CONNECT's Response to Ofcom Consultation on 3.8GHz to 4.2GHz band: Opportunities for Innovation

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About CONNECT

CONNECT is the Science Foundation Ireland research centre for Future Networks and Communications[1]. We recognise the centrality of networks to society and the economy and we take a system wide, end-to-end perspective and carry out research in all aspects of networks (from the components and systems that make up the networks, to the resources the network uses, to the network infrastructure design, to the software elements that create, manage, control and monitor the networks, to the services that run on the networks). We work on topics such as Internet of Things (IoT), 5G, and advanced wireless, optical and satellite systems.

The CONNECT vision is to change the way networks are designed, created, owned, and operated, so that we can expand the reach, the possibilities and the impact of a connected world of people and things. Our mission is to carry out impactful collaborative research at scale with academic and industry partners, from an end-to-end system wide perspective of networks.

I. General Response

We recognise the need to proactively influence policy around emerging technologies and future spectrum sharing system designs and contribute to contemporary regulatory and policy debates that do take into account technological advancements and aim to promote the ways in which spectrum resource can be shared more efficiently. CONNECT welcomes the opportunity to respond to Ofcom Consultation on innovative sharing[2], which we see as a promising step towards novel policy and regulatory approaches whose frameworks should reflect the ability to dynamically respond and adapt to the ecosystem of current technological innovation. Ofcom has initiated the change through the strategies towards a reform in spectrum management[3] and developed a spectrum sharing framework[4] to provide necessary tools and enablers of the sharing approach. In our opinion, these actions, supported by the comprehensive analysis of potential sharing scenarios could result in a well-

[1] http://www.connectcentre.ie

[2] Ofcom*, 3.8GHz to 4.2GHz band: Opportunities for Innovation*, April 2016.

[3] Ofcom, Spectrum Management Strategy, *Ofcom's strategic direction and priorities for managing spectrum over the next 10 years*, April 2014.

[4] Ofcom, *A framework for spectrum sharing*, April 2016.

defined, functional framework that promotes innovation in spectrum sharing and fosters the competition in spectrum bands by means of opening the bands for new entrants alongside the traditional mobile operators and introducing them as new spectrum users in these bands. The fact that spectrum needs are changing calls for a new approach to sharing and exploring more innovative and dynamic solutions, that will be sustainable on a longer term scale. It is important that these solutions are represented by the systems that are flexible and able to adapt to dynamic changes that the future of wireless will impose.

A fundamental starting point for CONNECT is the fact that communications networks are core components of our critical infrastructure, supporting many basic societal needs. To design networks that will continue to support these needs as demands grow, we face a series of conflicting requirements. The networks of the future will need to support tiny and simple machines as well as highly complex advanced nodes. They will need to accommodate traffic that will range from small, bursty messages to long-lived flows of three-dimensional, high-definition video. There is a growing demand for sharing of every kind of data to enable new applications and services, but an opposing demand for increased protection and privacy. There is the challenge of providing economical services in dense urban cities as well as in remote isolated communities, and the challenge of supporting concentrated and disbursed applications. There is the conflict between closing things down so that incumbents recoup investments and opening things up so new players can join the market. There is the unquenchable appetite for more of everything (connectivity, capacity, processing power, storage etc.), but an expectation that it comes at less cost.

As Ofcom emphasized in their spectrum management strategy, two current trends can be identified as drivers of these changes:

1. *Perpetual growth of requirements and demands* for wireless services (in mobile data over public and private networks, in M2M and IoT applications but also in other sectors that serve citizens and consumers such as PMSE, satellite services and DTT).
2. *The ability of technology to meet these demands* through: new transmission techniques so that more information is carried over a given amount of spectrum (LTE and emerging 5G standards, digital technologies for wireless microphones and business radio applications, new compression standards in TV broadcasting), more intense use of spectrum (frequency re-use using low-powered, small cells), providing services using higher frequencies (fixed wireless services above 60GHz) etc.

What will drive these changes the most is the problem of increased demand in highly localised, high population density areas spectrum environments, where the usage of spectrum is already intense[5]. In the longer term, technology will evolve to use higher frequencies more economically, capacity requirements are becoming bigger so that only large bandwidths can satisfy the demand. But in the meantime in lower range of frequencies where spectrum is not used efficiently, sharing amongst systems different in nature will increase because spectrum cannot be cleared, especially in a nationwide manner. We think it is

[5] In the range of 300MHz to 3GHz there is no unused spectrum available, which is the case with other spectrum bands with attractive propagation characteristics as well.

essential that sharing happens in a most efficient, flexible, adaptable and dynamic way possible.

