Ofcom Call for Input (CFI) – “Spectrum above 6 GHz for future mobile communications”

CFI Publication Date	16th January 2015
Response Closing Date	27th February 2015
Lead	Graham MacDonald
Document Date	27th February 2015, Rev-FINAL

Intel Response: Ofcom Call for Input (CFI) Questions

Introduction and Summary

Note: In this context where Intel refers to “mmWave” we mean “spectrum above 6 GHz”.

Intel Corporation (“Intel”) respectfully submits this response to Ofcom’s Call for Input “*Spectrum above 6 GHz for future mobile communications*”. Intel is a leader in designing and building the essential technologies that serve as the foundation for the world's computing and communications devices. Intel supports policies enabling high-quality, affordable broadband, including increased access to licensed, license-exempt and licensed shared spectrum frequency allocations for mobile communications use. Intel has led several efforts in millimetre wave (mmWave) technology, most notably in IEEE 802.11ad, and as president and chair of the Wireless Gigabit Alliance (WiGig), which is now part of the Wi-Fi Alliance. Intel has announced and demonstrated WiGig-based products operating in these higher frequencies that will be shipping in 2015.

The need for higher peak data rates, more bandwidth (especially during the busiest hour, which is growing faster than the average hour), reduced latency, and higher sustained throughput are some of the key drivers for the next generation wireless access networks. Intel supports access to mmWave frequency bands for mobile applications as well as assisting peak period congestion relief in densely populated locations, connected homes and cars, and also M2M/IoT (Machine-to-Machine / Internet of Things) applications.

If a new Agenda Item for WRC-19 is adopted under WRC-15 Agenda Item 10, the ITU-R will undertake analysis to determine suitable candidate mmWave bands as part of WRC-19 preparation processes. In that case, we advise against creating another ITU Join Task Group (JTG) like structure for future conference agenda items as we believe the JTG was costly and was not a conducive environment within the ITU for discussions. Intel supports initiatives to assess the viability of possible frequency bands and applauds Ofcom in seeking input from Industry. This initiative by Ofcom will assist influence the harmonisation process and the potential outcomes of the ITU-R, WRC-15 and WRC-19.

Intel maintains its position of support for technology and service neutrality in relation to any new spectrum allocations in higher frequency bands. Intel believes Ofcom should strive to provide such flexibility through its advocacy efforts in the development of least restrictive regulatory requirements.

Intel would like to re-iterate our support for additional allocations/identifications for IMT at WRC-15 under Agenda Item 1.1 for frequency bands below 6425 MHz in order to meet the increasing demands for mobile broadband applications. Intel believes it is crucial to make available spectrum in particular below 6 GHz in the near-term while securing access to spectrum in higher frequency bands above 6 GHz in the longer-term (e.g. WRC-19).

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?

Intel Response

Intel believes that wide, contiguous bandwidths are desirable to meet the service and application requirements of 5G users. Peak data rates of 20 Gbps for fast download of rich content, real-time video streaming, cloud services, etc. are anticipated. Multiple channels are required to meet these data demands and to allow for contention avoidance. It should be noted that 2 GHz wide channel implementations are already available for IEEE 802.11ad devices.

Carrier aggregation across non-contiguous bands is already part of existing 4G standards and such an approach could be leveraged to offer seamless user experience across low carrier frequency and higher carrier frequency bands. As Ofcom notes, “*However, there are likely to be technical constraints, which in practice limit the number of channels that can be aggregated efficiently in a mobile device.*”.

Carrier aggregation across even a few frequency bands has already introduced substantial complexity for RF design due to requirements for sharp filters, blocking characteristics, etc., as well as standardization and testing of various band combinations. Such challenges are more severe at higher frequencies therefore non-contiguous band allocations at higher frequencies are less desirable.

Intel does not believe that carrier aggregation of lower frequency bands alone will provide the necessary date throughputs to meet the service and application requirements of 5G users. In the CFI Intel notes that “*Ofcom has already identified possible bands below 6 GHz for future mobile services, including 5G, as part our Mobile Data Strategy, but large blocks of spectrum are difficult to find at lower frequencies. Therefore higher frequency bands, e.g. above 6 GHz, are also likely to be important.”* Intel concurs.

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?

Intel Response

Intel’s leading research and development is addressing the challenges associated with deploying mobile broadband in higher frequency bands. Areas of technological developments are in antenna arrays, power amplifiers, low noise amplifiers, and multi-element antenna arrays providing beam forming etc. Intel does not envisage major barriers to hardware design at these higher frequencies since we do not see major difference between 60 GHz (WiGig) and other mmWave frequencies.

