An Industrial 5G Spectrum Policy for Europe

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Written with expert input from

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COMPASS LEXECON

vodafone

Contents

A Note from Joakim Reiter, Vinod Kumar and Johan Wibergh

In the race for economic prosperity and sustainable development across the globe, digital is quickly becoming a new engine of economic growth. Policymakers recognise that Gigabit connectivity propels the digital transformation of both industry and society. A successful rollout of 5G across Europe is a necessary condition for this European digital transformation.

Vodafone is playing its part in this transformation. We have already invested around €5 billion in 5G spectrum across the EU, rolling out 5G services in 100 European cities across seven Member States. We are actively developing the innovative services and applications that will realise the benefits of 5G for all. Given the profound impact of 5G on the industrial and business sectors in particular, we are working closely with our business customers across a range of sectors as they embark on this digital journey.

Our ability to deliver on our commitment is determined by the conditions for investment set by governments and regulators. Investors, such as Vodafone, need to operate at efficient scale to earn the return that enables their investment in the first place. Consistent and predictable regulation is critical, supported by policies that promote development and tackle fragmentation.

Despite this, there is an ongoing regulatory discussion on the issue of whether internationally harmonised cellular spectrum should be 'set aside' for private localised use instead of auctioned to whoever is able to create the largest value to society, including nationwide public networks.

Set-aside results in less spectrum remaining available for deployment in national networks, giving marginal potential benefits to a narrow set of stakeholders at the expense of all other 5G users, society and the wider economy.

Our report demonstrates that set-aside policies will lead to a significant consumer welfare loss, reducing the incentive for investment by distorting competition, inflating the costs of spectrum licences and limiting the ability of operators to build the best 5G networks possible for everyone.

Regulators considering setting spectrum aside for local use should be required to justify policies that move away from established market-based solutions, particularly as national operators are already delivering innovative 5G and 5G-ready connectivity to a range of industrial partners across the continent. This innovation cuts across a variety of sectors, including manufacturing, transport, energy, agriculture, logistics and mining, as exemplified by the case studies in this report.

With a series of important European 5G spectrum auctions set to take place in the near future, this approach is vital if Europe is to achieve its Gigabit Society vision.

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Executive Summary

5G is an important new technological innovation that has the potential to transform the European economy by enabling the digitisation of a wide range of sectors.

In practice, there will be a number of considerations relevant to businesses seeking to harness 5G connectivity. These include their understanding of the availability of the different solutions, the capabilities and cost of each solution and how these will meet the needs of their core business.

Access to 5G connectivity and solutions will also to a large extent depend on the policy approach to 5G, in particular how spectrum is licensed. Governments, national regulatory authorities, public network operators, operational technology (OT) companies[1] and business end-users all have a voice in this important policy debate. When setting policy in this area, it is important to take into account the wider impact that 5G will have on the economy. So, in practice, the impact of 'industrial' 5G policy (for example, developed with industrial automation in mind) will also be felt across many sectors, impacting the economy as a whole.

Some stakeholders are arguing that internationally harmonised cellular spectrum needs to be set aside for localised licensing so that they are able to manage their own 5G network. This approach means moving away from market-based allocation of spectrum.

While some Spectrum Authorities[2] appear sympathetic to this argument (in Germany a quarter of the 3.5 GHz 5G spectrum band was reserved for localised services), other Spectrum Authorities have considered the wider implications of setting aside 5G cellular spectrum for local licences. For example, the UK Spectrum Authority promoted spectrum leasing and made other non-mobile bands available for sharing instead of setting aside spectrum. This was done in order to deliver very similar policy objectives to those identified by the German Spectrum Authority as the basis for setting aside spectrum.

We can now learn from experience in Member States where 5G spectrum has already been awarded. With auctions for the remaining 3.4-3.8 GHz spectrum expected in 17 Member States over the next two to three years, there is much still at stake.

This study sets out Vodafone's views on whether such spectrum 'set-aside' is justified, through analysis of both the industrial policy and spectrum policy considerations. By 'industrial policy', we primarily mean issues relating to innovation, economic growth, scale, security and coverage. By 'spectrum policy', we mean considerations relevant to ensuring efficient spectrum allocation while enhancing competition in the market. In developing and/or applying licensing policies, the relevant authorities (Spectrum Authority) will need to take into account both industrial policy and spectrum policy considerations.

