QUALCOMM

Qualcomm Technologies, Inc.

Ofcom consultation on

"Spectrum above 6 GHz for future mobile communications"

Qualcomm Response

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Qualcomm welcome Ofcom consultation on "Spectrum above 6 GHz for future mobile communications".

Wireless services make a leap approximately every 10 years with a new generation of services. 1G, which was introduced in the 1980s, brought mobility to analog voice. 2G introduced the benefits of digital voice globally and laid the foundation for mass communication in the 1990s. 3G provided improved data capabilities around the turn of the century and introduced true mobile broadband connectivity, which exploded with the introduction of the smartphone. In 2010, 4G services expanded mobile broadband connectivity with higher data rates and more capacity. In the smartphone era of today, mobile is driving new experiences like wireless 4K Ultra HD video, and brand new mobile data services are being introduced each week. Thus, it is not surprising that mobile device sales have overtaken personal computer sales, and mobile computing is expanding well beyond smartphone applications into the Internet of Everything ("IoE").

Qualcomm believes that 5G mobile services will transform societies and industries to an even greater extent than previous service generations. 5G mobile services will provide more than much higher data rates. 5G connectivity will create new services, new industries and devices, and empower brand new user experiences via support of ultra-low latency, ultra-low power, ultra-high reliability and ultra-high security devices with flawless connectivity. Over the next ten years during which 5G services begin to be released, devices will be transformed into a wider variety of form factors and capabilities at a much quicker pace. As a result, when compared to 4G services, 5G services will introduce much broader dimensions of improvements to meet our growing connectivity needs. To provide these new capabilities and communications needs, it is important to begin work today on defining the scope and capabilities of 5G services, which is what Qualcomm and its wireless industry partners are doing.

Thus, OFCOM's release of this consultation is timely indeed. While 4G LTE and LTE Advanced will continue to evolve to their full potential and be deployed well past 2020, it is important for the industry and regulators alike to start moving forward with 5G efforts so that 5G services can begin to be deployed around 2020.

Qualcomm view is that 5G services will use high-band, mid-band, and low-band spectrum to support and seamlessly unify the technologies that today are part of the 4G ecosystem, such as LTE Broadcast, device to device discovery via LTE Direct, and LTE in unlicensed spectrum, while providing significant performance improvements over 4G across all geographies. To achieve this vision, 5G services need scalability and adaptability across a wide variation of use cases and requirements — from mission-critical applications like remote controlled vehicles and medical procedures to less time-critical communications from *miniaturized* sensors and other M2M devices.

Qualcomm envisions 5G services to deliver unparalled forms of connectivity, not just in terms of capacity, data rates, and latency, but also in terms of the mode of connectivity (i.e., device to device, mesh, etc.), and the support of new device types, including drones, robots, and other industrial machines. 5G services will enable use cases that are not even imaginable today as supportable by traditional cellular technology. To scale for billions of connected things and enable instant experiences, we need a user-centric approach—around human, machines, things—one that will bring content, connectivity and computing close to the user. The user-centric connectivity means that devices are not just end-points; they are an integral part of the network with new ways of connecting– to form a truly edgeless connectivity. .

Qualcomm expects that 5G services will be supported by a unified air interface and enable low-cost and highly energy efficient operation across all spectrum bands including the bands above 6 GHz. The millimeter wave bands present an important opportunity to open up large contiguous blocks of spectrum to help meet today's surging mobile broadband data demands, particularly in major metropolitan areas and event venues where large populations of mobile users are concentrated. 5G services, however, will need to use more than just these millimeter wave bands to support a superior and more uniform quality of user experience ("QoE") with ultra-low latency and ultra-high throughput across all locations and to all devices. Additional sub-6GHz spectrum will also be needed.

Therefore, Qualcomm applauds OFCOM initiative on the millimeter wave bands for mobile broadband use and would like to highlight that it is equally important to find spectrum below 6 GHz that will be an important building block for 5G.

The amount of low-band spectrum available for 5G services needs to be great enough so that the 5G QoE is much better than 4G (which is already excellent) in all areas including areas where there is no millimeter wave coverage.

