Discussion Paper:

5G Spectrum and Neutral Hosting

A collaborative paper

DCMS Phase 1 5G Testbeds & Trials Programme

February 2019

This paper is the collaborative output of DCMS 5G Testbeds and Trials (5G T&T)[1] Phase 1 projects AutoAir, 5G RuralFirst, and Worcestershire, as well as 5G Innovation Centre (5GIC). In this paper, the combination of these three testbeds and the 5GIC testbed is referred to as 'the Collaborators'.

[1] DCMS 5G Testbeds and Trials Programme (5G T&T) https://www.gov.uk/government/collections/5g-testbeds-and-trials-programme

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1. Executive Summary

Spectrum and standards are enormous global complex activities in their own right. This discussion paper is distinctive in that it views these important topics through the prism of three fifth generation (5G) test bed projects to identify the constraints that would hold them back from being scaled-up into national deployments that can make a significant contribution to modernising our industries and ways of communicating. It is projected that the use of 5G services will contribute £7bn of direct economic value, with an additional £3bn per year from secondary supply chains [1]. The projects that have contributed inputs to this discussion paper are:

- AutoAir: 5G Testbed for Transport, Connected and Autonomous Vehicles
- Worcestershire 5G Consortium: Testbed and Trials Pioneering Industry 4.0
- 5G RuralFirst: Rural Coverage and Dynamic Spectrum Access Testbed and Trial

See APPENDIX A for more detail on each project.

Radio spectrum is often referred to as a 'scarce resource'. However, if one takes the entire electromagnetic spectrum and its potential for reuse, it is not actually all that scarce. The apparent scarcity comes from overlaying various constraints that turn spectrum into valuable products and services within the reach of almost anyone on the planet. The most important of these constraints is global harmonisation of bands, filtering down to national assignments to spectrum holders. Next come global standards written to work within globally harmonised bands. Finally come the choices made by a handful of the large system vendors, chip vendors and smart phone suppliers regarding which specific bands to focus large investments on, in order to make available technology and compatible consumer devices to address a global market.

Although several other bands are under consideration or in active implementation in the UK/Europe and internationally, the main bands of focus for emerging 5G systems being currently developed in the UK/Europe are:

- 700 MHz - low frequency, long range, low capacity
- 3.4 to 3.8 GHz - slightly higher frequency, medium range, fairly high capacity
- 26 GHz - high frequency (millimetre wave) band. Fairly short range, high capacity
- 57-71 GHz - high frequency (millimetre wave) band. Shorter range, ultra-high capacity

The paper has been developed based on bands which have been worked on by the Collaborators in the 5G T&T projects. Principles and approaches developed can be used for other bands. For example, 3.4 to 3.8 GHz band information and recommendations could be applied to the 3.8 to 4.2 GHz band, which Ofcom is currently consulting on the usage of, as a Shared Access band[2].

[2] Ofcom consultation: "Enabling opportunities for innovation Shared access to spectrum supporting mobile technology". Publication Date: 18 December 2018. Closing Date for Responses: 12 March 2019. https://www.ofcom.org.uk/__data/assets/pdf_file/0022/130747/Enabling-opportunities-for-innovation.pdf

The characteristics of these different bands are the main focus of this paper[3] and are illustrated in Figure 1 below. Used in the right context, each of the bands has properties which provide significant benefits compared to the others. 5G technology and the emerging use of these bands create new opportunities that can be used to solve traditional business model, coverage and capacity issues – in particular, the lowering of network deployment costs and the creation of new opportunities for sharing, which have not previously been viable or possible.

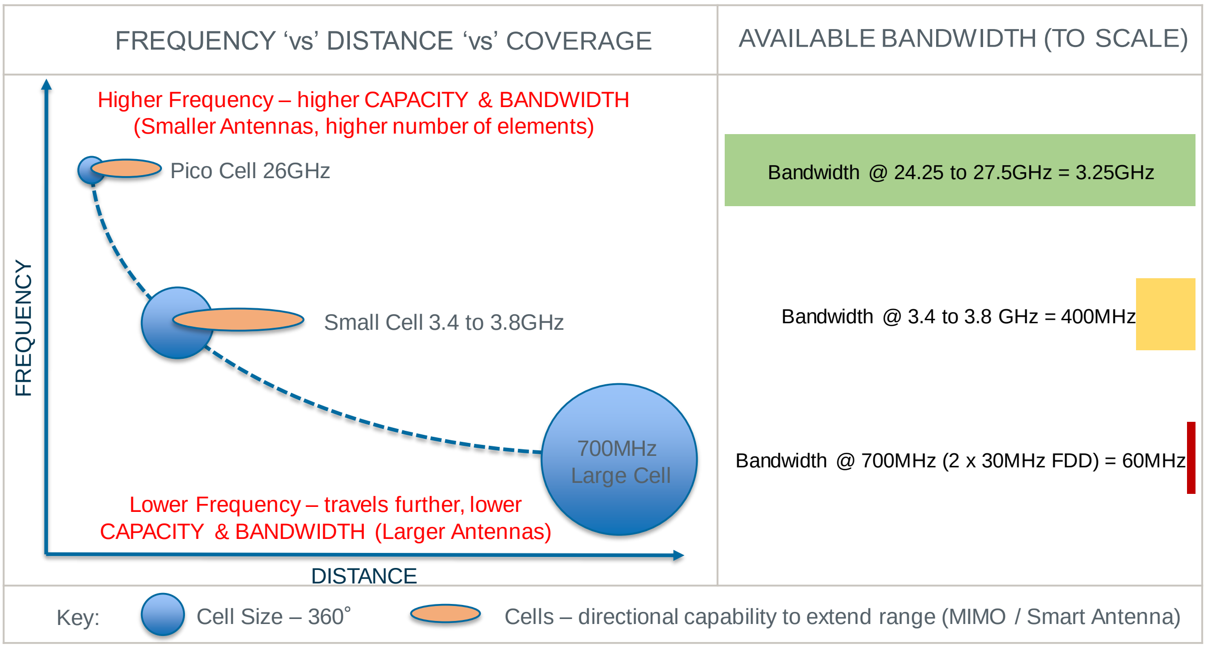

Figure 1: Illustration of frequency, distance, coverage and bandwidth

See APPENDIX B: Spectrum and the Types of Licensing in the UK for more information.

The mobile business model challenge is nicely illustrated in the UK population density chart shown in Figure 2. For example, the provision of 60% population coverage would need only 10% land area coverage. This chart also provides insight into Spectrum availability, as the more sparsely populated areas will often have the most unused spectrum. Such unused spectrum could be used to open up new models for usage and sharing to lower the network economic costs to not only provide coverage but also provide capacity in spot locations.

[3] The paper has been developed based on bands which have been worked by the Collaborators in the 5G T&T projects. Principles and approaches developed can be used for other bands. For example, 3.4 to 3.8 GHz band information could be applied to the 3.8 to 4.2 GHz band.

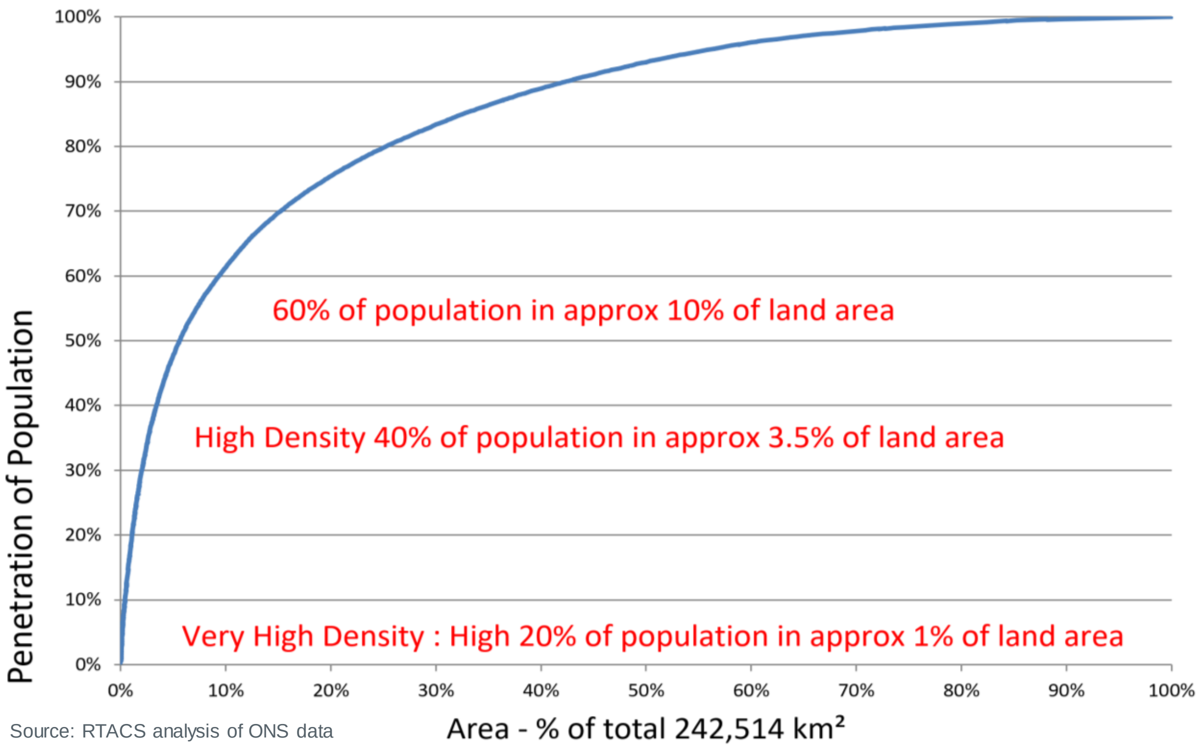

Figure 2 - % of Population penetration 'v' Area (square kilometres) of UK

The need for innovative hybrid solutions for different population and context types is essential for future 5G coverage and capacity solutions. Use of one technology, spectrum band and/or architecture is no longer a viable approach, as one solution does not fit all. This paper explores options and looks at how 5G and the 5G testbeds could technically show various models working in different:

1. Context settings:
    - Roads and rail, transport
    - Rural
    - In building, enterprise and factories
    - Indoor
    - Outdoor

2. Population / User / UE density scenarios
    - High density (e.g. major events)
    - Dense urban (highly populated area)
    - Urban
    - Sub-urban
    - Rural

The main recommendations from this discussion paper are for UK industry, academia and government to:

1. Invest in further innovation, test beds and trials to explore options to enable innovative spectrum usage outside of main population areas and where network economics do not support viable business models:
    a. 700 MHz for large area coverage,
    b. 3.6 to 3.8 GHz for medium capacity / coverage,
    c. mmWave bands for high capacity spot coverage,
    d. mmWave bands front haul / back haul for difficult to reach locations using enhanced antenna technology capability, where wired (e.g. fibre) deployment is not economically viable,
    e. Hybrid solutions, orchestrated by 5G networks to combine recommendations 1a, 1b, 1c and 1d,
    f. Technology demonstrators to show technical feasibility to support Recommendation 2.

2. Explore new approaches with respect to spectrum management and licensing models for different bands covering conventional national licensing for areas with high population densities, combined with alternative models for areas where it is economically challenging to deploy networks; e.g. rural, transport corridors and indoor solutions. Candidates for evaluation are listed below, where 'x' denotes a variable to be determined by band (see section4):
    a. Last x% by area, opened up for LOCAL USAGE / GEOGRAPHICALLY LIMITED to allow third-party and self-provision if not used by the primary licence holder FROM DAY 1 or AFTER A SET PERIOD,
    b. Last x% by area, unified national approach to share spectrum,
    c. Last x% by area or total UK - Dynamic Spectrum Access (DSA),
    d. Split band usage: set aside x MHz of band for shared registered use across all of the UK,
    e. Differentiation of indoor and outdoor through EIRP management,
    f. Combinations of all the above.