As recognized in its spectrum management strategy, Ofcom plans to address these challenges through combining the use of market mechanisms and regulatory action to drive these changes. We support the market driven approach to reforming spectrum management and adapting to the reality of sharing. In this sense we provide our input based on the work we have done on spectrum sharing models, Spectrum Access System (SAS)-based sharing in 3.5GHz in the U.S[6] and LSA-based sharing in 2.3GHz in the EU[7]. We put emphasis on: (1) the nature of adjacent service when it comes to coexisting in neighbouring geographical license areas and fighting co-channel interference, and (2) the importance of fostering competition and innovation through market based thinking in spectrum sharing, opening the space for new players beyond traditional mobile carriers to enter the sharing arrangements.

Three main points that we would like to raise as a response to this consultation and propose a way forward are framed as follows.

The unit of geographic licensing can be an enabler or a barrier. More consideration is needed prior to designing an effective licensing framework, to avoid the potential authorisation barrier to impact the effectiveness of the framework.

A multi-tiered approach to spectrum access is necessary enabler to foster innovation in sharing and competition in spectrum bands. Technological enablers are already there. Regulation and policy around dynamic sharing environments need to advance faster in order to come up with general frameworks which will allow different kinds of players to participate in sharing, beyond traditional mobile network operators.

There is a danger that technology and policy around spectrum sharing will be framed through a static apparatus of sharing rules which do not foresee flexibility, dynamics and adaptability and rely solely on traditional, legacy way of thinking in spectrum management.

[6] FCC, Report and Order and Second Notice on Proposed Rulemaking, *In the matter of Amendment of the Commission's Rules with Regard to Commercial Operations in the 3550-3650 MHz Band*, GN Docket No. 12-354, April 2015., available at: https://apps.fcc.gov/edocs_public/attachmatch/FCC-15-47A1.pdf

[7] ECC Report 2015*, Licensed Shared Access*, February 2014., available at: http://www.erodocdb.dk

II. Response to Question 1

Given the nature of the incumbents and their use of the spectrum, what new types of applications do you foresee could access this spectrum on a shared basis? Please provide details on the potential applications and their characteristics of use as identified in the spectrum sharing framework.

CONNECT has no specific comments to this questions, response can be found within responses to Question 2 and Question 3.

III. Response to Question 2

Based on information provided in this Section, can you identify any barriers to enhanced sharing in the 3.8GHz to 4.2GHz band? Please use the Spectrum Sharing Framework, which identifies four types of barriers to spectrum sharing: lack of information; market barriers; technology barriers; and authorisation barriers.

A potential authorisation barrier is the issue that could have a severe impact on the effectiveness of the licensing framework, issue of geographic licensing, particularly dimensions and nature of the licensing unit.

At the current stage of sharing proposals for 3.8GHz - 4.2GHz band, the licensing framework is still to be created and adopted. Therefore we raise few of our concerns based on the work done on the Spectrum Access System (SAS) in 3.5GHz band, in the U.S. As Ofcom already pointed out (it also reflects in the questions posed on stakeholders in the request for inputs), this consultation is an attempt to follow the pace of recent developments in spectrum sharing models across the globe. There are many similarities with the 3.5GHz approach to sharing. In order to draw parallels between the two regulatory approaches to sharing, we summarise the main characteristics of the FCC 3.5GHz sharing framework, to elaborate on the potential drawbacks of inappropriately designed geographic licensing framework.

The opening of the 3.8GHz - 4.2GHz band for sharing spectrum between new types of users and the users that encumber the band, should lead to development of a highly dynamic sharing framework. A spectrum license authorises the operation of a device within a defined spectrum space – geographic area and frequency band. Operating rights should be determined for a specific geographic area where incumbents would be protected so that the new systems can access spectrum without interfering with the primaries, while also accepting the risk of coexisting with other systems, some of which perhaps have even lower priority of access.

In this band, the primary users make only limited use of spectrum. The framework of multi-tier approach could unlock the potential of the band and make spectrum utilisation more efficient. For example, three tier approach envisions primary users with highest priorities to access spectrum. Secondary users have more limited protections and hold the right to not be interfered by third tier users. Third tier has the lowest priority in access and could use spectrum in some form of light-licensed framework (possible options to be considered) or akin to unlicensed mode.