To evidence the industrial policy considerations, we have asked the consultancy Arthur D. Little (ADL) to investigate and document a range of business case studies across the EU to examine whether there is a business requirement that national licensing or alternative technical approaches cannot address. ADL's research concluded that:

- the mobile industry is well placed to deliver the **innovation, scale, enhanced security and coverage** required by many businesses; and
- business requirements can be addressed under the **current national licensing regime**, combined with **alternative technical approaches where required** (e.g. use of unlicensed spectrum) and **policy alternatives such as spectrum leasing**.

The qualitative evidence that has been gathered by ADL is set out in full at **Annex A**.

To evidence the spectrum policy considerations, we have asked the consultancy Compass Lexecon to develop a policy framework to assess a set-aside policy and examine the economic impact of the recent German 5G spectrum policy and auction. Compass Lexecon estimates that the costs to German society of set-aside are significant, while any benefits are likely to be marginal, especially taking into account the benefits that can be delivered through both the technical and policy alternatives. Specifically, it finds that:

- there is **no evidence that a policy of spectrum set-aside is justifiable from a spectrum policy perspective**. There is **insufficient evidence of market failures** that would justify a departure from a market-based award mechanism and there are **less costly policy alternatives** that a Spectrum Authority could adopt that would deliver most if not all of any identified benefits;

[1] An operational technology company deals with the hardware and software that detects or causes a change through the direct monitoring and/or control of physical devices, processes and events in the business.

[2] In practice, the government (e.g. Ministry) and national regulatory authority for electronic communications both have a significant role to play in this area. For reasons of convenience, we refer to Spectrum Authority throughout the document.

- for a market the size of Germany, **set-aside of 100 MHz** – of the total 400 MHz of mid-band harmonised spectrum – **could cause consumers welfare loss around €6.2 billion to €15.6 billion for a licence ending in 2040** as a result of higher prices. Consumers may also suffer from a significant degradation in the quality of service;
- **public network operators paid €2.2 billion extra in the German auction than what they would have otherwise paid without set-aside**. Money that could otherwise have been used for faster and more extensive deployment of 5G; and
- the decrease in the capability of public mobile networks as a result of spectrum scarcity and **higher spectrum costs will have a ripple effect on the wider economy** which, even if small, is likely to be significant, possibly overshadowing the costs that have been identified above.

The full text of the Compass Lexecon study can be found at **Annex B**.

To inform the policy debate, and in light of the abovementioned evidence and analysis, we then make policy recommendations for those Member State authorities that may be considering the question of 5G spectrum set-aside, in particular for industrial use.

We outline the approach that policymakers should use to assess whether it is justifiable to depart from widely established market-based mechanisms to awarding spectrum. Specifically, we adopt the following three-stage policy approach:

1. **Assess if there is a market failure** to justify departure from a conventional market-based award procedure.
2. **Assessment of costs and benefits of setting aside spectrum** – taking into account that most of the benefits of 5G in industry can be delivered through a range of technical and commercial alternatives that do not require spectrum set-aside.
3. Assessment of **alternative policy options** to further facilitate the deployment of localised 5G networks. There are viable alternatives to spectrum set-aside, including spectrum leasing, which Spectrum Authorities could pursue as well as making other non-mobile network operator (MNO) spectrum available on a shared basis among others.

Guide to the use of footnotes and references in this document

Footnotes (1, 2, etc.) can be found at the bottom of each page.

References with links to source material (i, ii, etc.) can be found at the end of the document on page 23.

Chapter 1: Market and Regulatory Context

Market Context

5G improves productivity and efficiency while ensuring competitiveness for both consumers and businesses alike[3]. The economic benefits of 5G are clear. For example, a study for the European Commission focusing on the automotive, healthcare, transport and utilities sectors alone assessed that 5G would deliver benefits in these sectors of €62.5 billion per annum in 2025 and total economy-wide benefits from its use in these sectors of €113.1 billion[i].

For those countries that have already auctioned 5G spectrum, public network operators are now able to bring 5G to market, enabling businesses to take advantage of these benefits. At the time of writing, Vodafone has launched 5G in seven Member States and over 100 cities across the EU.

For business users, the primary focus of this study, this includes the dynamic configuration of networks and resources to address different customer demands, more resilient and ubiquitous networks and pervasive ultra-fast connectivity. 5G is also a positive opportunity for small and medium-sized enterprises (SMEs), as it will enable them to create new services and applications to compete in a larger market.