3. Engage with ***Ofcom's consultation on Enabling opportunities for innovation in shared access to spectrum supporting mobile technology*** (Closing Date 12th March 2019)[4]

[4] Ofcom consultation: "Enabling opportunities for innovation Shared access to spectrum supporting mobile technology". Publication Date: 18 December 2018. Closing Date for Responses: 12 March 2019.
https://www.ofcom.org.uk/__data/assets/pdf_file/0022/130747/Enabling-opportunities-for-innovation.pdf

See Section 4, for options for each band and Section 5 for projects.

The rest of the paper is organised as follows. Firstly, some historical background of previous spectrum allocation and extracts from the Future Telecoms Infrastructure Review are provided in Section 2. Then, Section 3 introduces different technologies to demonstrate the portfolio or 'toolbox' that 5G can create (Technology + Spectrum). Section 4 outlines the options by band explored by the Collaborators. Section 5 provides an overview of what each project is doing in support of the different spectrum usage options identified in the paper. Section 6 provides some architecture and sharing model ideas, showing how the various sections come together to demonstrate the proposition and capability of 5G. Section 7 provides Summary and Conclusions. Finally, Sections 8 to 12 provide supporting information in the form of appendices.

2. Historical background and Future Telecoms Infrastructure Review

When Cellular networks were first rolled out in the UK, the band at 900 MHz was the universal solution. When the band at 1800 MHz was first introduced, it was to allow more mobile operators into the market to provide identical services to those of the 900 MHz operators.

The economic challenge of doing this at 1800 MHz was recognised by regulators, and for a period higher termination rates were granted to the 1800 MHz operators to help subsidise the higher cost of wide area coverage. When the band at 2.1 GHz was introduced for 3G, few recognised that 'universality' was going to break-down. A decade of consumer complaints about poor 3G coverage followed. This had nothing to do with the 3G technology itself but rather the choice of 2.1 GHz. Regulators had to tighten up the coverage obligation and this has proved a challenge.

The arrival of 4G saw, for the first time, the introduction of a band at a lower frequency (800 MHz) than the prevailing cellular bands along with a band at a higher frequency (2.6 GHz). A coverage obligation was imposed on one of the 800 MHz licences with the expectation that competition would drive the other licensees to follow. But no thought was given at the time to imposing any sort of coverage obligation on 2.6 GHz. Equally, if a coverage obligation was deemed inappropriate at 2.6 GHz, it did not trigger a review of whether exclusive national licences were also no longer appropriate. It has led to large areas of the country where the spectrum owners have no intentions of using the band for coverage and/or capacity, yet their exclusive holding of spectrum prevents others with innovative business models from using it.

Spectrum trading was supposed to be a market mechanism whereby spectrum owners would sell on or lease their unused spectrum, but such a liquid market has failed to materialise. There are reasons for this, including MNOs wanting to preserve their freedom of action, not wanting to fuel rivals' success with more spectrum, and the price they would get for marginal uses not being worth their time and effort. The release of the 2.6 GHz band was a turning point for cellular mobile spectrum, but it was never properly recognised by regulators.

The issue of bands good for coverage but not for capacity or good for capacity but not for coverage was not addressed. This has consequences for geographic spectrum efficiency, as spectrum that could be used but is blocked as a result of the regulatory rules is spectrum wasted. Spectrum not used at any instant has its parallels with empty hotel rooms and empty seats on airlines: the lost opportunity value can never be retrieved, hence the term spectrum waste.

The delivery of a universal mobile service is a huge economic challenge, as there are always locations where the market fails to deliver coverage on the grounds of it being economically unviable to do so. Huge efforts in recent years have shrunk the 'economically unviable' area down to a few percent of the UK. However, that is only for delivering an insufficient 2 Mbps to a single user, and with only 90% reliability in the non-busy period (the basic parameters of the 800 MHz coverage obligation). Contrast that offering with the 5G vision of several Gbps at very low latency and high reliability and it becomes clear that 'coverage' of such high performing 'mobile' networks is the great challenge of the 5G era.

The market alone cannot be relied upon to deliver 5G coverage to maximise the economic and social benefits of high capacity 5G networks. The Government recently published its Future Telecoms Infrastructure Review, in which this question has been examined in depth. It has concluded that the best solution is what it terms the 'market expansion' model (Section 3.4 of [3]):

"This relies on competition between multiple national networks but also enables new infrastructure and spectrum access models. In this model, the UK would continue to benefit from network competition between multiple national operators. National networks would be supplemented by 'neutral host' infrastructure and private networks to, for example, deliver small cell deployments in urban areas and in-buildings, or to expand rural coverage beyond that delivered by the MNOs, or to serve new micro-markets such as industry 'verticals'. Such infrastructure models could be supported by promoting access to 5G spectrum, through spectrum trading or potentially new spectrum sharing models. At the service level, enhanced mobile broadband services would be provided by MNOs and MVNOs, alongside new services enabled by existing and new players."

This is a 'big idea' but it can work only if there is access to spectrum for the players willing to provide services in this 'outer zone' that, for economic reasons, the mobile network operators (MNOs) have little interest in covering (See Figure 3 in Section 4.1 and Figure 4 in Section 4.2 for an explanation of the proposed approaches for the 700 MHz band and the 3.4 to 3.8 GHz band, respectively). The outer zone does not just include areas with sparse population, but also areas such as road and rail networks and inside buildings, where there may be regulatory and/or business model reasons why it is expensive to deploy a network.

The concept of 'Neutral Hosting' has emerged as a strong 5G theme from running the numbers of what investment would be eventually needed to roll out a substantial 5G infrastructure. Such neutral hosting has also been facilitated by new technology to implement network slicing. The concept of infrastructure sharing of the radio access element does, however, challenge the current competition model. The Government and Ofcom have recognised this and shown their willingness to look at new models. The new models that challenge the radio spectrum status quo are those run by entities other than the MNOs who own the national 5G spectrum licences.

In view of the challenging economics of infrastructure in what we have termed 'the outer zone', the cost of this spectrum must be reasonable in order to make the business models work. More specifically, auction prices have driven the price of spectrum to levels that are quite unrealistic for the sorts of business model needed to attract investment and be sustainable. Capital spent on spectrum is not available to be spent on the network.

3. Spectrum and Technology 'Toolbox'

This section introduces summary tables of the different spectrum (Table 1) and technologies (Table 2) that can be used and orchestrated through 5G technology. The purpose of this section is to demonstrate the flexibility and capability of 5G, with the potential for global adoption, which previously may have been restrictive in terms of interoperability and availability of consumer equipment, due to poor economies of scale. Table 1 provides the spectrum 'toolbox'.

Table 1: Spectrum 'Toolbox'

High Level	Areas	Description
Spectrum Licensing - To use any radio transmitting device in the UK, it will need to either be licensed, or have a specific licence exemption – see Appendix 10	Licensed	Licensed spectrum devices operate within a defined band based on rules specified in the licence, including technical characteristics such as power and interference plus defined usage areas, e.g. total UK or specific area/geographic allocation. 2G, 3G and 4G MNOs use licensed spectrum based on exclusive national licences
	Licence-Exempt	Licence exempt devices can use their associated spectrum without the need for prior explicit authorisation or an individual right of use. However, these devices must comply with pre-defined rules to minimise the risk of interference, whereby their compliance (and hence their licence exemption) is confirmed by certification and associated testing.
	Lightly Licensed	Lightly licensed spectrum usage is typically used for shared approaches and uses techniques to ensure that users comply with pre-defined rules and can potentially share bands in different areas and/or context settings.
	Local Licensing for Spectrum Sharing Enhancement	Somewhat distinguished from both the licensed and lightly licensed cases is the concept of local licensing as introduced in the recent Ofcom "Enabling Opportunities for Innovation" consultation[5], whereby the issued licence is similar to a conventional licence but with a location or location bounds limitation, the express intention being localised sharing of the spectrum of an incumbent.
Spectrum properties, new bands	Low frequency <1 GHz (700 MHz)	700 MHz - low frequency spectrum characteristic in that it provides long range connections for covering large areas and is also good in terms of being able to penetrate buildings (outside to inside). Bandwidth availability is low and hence low frequency provides limited capacity. The 700 MHz band will be made up of 2 x 30 MHz TDD blocks and potentially an additional 25 MHz for supplementary downlink use.
	Medium frequency 1 to 6 GHz (3.6 to 3.8 GHz)	3.5 GHz - provides medium range, medium to high capacity. This spectrum provides reasonable propagation characteristics when combined with new multiple antenna techniques. The major advantage of the band is that it will provide 200 MHz of spectrum in TDD mode, which is ideal for small cell capacity solutions.
	High Frequency (24.25 to 27.5 GHz and 57 to 71GHz)	Millimetre wave spectrum bands provide very large bandwidth capability (e.g. at 26 GHz the bandwidth is 3.25 GHz) which make these bands ideal for high capacity pico cells (with a smaller coverage area than 3.6 to 3.8 GHz). The trade-off is that it does not travel as far. However, this is an advantage for re-use and spectrum management as this means it easier to manage co-existence and interference. It must also be noted that smart antenna techniques have significantly improved over recent years, providing much longer transmission distances.

[5] Ofcom, "Consultation: Enabling opportunities for innovation", December 2018, https://www.ofcom.org.uk/consultations-and-statements/category-1/enabling-opportunities-for-innovation

Spectrum Management	Dynamic Spectrum Access (DSA)	DSA allows systems to select the frequency spectrum in which they will operate at a given location and over a given period. TV White Space is an example of this. Typically, a third party provides a database to manage users and optimise the use of available spectrum to avoid interference with others.
	EIRP	EIRP is Effective Isotropic Radiated Power, also called the Equivalent Isotropic Radiated Power. EIRP is the equivalent power that must be input to a theoretical isotropic radiator in order to achieve the power measured in the direction of maximum radiation of an antenna, i.e., the power input to the antenna (in dB), plus the antenna gain (dBi), gives the EIRP. Lower EIRP results in less transmission range. Managing EIRP is an important variable and technique that could be used to manage coexistence and users.
	Local Licensing for Spectrum Sharing Enhancement	Further to the Spectrum Licensing entry above, this concept is also a tool to manage spectrum in a reliable way that is conformant with the regulator's requirements.
Spectrum modes	FDD - Frequency Division Duplexing	FDD is used where both uplink and downlink data transmission are simultaneous, with a piece of spectrum being dedicated for uplink channels and a separate piece of spectrum being dedicated for downlink channels. In the case of the 700 MHz band, it is expected that 30 MHz will be dedicated for uplink channels and 30 MHz will be dedicated for downlink channels.
	TDD - Time Division Duplexing	TDD is used where both uplink and downlink use the same spectrum, but take it in turns to use the band. Data rates can be asymmetrical, and the time slots can be fixed or dynamically adjusted.

Table 2 below provides a brief description of some the new techniques and technologies and provides a summary of the existing 3GPP assets which will form part of the future 5G eco-system and networks.

