical issues is the filtering required to isolate and protect against interference from services that may be using the intermediate spectrum blocks. Multiple PA and antenna/filters are needed on the transmit side and multiple filters on the receive side to suppress the

\textsuperscript{13} See NOI at ¶¶ 30-39.
intervening signals. If the intervening signals are strong, they may completely overpower the desired signals in intermediate channels, and thus block the use of the aggregated spectrum. A further consideration for aggregation of separated spectrum blocks is that the group of blocks must be within the bandwidth capability of the mmW antenna which typically will be less than roughly 10 percent of the center frequency of operation. Being able to utilize significant contiguous blocks of spectrum to achieve the use throughput of ~1 Gbit/s (or more) is the principal reason for configuring 5G systems to operate in the mmW bands where such continuous channel bandwidths may be available.

Historically, modulation schemes have evolved through development, deployment and experience over time. Huawei believes it is likely that initial systems incorporating mmW bands for mobile use will follow a similar course and initially use simpler modulation and coding schemes as implied in the NOI. Some 5G services or devices (e.g., M2M, sensors) that are size and power constrained may continue to use simple modulation schemes. The high throughput services, however, will likely evolve to use adaptive techniques enabling use of a multiplicity of modulation schemes—ranging from simple to more complex—chosen to suit the momentary propagation conditions and the desired user service. Huawei notes that there is already ongoing development of adaptive, more complex systems for the 60 GHz band that will accelerate the timelines and reduce the cost for availability of future systems across the other mmW bands.

Because of the potential diversity of systems/service that may be deployed in future mmW systems, Huawei believes an amalgam of different 5G technologies will be deployed. These may range from single simple antennas to complex multi-element arrays; from simple constant-envelope modulation to complex multi-state modulations; and from low data rates through to the highest data rates possible. In light of the variability in the propagation
conditions, most systems are expected to be adaptive and change their operations to suit the local and instant conditions for desired user services. Huawei believes the dynamic adaptive capability of the radio systems and the variety of services and levels of technology complexity that may be simultaneously operating in the mmW bands should be taken into account in the adoption of rules.

With respect to network architecture, Huawei believes that the small size of the mmW mobile cells and the very large numbers needed to be deployed (together with backhaul) for ubiquitous service coverage suggests that a variety of deployment models are likely to be adopted. A possible introduction of mmW services to users may occur through the inclusion of areas of mmW cells within operators’ networks in a deployment manner similar to that of hotspots. While still a significant challenge, the plans for the 5G networks include potential connection of base stations and subtending radio access in a single “flat” network which, together with self-organizing-networks (SON) capability, make the addition of cells to extend coverage (with massive small cell deployment) more readily possible. Within buildings and in areas of lower traffic density, other parties may install the mmW stations that are connected to the mobile networks in a hybrid model.

E. Frequency bands

5G systems are being designed to achieve maximum data throughputs of up to 10 Gbit/s and at least 100 Mbit/s performance levels at the cell edge with a maximum radio transmission latency of no more than one millisecond. Achieving these performance goals will require contiguous channel bandwidths in excess of 1-2 GHz available within each access network. The mmW radio equipment is expected to support operation over several (many) GHz of contiguous

---

14 See NOI at ¶¶ 46-87.
bandwidth. As previously noted, the wide contiguous bandwidth needed to support very high user throughput up to 10 Gbit/s is the principal reason for developing the new systems to operate in the mmW bands. Without the availability of sufficient contiguous bandwidth, the service goals of the 5G systems will not be met.

Over time, all of the factors identified in the NOI as being relevant to the choices of frequency bands above 24 GHz (i.e., required bandwidth, propagation, availability of electronic components, antenna designs and costs of deployment, and others) are important to the choice of suitable mmW frequency bands. Given the objective for 5G systems that very high throughput services are to be supported for mobile device links (e.g., > 1 Gbit/s), wide bandwidth systems (> 1 GHz bandwidth) will be necessary. The most advantageous mmW operating bands may thus be those where bandwidths in excess of 1 GHz can be assigned.

