Response to

Ofcom's Call for Input

on

Spectrum above 6 GHz for

future mobile communications

by

Angie Communications International B.V.

February 26, 2015

Ofcom

Mr. Justin Moore

Riverside House

2A Southwark Bridge Road

London SE1 9HA

United Kingdom

Sent per E-Mail

February 26, 2015

Dear Mr. Moore,

This document contains Angie Communications International B.V.'s (Angie) official comments and response, compiled by my colleagues and myself, to the questions listed in the Call for Input on the matter of spectrum above 6 GHz for future mobile communications.

We commend and applaud Ofcom for their vision and for having the foresight to engage with the industry and market with an eye on 5G mobile communications.

As per our email communications, we had requested an extension of the deadline to reply in even more detail; we are now submitting this document in order to guarantee that you can include (parts of) it in your review.

Just a few days ago, we submitted our Reply to Comments to the FCC's Notice of Inquiry (proceeding number 14-177) in the same regard. Our reply can be found at http://apps.fcc.gov/ecfs/document/view?id=60001032477. Similar to our urging the FCC, we would urge Ofcom not to wait for technical specifications and standardization with regards to whatever 5G may be,

and to go ahead, in parallel and as soon as possible, with rulemaking with regards to spectrum above 6 GHz.

Your leadership is sought as we are not talking about evolutionary growth from 3G to 4G to 5G. Instead the utilization of mmWave spectrum will bring about a revolutionary change that will cause an outright paradigm shift in communications.

I have personally been to the Ofcom offices in 2010, 2011 and 2012 on several occasions (as part of a panel on frequencies) and also once to give a presentation on Angie's future plans. (Back then we were called iUHBA Networks).

We pride ourselves in having a great relationship with a few (smaller) operators in the UK, and we are working on a daily basis on the preparation of our launch in the UK mid next year.

A summary on Angie's upcoming project can be found at http://www.ang.ie/the-projects.html and extensive information (including the Project Book) can be found at http://www.ang.ie/news/204-pb-uk.html.

We are pleased to engage with Ofcom again, and we look forward to being part of the solution.

Yours sincerely,

Neal Lachman

CEO, Angie Communications International B.V.

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?

Bandwidth here is synonymous for "capacity". In general terms, greater capacity will be achieved mainly by three ways:

1. Utilizing technology to increase spectral efficiency: MIMO, COMP, xQAM[1];
2. Creating denser network infrastructure: the so-called Heterogeneous Network (micro cells, small cells/ pico cells, femto cells);
3. Carrier aggregation and new carrier-cooperation types.

Furthermore, on the user-end it is quite common that people switch to their Wi-Fi connection at home, work (or even in the coffee shop), which lessens the burden on the mobile operator. In these circumstances, capacity can be increased by way of channel-bonding, which in turn could be across different bands (2.4 GHz and 5GHz, and –soon enough- 60 GHz).

However, carrier aggregation[2] at lower frequencies will have a ceiling where a few Gbps speeds per sector can be reached under ideal circumstances, and that also at 100 MHz. While this is impressive, it is still far from the speeds that most mmWave bands (on their own) can achieve.

Thus, while technological improvements may overcome the challenges for channel aggregation, it is highly unlikely that it would lead to double-digit (or even in the higher region of the single-digit) gigabit

[1] See, for example, on QAM, "NEC helps operators cut backhaul spectrum lease and power costs with new 2048 QAM solutions; http://www.nec.com/en/press/201501/global_20150129_02.html; Accessed 24 February, 2015

[2] For an excellent study in this field, please refer to "Carrier Aggregation/Channel Bonding in Next Generation Cellular Networks: Methods and Challenges; Zaheer Khan et al; November 24, 2014.

speeds, even under the most ideal circumstances. As such, the world is moving towards mmWave spectrum.[3] [4]

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?

In the past five years many essential advancements have been reached by researchers from universities and industry players all over the world. Most technological challenges and shortcomings that prevented mmWave spectrum to be efficiently (or at all) used in a point-to-multipoint setups have been overcome. There is truly nothing standing in the way of great progress in communications caused by advanced mmWave technologies.