Table 2: Deployed Infrastructure and New Technologies

High Level	Areas	Description
Existing technology, infrastructure and deployed bands	2G, 3G and 4G Licensed 900 MHz, 1.8 GHz, 2.1 GHz, 2.3 GHz and 2.6 GHz	3GPP based technology is used globally and continues to grow. In December 2018, these networks accounted for 9.25 billion mobile and M2M connections, which represented a 7% year-on-year growth (source https://www.gsma.com/ 18th December 2018). These networks have been built on harmonised spectrum bands shown in the Areas column. As we move into the 5G era, these technologies and bands will form the basis upon which 5G will built; therefore, when considering any options proposed it must be noted that the investment made in previous generations will be a vital part of the future capability. This is of importance when considering coverage and capacity obligations, as spectrum bands should not be considered in isolation. (See section 6.)
	Wi-Fi License-Exempt 2.4 GHz, 5 GHz and 60 GHz	Wi-Fi IEEE 802.11 specifies the set protocols for implementing wireless local area network computer communication in various licence-exempt frequencies, including 2.4, 5, and 60 GHz frequency bands. Wi-Fi continues to grow and carry high levels of traffic to mobile phones and devices and can operate simultaneously on most mobile UE platforms.
	mmWave backhaul	mmWave is extensively used for wireless Point to Point (P2P) and Point to Multi-Point (P2MP) solutions. These will continue to be used and provide vital low latency, high bandwidth connectivity. Pricing for

		designing and building radios for these applications are likely to reduce dramatically as 5G economies of scale are realised and advanced antenna techniques are implemented.
New approaches and technology	Neutral Hosting	Neutral Host solutions provide a technology capability where a third party can provide a part of the network, which can be used as a shared medium. This can be at the antenna level or can be an entire Radio Access Network (RAN) solution. See Section 6 for more information.
	Slicing	Slicing will provide the ability to use a single network 'sliced' into multiple virtual networks that can support different 'Quality of Service' (QoS) levels, based on UE requirements and an agreed Service Level Agreement (SLA). Initially, it is envisaged that network slicing will primarily be used at the core and transport network but as 5G evolves it will migrate to the RAN and potentially UEs to create fully end-to-end slices.
	Network Sharing	5G technology provides the ability to orchestrate older generation technologies such as 3G and 4G with new building blocks specified as part of 3GPP releases 15 and 16. Network sharing is in widespread use today and will be enhanced by new techniques such as 'Neutral Hosting' and 'Slicing', enabling defined usage of spectrum and network assets ensuring that rules for network owners and/or users can be clearly segmented to meet security, Quality of Service / experience, billing and SLAs.
	CUPS	Control and User Plane Separation (CUPS) provides the architecture enhancements for the separation of the control and user plane functionality. CUPS was introduced in 3GPP Release 14 - set to be a key core network feature for current 4G and future 5G evolution. See Section 6 for more information.
	MEC	Mobile Edge Computing (MEC) brings application hosting from centralised systems to the network edge, closer to users and the data generated by applications. MEC is one of the key functions required to meet 5G specifications, especially as far as low latency and bandwidth efficiency are concerned. MEC nodes can be in the form of Network User Plane Function (UPF) and/or Service and Application functions. The power of this technology means that, in many cases, the network uses local bandwidth and will only use the external network for low bandwidth control, security and authentication purposes.
	Broadcast modes	Broadcast modes are extremely spectrally efficient when multiple users are consuming the same content, such as live radio or video. As new capabilities bring more intelligence across the whole of the network, broadcast modes can be used to push content to the edge network into the MEC nodes for local consumption. In some cases this could actually be direct to the UE equipment.
	Antenna advances	As frequencies increase, the size of antennas decreases, which means more antennas can be used in smaller form factors. Increasing the number of antennas enables the ability to transmit further, focus power into smaller areas and re-use spectrum more efficiently, as the beam gets directed more precisely. Multiple-input and multiple-output (MIMO) allows increased capacity over a radio link using multiple transmit and receive antennas to exploit multipath propagation.

The above tables provide a high-level overview of different techniques and technologies which are used in this paper. These tables do not cover every option, and various other techniques and technologies are available, but not covered in this discussion paper.

4. Spectrum options by band

The spectrum options, namely 700 MHz, 3.6-3.8 GHz, 26 GHz and 57-71 GHz, have been examined, and the emerging consensus of the Collaborators is summarised in the sub-sections below. Each section outlines identified licensing options in the bands, with a short description, and highlights key advantages, opportunities and challenges by band.

The Collaborators assumed that 700 MHz options explored will have 76% to 92% coverage obligations, whereas 3.6 to 3.8 GHz and mmWave will not have coverage obligation options. The characteristics of the 3.6 to 3.8 GHz and mmWave bands mean that these will not be used for coverage but can provide very good capacity solutions in spot locations, this presents more options for spectrum reuse innovation, sharing and dynamic access options.

4.1 700 MHz Band options

700MHz 2 x 30MHz 25MHz SDL	Option 1: Conventional approach of exclusive national licences (Coverage obligations being proposed vary between 76 to 92%)	Option 2: GEOGRAPHICALLY LIMITED of 8-24% to allow 3rd party and self provision if not used by primary licence holder AFTER SET PERIOD	Option 3: GEOGRAPHICALLY LIMITED of 8-24% to allow 3rd party and self provision if not used by primary licence holder FROM DAY 1	Option 4: UNIFIED NATIONAL APPROACH Shared Access Neutral Host to serve last 8 to 24%
TECHNICAL FEASIBILITY / TIMING	Technically feasible, starting from Spectrum release date.	Technically feasible, starting from Spectrum release date.	Technically feasible, starting from Spectrum release date.	Technically feasible, starting from Spectrum release date.
COVERAGE AND CAPACITY IMPLICATIONS	Unlikely to see use of band in last 8 to 24%	Last 8 to 24% - Could be addressed through Neutral Host usage, managed by third parties	Last 8 to 24% - Could be addressed through Neutral Host usage, managed by third parties	Last 8 to 24% - Could be linked to Neutral Host usage, unified National approach
IMPLEMENTATION CHALLENGES	Easy to implement	Spectrum management required. Permission and conditions.	Spectrum management required. Permission and conditions.	Spectrum management required. Permission and conditions.
COMPLEXITY	Known model	Co-existence and radio planning with main licence holders could be challenging.	Co-existence and radio planning with main licence holders could be challenging.	Co-existence and radio planning with main licence holders still challenging, but easier than option 2 and 3.
ACCESS TO SPECTRUM / CHALLENGES	No access for local usage unless granted by Spectrum owner	Fixed period to allow primary spectrum licence holder to roll out infrastructure	Agreed geographic split from Day 1 (regional licences)	Could limit scope of Spectrum usage / difficult to set up.

Table 3: Proposed options for 700MHz, extending geographic coverage to the uneconomic 8-24%.

Currently, in England and Northern Ireland MNOs provide mobile coverage to 92% of the land, while in Wales it is down to 83% and 76% in Scotland. (Source: Ofcom Consultation: Improving mobile coverage - Proposals for coverage obligations in the award of the 700 MHz spectrum band, March 2018.[6]) To ensure that the 700 MHz band is fully utilised as a frequency, which can propagate with the furthest reach so as to provide national coverage compliant with the broadband Universal Service Obligation, a solution is required whereby it will enable an economically viable solution to extend the coverage to much nearer 100%, including areas that MNOs do not cover. Clearly, 100% coverage is not feasible in practice, except perhaps with satellite technology. But that option is a long way into the future, particularly as a mainstream mobile band fitted to every smartphone.

Option 1 in Table 3 above describes the conventional approach for a coverage obligation. Options 2, 3 and 4 work in combination with Option 1, enabling the remaining 8-24% to be covered by a third parties who would be established to support public and private services.

[6] Ofcom, Improving mobile coverage: Proposals for coverage obligations in the award of the 700 MHz spectrum band. Section 1.11 https://www.ofcom.org.uk/__data/assets/pdf_file/0022/111937/consultation-700mhz-coverage-obligations.pdf and https://www.ofcom.org.uk/consultations-and-statements/category-2/700-mhz-coverage-obligations

This would improve the marginal business cases. Such opportunistic use of spectrum by third parties would have to be carefully planned with Ofcom to ensure no harmful interference with the primary spectrum users. Such use would also have to be signalled in the prospectus to prospective bidders for the 700 MHz spectrum, so it could be taken into account in their bids.

The Ofcom consultation document “Improving mobile coverage: Proposals for coverage obligations in the award of the 700 MHz spectrum band” [9] sets out a very powerful case for action to address national coverage limitations, particularly in rural areas. The proposal they are consulting on is to have three coverage obligations (one for indoor coverage and two for outdoor coverage) attached to three respective blocks of 5 MHz of paired spectrum at 700 MHz. These are to deliver a fairly basic voice and data connectivity. The speed value chosen for data is 2 Mbps. The coverage requirements are drawn up to reflect the specific economic challenges within each of the Nations: a) 92% in England, b) 92% in Northern Ireland, c) 83% in Wales and d) 76% in Scotland. It is proposed that the coverage obligations should be achieved within 3 years. This, according to the Ofcom numbers, would leave 8-24% of the geographic area of the nations with no mobile coverage at 700 MHz, leaving opportunities for third party usage as described in Table 3.

A potential approach could be for the market expansion model proposed by the Government in its Future Telecoms Infrastructure Review (FTIR) [3] for the 3.6 GHz band to be applied, in a more geographically limited way, at 700 MHz.

For the 3.6 GHz band, the Government, with the Department for Digital, Culture, Media and Sport (DCMS) in the lead, has come up with an idea of how this could be done through a change of the competition model they term the ‘market expansion’ model. The Government proposes in its FTIR that just such a model could be targeted at the 5G pioneer band at 3.6 GHz. It involves setting aside an unspecified relatively small amount of spectrum in the 3.6-3.8 GHz band which is yet to be released and to couple this with opportunistic DSA.

The Collaborators believe that the ‘market expansion model’ and the innovative spectrum model could be adapted to work at 700 MHz. This is because the unserved geographic area will have been well defined three years after the spectrum release, the time period Ofcom proposes for the coverage obligations to be met (see option 2). The way this could work is for one of the 5 MHz blocks of paired spectrum with a coverage obligation to also be designated for use in the market expansion zone. For the first 3 years it could be brought into use in rural areas only with the agreement of the owner of that block of 700 MHz but after 3 years the block would be available for use by anyone willing to establish coverage via database access (with enhanced mapping models). Since this could only take place outside of the coverage established by that MNO, there would be no conflict of interest. Furthermore, dynamic spectrum expansion rights could be attached and enabled also by database access. This would allow a provider to use any or all of the 30 MHz of paired spectrum that was unused in a location. In this way, remote rural communities could enjoy data speeds considerably in excess of 2 Mbps.

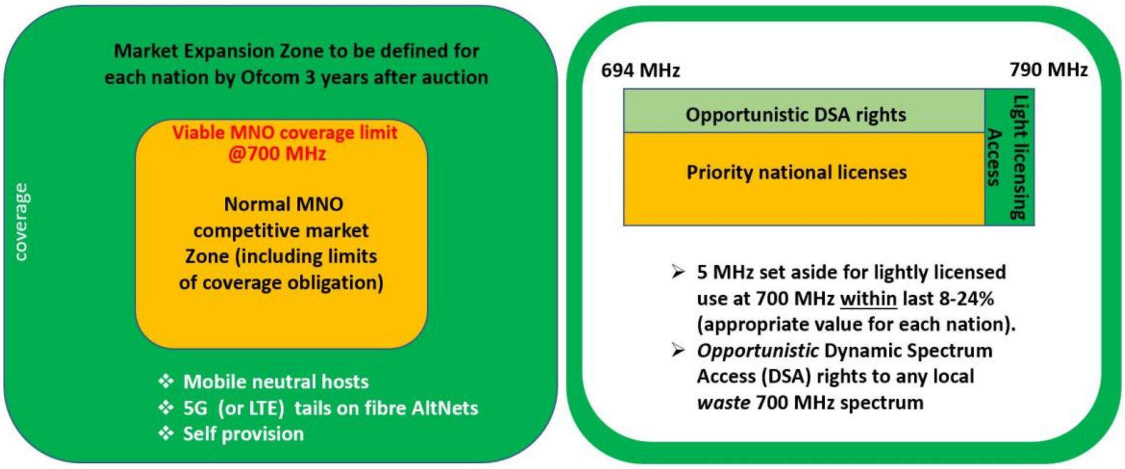

Figure 3: Market expansion model example at 700 MHz. Duration used in this example is 3 years.