To the extent that all mmW bands have propagation characteristics largely limited to line-of-sight, Huawei believes the bands discussed in the NOI are all technically suitable. The lower frequencies may be slightly preferred due to reduced losses and penetration, but are disadvantaged by smaller available bandwidths. The upper bands have somewhat higher RF losses but may also benefit from increased specular reflections that may provide some in-fill. The higher frequency bands also provide the opportunity for assignment of suitably wide channel bandwidths. While the lower bands may benefit initially from slightly lower costs of devices and reduced RF losses, these benefits will decrease over time as new designs and devices are developed. The development and availability of mmW devices for all of the bands above 24 GHz will benefit from the experience of developing devices for use in the 60 GHz band for unlicensed or equivalent systems.
While a global consensus is forming that 500 MHz to 1 GHz bandwidth of additional spectrum is needed for mobile services, spectrum band availability by region and local rules that govern usage must be addressed. To meet the additional spectrum requirements for 5G, Huawei strongly believes that spectrum assignments, including those in the mmW bands, must be harmonized globally. This will both facilitate the interoperability of 5G devices across geographic regions and ensure that there are economies of scale for manufacturers producing needed 5G equipment and devices. Recognizing that the spectrum harmonization process is lengthy and complex, Huawei believes that early attention to global harmonization of spectrum bands for 5G services will both ensure a more efficient process and facilitate the more rapid development and deployment of 5G network technologies and devices.

F. Licensing Schemes

High-throughput mobile services utilizing mmW systems will typically be provided where there is a high density of users, such as indoors or in dense urban settings. When coupled with the short line-of-sight propagation practicality, the systems will be deployed locally, indoors and within the “clutter” propagation region. Thus the high density of base stations may preclude the assignment of individual licenses for each station. A form of area licensing based on local population and geography may be appropriate. Further, the coordination of spectrum assignments and use among incumbent users and new mobile services will be aided by the rapid deterioration of signal strengths in the local clutter or indoor environments. A form of licensed shared access (“LSA” or sometimes Authorized Shared Access, “ASA”) and, in some cases, unlicensed deployments may be appropriate. It is expected that protocols already in use for

---

15 See NOI at ¶¶ 88-102.
16 Because of the line-of-sight limited propagation of mmW systems, cells in different rooms or beyond street corners will be sufficiently isolated to permit operation with minimal mutual interference.
multiple-access mobile systems may provide the ability of multiple systems to coexist with, or share, spectrum within similar geographic area.

IV. Conclusion

5G is the next frontier of innovation for the wireless industry and the broader ICT ecosystem. Huawei is at the forefront of initiatives to drive 5G technologies forward and is committed to collaborating openly and extensively across the global ICT industry to make 5G a reality. While many issues and challenges need to be resolved—including the availability of spectrum for 5G mobile service and network architecture engineering to support high data volumes and transmission speeds—Huawei is already at work to tackle those challenges. We welcome the opportunity to do so with the Commission and all other stakeholders as this and related future 5G proceedings progress.

Respectfully submitted,

HUAWEI TECHNOLOGIES, INC. (USA) AND HUAWEI TECHNOLOGIES, LTD.

Dr. Wen Tong
Huawei Fellow
Head of Wireless Research
Head of Communications Technologies Laboratories, Huawei 2012 LAB

Timothy Jeffries
Director
Standards—North America Regulatory & Policy

Dennis J. Amari
Director
Federal and Regulatory Affairs
875 15th Street, NW, Suite 825
Washington DC 20005
(202) 289-6510
dennis.amari@huawei.com

January 15, 2015
APPENDIX TO

COMMENTS OF HUAWEI TECHNOLOGIES, INC. (USA) and
HUAWEI TECHNOLOGIES CO., LTD.

5G: A TECHNOLOGY VISION

WHITE PAPER
HUAWEI TECHNOLOGIES CO., LTD.