5G enables, among other things, more industrial automation, more flexibility on the factory floor and higher productivity. 5G brings the performance and reliability to 'untether' previous fixed assets/equipment and enable new methods of production, with both existing (legacy) and new (for example, robotic) tools.

However, 5G will benefit a wide variety of sectors. A summary of the broader business benefits resulting from 5G is set out in Figure 1 below.

Figure 1: Benefits of 5G to industry[ii]

	Challenge	Need	How 5G will help
Automotive	• Strict CO_2 emission goals • Strong competition • Pressure for innovation • Globalisation	• Autonomous and connected cars • Innovative infotainment solutions	• Dynamically configure networks and resources to address different demands
Media and entertainment	• Quality of experience constantly increasing • New devices and services • Explosion of mobile data usage	• Networks which can support new media and entertainment services and devices (VR & AR)	• Support massive increases in data rules • Guarantee a good quality of service
Energy and utilities	• Decentralised generation • Pressure on consumption • Increase in renewables • Fines when outage	• Dynamic smart grids, which can be monitored and controlled remotely throughout the entire network	• Real-time control of grids and remote generators where fibre has not been rolled out
Public transport	• Stronger focus on safety and security • Growing number of passengers • Higher service expectations	• Real-time information and entertainment for passengers • More efficient operations and maintenance of infrastructure	• Provide coverage and bandwidth for infotainment and more efficient operations
Agriculture	• Growing global population • Pressure on use of pesticides • Lack of farmers • Climate change	• Increased productivity and efficiency of farming • Sustainable farming solutions	• Remotely connect and control farming equipment • Provide bandwidth for advanced imagery and use of drones
Healthcare	• Ageing population • Increase in people with chronic diseases • Personalised care expectations	• Affordable healthcare solutions • Personal, wearable devices for monitoring and treatment • Remote patient care and follow up	• Enable mobile remote care solutions through guaranteed and secured connection
Manufacturing	• Ageing workforce • Manufacturing skills gap • Pressure on costs • More environmental concerns	• Robotics and automation inside the factory • Solutions which decrease the production costs	• Provide the highly resilient, secure and low latency communication platform in the factory
Security	• Higher security alerts • Increased terrorist threats • Focused cyber security	• More monitoring and screening in public places • Better and faster information to law enforcement agencies	• Support wireless security applications both for monitoring and detection

Source: ADL: Creating a Gigabit Society – the role of 5G

[3] 5G is defined in a set of standardised specifications that are agreed by international bodies, in particular ITU-R IMT-2020 which identified the following usage scenarios: (1) massive mobile connectivity, which drives the need for enhanced mobile broadband (eMBB); (2) connectivity of millions of devices, which drives the need for massive machine-type communications (mMTC); (3) resilient, instantaneous connectivity, which drives the need for ultra-reliable and low-latency communications (URLLC). The pioneer 5G bands that have been earmarked in Europe include the 5G mid-bands (700 MHz and 2.4-3.8 GHz) and the millimetre wave bands (26/28 GHz).

Given the important role that 5G will play in relation to this variety of industry sectors, specific sectors are becoming increasingly aware of their connectivity requirements, working with technology companies in the process.

For example, Vodafone has recently collaborated with industry stakeholders on a Smart Port White Paper. Ports play an important role in promoting international trade and regional development. In the port sector, the move towards 5G is stimulating port automation to address the business challenges of increased labour costs, harsh working environments and declining productivity[iii]. Figure 2 sets out the port application requirements on a 5G network in greater detail.

Figure 2: Summary of port application requirements on 5G wireless network[iv]

Application scenario	Scenario description	Overall requirement	Network KPI requirement		
			Latency	Bandwidth	Reliability
Remote control based on video	Remote control (signaling)	Low latency, high reliability and low bandwidth	<30 ms	50-100 kbps	99.999%
	Video feed (video streams)	Low latency, high reliability and large bandwidth		30-200 Mbps	99.9%
IGV/AGV[4]	Autonomous truck	Low latency and high reliability	<50 ms	10-20 Mbps	99.9%
Video surveillance	Video monitoring with massive data transmission	Large bandwidth and multi-stream concurrency	<200 ms	2-4 Mbps	90%
Sensor data collection	Data collection with low power consumption sensors	Massive concurrency	Best effort	Best effort	90%

Source: 5G Smart Port White Paper

Summary of technical and commercial options available to businesses for 5G connectivity

The transition to 5G should be seen as part of a general move by businesses towards deeper digitalisation, reshaping business solutions and processes to be 'digital first' and deploying intelligent, flexible and scalable cloud-based and software-defined digital infrastructure.