According to the Ofcom analysis on incumbent geographic distribution and frequency assignments of fixed links and satellite earth stations[8] in the 3.8GHz - 4.2GHz band, huge unused spectrum regions can clearly be identified (entire Northern Ireland, Wales, Northern England, the South West and the majority of Scotland). Satellite services and fixed links that encumber this band are characterized by predictability and deterministic usage of spectrum. The usage patterns of satellite operations show that they are limited in time and geography.

The nature of incumbents in 3.8GHz - 4.2GHz in the UK, resembles the incumbent usage patterns of 3.5GHz band in the U.S., where incumbents are federal users (military high powered radars on ship platforms across the coastline) and grandfathered fixed satellite services. Propagation characteristics of 3.8GHz - 4.2GHz also resemble those of 3.5GHz, being above 3GHz threshold up to which mobile cellular spectrum usage is ideal. These bands are extremely suitable for small cell deployments to be introduced as additional spectrum users through a multi-tiered spectrum access. Having low powered deployments with limited propagation range of the band will allow more users to operate in closer proximity, exploiting in such way the core advantage of these bands: huge potential for geographic sharing empowered by the fact that incumbents operations are predictable.

The framework for sharing the 3.5GHz band adopted by the FCC envisions a sophisticated system of multiple databases called Spectrum Access System (SAS) that is responsible for processes of: managing, reporting, updating, monitoring, securing, authorising, assigning, protecting from interference and enforcing policy rules on Citizens Broadband Radio Services (CBRS) devices[9] - new class of users created for this band, classified according to their priorities to access spectrum. The two additional classes of users are called Priority Access (PA) users and General Authorised Access (GAA) users. Initially, PA users were only critical mission users, i.e. Contained Access users, but the FCC expanded the size of PA tier to a broader class of users. As we interpret the framework, they can be any type of network operators: MNOs or MVNOs, IoT, OTT, mobile broadband, small scale, large scale operators, deploying small cell technology or macro, infrastructure providers, C-RAN operators - as long as they obtain a license to operate. The open eligibility concept means that any entity that is eligible to hold the FCC license, can apply for PAL (PA license) with an entry point of paying for the usage rights. GAA use can be any type of usage which access spectrum opportunistically, wherever and whenever it's free from PA use. GAA applications can be M2M communications such as environmental monitoring sensors, transportation monitoring, utility meters, home and car maintenance and entertainment etc.

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[8] Illustrated in Fig.2, Fig.6 and Fig.7, Ofcom Consultation document

[9] FCC, NPRM, In the Matter of Amandment of the Commission's Rules with Regard to Commercial Operations in the 3550 – 3650 MHz Band, GN Docket No. 12-354, December 2012., available at: https://apps.fcc.gov/edocs_public/attachmatch/FCC-12-148A1_Rcd.pdf

The FCC adopted census tract[10] cartographic boundaries to serve as the boundaries of allowed licensed operation in 3.5GHz band. We are aware of the fact that Ofcom does not issue licenses using census data or pre-defined license territories. Instead, licensing area is determined based on real-time interference protection computations on a pixel-based approach designed for TVWS sharing. However, for diverse types of usage (e.g. see previous paragraph), small cell deployments should be introduced through the sharing framework to empower this band and to really utilise spectrum efficiently and promote competition. Smaller license areas are needed to support this goal, because the practice of issuing the licenses to an operator for entire cities, regions and even nationwide, needs to be abandoned. It criples the potential of sharing, especially if we have in mind that there are not many possibilities in the regulatory space for the new entrants to be introduced in the band. The new kinds of players that are emerging[11], differ from traditional cellular carriers in many ways, particularly in the change of ownership model and the fact that their service drives their network roll-outs and deployments.

Under the assumption that Ofcom's efforts towards reformed spectrum management and new sharing frameworks for identified spectrum bands (in which spectrum still lies fallow or is dedicated to incumbents who do not use it) – will result in innovative sharing frameworks that could potentially be applicable globally, we give an insight into the framework components to be especially addressed and to be supported by sufficient technical and economical analysis conducted on these bands. Users and systems that will share the spectrum are very different in terms of usage patterns, services they provide, technology they use, business models they are guided by, the socio-economic value of spectrum that their usage derives etc. It is clearly a daunting task to design a flexible but functional licensing framework to avoid these systems interfering with each other. The issue in particular concerns the question of defining operational restrictions to avoid interference due to adjacent users interaction, which in return dictates the license boundary and the area of allowed operation within that boundary.