Ever since the seminal research on mobile access in mmWave spectrum by Samsung's Farooq Khan and Jerry Pi, as such presented in 2011,[5] the world began to take notice. Much has been achieved since. Huawei has been working on 5G and mmWave technology research since 2009. Huawei has a R&D budget for 5G (2013-2018) of $600M with a clear understanding that mmWave spectrum is needed for 5G mobility;[6]

Huawei listed in their 2013 White Paper on 5G several necessary essential breakthroughs needed for the development of 5G:[7]

[3] As you are aware of the MiWeBa Project, please see http://www.miweba.eu/wp-content/uploads/2014/10/CEATEC2014_Handout_1.pdf
[4] Also, see *mmWave as a key Enabler for 5G* (pp 16-20) by Wonil Roh, Ph.D; Samsung; 5G North American Workshop; November, 2014.
[5] Millimeter-wave Mobile Broadband: Unleashing 3-300GHz Spectrum; Farooq Khan, Jerry Pi; Samsung; March 28, 2011.
[6] Huawei to Invest $600M in 5G Research & Innovation by 2018; Huawei; November 6, 2013; http://pr.huawei.com/en/news/hw-314871-5g.htm - accessed 24 February, 2015.
[7] 5G: A technology Vision, Huawei. See pp. 6-7, and also see page 8 for their vision on multi-spectrum access - http://pr.huawei.com/en/news/hw-314871-5g.htm#.VO7f8PnF8e0

1. Multiple Access and Advanced waveform technologies combined with advances in coding and modulation algorithms;
2. Baseband and RF architecture to enable computationally intensive and adaptive new air interfaces;
3. Advanced RF domain processing to enable efficient and flexible usage of spectrum;
4. Integrated access node and backhaul design;
5. Radio technologies for mobile devices (miniaturized antenna technologies, extending capability of mobile devices to support certain base station functionalities).

Most of these challenges have now been overcome, have already been researched/studied in-depth or are on the verge of being developed.

Ofcom is aware of the advancements in this industry, but to list a few recent advancements:

1. Just a few days ago, it was announced that researchers from the University of Surrey achieved one terabit per second wireless speeds;[8] [9]
2. Samsung and SK Telecom are to demonstrate 7.55 Gbps data wireless transmission speeds in mmWave spectrum, using 3D Beamforming, at the MWC in Barcelona, next week;[10]
3. This speed was already shown in October 2014 (stationary), and speeds of 1.2 Gbps at vehicular speeds of 100km/h;[11]

[8] University of Surrey achieves 5G speeds of 1Tbps; V3, February 24, 2015; http://www.v3.co.uk/v3-uk/news/2396249/exclusive-university-of-surrey-achieves-5g-speeds-of-1tbps -
[9] In its update of 25 February, ISP Review reports on the specific methods of testing; http://www.ispreview.co.uk/index.php/2015/02/university-of-surrey-claims-1tbps-speed-over-future-5g-mobile-tech.html
[10] SK Telecom – Samsung Electronics to Demonstrate 7.55Gbps Data Transmission Speed at MWC 2015, February 24, 2015 - http://www.sktelecom.com/en/press/detail.do?idx=1102
[11] Samsunf Electronics sets 5G Speed Record at 7.5 Gbps; October 15, 2014, Samsung website; http://www.samsung.com/uk/news/local/samsung-electronics-sets-5g-speed-record-at-7-5gbps-over-30-times-faster-than-4g-lte

Professor Theodore Rappaport, one of the earliest researchers conducting mmWave field trials, has provided great insight and references on the current status of mmWave advancements in his Comments[12] and Reply to Comments on the USA's FCC's Notice of Inquiry in the matter of use of spectrum bands above 24 GHz for mobile radio services.[13]

We, Angie Communications, also provided some further details on specific questions in the same regard.[14]

With regards to antenna technologies, as of yet, this is still a topic of study for most of the mmWave spectrum. With regards to mmWave spectrum in the E-band, multiple antenna techniques will be essential to provide beamforming gain to compensate the inherent propagation loss.

Researchers Peng Wang et al state[15] that

> ... *"[T]he high transceiver complexity in large MIMO systems with a massive number of antennas as one of the few remaining challenging technical issues."*

and

> ... *"[E]-band transmissions suffer much more power loss than those over conventional microwave bands. For example, the propagation at 75GHz is 30dB worse than that at 2.4GHz (the operating frequency for WiFi networks). Thus to guarantee the same signal*

[12] Comments of NYU Wireless on FCC's Notice of Inquiry; Theodore Rappaport; January 15, 2015; http://apps.fcc.gov/ecfs/document/view?id=60001013346
[13] Reply to Comments on FCC's Notice of Inquiry; Theodore Rappaport; February 20, 2015; http://apps.fcc.gov/ecfs/document/view?id=60001032050
[14] Reply to Comments of FCC's Notice of Inquiry; Neal Lachman, Diepak Kasi, Gregory Nemitz, February 23, 2015; http://apps.fcc.gov/ecfs/document/view?id=60001032477