When businesses are considering the options for setting up 5G connectivity, they are focused on understanding the availability of the different solutions, along with the capabilities and cost of each solution that will meet their needs, allowing them to focus on their core business.

In considering how to implement 5G connectivity, two aspects will be of particular relevance to business end-users: a) the parties to be involved in providing the solution and b) how access to spectrum is to be provided. The options which are possible in a given market will depend on the spectrum policy approach adopted at Member State level.

The main technical options are as follows:

- **MNO-provided service** – an MNO takes full responsibility for delivering the 5G connectivity service to the business customer. This solution is available across the EU, wherever 5G spectrum has been licensed nationally. It may involve a solution utilising a public network or a dedicated private network.
- **Self-managed network** – the business takes full responsibility for managing the 5G connectivity solution via its own private network.
- **Hybrid solutions** – the business chooses to manage some aspects of the 5G solution but partners with an MNO and/or OT company to deliver the full solution. The business could manage its 5G network but relies on the MNO and/or OT company to offer localised access to its nationally licensed spectrum, or could seek its own spectrum and rely on the MNO to operate the 5G network.

[4] IGV- intelligent guided vehicle/AGV- automated guided vehicle

In terms of how access to spectrum is provided, the main technical and commercial options are as follows:

- **Dedicated licensed spectrum** – in the majority of cases, spectrum is offered through an open award process to players who intend to deploy 5G, generally on a nationwide basis.
- **Leased spectrum** – businesses that want to operate their own 5G infrastructure can lease spectrum on a localised basis from public network operators holding national 5G spectrum licences. This solution will be available in all EU markets where 5G spectrum has been licensed nationally and sub-leasing is supported by Spectrum Authorities.
- **Shared spectrum**[v] – businesses that want to operate their own 5G infrastructure can apply for licences in a shared spectrum band, but will need to be coordinated with other users in the same band.
- **Unlicensed spectrum** – anyone planning to operate 5G infrastructure can use licence-exempt bands, such as 2.4 GHz, 5 GHz and 66 GHz, but will need to be coordinated with other users in the same band.

Across all Member States, over €10 billion has so far been spent by public network operators in 5G auctions for licences in the 3.4-3.8 GHz band alone[5], with a number of further auctions on the horizon. This expenditure has been a prerequisite before investment can begin in 5G rollout, which in turn will have a multiplying effect through the economic value generated for the EU economy. This economic value is due to the growth in productivity through the increased digitisation of a range of different industry sectors along with the additional benefits for European citizens.

Success of all sectors and a diverse range of businesses in the 5G era will be significantly influenced by the ability of governments to implement spectrum policy that encourages sustainable investment and drives innovation. In particular, the extent of the transformation and deployment of new services across the EU depends critically on whether public network operators can gain access to the spectrum bands on suitable terms necessary to deliver services cost-effectively and make a return on investment.

Regulatory policy context relevant to spectrum set-aside

European Union policy

To deliver the economic and social benefits of the European Single Market, and so that the EU remains competitive on the global stage, the European Commission has set connectivity objectives for 2025, which include[vi]:

- "All European households should have access to 30 Mbps connections by 2020 and 100 Mbps by 2025, with the possibility to upgrade those networks to reach much higher speeds;
- All main socio-economic drivers – such as schools, universities, research centres, transport hubs, hospitals, public administrations, and enterprises relying on digital technologies – should have access to gigabit connectivity by 2025;
- Uninterrupted 5G coverage should be available in all urban areas and all major terrestrial transport paths to connect people and objects by 2025; and
- Access to mobile data connectivity everywhere, in all places where people live, work, travel and gather."

[5] Based on auctions in Germany, Italy, UK, Spain, Austria and Ireland

The Commission's vision is complemented by the International Telecommunication Union Radiocommunication Sector (ITU-R) IMT-2020[6] vision for 5G. This vision recognises that an increasing number of innovative solutions will be required to address new demands, "such as more traffic volume, many more devices with diverse service requirements, better quality of user experience (QoE) and better affordability by further reducing costs."[vii] In order to meet the goals of IMT-2020, MNOs would need to have access to at least 80-100 MHz of contiguous spectrum in the 3.4-3.8 GHz band and around 1GHz in the 26/28 GHz band. The Commission has already set out in the implementing decisions of the European Electronic Communication Code[vii] ('Code') that this block of contiguous spectrum should be pursued by Spectrum Authorities across the EU.