There are examples of commercial systems operating in the mmWave bands e.g. WiGig (IEEE 802.11ad) at 60 GHz, that establish the viability of short-range mmWave operation. WiGig provides the example of a wideband system (2 GHz bandwidth) deploying antenna arrays, power amplifiers, low noise amplifiers etc., operating in the 60 GHz band. This has been accomplished at bill-of-materials (BOM) costs consistent with mobile devices such as tablet and client devices. Given this established operation at 60 GHz, and the broad similarity of expected modes of operation across the mmWave spectrum, Intel anticipates the same underlying technologies can be re-applied at other frequencies, supporting a wide-variety of operational bandwidths in the 100 MHz to 1+ GHz range depending on the frequency band, channel partitioning, and mode of deployment.

As the market for WiGig develops, the underlying component development costs can be underwritten and electronic components can be made available for the mmWave bands. However, due to radio tuning range considerations at these frequencies, international harmonisation will be important.

Modular phased antenna arrays are a promising technology enabling state-of-the-art solutions for building a cost and energy efficient large-scale adaptive antenna arrays not requiring ADC/DAC per antenna element. Recent advancements in semiconductor technology processes in manufacturing RFICs for the bands above 6 GHz allow for using several different processes such as CMOS and GaAS MMIC to be used to manufacture integrated and cost effective system-in-package modules consisting of mixers, LNAs, power amplifiers and IF amplifiers.

It is well understood that in addition to the substantial path losses applicable to mmWave operation, penetration losses, and losses related to diffraction around obstacles are substantial. This means that interference between mmWave cells and devices will be limited e.g. given the building penetration losses, indoor and outdoor mmWave system deployments in the same spatial location may be subject to limited mutual interference. Similarly, mmWave systems in adjacent geographic locations will tend to be similarly interference-decoupled.

The extensive use of beam forming will localise transmissions in azimuth and elevation and will minimise mutual interference between mmWave cells and devices operating in such cells. As a result, we expect deployments to be thermal noise-limited rather than interference-limited.

Intel expects penetration losses between outdoor and indoor deployments to be significant thus these effects, when taken together, will permit substantial isolation between individual cells and between individual deployments.

Intel also expects mmWave access technology to be developed at the same time as network technologies migrate towards general information technology (IT) infrastructure that enable Software Defined Networks (SDN) and Network Function Virtualisation (NFV). This could enable the deployment of self-contained, localised mmWave access networks, controlled by local IT infrastructure and connected to the broader Internet. Also, high performance and highly efficient mmWave traffic channel set up is an essential design requirement for future mmWave networks.

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?
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?

Intel Response

Intel believes future mobile broadband systems (i.e. 5G), similar to their 4G predecessors, will need to provide a variety of services and applications. We observe that applications have varying requirements in terms of bandwidth, latency, frequency, and propagation conditions to reach optimum utilisation. As such, Intel believes a flexible regulatory framework applied across multiple 5G bands (including those suitable sub-6 GHz bands where appropriate) is best suited to accommodate the diverse and changing needs for 5G above 6 GHz.

Intel anticipates operational bandwidths from in the 100 MHz to 1+ GHz range depending on the frequency band and mode of deployment. As Ofcom noted, "*There is a direct correlation between the bandwidth of a signal and the achievable data rate.*". Although channel bandwidths of 100 MHz could be acceptable for certain applications, we believe there should be enough bandwidth available to 5G systems to ideally accommodate multiple contiguous channels of 500 MHz and even higher to simplify transceiver design. Intel believes that it would be highly advantageous for the spectrum for multiple operators to be contiguous due to a variety of factors including simplified radio architectures, minimization of transceiver chain count, and simplified adjacent channel management.

As mentioned in the introduction, Intel believes licensed, license-exempt, and licensed shared spectrum allocations have potential value for future mobile communications use. We believe that ruling out any viable frequency band options at this early stage of the analysis would not be prudent. We believe there are various mmWave bands that have the potential to be used for numerous applications that would be supported and provided by 5G thus we remain open-minded on the possibility for all bands to be considered.

Due to radio tuning range considerations at mmWave frequencies, international harmonisation will be important factor to consider. Intel believes striving for global harmonisation is an important element towards success of future 5G mobile broadband as it has been for previous generations. The benefits of economies of scale and products that could roam globally are well known. Operation on such global scale would reduce cost to consumers while at the same time promote innovation through opening global markets. It should be noted that even though progress has been made in recent years on digitalisation of RF subsystems and components leading to increasing number of radios in mobile devices, form factor constraints limits such increase through cost/performance trade-offs. As a result, it is important that mmWave bands being considered have the potential for being globally harmonised as far as reasonably possible, in order to avoid infeasible numbers of radios required within each device.