[15] Multi –Gigabits Millimeter Wave Wireless Communications for 5G: From Fixed Access to Cellular Network; Peng Wang, Yonghui Li , Lingyang Song , Branka Vuccetic; October 16, 2014. Pp. 7-12.

power (and in turn the same quality of service) at the receiver, the transmitted power at 75GHz must be 30dB higher than that at 2.4GHz. This makes the signal transmission/reception through a single omnidirectional antenna practically infeasible in E-band systems."

however

... *"[O]ne approach to compensate the severe E-band power loss is to equip a massive number of antennas at both link ends to provide a large beamforming gain… The synthesized low-cost antenna arrays can be electronically steered to provide adaptive yet highly directional links permitting a flexible deployment. In principle, the number of antenna elements that can be packed into a given aperture size is increased by four times for every doubling the operating frequency, providing about 6dB beamforming gain at each link end if these antennas are compactly located to form an equivalent directional antenna for steering a "pencil beam". To further enhance the link capacity, we need rely on multiple antenna techniques to achieve a multiplexing gain such that transmissions of multiple spatially independent signal streams can be supported simultaneously without interfering with each other."*

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 (ie 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?

a) As research by Zaheer Khan et al (see footnote 2, above) -and many others in other research- show, there are some challenges, but these will be overcome one way or the other due to daily, dramatic technological advancements.

This doesn't seem to us to be an either/or issue. It will be possible for multiple operators to cooperate and coexist in the same band and it will be possible for multiple operators to cooperate, aggregate and work in multiple bands.

b) We assume this question is asked in regards to mobile access. No, hundreds of researchers have proven that most mmWave bands have almost-similar characteristics (except the 60GHz band, but this is also subject to huge improvements). For example, it has been proven that the E-Band (namely 73 GHz) propagation and data rate characteristics do not differ much from those of the 28 GHz bands in terms of point-to-multipoint and/or mobile access.

> *... We observe that the predicted value are very close the measured values, and the path loss exponent and the shadow fading standard deviation at 73 GHz are not much worse than the NLOS values seen at frequency bands below 6 GHz.... And… 28 and 73 GHz channels are surprisingly similar, where 73 GHz are not much more lossy.*[16]

[16] Evaluation of Empirical Ray -Tracing Model for an Urban Outdoor Scenario at 73 GHz E-Band; Huan Cong Nguyen, George R. MacCartney Jr., Thimothy Thomas, Theodore Rappaport, Benny Veijlgaard, Preden Mogensen; 2014

And even then, others are of the opinion that the E-band is superior to all others:

Wang et al state: [17]

> *… The superior propagation characteristics of E-band frequencies enable this band a preference over the other segments of MMW bands. Although E-band transceivers are presented with new design challenges such as increased phase noise, limited amplifier gain and the need for transmission line modelling of circuit components, the electronics industry develops rapidly that produces component electronics with ever reducing physical sizes and power consumption.*

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?

In our case, we would recommend access on a nationwide basis. This creates an opportunity to reach critical mass, which in turn will serve economies of scale. On the other hand, the very nature of mmWave (as of yet) will mean that mobile access, while possible, will be restricted to a 200 to 400 meter range. Thus, the network characteristic will essentially be a patch-work in terms of multi-street level/area segments. The unique characteristics of mmWave will allow mesh networks for the first time to be truly successful.

Overall, while Angie has its eyes set on a nationwide rollout, we recommend Ofcom to create a liberal, enabling and facilitating environment where operators of all size could start operations. This will

[17] Multi –Gigabits Millimeter Wave Wireless Communications for 5G: From Fixed Access to Cellular Network; Peng Wang, Yonghui Li , Lingyang Song , Branka Vuccetic; October 16, 2014; pp. 7-12.

mean the creation of tens (if not hundreds) of small players, which in turn will mean more competition and thus more opportunity for the people.

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?

While dedicated spectrum would be hugely beneficial for Angie, we don't think and believe that anyone should have any dedicated spectrum or any exclusive licensing.

Ofcom should avoid future spectrum-hoarding, spectrum-speculation and other kinds of "abuse". With the advent of mmWave for mobile communications, Ofcom has the unique opportunity to prevent such abusive tactics. Again, while Angie would be able to buy spectrum if it were to be sold, as a socially-responsible company we do not believe "ownership" of any frequency by anyone would be to the benefit of the people. On the contrary, this would kill potential competition.

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

Operators should be allowed to provide networks (and services) in and on fixed, data, mobile and even indoor/in-building environments and levels. With other words, operators should not be restricted by any regulator in any way or form of their (upcoming) commercial activity in the 5G realm.