In addition, the Code seeks to bring a more consistent internal market approach to radio spectrum policy and management. A number of the provisions of the Code (which must be implemented at Member State level by 21 December 2020) emphasise the objective of ensuring efficient use of spectrum resources to facilitate continuous infrastructure development[viii].

The Code recognises in Article 52 that spectrum is a scarce resource, and limiting access hampers investments for network rollout, innovation of new services or applications, and ultimately competition. In order to grant spectrum licences, the Code highlights the need for a transparent framework when demand of spectrum exceeds availability, to avoid discrimination in the award process and more importantly optimise the use of a scarce resource to deliver maximum value[ix].

The Code further endorses the effective, efficient and coordinated use of radio spectrum for the establishment and development of pan-European networks as highlighted in Article 3. A pan-European approach is beneficial to overall innovation, which is often slowed down due to fragmentation caused by varying national policies[x]. Fragmentation also inhibits the creation of ecosystems at scale that enable the same devices and equipment to work seamlessly in any market.

While the EU has the authority to define the technical aspects of spectrum use, Member States ultimately decide when it is made available and under what term and price conditions. A number of Member States are considering taking measures relevant to spectrum set-aside. A selection of recent examples of Member States exploring set-aside are set out next.

Member State policies

Netherlands

Given the severe current usage restrictions on the 3.4-3.8 GHz band, the Dutch government is planning to make the band available in stages[7]. The middle 200 MHz (3.5-3.7 GHz) will be available in 2022, with an additional 100 MHz to be made available by 2026. In June 2019, the Ministry of Economic Affairs published its Long Term Spectrum Policy in which it expressed its intention to set aside the top 50 MHz and bottom 50 MHz of the band for local licences.

The justification provided in the Long Term Spectrum Policy was that users above and below the band need to be protected along with the great demand from possible local licensees[xi]. In addition, it was stated that "[i]n order to realise this ambition, the action plan stipulates that the Ministry of Economic Affairs makes frequencies available for enterprise-specific applications so that specialised providers can also serve the increasing demand for different forms of wireless connectivity, or that parties can create a network for their own use" (unofficial translation)[xii].

Sweden

The national regulatory authority (PTS) held a consultation in summer 2019, which proposed to set aside 80 MHz for local licences. PTS noted in its 2018 preliminary study on this topic that "[i]t is also important that a possibility be given for more actors to compete for local applications where a very limited coverage area is desired, such as mines and other industrial applications. This could be achieved through the assignment of block licences for smaller geographic areas. Such licences are proposed to be assigned on a one-by-one basis and not in connection with other licences for other geographic areas."[xiii]

Comparison: Germany and the UK

While countries such as Netherlands and Sweden have yet to make a decision on measures related to spectrum set-aside, Germany and the UK have reached two rather different decisions based on a similar objective.

In Germany, the national regulatory authority (BnetzA), in promoting industrial policy, set aside 100 MHz of dedicated licensed spectrum for nationwide use in the internationally harmonised 3.5 GHz band for local licences aimed at industrial users. This, coupled with the encouragement for a fourth MNO to enter the market, resulted in severe spectrum scarcity with less than 300 MHz of unrestricted spectrum to be allocated to four MNOs[8].

[6] International Mobile Telecommunications-2020

[7] To prevent interference with a satellite ground station facility considered by the Dutch government as an essential asset for national security.

[8] Of the 300 MHz, 20 had use restrictions.

As part of its set-aside decision, BNetzA provided the following justification for such a policy approach: "The provision of 100 MHz for use in regional and/or local business models was said to be urgently needed. Local and regional assignments would allow companies to share in the advantages of 5G. The band's propagation characteristics make it particularly suited to use in industrial automation with 5G technology. The provision of less than 100 MHz would restrict the implementation of regional and local business models. Only adequate spectrum resources will enable Germany to take a leading role in 5G applications. It must be possible to operate a local radio network in production facilities independently of any nationwide provision of broadband services by mobile network operators. The operation and monitoring of a production site's radio network must be carried out internally for reasons of liability, the protection of trade secrets and patents."[xiv]