[10] Census tracts are geographical areas defined on the basis of population statistics with their area boundaries not expected to change too much over time. Entire U.S. is divided into 74,000 census tracts. For more information see: http://www.census.gov/geo/maps-data/index.html

[11] Virtual operators, OTT operators, e.g. Google, Facebook

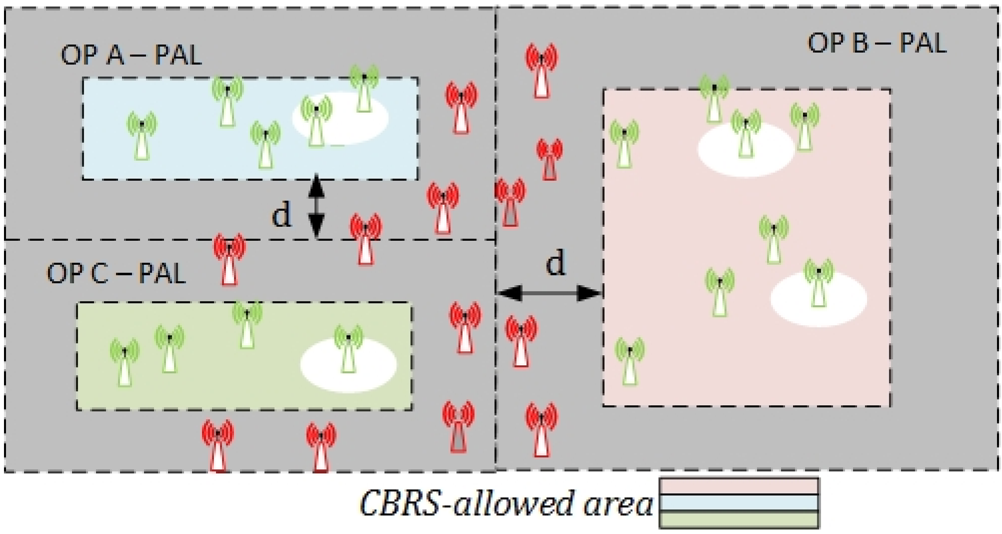

Figure 1: Adjacent census tracts allocated to different operators: the set-back distance and the sterile, grey space area in which the red nodes cannot be used.

Though census tracts are not suggested by Ofcom as license areas, the issue analysed with census tracts allow us to look at the challenges in selecting the licensing area unit. Hence, we will look at them in some detail. A PA user will be assigned a PA license (PAL) for 10MHz channel within one census tract. Besides the PA user, census tract also accommodates GAA users who access spectrum opportunistically when it's free from PA use. Despite the evident natural correlation of census tracts areas and the planning for a radio (census tracts group the population in a way that it's easier for operators to target certain groups of customers and deploy their base stations), issues will occur when there are different users of spectrum with different usage pattern neighbouring in census tracts and facing the challenge of co-channel interference (see Fig.1). The core idea of 3.5GHz framework is to allow operators to operate locally. Therefore, when adjacent census tracts are allocated to different operators, which is a realistic assumption of spectrum sharing environment in 3.5 GHz with diverse systems sharing the resource – the boundary issue becomes a disabler of efficient sharing.

To show an example, we did a study on census tract license areas[12], based on the technical requirements for CBRS users in 3.5GHz adopted by the FCC. These rules specify the conditions in which neighbouring CBRS deployments should operate to reduce the risk of interference due to tier-interactions. The power limits on a license boundary proposed by the FCC specify the signal strength level limit anywhere along PA service area (i.e. census tract) boundaries between different CBRS users. Under the propagation conditions, the required set-back distance creates an area in which CBRS deployments will not be allowed. We have computed the CBRS-allowed area using the data from the US census databases and the results have shown that entire cities, particularly highly dense, urban areas such as Manhattan, Washington DC and San Francisco would be almost completely unavailable for these deployments under 3.5GHz sharing rules. Fig.2 shows one set of results for Washington DC area, with two different set-back distances computed based on propagation analysis and

[12] E. Avdic, I. Macaluso, N. Marchetti and L. Doyle: Census Tract License Areas: Disincentive for Sharing the 3.5GHz band?, April 2016., available at: http://arxiv.org/pdf/1605.09184v1.pdf

allowed parameters of operation, proposed by the FCC for this band. The green areas show where CBRS nodes can be deployed, the red where they cannot. This is due to the fact that census tracts are smaller in places with high population density, where wireless demand is much higher.