Qualcomm expects 5G services to take advantage of new spectrum opportunities that will become available beyond 2020 and include 2G/3G/4G re-farming and millimeter wave spectrum.

Question 1: Are there practical ways of achieving the very high performance that use of wide channels above 6 GHz could offer, for example using carrier aggregation of lower frequency bands?

There are two aspects of high frequency bands that offer benefit: large bandwidth for high peak rates and dense spatial reuse resulting from the natural isolation from narrow beams in space. Methods that could be considered for increasing peak rates and capacity for lower frequency bands include (1) Use of a very large number of antennas at the base station (e.g. massive MIMO) and (2) Carrier aggregation over fragmented lower frequency bands. However, there are some limitations in these cases. The longer wave length at lower frequency bands could make the needed MIMO array very large and, both features, could make the receiver (radio and digital) more complex. While there exist methods that could potentially increase the lower frequency throughput, they also come with their own challenges.

Question 2: What recent or emerging advances in technology may provide effective solutions to the challenges in higher frequency bands? For example can increased propagation losses be mitigated by using the high gains available with massive MIMO?

Beamforming using multi-antenna arrays is a potential method to mitigate the poorer path loss at higher frequencies. This requires larger number of elements in the antenna array than is typically used in lower frequency, but the smaller wavelength also allows for these arrays to be fit in practical physical dimensions. There has been tremendous progress in development of CMOS based electronics, improved efficiency for power amplifiers, high-speed data converters and digital processing to handle complex algorithms related to dynamic beam steering and processing large sample and data rates.

Question 3: Are there any fundamental/inherent frequency constraints of the 5G technologies currently being investigated with regard to:

a) minimum contiguous bandwidth per operator? Will the spectrum for multiple operators need to be contiguous (i.e. a single band) or could multiple operators be supported through multiple bands?

While there is no fundamental minimum bandwidth requirement, channelization of at least 100 MHz or higher would make the offering of rates and services compelling to operators and end-users for adopting this technology.

Using non-contiguous bands for different operators may have issues with the requirement that the RF/antenna hardware design should work well around both center frequencies. Including multiple antenna modules and associated RF in an end-user device could add cost and complexity.

b) frequency range over which the technologies are expected to be able to operate, for example due to propagation, availability of electronic components, antenna designs and costs of deployment? For example, is 10-30 GHz better or worse than 30-50 GHz and why?

In general the propagation in lower frequencies tends to be more robust due to, for example, better propagation around obstacles (e.g. diffraction losses get worse at higher frequencies). In terms of implementation as well, there are lower losses in RF components/feeds, more efficient power amplifiers etc. at the lower bands. The spectrum at 30-50 GHz can also be useful for mobile use. It is possible that the ability to fit in more antennas at the higher frequencies make it possible to achieve higher beamforming gains to overcome the additional losses. Higher bands tend to have more available bandwidth as well. At this time, we believe that OFCOM should not limit number of potential bands for mobile broadband communications.

Question 4:

Will 5G systems in higher frequency bands be deployed, and hence need access to spectrum, on a nationwide basis or will they be limited to smaller coverage areas? And if so, what sort of geographic areas will be targeted?

Qualcomm view is that 5G services in bands above 6 GHz will supplement 5G operations in lower bands to provide ultra-high-speed broadband where data demands are high in specific areas. Qualcomm is investing heavily in the development of advanced mobile technologies, and believe that wide channels available in these higher spectrum bands will be needed to support growing traffic demands, particularly in dense urban areas and many event venues, both indoors and outdoors. However, with time, the demand for such high data rates may become common in all areas of use. The user's expectation of managed and homogeneous quality of experience may dictate a benefit to nationwide licensing.

5G operations in these bands will also need to access lower band spectrum (*i.e.*, below 6 GHz) to provide ubiquitous coverage in a cost effective manner. Coverage using the millimeter wave bands may have regions of outage due to the geometric nature of signal propagation, and access to lower frequency bands will be essential to making overall system operations more robust and reliable.

Users in many cases will connect to the network through lower band spectrum and then access the millimeter bands as needed where those bands are available. It also will be possible, however, to directly access the network via millimeter wave network infrastructure. Given the wide bandwidths that are available above 6 GHz, user devices and base stations can use highly redundant transmissions (or directed identification signals) for device discovery to overcome higher path loss.