For outdoor operation where maximisation of inter-site distances is essential to minimise deployment costs, well known propagation loss characteristics (e.g. O_2 and H_2O absorption, rain scattering etc.) will tend to favour those bands with minimum propagation loss, but the likely range of coverage of a single outdoor mmWave cell (i.e. typically, 100-200m) means that successful link budgets can be established for all mmWave frequency bands. Overcoming the resulting link budget challenges will require the development and deployment of multi-element antenna arrays providing beam forming gains. Nevertheless, from our experience of WiGig, Intel believes the realisation of such arrays to be technically feasible.

Intel anticipates the interference-limiting effects resulting from mmWave propagation characteristics, penetration losses (buildings, foliage etc.) and beam forming will substantially limit interference between the devices and base stations comprising a mmWave mobile service deployment and existing or legacy deployments. These effects will reduce mutual interference between nearby uncoordinated systems or with incumbent services.

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?

Intel Response

Intel anticipates the cell size of the mmWave technology to be relatively small, and lie between 100-200m in outdoor deployments. In general, we expect base stations with both omni-directional and sectorised architectures to be deployed, with power control and beam forming providing the primary means of controlling radiated power flex density in a specific direction.

Some recent measurements point to similar path loss models for mmWave propagation in suburban and urban environments. We therefore expect that small cell deployments that are suited for dense urban areas may lead to cost-limited deployments when used in suburban areas, unless different EIRP limits are used for such deployments.

Noting the above, it is difficult for Intel to provide a definitive response on geographical coverage areas. Intel believes that Network Operators are likely better placed to clarify geographical coverage requirement.

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?
b) If they can share, what other types of services are they likely to be most compatible with?
c) What technical characteristics and mitigation techniques of 5G technologies could facilitate sharing and compatibility with existing services?
d) Could spectrum channels be technically shared between operators?

Intel Response

On the issue of protection of incumbent services, Intel notes the scope of this issue varies from band to band due to the variety and level of usage of incumbent services. However, as a general rule, sharing and compatibility studies could be conducted to assess the impact of future mobile systems in the mmWave bands on incumbent services. It should be noted that any meaningful study will require realistic scenarios and detailed information about the incumbent services e.g. deployment scenarios, and their protection criteria, as well as typical values for characteristics expected for future mobile systems.

Intel expect factors such an indoor-outdoor penetration losses associated with mmWave operation, plus interference limiting beam forming etc. to limit interference between cells/users.

There are a number of options for licensing that could be considered which relate to possibilities for spectrum sharing. There is the classical approach where spectrum is licensed by auctioning the exclusive rights to a particular geographic area. Another option is to allow forms of license-exempt usage and there is also a hybrid approach involving licensed spectrum sharing, which may include elements Licensed Shared Access (LSA). This likely needs further investigation and it may well be different between Administrations due to national circumstances.

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?
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?

Intel Response

The ubiquitous presence of user-perceived Gbps performance can be achieved through deployment of many small cells working in conjunction with the macrocell networks of the future which provide for seamless coverage and capacity. Deployment of large numbers of small cells will, however, require new and innovative ways of backhauling the data from the small cells to the nearest network nodes and to the core network.

Intel believes that fibre will likely play an important element required to provide base station backhaul and where this is not feasible, suitable wireless solutions will be required which will need to provide an appropriate level of guaranteed quality-of-service. We foresee the deployment of both indoor and outdoor base stations utilising mmWave bands not just for access but also for providing backhaul.

The presence of high-capacity wireline backhaul through optical fibre is not always guaranteed given the deployment scenarios envisaged for 5G systems. It is important to note, however, that wireless backhaul will play an integral part in the future network for all kinds of small cells, and not only those supporting 5G deployments.

In-band backhaul in mmWave bands is possible, although a dedicated backhaul apparatus that is not necessarily based on a future 5G specifications may be deployed first, including for in-band scenarios. In-band operation that does make use of an integrated access and backhaul specification has the potential for intranet work interference management and hence the optimised reuse of radio resources. In addition, using the same Remote Radio head (RRH) for both access and backhaul could avoid additional backhaul radios at each and every small cell, thus reducing the cost of network deployment.