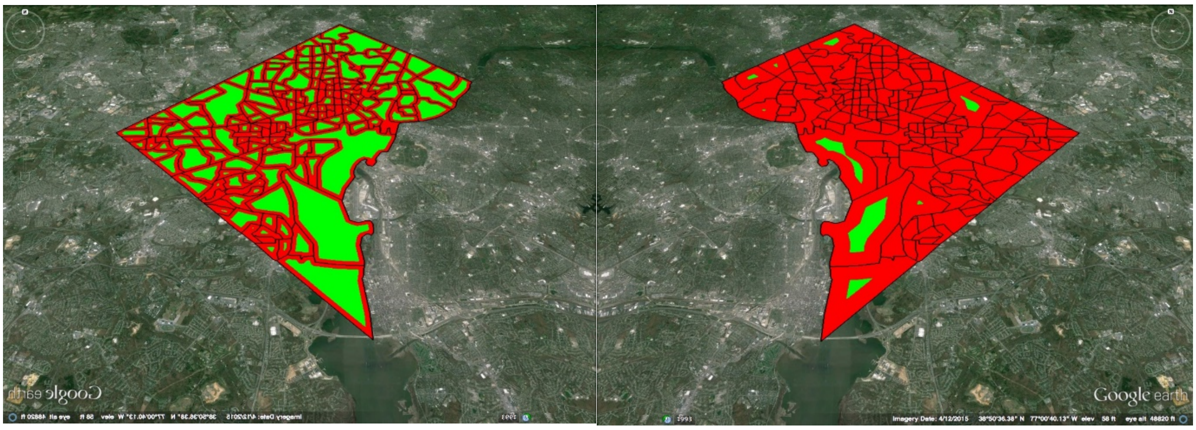

Figure 2: Washington DC area: Case I, set-back distance of 210m and Case II, set-back distance of 663m

The problem of spectrum waste over the license area, reflected through the percentage of area loss and number of people precluded from spectrum use points to the fact that the boundaries of census tracts are not appropriate boundaries for a license area in a geographic licensing scheme envisioned for 3.5 GHz band. Not only that they mismatch with the spectrum propagation of small cell deployments, the main deployments that could put 3.5 GHz spectrum to more efficient use, but in highly dense urban areas, census tracts are so small that it is not possible to form the CBRS-allowed area at all to fit the diverse spectrum usage so the interference between adjacent tracts is reduced. In addition to that, census tracts are non-convex polygons, irregular in shape and size. The boundary-to-area ratio is higher in smaller census tracts and where boundary is irregular, because the area within the boundary decreases faster than the boundary itself, which results in higher area loss under the technical conditions of sharing. This leads to spectrum being underutilised, i.e. the smaller the census tracts are, more spectrum is wasted over the area.

A. Recommendation I: The size of the license area should not be fixed nor created for purposes other than spectrum usage

The licensing model in the spectrum sharing framework needs to be flexible but more work needs to be done in that direction, particularly to address the issue of granting geographical licenses. The size of the license area should not be fixed. Instead, the boundary of a license area should follow the boundary of a wireless network coverage. We believe that the license area needs to be more dynamic so that the licensing framework is flexible enough to accommodate diverse use, but the question is open to what kind of solutions would be able to deal with this challenge. One obvious way to meet the high level goals of fully flexible sharing systems that dynamically respond to real-time change in conditions, is to focus on *actual spectrum usage* when designing a licensing framework. In particular, the license area should not be any fixed territory created for the purposes other than spectrum usage, but should be based on interference protection framework, especially because the nature of adjacent service cannot be ignored in geographic sharing.

The rules of technical operations that restrict signal strength limits of the licensee should be carefully designed, so that they do not restrict every possible usage in every possible situation. Every license should allow operation on a maximum power levels at least in one specific location within a given license area. The licensee should also be requested to scale down its operations and adapt to the presence of incumbents (the need to vacate the spectrum or respect the protection/exclusion zones) or other neighbouring use. Interference protection should be calculated for real world conditions, based on the actual spectrum usage of sharers. To investigate how different network deployments need to be so that the can be allocated in the same license area or in the same spectrum chunk is a challenging task to address. What would assist this task is the regulatory request to license applicants to submit the information on their network equipment and location, and also to take into consideration actual physical characteristics of the area in which they ask for a license. This way the license area would reflect the actual area of operation. Revealing information about their network deployments in this way is not something that the operators are willing to do, which is why a lot of effort needs to be put to design appropriate incentive system for all the parties involved in sharing. We believe it would serve as an important enabler of a functional, dynamic and flexible sharing framework alongside the licensing framework that needs to support it. It is important to challenge traditional ways of regulating spectrum and to speed up the processes involved by addressing many aspect of technological, economic and policy implications on sharing.