Handoffs between sites operating in millimeter wave band spectrum would rely on measurement procedures, similar to what is used in cellular networks today, except that the directional nature of this higher band spectrum will need to be accounted for. Handoffs between indoor and outdoor base stations present challenges because indoor-outdoor penetration losses are generally higher at higher frequencies. Also, broadcast type operations will continue to be best supported by lower band spectrum due to its inherent omnidirectional transmission capabilities.

Question 5:

a) **To what extent will 5G systems in higher frequency bands need dedicated spectrum on a geographical and/or time basis or can they share?**

Qualcomm believes that Ofcom should consider clearing bands above 6 GHz for mobile use, to the greatest extent possible, because it may be too restrictive to require new mobile use of these bands to protect current incumbent users and this could limit the feasibility of supporting mobile services in millimeter wave frequency bands.

At the same time, Qualcomm believes that it is worth exploring technical and regulatory tools that may be used to protect current incumbent users. For example, due to the narrower beams that are possible in the bands above 6 GHz, the interference to incumbent users can potentially be more easily controlled and thus support new sharing scenarios.

Additionally, a licensed spectrum sharing framework such as LSA (Licensed Shared Access) could play a useful role to free up spectrum for mobile use while protecting incumbent use.

b) If they can share, what other types of services are they likely to be most compatible with?

Directional setups – links like fixed backhaul and/or satellite communications that are directionally limited could potentially coexist with mobile links in higher frequencies which are also spatially constrained – specific use-cases need to be studied to see if the spatial domains of the services can be made non-interfering.

c) What technical characteristics and mitigation techniques of 5G technologies could facilitate sharing and compatibility with existing services?

Qualcomm believe that advanced antenna designs coupled with the directional nature of transmissions in the millimeter wave bands can facilitate coexistence with incumbents. The narrower beams that can be generated in bands above 6 GHz could help limit interference to incumbent users of the band. Antennas that operate in millimeter wave spectrum can use beamforming to generate thin beams, and may be steerable in both azimuth and elevation. These antennas can reject interference from all directions other than the desired direction, allowing for much more intensive frequency reuse than is possible with lower band spectrum.

Qualcomm has found that base station antenna arrays with many elements, *e.g.*, from 16 elements to 256 elements, are possible in these bands, with each individual element having some gain. Patch antennas can have 5-6 dB gain per element, and column antennas with fixed elevation can have 15 dB gain per element. However, each antenna element that needs to be individually controllable would require its own Power Amplifier ("PA"). In order to provide a desired level of connectivity to a mobile device, antenna arrays may use varying beamwidths and have multiple antenna subarrays that can be turned on and off as needed.

Additionally, medium access control schemes could be employed to recover or avoid interference in specific scenarios.

d) Could spectrum channels be technically shared between operators?

In principle, sharing may be possible. However, the standards/techniques have to be developed for such joint operations. For example, certain restrictions may need to be placed on timeslot configurations between operators in TDD, overcoming near-far problems if another operator’s user happens to be closer to the alternate operator’s base station etc. Aspects related to medium access control (including medium sensing for example), co-ordination and restrictions on directionality may need to be investigated to realize sharing in practice.

Question 6:

a) Given the capacity and latency targets currently being discussed for 5G how do you anticipate backhaul will be provided to radio base stations? Are flexible solutions available where the spectrum can be shared between mobile access and wireless backhaul?

The millimeter wave bands could be very well suited for backhaul. In fact, a number of these bands already support point-to-point microwave links. 5G operations in these bands may be able to seamlessly integrate and dynamically share spectral resources in a single band between mobile access links and backhaul links[1].This deployment scenario would be particularly useful for mesh-relaying due to the shorter transmission ranges that the millimeter wave band spectrum supports. While millimeter wave band spectrum can be used to backhaul small cells that provide mobile connectivity using sub-6 GHz band spectrum, networks deployed with integrated access and backhaul can lower deployment costs and operating costs of maintaining backhaul and access networks that use different technologies.