Recent innovations in antenna array technology that enable mmWave antenna arrays, add the capability of integrated access and backhaul to 5G small cells. Small cells operating in mmWave could then support both access links to users and backhaul links to other network nodes (e.g. other small cells or macro-cells) on an as needed basis by creating different beams with varying levels in both directivity and direction.

Some of the frequency bands being considered, e.g. 28 GHz and 39 GHz, already allow fixed operation and are already being used for backhaul of various systems including commercial mobile networks. These systems are typically based on line-of-sight point-to-point links that connect a cell site to a core network node. Intel anticipates extension to support mesh architectures to be a required component of high performance backhaul.

mmWave backhaul creates a significant opportunity in the form of opening a potential new market. With appropriate emission limits which allow for higher gain antennas, it is now possible to use large antenna arrays and extend the reach of mmWave signals to levels that would sustain a reasonable link budget in distances appropriate for various types of point-to-point including backhaul operations. Recent findings in academia and industry suggest that use of antenna arrays will provide sufficient link margin and even the use of indirect paths may support reliable communication links in mmWave frequencies in non-line-of-sight conditions.

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

Intel Response
No but noting the wide range of applications envisaged for 5G, Intel would like to clarify that 5G systems are also likely to utilise spectrum below 6 GHz.

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?

Intel Response
Intel concurs with Ofcom's view that it would be preferable for bands being considered for 5G to already have a primary mobile allocation, but that "*the fact that a band is not yet allocated internationally to the mobile service is not necessarily a constraint.*".

Intel agrees that bands that are internationally harmonised are likely to be economically viable for 5G services. We concur that harmonising 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. However, if a band is identified as viable for harmonisation but has not yet allocated internationally to the mobile service, this should not necessarily remove it from consideration.

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?

Intel Response

Intel agrees that there is some merit in identifying some basic criteria to help focus the ranges of frequency bands that could be considered but we, like Ofcom, do not think such criteria should be applied rigidly thereby ruling out other options. Intel also agrees that relevant factors are "international harmonisation" and "availability of sufficient bandwidth".

Intel sees some limitations with the current Ofcom criteria for initial filtering of spectrum. While we agree ideally there should be an existing global primary allocation to the mobile service in the Radio Regulations, we also support evaluation at an ITU Regional level if this increases the possibility to secure access to suitable spectrum in higher frequency bands above 6 GHz.

Additionally, as stated above, noting the wide range of applications envisaged for 5G, Intel would like to clarify that 5G systems are also likely to utilise spectrum below 6 GHz. For lower frequency bands, the contiguous bandwidth filter could be lower.

We are supportive of Ofcom's position in so much that "*the objective of a future WRC agenda item would be to harmonise these for mobile broadband applications, for example by identifying them for IMT in the Radio Regulations*".

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

Intel Response
Intel has some concerns with an approach that tries to prioritise frequency ranges over others when in fact we are still at the early stages in identifying suitable ranges for consideration. As detailed in our response to Q11 if Ofcom were to solely focus on the ranges identified by applying their initial criteria, this would likely preclude some frequency ranges that might be considered by other Administrations.

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

Intel Response
Intel is open to having a variety of bands suggested for consideration at this point in time. We do believe global harmonisation is important in creating economies of scale but regionally harmonised bands, in cases where there are sufficiently large enough markets, are also worth considering.

That said, Intel has some concerns if Ofcom were to solely focus on the ranges that are identified by applying the initial criteria (existing primary global allocation to the mobile service and contiguous bandwidth of at least 1 GHz) since this precludes, for example, some frequency ranges that might be considered by other Administrations thereby adversely affecting the chances of securing global harmonisation. For example, we note that if Ofcom were to apply their criteria, the following frequency bands listed under the US FCC NOI would **not** be considered and we feel this has significant disadvantages especially at this early stage -

- 24.25-24.45 GHz
- 25.05-25.25 GHz
- 31-31.3 GHz
- 42.0-42.5 GHz

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

Intel Response
Intel would not, at this moment in time, discount any of the bands that have been listed by Ofcom using the initial criteria but we equally request that other bands (see response to Q11) are also not discounted. We understand the difficulty in trying to provide a certain level of specificity but we are cautious at the moment in being too prescriptive.

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?

Intel Response
Intel appreciates the information provided in Annex 5, which is useful to stakeholders.

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

Intel Response

Intel provides the following non-exhaustive points for consideration -

- Greatest opportunity for global (or at least Regional) harmonisation
- Ideally already has a primary allocation to the Mobile Service
- Sufficient contiguous spectrum
- Minimum number of incumbents or low level of incumbent usage to facilitate sharing