B. Suggestion I: Another approach to geographic licensing

Furthermore, the currently existing geographic licensing models for spectrum sharing are implemented on the borders of the U.S. with Canada and Mexico in 800MHz band[13]. It is worth considering this cross-border coordination model because of its potential applicability to designing a licensing framework for spectrum sharing in 3.8GHz - 4.2GHz band. These models are built on the basis of geographic sharing while giving assurance that spectrum is assigned in a fair manner to adjacent operators, whose edge users will get the service under these conditions. The model proves the feasibility of very localized sharing on the border and the fact that networks can overlap and still avail from spectrum use. For the operations within US/Mexico and US/Canada border areas, there are defined sharing zones and protection zones, but frequency allotment and the priority to access is given in a interchangeable way, so that each side is a primary and then secondary. The channel regions created through horizontal or vertical grouping of frequencies, define the eligibility on specific services in terms of signal levels not to be exceeded at the border, but these requirements are dependent on the nature of their services. Each side of the border has primary and secondary channels and knows when to access certain frequencies,

[13] http://www.ic.gc.ca/eic/site/smt-gst.nsf/eng/sf10069.html
https://www.law.cornell.edu/cfr/text/47/90.619

so that along the border itself there is no spectrum wasted. This type of frequency planning which relies on geolocation is important to consider when issuing geographic licenses over certain area units.

C. Recommendation II: Market-based approach to sharing and small license areas

The problems around geographic licensing we addressed in this response will be particularly severe in urban, highly dense areas where the demand is also higher. For the license area units which are created on the basis of something other then actual spectrum usage, the boundary issue will cause the spectrum waste. The technical requirements that specify the rules of operation are imposed on the license applicants regardless of the nature of adjacent service and if it exists or not. As shown with the census tract analysis for 3.5GHz Licensing framework in the U.S., the smaller census tracts naturally correlate with small cell deployments. As license areas, they give operators the opportunity to provide service to a targeted group of population or buildings where they have commercial interest. However, their boundaries do not follow wireless network coverage and census tracts also often intersect. Their intersection as a location where several census tracts meet makes it actually impossible to provide service by deploying small cells to cover single, strategically selected building - without having to aggregate several licenses for all census tracts that intersect there. This would not foster competition or put spectrum into more efficient use. Instead, it will add up to the spectrum cost of the entire band.

In a market based approach to spectrum sharing, spectrum auctions are a highly important market-based incentive to enable efficient sharing. The size and the shape of the licenses matters. If the license of a wrong size is auctioned, that will cause the spectrum allocation process to be inefficient as well. With the wrong-sized licenses, you increase the probability that the licensees would bid and compete for the licenses in the areas that they did not target and do not match their service needs. They would end up with for example a large license area that they cannot serve entirely, and the transaction costs would represent a significant barrier to efficient sharing.

With large and inappropriately sized licenses, rural operators do not get any chance to compete in the market. For the rural regions, smaller license areas would enable rural operators to bid and compete, these licenses are also cheaper and they should make even highly complex auction procedures a bit easier and more effective - the smaller size and better price would cause a higher auction participation. We would propose to end the practice of issuing licenses for a long, 10-15 years terms and instead enable small and large scale operators to get the license driven by the service they aim to provide in a targeted area. License duration should be reduced to 1-3 years and without renewable expectancies, scaling down to the license duration of only a couple of hours or even minutes.

Smaller licenses lead to dynamic spectrum markets which should be a part of a greater vision that drives policy-shaping and reform in spectrum management which will become more granular in the future. At the start of building the framework, designing the right-sized licenses is extremely important part to define through flexible rules, under the objective of maximising spectrum utilisation. As in any framework that regulates resource usage, rules should be set in a clear, well-defined way but also reflect the sharing situation awareness and real world conditions, relying on measurements and extensive interference analysis - to account for flexibility.

IV. Response to Question 3

Do you agree with our initial assessment of a potential application of a tiered authorisation approach in this band? If yes, please describe the spectrum access method that you consider may best meet any requirements you have to have to access spectrum in 3.8GHz to 4.2GHz band. Please give specific details of how you would envisage this working in practice, where appropriate with reference to the tools and enablers identified in Spectrum Sharing Framework.