Pricing of the lightly licensed spectrum needs careful consideration. It should be priced only to cover the administrative costs of running the database access but little or nothing more. The fragile nature of the economics would have been proven by the unwillingness of the mobile operators to cover these areas, even with their scale economies. The case is strong for the spectrum accessed by dynamic spectrum access to be free, as it is essentially unused spectrum being brought into use. However, there is a case to be made that a 'benefit in kind' in the form of some of the capacity being available to, say, a mobile operator or other entity to run a neutral host could be considered. In other words, 'a public good' in the form of extending public access in exchange for 'nearly free' access to public spectrum.

Another possibility would be that third parties using this spectrum must do so using a neutral host model and must provide the incumbent of the spectrum they are using with neutral host access on some agreed terms, possibly in return for national roaming rights.

Another option is to deal with the final 8-24% via a subsidy to fund a neutral host approach. The model is unlikely to deliver contiguous coverage but could provide coverage where it is most valued by those in the affected areas. Other options include satellite technology and 6G, with the disadvantage of both being that these possibilities lie well into the future and will not be able to leverage the huge installed base of 5G devices likely over the coming decade.

4.2 3.6 - 3.8 GHz Band options

In order to provide Gbps mobility, at least in urban areas, Europe has identified the band 3.4-3.8 GHz. Only the spectrum in the band 3.6-3.8 GHz remains to be released for 5G. Table 4 sets out options for spectrum sharing in this spectrum band, balancing the needs of capacity and coverage.

3.6 to 3.8GHz **200MHz TDD**	**Option 1:** **Conventional approach of exclusive national licences**	**Option 2:** **LOCAL USAGE / GEOGRAPHICALLY LIMITED to allow 3rd party and self provision if not used by primary licence holder AFTER SET PERIOD**	**Option 3:** **LOCAL USAGE / GEOGRAPHICALLY LIMITED to allow 3rd party and self provision if not used by primary licence holder FROM DAY 1**	**Option 4:** **Split band usage 'X' MHz lightly licensed (200 MHz example: 20 MHz shared, registered use, like CBRS and 180 MHz conventional)**	**Option 5:** **Split band usage 'X' MHz lightly licensed (e.g. 20 MHz shared) + Opportunistic DSA across all of band 200 MHz**
TECHNICAL FEASIBILITY / TIMING	Technically feasible, starting from Spectrum release date.	Technically feasible, starting from Spectrum release date.	Technically feasible, starting from Spectrum release date.	Technically feasible, starting from Spectrum release date.	Technically feasible, but may be challenging to start from Spectrum release date.
COVERAGE AND CAPACITY IMPLICATIONS	Unlikely to see use of band in last 90 % (60% of population in 10% of land area assumption)	Last 90% - Could be linked to Neutral Host usage, managed by LOCAL third parties	Last 90% - Could be linked to Neutral Host usage, managed by LOCAL third parties	Opens up 100% UK availability of 'X' MHz and opportunity to create economies of scale through alignment with CBRS.	Same as Option 4 + Opens up 100% UK availability of 200 MHz
IMPLEMENTATION CHALLENGES	Easy to implement	Spectrum management required. Permission and conditions.	Spectrum management required. Permission and conditions.	Complex to organise, Spectrum management required. Permission and conditions.	Increased Spectrum management required, compared to option 4. Permission and conditions.
COMPLEXITY	Known model	Co-existence and radio planning with main licence holders could be challenging.	Co-existence and radio planning with main licence holders could be challenging.	Co-existence and radio planning with main licence holders organised through agreed band plan and conditions	Same as Option 4 + DSA technology used to address Co-existence and radio planning
ACCESS TO SPECTRUM / CHALLENGES	No access for local usage unless granted by Spectrum owner	Fixed period to allow primary spectrum licence holder to roll out infrastructure	Agreed geographic split from Day 1 (regional licences)	Reduces Options 1, 2 and 3 by 'x' MHz e.g. 20 MHz examples would result in 180 MHz left from total 200 MHz	Same as Option 4, opens up all of band. DSA could be open from day 1 or after fixed period to allow primary spectrum licence holder to roll out infrastructure

Table 4: Proposed options for 3.6 - 3.8 GHz.

Explanatory notes for Table 4:

Note 1: The 90% figure for spectrum waste is an *__estimate__* *used in this paper based upon Figure 2 - % of Population penetration 'v' Area (square kilometres)* of UK*, which shows that 60% of the population resides in 10% of the land mass; this is subject to debate and has been used for illustrative purposes only. It also takes into account data points for 2.1-2.6 GHz. 2.1 GHz has been used for national coverage for the third-generation technology and 2.6 GHz, the extent to which it has been used at all, for local 4G capacity enhancement. Efforts are expected to be made at 3.6 GHz to cover dense urban (high footfall) centres and major roads. Thus, the ultimate coverage is likely to fall between the two data points.*

Note 2: DSA [3] is proposed whereby additional, otherwise unused, spectrum is allocated to users at points of underutilisation. Opportunistic spectrum users are provided with strict operating conditions, designed to minimise the possibility of causing interference to licence holders. The aim is that primary users should not be able to notice any difference whether DSA is in use or not.

Note 3: Other options not considered here might include satellite technology (well down the road), waiting for 6G (even further down the road) and taxpayer subsidy to pay MNOs to extend their networks.

Option 1 in Table 4 describes the conventional approach. Options 2, 3, 4 and 5 provide options that work in combination with Option 1, enabling the remaining 90% to be covered by third parties who would be established to support public and private services.

In reviewing options, the starting point should be to examine whether a continuation of the status quo of Ofcom auctioning the spectrum based on conventional national licences is likely to solve the problem of 5G enhanced coverage and capacity?

The Government's Future Telecoms Infrastructure Review in paragraph 221, which can be summed up in the simple illustration shown in Figure 3, suggests the spectrum supporting framework for what DCMS identify as the 'market expansion model'. The yellow competitive market zone gives priority to national licensees where spectrum is allocated for providing broadband service by MNOs within a viable coverage limit in urban and built up areas, while the green zone is providing market expansion in locations where there is unused (or wasted) spectrum, which could be accessed via opportunistic DSA, while for areas where such spectrum is occupied, an amount of spectrum (for example, 20 MHz) could to be set aside and reserved for semi-open access (SOA). This solution would provide the spectrum access for specialist use cases such as an indoor factory requiring exclusive spectrum or a rural location with a requirement to exclusively access remote controlled agricultural equipment.

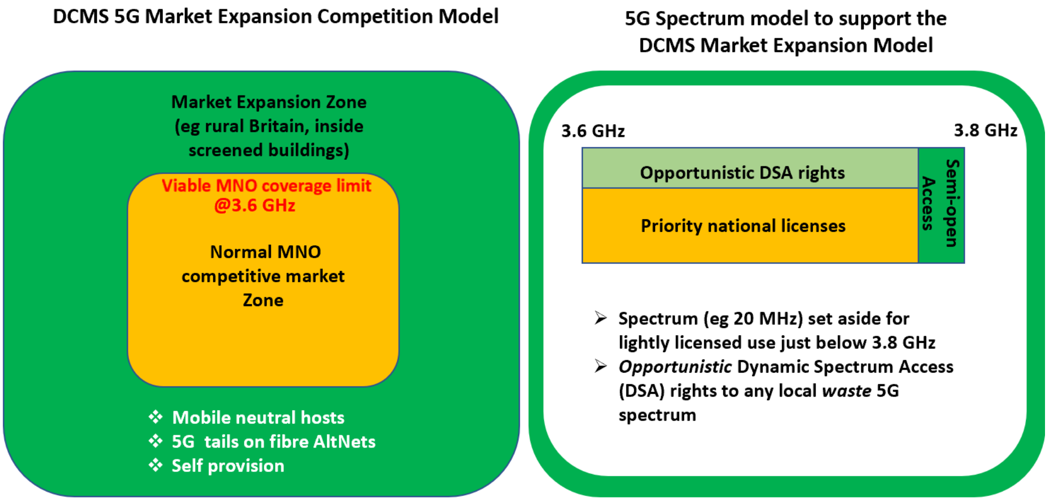

Figure 4: Simplified Illustration of Spectrum Allocation between licensed, DSA and semi-open access spectrum in the 3.4-3.8GHz band.

The options described in Table 4above provide variations of this model. All of these options are technically feasible and could be operated from day 1 of Spectrum release. Advantages of the approach include:

- A small amount of spectrum set aside for lightly licensed use provides security that entities will always be able to offer a level of minimum service (an anchor band).
- DSA turns 'waste spectrum' into high performing cells.
- The cost of access to the spectrum will be low, as it is waste spectrum that would otherwise not be used outside of the 10% land area estimate.
- The global momentum behind 3.6 GHz and U.S. CBRS means equipment prices will also eventually be low and widely available from competitive sources.
- The probability is high in rural areas that some gains from DSA will always be possible: not only is it unlikely that the spectrum licence owner will turn up in rural areas of the UK, the probability of all four of them turning up is very low indeed.

The main down-side of what otherwise appears a perfect option to the coverage issue is that removing 20 MHz from the 200 MHz of the band still to be released increases the contention (and hence price per MHz) in the coming auction amongst the MNOs trying to top up their radio channel bandwidths. This conflict of interest is a matter for Ofcom and the Department for Digital Culture, Media and Sport to resolve. The same conflict of interest does not exist with the opportunistic DSA for 'waste spectrum' as it gives MNOs an ultra-low cost means to expand capacity for their cells located away from main centres.

A 20MHz band is considered a suitable size for the lightly licensed component because it is a relatively small proportion of the total amount of spectrum in the band, which, if offered alongside DSA opportunities, would be capable of supporting many advanced 5G applications and use cases.

4.3 26 GHz Band (24.75 to 27.5 GHz) options

Five options are presented in Table 5 for the mmWave band at 26 GHz.

24.75 to 27.5GHz 3.25GHz TDD	Option 1: Conventional approach of exclusive national licences	Option 2: LOCAL USAGE / GEOGRAPHICALLY LIMITED to allow 3rd party and self provision if not used by primary licence holder AFTER SET PERIOD	Option 3: LOCAL USAGE / GEOGRAPHICALLY LIMITED to allow 3rd party and self provision if not used by primary licence holder FROM DAY 1	Option 4: DSA across all of band 3.25GHz	Option 5: Indoor low power mode. Lower EIRP management based on context and location
TECHNICAL FEASIBILITY / TIMING	Technically feasible, starting from Spectrum release date.	Technically feasible, starting from Spectrum release date.	Technically feasible, starting from Spectrum release date.	Technically feasible, starting from Spectrum release date. Could use GPS and/or lower frequency band management for positioning and allocation.	Technically feasible, starting from Spectrum release date. Approach could also be applied to options 1, 2, 3 and 4 through power management.
COVERAGE AND CAPACITY IMPLICATIONS	Unlikely to see use of band in last 96.5% (40% of population in 3.5% of land area assumption)	Last 96.5% - Could be linked to Neutral Host usage, managed by LOCAL third parties	Last 96.5% - Could be linked to Neutral Host usage, managed by LOCAL third parties	Opens up 100% UK availability on managed basis.	Opens up 100% UK availability on managed basis.
IMPLEMENTATION CHALLENGES	Easy to implement	Spectrum management required. Permission and conditions. Much easier to manage than lower frequency bands.	Spectrum management required. Permission and conditions. Much easier to manage than lower frequency bands.	Spectrum management required. Permission and conditions. Much easier to manage than lower frequency bands.	Spectrum management required. Permission and conditions. Much easier to manage than lower frequency bands.
COMPLEXITY	Known model	Co-existence and radio planning with other licence holders.	Co-existence and radio planning with other licence holders.	DSA manages Co-existence and radio planning through position and database approach	Co-existence and radio planning with other licence holders. Variable EIRP linked to context
ACCESS TO SPECTRUM / CHALLENGES	No access for local usage unless granted by Spectrum owner. Spectrum not used over vast areas.	Fixed period to allow primary spectrum licence holder to roll out infrastructure. Spectrum not used over vast areas.	Agreed geographic split from Day 1 (regional licences)	Opens up 100% UK availability on managed basis.	Opens up 100% UK availability on managed basis.