Indeed, the ability to use high-gain antennas at both ends of the fixed link make these bands attractive for backhaul use for it provides a transport network that is convenient to deploy and has higher capacity than the access network. However, in contrast to using these bands for access, where link failover to lower bands may be tolerable from the end-user perspective, backhaul use needs to be substantially more tolerant to link failures due to propagation and misalignment issues, among other technical challenges. Support of such robustness can be addressed through flexible regulations and technology innovation.

b) What, if any, spectrum will be required? What channel sizes will be needed? Will the bands used be similar to those currently used for wireless backhaul?

[1] Techniques such as SDMA and full-duplexing, in addition to inter-cell co-ordination and scheduling can support for flexible use between mobile access and backhaul.

Qualcomm believe it is premature to say at this time.

Question 7: Should we expand the scope of bands being reviewed beyond the 6-100 GHz range?

It is difficult to say at this time if bands above a 100 GHz could be considered. One approach would be to first deploy in bands lower than 100 GHz initially as this could prove out technologies and also grow ecosystems to lower cost, allowing for a migration to bands higher than 100 GHz. On the other hand, for short-range, line-of-sight situations, bands above 100 GHz could be contemplated right away, provided devices can be made at reasonable cost/power.

Question 8: Do you agree that it is likely to be necessary for bands to have an existing allocation to the mobile service? Does this need to be a primary allocation?

Qualcomm agree with Ofcom to consider, first, bands that have already an existing global primary allocation to the mobile services. Qualcomm agree with Ofcom that the objective of a future WRC agenda item would be to harmonize these for mobile broadband applications, for example by identifying them for IMT in the Radio Regulations. Only bands that are internationally harmonized are likely to be economically viable for the delivery of mass market mobile data services. Moreover, the fact that a band is not yet allocated internationally to the mobile service is not necessarily a constraint. This is because there may be opportunities over the coming years to build international consensus over allocating additional bands. However, harmonizing bands with an existing mobile allocation for mobile broadband applications is likely to be easier than for bands where a mobile allocation does not yet exist. Furthermore, Qualcomm agree with Ofcom that a 1 GHz minimum bandwidth is an appropriate criterion for initial filter of bands in the millimeter wave range of spectrum based on the expectation that higher bandwidths would be needed to achieve significantly increased data rates. That said, for the lower parts of the frequency range, narrower bandwidths than the initial selected criterion of 1 GHz could be considered at some point in time and should not be completely ruled out.

Question 9: Do you agree with the criteria we have used for our initial filter of bands, and are there other criteria that could also be used?

Qualcomm agree with the criteria set by Ofcom for initial filter of bands above 6 GHz. Ofcom should favor global harmonization in the millimeter wave bands used for mobile operations where possible because it lowers equipment costs, particularly antenna and RF transceiver complexity, and also offers end users a more predictable QoE when traveling[2]. At the same time, the desire for global harmonization should not stop Ofcom from taking action to define a new mobile service in the identified millimeter wave bands at the regional level despite the fact that other regions might not have plans to do so; setting rules to support mobile operations in the millimeter bands will help to spur innovation, which is clearly in the public interest.

Question 10: Of the spectrum bands/ranges mentioned in this section, are there any that should be prioritised for further investigation?

Question 11: Are there any bands/ranges not mentioned in this section that should be prioritized for further investigation? If so, please provide details, including why they are of particular interest.

Questions 12: Are there any particular bands/ranges that would not be suitable for use by future mobile services? If so, please provide details.

Question 13: What additional information, beyond that given in Annex 5 would be useful to allow stakeholders to develop their own thinking around spectrum options?

Question 14: What are the most important criteria for prioritizing bands going forward?

Qualcomm believe that the following criteria could be used for prioritizing bands going forward:

- Pathloss/Link budget that is achievable in different bands as well as availability of contiguous large chunks of spectrum in large number of geographical areas should be included in the set of selection criteria, in addition to Performance/Cost of RF/hardware components in the band (e.g. PA efficiency).
- Scope for global harmonization

2 The air-interface definition at baseband, network architectures and procedures can be made mostly band agnostic. 4G LTE has provided a precedent for defining scalable bandwidths, and 5G interfaces can implement a similar approach. Efforts should be aimed at providing large blocks of contiguous spectrum because it lessens device complexity, size, and cost.