For those who fundamentally believe in spectrum sharing, the release of a Licensed Shared Access (LSA) regulatory tool meant that regulation is moving in the right direction, challenging the notion that incumbents who do not make optimal use of their frequency allocation can simply sit in these frequency bands without consequence. However, as we have shown in the case study on LSA and advanced network platform of C-RAN that could support it[14]- regulations and use case scenarios were limiting the potential of LSA. As it is clear now, after two years of regulatory, standardization and implementation activities around LSA, it will remain a complementary regulatory tool to enable sharing in environments where existing regulations do not foresee multiple users or multiple usage (i.e. in the UK, this approach is already facilitated through the Wireless Telegraphy Act). The LSA approach as a two-tier model offers a straightforward way for MNOs to get access to some additional spectrum that otherwise would not be available and it provides certainty through a well-regulated, clear set of rules that guarantee QoS to both tiers in sharing. Regardless of the advantages of an LSA two-tier approach, there are many drawbacks that could be solved through a multi-tier approach. LSA exists practically as a way of spectrum leasing. It is intended for traditional mobile carriers and does not open the band for new players through any kind of market incentives or shorter term licenses or disabling renewal expectancies from operators.

To make LSA more flexible and useful for more than traditional carriers, we did a study that combines advanced perspective of a C-RAN (we coupled C-RAN with MD-MIMO deployment of antennas in remote network) and the introduced elements of what we term an advanced version of LSA (multiple incumbents and multiple licensees which share the LSA spectrum and the infrastructure). The infrastructure dimension allows us to introduce multiple virtual operators as LSA licensees - we refer to virtual operator as a service provider which does not fully own all of the resources necessary to deliver a certain service (spectrum or

[1414] E. Avdic, I. Macaluso, H. Ahmadi, I. Gomez-Miguelez, L. Ingolotti, N. Marchetti and L. Doyle: LSA-Advanced and C-RAN: A (5G) Romance of Many Dimensions, Dec. 2014., available at: http://arxiv.org/pdf/1606.02142v1.pdf infrastructure or computational resources etc.). In the scenario setting where we have an LSA system (Repository and Controller) and MVNOs interacting via C-RAN shared infrastructure, we shorten the crucial factor of an LSA system performance, evacuation response time (shown to represent a significant delay in LSA trials). There is no need for OA&M to communicate with each active eNB in the region where incumbents need spectrum back. It is done in the Cloud, one control point. The only additional messaging in evacuation information flow is the one between C-RAN and MVNO but only in case they are not the same entity, which they can be. In principle, it is possible to virtualize and hence share resources over almost any wireless or fixed network. We are interested in pushing sharing to the extreme and operating on the principle that network architectures need to be designed with extreme sharing in mind. On the wireless side, sharing of infrastructure happens in a passive way (towers, sites, masts) and active way (RAN and core network sharing) manner. Solutions tend to be designed for network mobile operators without new kinds of players in mind, e.g. virtual service providers. Sharing is considered in a fragmented manner in general: ether focusing on spectrum sharing architectures (TVWS) or a particular regulatory tool for sharing (LSA). It is our intention to understand the potential and limits of sharing in general (i.e. think about sharing of all kinds of network resources collectively), but we started out with a case study that incorporates many of the concepts of our vision.

The architectural principles of C-RAN and MD-MIMO based case solution gave us an opportunity to showcase what kind of dynamic scenarios can infrastructure sharing enable if it is coupled with spectrum sharing. It is a way to use spectrum more efficiently, to reduce investment costs significantly, to introduce competition, to use technologies that improve network capacity, to cover the area of high density, high and varied usage demand etc. In a static scenario each MVNO uses C-RAN with a fixed number of antennas and the pool of shared resources only contains LSA spectrum. In a dynamic scenario we quantify the capabilities of C-RAN to enhance the sharing features of LSA. We observe the change in efficiency of resource usage: dynamic C-RAN was able to accommodate all MVNOs even in the presence of an incumbent. The MVNOs also needed smaller spectrum chunk to meet the minimum rate constraint. The trade-off in sharing the spectrum and sharing the infrastructure has shown that the number of market players increases significantly in the dynamic spectrum sharing scenario enabled by C-RAN MD-MIMO and advanced LSA sharing features.

Based on this study several points can be made that revolve around the concept of extending the dimensionality to overcome limitations. The advanced versions of spectrum and infrastructure sharing platforms brought together in a highly dynamic, heterogeneous, virtualised network represent a showcase of an extreme sharing scenario. Such scenario accommodates a diverse range of players, users, resources and technologies and reflects how we shape the future networks for an expressive, competitive market.

In this sense, CONNECT would like to lay out a set of recommendations and directions in policy-shaping process for the band in question. We hope that our proposal and suggestions towards introducing three-tier spectrum access model clearly reflect our support for adoption of multi-tier based spectrum access. Ofcom already expressed their intentions to go in this direction and elaborated that the conditions are right for a three-tier model in this band. Therefore, we point to some of the components of regulatory analysis, which we think are crucial to consider in order to embed proper rules and definitions in a dynamic, flexible and comprehensive sharing framework that will be based on a multi-tier access to spectrum.