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

We refer to the research by Zaheer Khan et al (see footnote 2) for in-depth answers to this very question.

d) Could spectrum channels be technically shared between operators?

Yes, they can.

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?**

With regards to mmWave, where there is still a lot to be had, we still need to look 10-15 years ahead for planning and developments.

Angie still believes in fiber as the most critical and essential part of backhaul. We will use mmWave backhaul where fiber is not an (immediate) option. Overall, mmWave Point-to-Point backhaul will still be a viable alternative.

Furthermore, in their book, *Introduction to Millimeter Wave Wireless*, Robert Heath et al state:

> … [W]e envisage future cellular and wlan infrastructure to be able to simultaneously handle backhaul, fronthaul, and position location connections using mmwave spectrum.

Nonetheless, backhaul will create further depletion of resources. In their 2014 research[18], Rappaport et al state:

> *… The 28 GHz bands were previously targeted for Local Multipoint Distribution Systems (LMDS) systems and are now attractive for initial deployments of mmW cellular given their relatively lower frequency within the mmW range. However, as mmW systems become more widely deployed, these lower frequency mmW bands will likely become depleted, particularly since they must compete with existing cellular backhaul systems.*
>
> *… Expansion to the higher bands is thus inevitable. In contrast, the E-Band frequencies (71-76 GHz and 81-86 GHz) have abundant spectrum and are adaptable for dense deployment, providing a major option for carrier-class wireless indoor and outdoor transmission, should the lower frequency become congested…[T]he atmospheric absorption of E-band is only slightly worse (e.g. 1 dB per km) than today's widely-used lower frequency (UHF/microwave) bands.*

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

Yes. On the matter of spectrum above 100 GHz, we agree with the summarized outline and statement provided by NYU Wireless to the FCC. The same issues apply for Ofcom.

> *… [T]he FCC should work with all parties to develop rules for access of the spectrum above 95 GHz that respect all legitimate concerns. Particularly given the fact that international standards bodies (IEEE 802.11 and 802.15) already are working on*

[18] Millimeter Wave Cellular Wireless Networks: Potentials and Challenges; Sundeep Rangan , Theodore S. Rappaport, Elza Erkip); January 11, 2014.

Terahertz wireless devices (from 275 to 3,000 GHz), the US must have spectrum allocations for its wireless industry to compete for products, services, and human capital. [19]

and

… [I]nternational competitiveness issues require the FCC to begin to dismantle the artificial spectrum ceiling that now exists at 95 GHz, so that higher frequencies may be immediately supported for wireless communications. Technologies at or above these frequencies are either here already, or are rapidly coming…"

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?

No. A present mobile allocation should not be necessary nor required. We recommend to widen the allocation for mobile use to almost all bands, and where possible, make mobile the primary allocation, even in the E-Band. Ofcom should also revise its power level requirements so that range could be increased and mobility can be ensured when technology improves and so allows.

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?

Yes, we agree.

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

[19] Reply to Comments of NYU Wireless on FCC's Notice of Inquiry, p. 26

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.

We urge Ofcom to *not* prioritize any bands/ranges and instead create a leveled playing field for all bands, including above 100 GHz. We have provided ample evidence in the answers above why the importance of bands in the higher regions of the mmWave spectrum (<100 GHz as well as >100 GHz) should not be underestimated.

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

No. We believe there is a lot to be gained if Ofcom doesn't exclude any bands based on current (technological and practical) limitations.

Even for the 60 GHz band, the most limiting among the mmWave, there is much hope.

While 60 GHz will be used in the near future for in-door/in-building wireless connectivity, some have voiced their doubts about the 60 GHz band with regards to its usefulness in the mobile services realm,. But there is a lot of technological improvement on an almost daily basis. In the USA, the FCC has recently (in their infinite wisdom) increased the radius opportunity for its unlicensed use in the 60 GHz band. This will be a major boon to the industry, and it will empower people and smaller operators alike.

Furthermore, even better power levels would mean even more empowerment of the 60GHz band. Therefore it would be wise to let the industry, the market and the people find their way, without imposed limitation (other than interference wise) by regulators such as Ofcom.

In September 2014, researchers published their findings, demystifying 60 GHz pico cell for outdoor environments.[20]

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 prioritising bands going forward?

We urge Ofcom not to prioritize any bands. See our comment on question 11, and our findings throughout this document.

[20] **Demystifying 60 GHz Outdoor Picocells;** Yibo Zhu, Zengbin Zhang, Zhinus Marzi, Chris Nelson; Mobicom; September 2014.