Table 5: Proposed options for 26 GHz.

Explanatory notes for Table 5:

Note 1: The 96.5% figure for spectrum waste is an <u>estimate</u> used in this paper based upon Figure 2 - % of Population penetration 'v' Area (square kilometres) of UK*, which shows that 40% of the population resides in 3.5% of the land mass; this is subject to debate and has been used for illustrative purposes only.*

Note 2: Dynamic spectrum access (DSA) [3] is proposed, whereby additional, otherwise unused, spectrum is allocated to users at points of underutilisation. Opportunistic spectrum users are provided with strict operating conditions, designed to minimise the possibility of causing interference to licence *holders. The aim is that primary users should not be able to notice any difference whether DSA is in use or not.*

Option 1 in the table above describes the conventional approach. Options 2, 3 and 4 provide options that work in combination with Option 1, enabling the remaining 96.5% to be covered by third parties who would be established to support public and private services. Option 5 provides a simple approach that could be managed through lower power levels for indoor use, therefore using the building to prevent propagation in and out of the building / room.

The term ‘Spectrum not used over vast areas’ reflects the even smaller geographic footprint that MNOs are likely to achieve at 26 GHz, due to small practical cell sizes for use only in very high capacity areas, not for wide area coverage. This leads to an even larger number of geographic areas of the UK where exclusive national licences would block all other users across the country who might have viable innovative cases to invest in wireless local loop, back-haul and high capacity industrial uses.

It is often claimed that there is a lack of end-user devices to enable the use of the 26 GHz band. This is no longer true, as portable 4k video devices have been demonstrated at trade shows in 2017 and are known to be in existence. It is also inaccurate to say that there is no interest in the band: it is typically being used for back-haul already in the UK, with the *Joint Radio Company* being a key user where important connectivity for the energy sector is being provided, implicating threat to life if switched off. There would be no need to clear the band – due to the short ranges involved in typical transmission links, the potential for multiple users to co-exist sharing the band without causing harmful interference is good, contrary to the limitations of dense Wi-Fi deployment over the same range. Consequently, whilst it is technically possible, on any rational analysis it would make absolutely no sense whatsoever to issue exclusive national licences. At the time of writing, it appears that Ofcom shares this view.

Given the short ranges involved, it would seem entirely appropriate to manage the band with the lightest possible regulatory touch, so as to maximise its efficient use and hence support the requirement in paragraph 185 of the Future Telecoms Infrastructure Review [3] that “Operators will need to work together with local stakeholders to improve processes to enable more efficient small cell deployment”. A mixed model of exclusive national licences alongside blocks of lightly licensed spectrum with DSA rights, as well as a block of licence-exempt spectrum, has the edge over a very similar policy which excludes the possibility of any licence-exempt use.

Ofcom has a legal duty to maximise spectrum efficiency as this generates the maximum economic benefit and social welfare from this natural resource. The objective, therefore, is to find approaches that maximise the utilisation of the band.

Another option would be to make this licence-exempt spectrum. Experience shows that whenever licence-exempt spectrum is available, it is rapidly filled, meaning high spectrum usage is achieved. However, Quality of Service (QoS) cannot be guaranteed; consequently, the option is not clear cut.

4.4 57-71 GHz Band options

The frequency band spanning 57-71 GHz is currently licence exempt and was also the subject of a recent Ofcom consultation[7] on the use of this spectrum for Short Range Devices and Fixed Wireless devices. This further aligned regulatory rules to those currently applicable in the USA under FCC Part 15.255 rules, thus enabling economies of scales for wireless technology which is already exploiting these bands, notably based on IEEE 802.11ad/ay specifications which are part of the Wi-Fi 'WiGig' wireless family. Notably, the sophisticated protocols defined in these standards are designed for robust operation in un-coordinated bands (similar to 2.4 and 5.8 GHz licence-exempt bands) where significant levels of interference can be tolerated – more so than in licensed bands used for 4G mobile or similar.

Operation in this band is also harmonised at European level through CEPT SE(19), and ETSI also makes significant contributions to the technical conditions for this band via its Millimetre Wave ISG[8] industry group. Discussions are also under way on designating the 66-71 GHz band as an IMT mobile band and indeed the 66-71 GHz band was the preferred 'pioneer band' for 5G in the original Ofcom report on frequency allocation for 5G in 2015, before this was superseded by the 26 GHz band.

The characteristics of this frequency band encourage short range line-of-sight operation (up to 500m) and high data rate (up to 10 Gbps) based on the availability of very wide bandwidth frequency channels (2 GHz to 4 GHz). This is turn enables the use of robust modulation techniques which, when combined with RF System on Chip (SoC) phased array antenna technologies, enable very flexible self-aligning gigabit rate links. Such links can be used for low visual impact street level gigabit mesh networking - as demonstrated in the 5G Liverpool Health Test Bed and in the AutoAir project for V2X mobile applications. Moreover, the 14 GHz of bandwidth is also perfectly suited for delivering what is arguably the UK's most important 5G use case: the delivery of gigabit grade wireless connectivity from track to train[9] where a leading UK train operator is already testing the use of gigabit wireless technology operating in the 57-71 GHz band, based on technology being developed and delivered by a UK based millimetre wave systems vendor[10].

With this background in mind, we recommend that:

1. Licence exempt operation based on current and soon to be adopted regulations from Ofcom is maintained for transmitter power levels below +40 dBm (for SRD) and +55 dBm (for Fixed Wireless applications).
2. Lightly licensed operation based on a geographical database are considered for operation at increased power levels of between +55 and up to +60 dBm - similar to power levels for other licensed millimetre wave bands at 26, 28 and 39 GHz.
3. Special consideration is given to enabling road and rail transport corridors to enable 5G gigabit wireless coverage due to the national importance for the UK economy [1].

[7] https://www.ofcom.org.uk/consultations-and-statements/category-3/implementing-decisions-57-71-ghz-band
[8] https://www.etsi.org/technologies-clusters/technologies/millimetre-wave-transmission
[9] https://www.nic.org.uk/publications/future-use-cases-mobile-uk-real-wireless-report-nic/
[10] http://www.bluwirelesstechnology.com/applications/mmwave-for-transport/

Noting also that the nature of millimetric propagation is well matched to being constrained within such rail corridors, particularly through the use of directional antennas, this allows very efficient re-use for other 5G applications outside these transport corridors.

4. Most importantly, the key advantage of the use of ultra-wide 2 to 4 GHz within this band should be maintained as this allows robust cost and power effective technologies to deployed to deliver cost effective gigabit grade wireless services. The temptation to divide the spectrum into channel widths of less than 1 GHz should be vigorously resisted, as this will be detrimental to the exploitation of this frequency band.
5. It is recognised that there will be public health concerns in the coming years as ever higher frequency bands are utilised. The latest medical advice, based on research conducted over several decades, states that millimetric is safe to use, but as a sector we have a duty to properly inform the public – lest 5G mmWave be derailed simply on grounds of consumer perception (even if that perception may be incorrect). DCMS should consider this as part of a future study.

4.5 Summary of Spectrum Options

The above sections capture the high-level options, a summary of which is as follows:

- 700 MHz - Will need some sort of geographic spectrum management to allow self or third-party provision to serve the last 8-24%.
- 3.6 GHz - Opportunities exist to explore multiple models, including approaches to Dynamic Spectrum Access, Split Band Usage (e.g. 20 MHz open usage, 180 MHz conventional) and combinations of primary and third-party users working collaboratively, maximising spectrum usage and efficiency
- 26 GHz – A mixed model of lightly licensed spectrum and DSA is likely to deliver the optimal result, possibly with local licensing improving geographic spectrum efficiency. National licensing is beyond reason, while entirely local based licensing is burdensome to local authorities.
- 57-71 GHz – A mixed model similar to that proposed for 26 GHz is likely to deliver the optimal result, with the inclusion of licence exempt provision, and possibly also being permitted to operate at higher power levels to increase range.

5. Project Summary Tables – mapped to Spectrum usage models

5.1 700MHz project matrix

The following matrix provides information on what each project is working on in the 700 MHz band.

700MHz 2 x 30MHz 25MHz SDL	Option 1: Conventional approach of exclusive national licences (Coverage obligations being proposed vary between 76 to 92%)	Option 2: GEOGRAPHICALLY LIMITED of 8-24% to allow 3rd party and self provision if not used by primary licence holder AFTER SET PERIOD	Option 3: GEOGRAPHICALLY LIMITED of 8-24% to allow 3rd party and self provision if not used by primary licence holder FROM DAY 1	Option 4: UNIFIED NATIONAL APPROACH Shared Access Neutral Host to serve last 8 to 24%
AUTOAIR	AutoAir is not using this band.			
5G Rural First	Test Bed is capable of operating in this mode	✓	✓	✓
Worcestershire	✓	Test Bed is capable of operating in these modes		

5.1.1 AutoAir

AutoAir is not using this band.

5.1.2 5G Rural First

5G RuralFirst is exploring ways in which frequencies in the 700 MHz band might be made accessible for underserved communities to allow third party and self-provision. Several potential models are being explored, including local licences, dynamic sharing, and various neutral hosting models.

5.1.3 Worcestershire

Conventional approach taken. WLEP has been granted 96 MHz TDD bandwidth in this band and our plan is to use this on the outdoor mast to test use cases such as beyond line of sight control of drones for industries such as Agritech.

5.2 3.6 - 3.8 GHz project matrix

The following matrix provides information on what each project is working on in the 3.6 to 3.8 GHz band.

3.6 to 3.8GHz 200MHz TDD	Option 1: Conventional approach of exclusive national licences	Option 2: LOCAL USAGE / GEOGRAPHICALLY LIMITED to allow 3rd party and self-provision if not used by primary licence holder AFTER SET PERIOD	Option 3: LOCAL USAGE / GEOGRAPHICALLY LIMITED to allow 3rd party and self - provision if not used by primary licence holder FROM DAY 1	Option 4: Split band usage 'X' MHz lightly licensed (200 MHz example: 20 MHz shared, registered use, like CBRS and 180 MHz conventional)	Option 5: Split band usage 'X' MHz lightly licensed (e.g. 20 MHz shared) + Opportunistic DSA across all of band 200 MHz
AUTOAIR	Test Bed is capable of operating in this mode	✓	✓	Test Bed is capable of operating in these modes	
5G Rural First	Test Bed is capable of operating in this mode	✓	✓	✓	✓
Worcestershire	✓	Test Bed is capable of operating in these modes			

5.2.1 AutoAir

AutoAir is using in both a conventional way and exploring options for third parties to use this spectrum in a neutral host model providing the incumbent of the spectrum they are using with neutral host access on some agreed terms, in future this could be in return for national roaming rights.