A. Recommendations

In the subject of tools and enablers that Ofcom identifies in the spectrum sharing framework, we see them being applied in combination to create new sharing models. Enablers such as *new types of spectrum information, market mechanisms and technological capabilities* could feed the *tool of authorisation* so that these efforts result in a well-defined, flexible licensing framework. Specifically, with the right way of collecting spectrum information, with the market based incentive to make the users be willing to share and with the technological capabilities of geolocation databases that rely on cloud-computing principles assisted with spectrum sensing - license conditions could be well resolved through a technological solution.

Many-networks and many-frequencies wireless communication of the future will enable sharing to become a norm, as advocated in the PCAST report[15]. Sharing approach should not be implemented as a one-to-one relationship between the incumbent and the sharer but extended to enable many-to-many type of relationship. Incumbent-licensee interaction should be at its most dynamic interpretation, with flexible rules, adaptable to spectrum environment in a CR fashion to get through the benefits of sharing. In the 5G context, it is crucial that the licensee is not simply seen as a traditional MNO (as in the most of the current use-cases across EU regulation) but rather that other types of systems and services can share. The sharing framework should have an identifiable market oriented component, enabled through policy.

Different mechanisms of assignment should be considered ranging from simple rule based assignments to auctions held at specific intervals to dynamic spot auctions. The number of actors who can play a role in competitive auctions is limited when long-term, expensive licenses are issued. Small scale operator not in need for a big coverage area would purchase a cheaper license and for a short term.

There are benefits in the combination of the licensing models (licensed, light-licensed, license-exempt), which will fully be unlocked only if there is sufficient spectrum reserved and planned for these kinds of users. What initially needs to be done is the proper analysis of incumbent usage. The combination of clearing, relocating and auctioning the spectrum will lead to frequency planning and effective allocation, as a second step. As a technological enabler, in license exempt cases, DSA could enable releasing spectrum very fast and at low cost, which reduces barrier to market entry. If Ofcom reserves a significant portion of unused frequencies in this band (which can clearly be seen through geographic distribution of incumbent usage illustrated in Consultation), then the market will respond through the devices and chipsets being produced. Policy-shaping process should not ignore international development and potential for harmonisation, globally.

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[15] Report to the President: Realizing the full-potential of government-held spectrum to spur economic growth, July 2012., available at: https://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast_spectrum_report_final_jul_20_2012.pdf

In order to not discourage future deployments in the band, rules should be simple so that regulatory tool does not become an administrative burden and a lengthy process. The first steps towards setting the framework should be based on these principles: (1) avoid static framework and use dynamic approaches from the beginning and set them for multi-band usage, (2) open the spectrum market for new actors and different kinds of operators, (3) define dynamics through many-to-many interactions of incumbents and licensees, (4) regulate the sharing of the infrastructure, (5) issue the licenses for smaller license areas and in shorter terms, (6) design auction processes that will produce incentives for all parties engaged in sharing, (7) enforce appropriate policy violation frameworks, (8) centralise the spectrum management through sophisticated system of multiple databases aided with spectrum sensing of the devices registered etc.

Multi-network and multi-frequency wireless communication will be the norm in future sharing. If Ofcom pioneers these steps and adopts a multi-tier approach through a well-designed, flexible sharing framework - first successful trials and implementations would raise interest for all different and new kinds of actors and entities that provide services today, across entire EU. It would mean that the sharing framework can dynamically respond to the needs of the service and promote the most efficient usage of spectrum while keeping up with the demand for more of everything. It would also be an opportunity for Europe and the U.S. regulatory and standardisation bodies to combine the two- and three- tier implementation experiences into a comprehensive regulatory and technical spectrum sharing model, applicable globally.

V. Response to Question 4

Should a potential future tiered authorisation approach to spectrum access in the 3.8GHz to 4.2GHz band accommodate changes from incumbent services of the spectrum? i.e. should new licenses or variations to existing fixed link and satellite earth station licenses be allowed to continue on a first-come-first-served co-ordinated basis?

No, we believe that new incumbent usage should not be allowed in the band on a FCFS basis. Instead, we encourage the authorisations of new entrants in the band, different kinds of operators that can be introduced and regulated through the framework. This would mean that tiers of users could scale down within the rules of the framework so that they exchange roles and modes of access.