5.2.2 5G Rural First

5G RuralFirst is exploring ways in which frequencies in the 3.5 GHz band might be made accessible for underserved communities to allow third party and self-provision. Several potential models are being explored, including local licences, dynamic sharing, and various neutral hosting models.

5.2.3 Worcestershire

Conventional approach taken. WLEP has been granted 390 MHz TDD bandwidth on this band. This is primarily being utilised to provide in-building coverage across all the partner locations including within their factory floor environment.

5.3 26GHz Project matrix

The following matrix provides information on what each project is working on in the 26 GHz band.

24.75 to 27.5GHz 3.25GHz TDD	Option 1: Conventional approach of exclusive national licences	Option 2: LOCAL USAGE / GEOGRAPHICALLY LIMITED to allow 3rd party and self-provision if not used by primary licence holder AFTER SET PERIOD	Option 3: LOCAL USAGE / GEOGRAPHICALLY LIMITED to allow 3rd party and self-provision if not used by primary licence holder FROM DAY 1	Option 4: DSA across all of band 3.25GHz	Option 5: Indoor low power mode. Lower EIRP management based on context and location
AUTOAIR	**AutoAir is not using 26 GHz. Project is using 55 – 71GHz band.**				
5G Rural First	**Test Bed is capable of operating in this mode**	✓	✓	✓	
Worcestershire	✓	**Test Bed is capable of operating in these modes**			**Test Bed is capable of operating in this mode**

5.3.1 AutoAir

AutoAir is not using this band. This is partly for commercial reasons (the project partners do not offer equipment) and partly because we can demonstrate that a combination of sub-6 GHz with 60-70 GHz access and backhaul is superior and more economic for our applications.

5.3.2 5G Rural First

5G RuralFirst is exploring ways in which frequencies in the 26 GHz band might be made accessible for underserved communities to allow third party and self-provision. Several potential models are being explored, including local licences, dynamic sharing, and various neutral hosting models. Our specific use case for this band is connectivity to a local inter-island ferry, where on-board Wi-Fi will allow passengers to connect with their phones, tablets, lap-tops, etc.

5.3.3 Worcestershire

Conventional approach taken. WLEP have been granted 500 MHz TDD bandwidth on this band. The plan is to test this within the factory floor environments to add capacity to partner locations. There is a dependency on equipment and end user devices to facilitate this testing.

6. 5G Capability and opportunities

6.1 Neutral Hosting

As discussed earlier in this paper, and highlighted in [5], coverage and capacity in the right places will be perhaps the biggest challenge of the 5G era. Competition and likely public funding simply will not be sufficient to roll out Gbps coverage over enough of the UK's urban areas to be transformational, nor will it fill in all of the 'basic' coverage gaps for mission critical national connectivity. 'Neutral hosting', also acknowledged in the Future Telecoms Infrastructure Review [3], is now being widely discussed as a means of avoiding duplicative investments in less economically viable areas. Neutral hosting could be provided by a pure third-party carriers' carrier or by an MNO acting as a site-specific carriers' carrier, or as an outcome of 'self-provision'.

Figure 5 shows three examples of neutral hosting, demonstrating models where different owners of spectrum, sites and communication equipment can create multiple scenarios to address different business models and context setting requirements (see option tables in Section 4). Using Option 3 as an example, Spectrum blocks 1 and 2 have been combined to create a larger bandwidth third party spectrum carrier for shared access and in this case it is split between two entities operating networks / services using Core A and Core B with a shared common RAN infrastructure (the RAN could be owned by A and/or B or another third party).

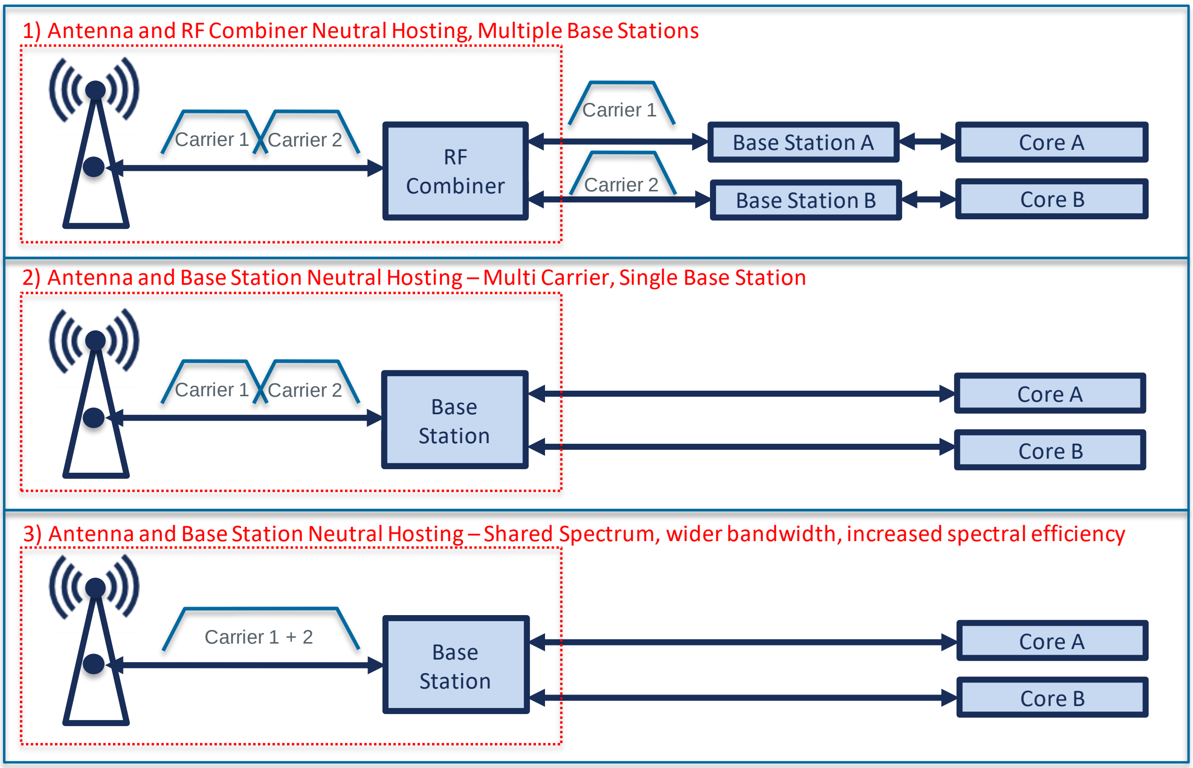

Figure 5 - Neutral Host examples and partitioning

A critical issue for the success of neutral hosting is to have policies that differentiate between *whose spectrum* is being used for neutral hosting.

Where an Operator's Spectrum is being used

The spectrum licence belonging to the MNOs is bought in the expectation of freedom to use the spectrum how they wish and where they wish. Policies to encourage neutral hosting will need to be based on the consent of existing spectrum owners driven by their own business decisions. A commercial issue will then be whether to maintain spectrum partitioning along ownership lines or to pool spectrum. One idea is that MNOs could be encouraged to translate their quantity of spectrum into equivalent quantity of time slots on a 5G new radio. This would simplify shared equipment as well as offering a mutual benefit of sharing the benefit of unused time slots (trunking gain).

Under the scenario of neutral hosting using operator spectrum, it will be for the operators to decide whether one of them acts as 'the neutral host' or they come to a commercial deal with a third party neutral host provider. There would be value to the operators in fostering a limited number of third party neutral host providers to secure scale economies. The choice of sharing model and technology will depend upon the commercial agreements mobile operators elect to make.

Where a carriers' carrier or self-help group provides 'own initiative' coverage

There exists a gap in the market today - where MNOs have no commercial interest in providing coverage. If no operator can see a profit, then it follows that a third-party business case will be marginal, and will depend on, among other things, access to spectrum at approaching zero cost or value.

Spectrum trading is not a solution to finding access to spectrum for this purpose, since trading presupposes the concept of 'value', and there is likely to be little or none to be had. Certainly, yesterday's unused spectrum has no value.

Where such an approach could be used, the options of *which* bands to use are few, as spectrum bands which are never likely to appear in popular global smart phones are of no use to consumers and therefore of no interest to those investing in new networks. This limits the choice for 5G development to 700 MHz for coverage (but with low capacity), sub-band 3.6-3.8 GHz or 3.8-4.2 GHz (for capacity but limited coverage) or 26 GHz for very high capacity (but with very low coverage). The choice between 3.6-3.8 GHz or 3.8-4.2 GHz is one of timing. The first could deliver mass 5G benefits within 3 years and the latter is likely to be well beyond 7 years. (Note: spectrum in the band 3.4-3.6 GHz has already been released so that its conditions of use (e.g. spectrum sharing) cannot reasonably be imposed retrospectively.)

Various policies have been proposed for free access to valuable 5G globally harmonised spectrum. "Use it or lose it" or "use it or share it" options fundamentally attack operators' ability to have long term network roll-out plans and attract necessary investment from the markets.

Neutral hosting on DSA spectrum raises a policy issue of how congestion is handled on ‘shared capacity’. Each MNO and virtual network operator (VNO) will have its own commercial policy that may vary between unlimited data use but variable quality of service or a high quality of service with data caps to sustain that quality. If both extremes are handled in the same contended medium, then the service provider loses control of the quality of service.

There are market and non-market solutions to this issue. One option is ‘spot pricing’ - rationing by price. The other extreme is rationing by queue. *A third option is to set down a universal minimum quality of experience (delta-Q) and for the neutral host to be able to traffic filter to sustain the universal quality of experience for everyone in traffic peak periods.* Of course, none of this is necessary if the neutral host has access to spectrum always greater than that needed to meet peak traffic demand (as might well be the case in some deep rural locations). A policy approach that ensures all 5G spectrum is used at every site will, in many cases, allow such excess capacity to be provisioned economically.

Self-provision through access to 5G spectrum using DSA techniques raises a new policy issue as to what price users should pay for access to this spectrum. The price could be non-monetary; for example, an obligation to partition-off some of the capacity (e.g. 20%) to be made available to a neutral host (which could be a network operator or not, as explained earlier) to provide public access. This would drive 5G coverage into areas (particularly inside commercial and private properties) that would be of significant benefit as smartphones become indispensable even when visiting business premises or residential sites.

There is an issue of what happens to an enterprise basing its business entirely on opportunistic DSA if the mobile operators owning spectrum licences eventually decide to operate at that location. The probability might be small, particularly in remote locations, but it is still finite, nevertheless. It is not good public policy to have a framework where one enterprise can be driven out by another.

One solution is to split out a small amount of spectrum as a backstop, for example, a 20 MHz channel for shared access, perhaps requiring a licence, in the band 3.6-3.8 GHz, and to couple this with licence-exempt opportunistic (non-interfering) use of spectrum that is otherwise being wasted across the entire 3.6-3.8 GHz band in a specific geographic location. DSA is viable, as bands (typically above 2 GHz) are being driven by MNOs’ capacity needs rather than coverage needs. On this basis, and in the absence of a coverage obligation, it is estimated, based upon existing data points for 2.1-2.6 GHz, that sizable amounts of spectrum in the 3.6-3.8 GHz band will never otherwise be used in large areas of the UK landmass. These two components are mentioned in the Government’s FTIR, although without any specific number of MHz being specified. This will increase contention for the remaining spectrum and may increase the price per MHz at auction.

6.2 Control and User Plane Separation

Control and User Plane Separation (CUPS) provides the architecture enhancements for the separation of the control and user plane[11] functionality. CUPS was introduced in 3GPP Release 14 - set to be a key core network feature for current 4G and future 5G evolution.

This functionality provides flexible network deployment and operation through distributed or centralised deployment. Splitting the control and user plane functions enables the ability to scale - while not affecting the functionality of the existing nodes subject to this split.

In 5G networks, CUPS can assist in reducing latency on applications by placing User Plane Function (UPF) nodes closer to the User Equipment (UE), supporting the context of the connection required, which can be achieved and managed through a higher-level control plane node.

The Collaborators believe that the CUPS concept could be applied to spectrum (different frequencies for control and user plane) and could be used to address challenges where one approach does not provide a viable solution for coverage and/or capacity. The example below shows how a higher-level control node could control multiple user nodes using different air interfaces controlled and orchestrated using a 5G network. This could also be combined with neutral hosting options to provide a library of hardware and software functions that could be selected depending on the challenge to be addressed.

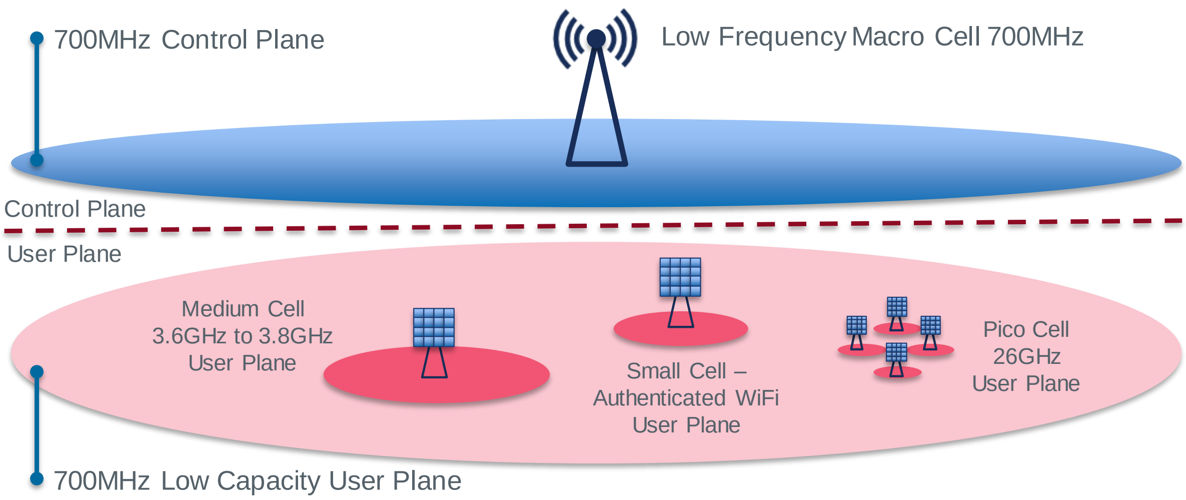

Figure 6 - CUPS example using high, medium and low frequency options

Please note that the example shown in Figure 6 could also use Carrier Aggregation, with 700 MHz being used as an umbrella cell and other frequencies being used locally when they are available; this approach can be used with or without CUPS. The advantage of adding CUPS means that the 700 MHz umbrella cell could be used for control functions, guaranteeing an

[11] User Plane - provide the data connection used for calls, services and applications.

always-connected Control Plane while using multiple higher frequency / bandwidth User planes (3GPP and/or 3GPP air interfaces, licensed and/or licence-exempt spectrum use). When the higher bandwidth User planes are not available, the 700MHz umbrella cell can then default back into normal Control and User plane mode.

6.3 Multi Band Usage

Figure 6 above provides a good example of how multiple bands with different characteristics can provide solutions to provide seamless connectivity, capacity and coverage optimised based on location and context, including indoor and outdoor solutions.

In this example, the 700MHz high level control plane provides wide area coverage connectivity to all User Equipment (UE) in the Cell area. Where UEs are within range of the Medium, Small and Pico Cells, the UE User Plane can be delivered by these cells. Where the UEs are not in range of the Smaller User Plane Cells, the 700MHz Macro layer can also utilise the User Plane for low bit rate services and connectivity. As stated in previous sections, the benefits of this approach are that the User Plane cells can provide high bandwidth ‘spot’ coverage where it is required and could be delivered on licensed and/or licence-exempt spectrum and by third parties / private networks potentially working in partnership with the Macro Layer owner. A key feature of 5G is the connectivity of non 3GPP nodes, authenticated by 5G, to the network. As can be seen in Figure 6, this could be a Wi-Fi node, for example.

7. Summary and conclusions

This paper has explored options for deploying 5G spectrum in innovative ways to solve traditional business model, coverage and capacity issues. Competition and likely public funding simply will not be sufficient to roll out Gbps coverage over enough of the UK's urban areas to be transformational, nor will it fill in all of the 'basic' coverage gaps for mission critical national connectivity. 'Neutral hosting', acknowledged in the Future Telecoms Infrastructure Review, is now being widely discussed as a means of avoiding duplicative investments in less economically viable areas. Neutral hosting could be provided by a pure third-party carriers' carrier or by an MNO acting as a site-specific carriers' carrier, or as an outcome of 'self-provision'.

The main recommendations from this discussion paper are for UK Industry, Academia and Government to:

1. Invest in further innovation, test beds and trials to explore options to enable innovative spectrum usage, outside of main population areas and where network economics do not support viable business models:
    a. 700 MHz for large area coverage.
    b. 3.6 to 3.8 GHz for medium capacity / coverage.
    c. mmWave bands for high capacity spot coverage.
    d. mmWave bands front haul / back haul for difficult to reach locations, using enhanced antenna technology capability.
    e. Hybrid solutions, orchestrated by 5G networks to combine recommendations 1a, 1b, 1c and 1d.
    f. Technology demonstrators to show technical feasibility to support Recommendation 2.
2. Explore new approaches with respect to spectrum management and licensing models for different bands, covering conventional national licensing for high population areas combined with alternative models for areas where it is economically challenging to deploy networks, e.g. rural, transport corridors and indoor solutions. Candidates for evaluation are listed below, where 'x' denotes a variable to be determined by band (see section 4):
    a. Last x% by area, opened up for LOCAL USAGE / GEOGRAPHICALLY LIMITED to allow third party and self-provision if not used by primary licence holder FROM DAY 1 or AFTER A SET PERIOD.
    b. Last x% by area, unified national approach to share spectrum.
    c. Last x% by area or total UK - Dynamic Spectrum Access.
    d. Split band usage, set aside x MHz of band for shared registered use across all of UK.
    e. Differentiation of indoor and outdoor through EIRP management.
    f. Combinations of all the above.
3. Engage with ***Ofcom Enabling opportunities for innovation Shared access to spectrum supporting mobile technology consultation (Closing Date 12th March 2019).***[12]

[12] Ofcom consultation: Enabling opportunities for innovation Shared access to spectrum supporting mobile technology consultation. Publication Date: 18 December 2018 Closing Date for Responses: 12 March 2019.

Coverage and capacity in the right places will be perhaps the biggest challenge of the 5G era, and the need for innovative hybrid solutions will be essential for opening up new models for usage and sharing to lower the network economic costs to provide not only coverage but also capacity in spot locations. The use of just one technology, spectrum band and/or architecture is no longer a viable approach, as one solution does not fit all.

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https://www.ofcom.org.uk/__data/assets/pdf_file/0022/130747/Enabling-opportunities-for-innovation.pdf

8. APPENDIX A: The Projects

The purpose of this section is to briefly summarise the activities of three of the projects within the 5G testbed and trial programme, namely the Worcestershire 5G Consortium (W5G), AutoAir and 5G RuralFirst (5GRF), with 5GRF taking responsibility for creating the document, supported comprehensively by The University of Surrey's 5G Innovation Centre '5GIC'). For further details please refer to the websites of the individual projects.

5GRF – Rural Connectivity – www.5GRuralFirst.org
5GRF is pioneering new approaches to the deployment of connectivity in rural areas, empowering organisations and communities and working to evolve more efficient business models for nation-critical industries such as agriculture, tourism, renewable energy, and manufacturing that operate in rural environments.

5G presents a tremendous opportunity for industry and rural communities in the UK, yet they are hindered by one thing - connectivity. More specifically, there is a lack of secure, reliable, mobile connectivity. This problem is recognised and clearly documented in the Institution of Engineering and Technology (IET) report, 5G Networks for Policy Makers [5], which observes that "the greatest network infrastructure challenge of the 5G era will be coverage."

Trialling 5G in some of the most remote and challenging environments in the UK, 5GRF aims to excite governments, policymakers, regulators, mobile network operators, and other service providers about the partnership potential of 5G in rural areas. The project is specifically looking at three rural testbeds located throughout the United Kingdom from the Orkney Islands to Somerset. The Orkney Islands testbed spans some 2,000 km^2, and is looking at how spectrum can be shared at 700 MHz and 3.5 GHz and 26 GHz (including at sea, within UK territorial waters), whilst in Somerset and Shropshire, 5G agri-tech solutions are being developed, pushing the boundaries of connectivity coverage, speed, and latency.

W5G – Industry 4.0 Connectivity – www.wlep.co.uk/current-projects/worcestershire-5g/
The Worcestershire 5G Consortium, part of the Worcestershire Local Enterprise Partnership (WLEP), is developing what they believe to be the country's most comprehensive industrial 5G Testbed trial with a team of 5G specialists and business experts pioneering the concept of 'Industry 4.0'. The consortium of partners includes local infrastructure providers, national network operators and research and development facilities.

The 5G Testbed will provide a revolutionary platform for local and national businesses to develop next-generation technology focused on improving the UK's industrial productivity. The focus is therefore upon indoor connectivity but also to advance cyber security application, providing assurances on the 'security by design' of IoT technology. This will adopt higher frequency spectrum for shorter range links; notably, 3.5 GHz and potentially frequencies above 24 GHz have use in this application.

AutoAir – Transport connectivity – https://uk5g.org/discover/research/autoair-overview/
The AutoAir project brings together many industry-leading 5G players and 5GIC, the common thread in all three projects. The initial application will focus on delivering pervasive 5G connectivity at the Millbrook Vehicle Testing Ground that will enable connected autonomous vehicle (CAV) developers and research companies to accelerate their testing. The network will operate at Millbrook and will allow access to existing MNOs on a shared / neutral host basis. The focus of this project will therefore be utilisation of spectrum at 2350-2390 MHz and 3400-3800 MHz via a radio access network supported by a backhaul mesh at 60 GHz as well as in the 66-71 GHz band. The intention of the 5G pioneer bands is to focus global efforts to achieve the best launching conditions for 5G, early scale economies and certainty of wide inclusion in smartphones and other devices. Other bands may well be worth examining in due course, including the possibility of sharing the 2300-2350 MHz MoD band.

Upscaling Rural, Industry 4.0 and Transport – what is needed
Where rural connectivity is required, the impact on the current spectrum allocation regime would be minimal. The reason for this has to do with the fact that it is uneconomic for operators to provide coverage in remote areas of the UK. Where there is no coverage, it follows that prime spectrum is left fallow and an opportunity exists for others to use it to help extend rural coverage. This should be done in such a way so as not to undermine both current and future investments from those who have a legitimate expectation to gain a return on their investments, but also so as not to allow spectrum to be left underutilised, which could be seen as a breach of a current statutory duty to make the most efficient use of spectrum. A role for both neutral network hosts and spectrum sharing clearly exists, as two of the Ofcom-approved TV White Space spectrum database providers are contributing partners in 5GRF.

In the case of connectivity in factories, the real challenge in up-scaling is the need to have far more sophisticated spectrum mapping and propagation models to facilitate increased utilisation (particularly of frequencies above 24 GHz). These are big assumptions. However, we can immediately deduce that in spectrum management terms it should easily be possible to have an extremely light licensing regime, which combined with enhanced mapping, would have the effect of minimising interference whilst simultaneously maximising spectrum availability. Neutral hosting has a role here. For example, recent work carried out by Ordnance Survey and 5GIC, commissioned by the Department of Digital, Culture, Media and Sport (DCMS) [6], led to internal findings that it could take up to 7 million cells to cover the UK geography.

As regards connected vehicles, the up-scaling of spectrum to be used from the testbed to full national deployment creates significant problems. One issue is that the 3.6 GHz band is already heavily utilised. Another issue is caused by the 60 GHz band, which cannot be up-scaled with sufficient guarantees in quality of service (“QoS”) to support vehicle to infrastructure (V2X) connectivity, due to being unlicensed spectrum.

We conclude from the above that there is a case for spectrum sharing and neutral network hosting in all of the above scenarios but potentially using different techniques according to the individual characteristics of the bands to be used. Were this to be done, it is certain that up-scaling these projects would provide three immediate economic benefits:

1) significantly improved rural coverage;
2) the facilitation of industry 4.0 solutions in the UK;
3) an accelerated programme of national trunk road coverage deployment to facilitate V2X.

9. APPENDIX B: Spectrum and the Types of Licensing in the UK

Spectrum is not all the same due to the laws of physics. Low frequency spectrum (under 1 GHz) travels long distances but typically supports relatively low bandwidth/throughput. (For example, the entire 4G band at 800 MHz has only 2x30 MHz of usable bandwidth.) In general, the higher the frequency the shorter the range, with the possible addition of atmospheric losses; but substantially more bandwidth / throughput is generally available in these higher-frequency bands. 5G presents a particular challenge because it is designed to convey both low and high data-rate services with varying levels of range and reliability, and so it must have access to both low and high frequency bands.

The spectrum policy and strategy which governs these is ultimately controlled by a complex process of international agreements, ultimately orchestrated by the United Nations' International Telecommunications Union (ITU) but with some EU intervention and much national autonomy within this framework. Key current considerations in this environment include:

1. Reaching agreement on band use, taking account of conflicting industrial interests.
2. Policy goals from the Government and regulators together aiming to secure efficient use of spectrum alongside making the UK a world leader in 5G.
3. Sharing and hosting whereby all agree that sharing it is a good principle but any party typically would prefer to share common resource, not their own.
4. Licensed spectrum activity is mainly controlled by a form of spectrum licence that doesn't permit commercial use to anyone but the licence holder. Opportunistic use on a non-interference basis could be permitted on a licence-exempt basis, but does not necessarily provide adequate security of tenure to attract investment. The government's FTIR market expansion model seeks to overcome these barriers.
5. Agreement on 5G spectrum must focus on International Mobile Telecommunication (IMT) 2020 bands to be determined by the ITU and particularly those identified across the EU by the RSPG and the standards process of 3GPP, or it will be impossible to commercialise, and technological dead-ends could result.

Through a complex international and European process, it has been agreed that the main candidate bands for IMT-2020will focus around the following carrier frequencies:

- 700 MHz – low frequency, long range, low capacity.
- 3.5 GHz – slightly higher frequency, medium range, fairly high capacity.
- 26 GHz – High frequency, millimetre wave band. Fairly short range, high capacity.
- 40 GHz – High frequency, millimetre wave band. Short range, high capacity.
- 60 GHz – High frequency, millimetre wave band. Shorter range, ultra-high capacity.

10. APPENDIX C: High Level Analysis of Current Spectrum Licensing

There are four main types of spectrum allocation – and a fifth 'override' option for Government that could be used should change not be delivered to their satisfaction.

1. Licence exempt - Listed in the Ofcom Frequency Allocation Table [7] – Wi-Fi in a home is implemented in this way; it is popular, but it provides no guaranteed quality of service.
2. Licensed - Auctioned by Ofcom – such spectrum is typically held by MNOs, for example.
3. Shared Access – May require a licence or may be licence-exempt. May also be implemented on an automated and dynamic access basic, authorised by a database commissioned by Ofcom – Available as an option but not widely used yet; for example, Television White Spaces.
4. Non-Operational – Provided by Ofcom – For testing and development, and of limited duration.
5. Direction by Government to Ofcom regarding spectrum regulation.

Telecommunications worldwide are moving towards sharing as the only practical method of coping with the vast traffic increases being seen. The forms that sharing could take are of great importance to all 5G projects as this impacts what can move to commercial deployment and what cannot. Given that Ofcom already has a geolocation database for TV spectrum, this is obviously helpful since timeliness of spectrum release is also a major issue.

11. APPENDIX D: Global harmonisation of Mobile Spectrum and Standards

Setting the Scene – Global Harmonisation of Mobile Spectrum

In the world context, there are three levels of cellular technology harmonisation, beginning with the International Telecommunications Union (ITU), which harmonises bands to very broad definitions of services through World Radio Conferences. The main purpose is to minimise harmful interference across national frontiers. On the second level, national governments are then free to do whatever they want, provided that they respect these negotiated boundary conditions. The time scales for changes to the international table of frequency allocations are exceedingly long. It is a political process with sometimes unpredictable outcomes. A further barrier to global harmonisation is the ITU's traditional regional approach to spectrum allocations, and the time scales involved.

At the second level of national regulators (or in the case of the EU a group of national regulators cooperating voluntarily through CEPT and the RSPG) they add sub layers of harmonisation to secure more efficient use of the spectrum for mobile services. This includes many technical characteristics often set by reference to the technology state of the art. They are not entirely technologically neutral as it will be 'the state of the art' applying to earlier generations of technology. The EU Commission has identified 'time to market' as a significant problem with the current EU spectrum framework in bringing the entire Single Market into step for new EU wide networks and services. The RSPG has pointed out the challenges of achieving this due to Member States having very different national spectrum legacies. That said, the 5G pioneer band initiative was an exceptionally successful collaborative effort of national regulators, industry, the academic community and the European Commission.

The third level of harmonisation is negotiated within global standards bodies to enable the air interface to allow terminal devices produced by one set of industries to successfully connect by radio means to networks supplied by another. The lack of a linkage between new standards and a few designated spectrum bands has led to a runaway world for mobile device designers of ever more bands demanding ever more antennas to be packed into the tiny space of a modern smartphone. This drives down RF performance and leads to an effective shrinkage of coverage.

A large number of bands have been identified for 4G in 3GPP standards, but not all appear in popular global smartphones. The bands that are commonly selected become far more valuable than those that are not – a new factor in mobile spectrum management. This is the enormous economic impact of the 5G bands in focussing investment behind particular bands to drive rapid economies of scale and making technology affordable to a mass market sooner. It makes the choice of other bands less viable, particularly for niche applications that will never generate scale economies. The issue of standards is every bit as vital to the success of 5G as spectrum. We show below that there is no shortage of standards-making capacity for 5G technology. But when that technology is put to work across a raft of industrial and commercial sectors that each sit in their own eco-system silo, there will emerge standards issues that do not sit comfortably in any particular silo. That is the specific 5G standards challenge.

First we show that there is not a problem within our own sector (silo). Standards making generally involves two distinct steps. The first is the creation of the technical specification that may be the subject of a standard and the second is the implementation of that specification in the market with the economic force for it to become a ‘standard’. Formal standards making (the creation by consensus of the technical specification) is divided amongst three recognised standards bodies: European Committee for Standardisation (CEN), Electrotechnical Standardisation (CENELEC) and European Telecommunications Standards Institute (ETSI).

They broadly map at the global level on to the International Organisation for Standardisation (ISO), International Electrotechnical Commission (IEC) and the ITU. At the national level, the British Standards Institute (BSI) is the gateway into CEN and CENELEC. ETSI was founded on direct participation from the outset. The 5GIC is a member of ETSI, as are most of its industry members.

One of the problems faced by all the formal standards making bodies is that they are unable to keep in step with fast moving markets. ‘Consensus building’ takes time, and markets do not wait. This has led to the emergence of a huge number of industry standards groups who have had varying degrees of success. Some rise very quickly, face the same old problems of conflicting industrial interests, and fail.

The second step in the process makes or breaks the success of a standards body or industry grouping. How successfully does a market align around a standard? There are four broad ways this can happen. A dominant industry interest (or oligopoly of large interests) can simply impose the standard on the market. Microsoft and IBM have sustained wide market compliance with their standards. The second is a ‘consensus’ model that is supported by an entire industry eco-system. The sheer number of companies brought together create the dominant market power behind a new standard. 3GPP’s success is based upon this model. The same consensus model is true of the Institute of Electrical and Electronic Engineers (IEEE) for Wi-Fi standards and the Internet Engineering Task Force (IETF) for Internet protocol standards. The third model is the ‘chance in a million’ of the right technical specification, perhaps drawing upon many contributions, emerging at the precise point in time when a strong market need emerges and nothing else is around to challenge it. The World Wide Web falls into this category. There is a fourth model, and that is for governments to take a technical specification into law as a technical regulation. Only the US, EU, Japan and China have the economies of scale and industry base to do this. The issue with mandating standards in law is the inability of the market to sort out a bad technical standard.

From this analysis, it is clear that there is no shortage of ways of making standards, nor is there a shortage of successful models in delivering them into the market. *The issue for this report is to ask the question: what is new with 5G that challenges any of the above standards landscapes?*

Many of the sectors that drive 5G use cases may have scant understanding of the importance of the standards process, or they may have their own eco-system standard-setting processes. The new issue is what happens to those standards that sit across the new boundaries - for example, hands-free farming of the future, and telecommunications connectivity to support it. Therefore, who picks up the task of writing the technical specifications and how are those standards delivered into the market?

The ambition for 5G to facilitate the transformation and modernisation of whole industries could be slowed down by uncertainty of who does the standardisation. It is a gap analysis challenge, and from that is a mapping challenge in the two or more overlapping zones. And who has the policy lead in government to ensure that a process exists to handle the gaps identified? In the above example, would it be the Department for Digital, Culture, Media and Sport or the Department for Environment and Rural Affairs, who will already be managing a vast plethora of food, aquaculture, and other sector-specific standards? The ambition of this report is to articulate the question and trigger the debate on the right solution(s).

12. APPENDIX E: References

[1] “5G infrastructure will boost UK economy by £10bn a year, says O2”, Article, *Capacity Media*, 17th February 2017.

[2] T. Tjelta et. al, “Spectrum for 5G”, Deliverable D5.4, *Euro-5G – Supporting the European 5G Initiative*, v1.0, 2017.

[3] “Future Telecoms Infrastructure Review”, Policy Paper, *Department for Digital, Culture, Media and Sport*, 2018.

[4] https://5g.co.uk/guides/what-is-wigig/ (Accessed September 2018)

[5] 5G Networks for Policy Makers, *Institution of Engineering and Technology*, 2016, www.theiet.org/5GNetworks

[6] “The effect of the built and natural environment on millimetric radio waves”, *Final Report for Department of Digital, Culture, Media and Sport*, 2018.

[7] “The United Kingdom Frequency Allocation Table” https://www.ofcom.org.uk/spectrum/information/uk-fat (Accessed September 2018)

[8] 3GPP Standards Release 14, http://www.3gpp.org/release-14 (Accessed September 2018)

[9] “Improving mobile coverage: Proposals for coverage obligations in the award of the 700 MHz spectrum band”, Office for Communications, Closed Consultation, 4th May 2018. https://www.ofcom.org.uk/consultations-and-statements/category-2/700-mhz-coverage-obligations (Accessed September 2018)

13. Disclaimer

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