Conversely, the national regulatory authority (Ofcom) in the UK considered and rejected the idea of setting aside spectrum in its upcoming 3.6-3.8 GHz auction for alternative uses[9]. Specifically, Ofcom states that "(…) we do consider that making all the remaining 120 MHz available for national mobile use would increase MNOs' opportunity to develop their new services effectively, and the likelihood of investment, innovation and effective competition in the provision of mobile services, including 5G, to UK consumers in future"[xv]. Rather, Ofcom introduced a spectrum sharing framework in which the following three elements are incorporated[xvi]:

- Making available the 3.8-4.2 GHz, 1800 MHz shared spectrum and 2300 MHz shared spectrum bands for new users.
- Where spectrum is licensed on a national basis to mobile network operators and is not being used in every location, Ofcom will enable access to this spectrum for new users through sub-leasing.
- Making available the 24.25-26.5 GHz band in a spectrum sharing framework for indoor use.

Ofcom states that its approach "could support growth and innovation across a range of sectors, such as manufacturing, enterprise, logistics, agriculture, mining and health. It could enable organisations to set up their own local networks with greater control over security, resilience and reliability than they may have currently. For example, manufacturers connecting machinery wirelessly, farmers connecting agricultural devices such as irrigation systems and smart tractors wirelessly, enterprise users setting up secure private voice and data networks within a site."[xvii]

It is therefore interesting to note that in reaching two very different policy outcomes, each Spectrum Authority referred to very similar justifications, in particular the ability of businesses to realise the benefits of 5G.

We will now consider and analyse the industrial policy considerations associated with spectrum set-aside, to assess whether on currently available evidence there is a market requirement that dedicated licensed spectrum cannot address.

[9] In annex 5 of the consultation on the upcoming 700 MHz and 3.6-3.8 GHz auction, Ofcom sets out its assessment of the case for local or regional licences, including the opportunity cost of reserving spectrum for local or regional use and why it considers that its proposals on spectrum sharing are a better policy solution.

Chapter 2: Analysis of Industrial Policy considerations relevant to spectrum set-aside

From the examples set out in Chapter 1, it is clear that Spectrum Authorities consider the licensing of 5G to be important in relation to industrial digitalisation and the resulting economic and innovation benefits. One critical issue is the question of whether internationally harmonised cellular spectrum should be set aside so that business users can operate private 5G networks. This may partly be driven by a belief that the mobile industry may not be able to meet the needs of some business users.

With this in mind, Vodafone engaged ADL to research the needs of a variety of industry sectors and assess how these needs were met and the role that public network operators played. As part of this qualitative review, we also asked ADL to document alternative technical and commercial approaches to addressing business requirements in this (in particular, the use of unlicensed spectrum) and also alternative regulatory approaches to spectrum set-aside, specifically spectrum leasing. The results of this qualitative review are set out in detail at **Annex A** and summarised on the following pages.

While it is plausible that industry could benefit from having its own spectrum set-aside in some cases, Vodafone considers such cases are likely to be a small subset based on the findings from ADL. It is therefore very unlikely that the social value that this small subset could create (if it were to even exist) would be comparable to the benefits that the spectrum would have generated if it were deployed through national public mobile networks.

Licensed Spectrum Case Studies

The licensed spectrum case studies ADL showcased on the following pages demonstrate that:

- the mobile industry has been able to meet the needs of a broad range of industries across the EU, including through the use of innovative techniques such as network slicing ***(Innovation)***;
- the businesses interviewed have been satisfied with the enhanced security benefits associated with these solutions ***(Enhanced Security)***;
- scale is an important consideration, with the ability to connect the same devices using the same network at both short range and in a wide area being seen as a significant advantage, which could help achieve more harmonised service provision across the EU ***(Scale)***;
- coverage can be improved to meet specific needs in rural or remote areas through dialogue between the business and mobile operator provider ***(Coverage)***; and
- the use of a portfolio of spectrum bands rather than a single band facilitating the deployment of a range of applications ***(Multi-band)***.

e.GO Germany

Vodafone, together with Ericsson, deployed a private network for e.GO, an electric vehicle company. Mobile network slicing is being used for the first time in Germany to dedicate a slice of spectrum for e.GO's 'Industry 4.0' factory to ensure that critical manufacturing processes are never interrupted. In addition, Vodafone's private mobile network solution ensures secure, encrypted communications.

"e.GO values Vodafone's expertise in setting up such a project from end to end as well as the MNO's large scope, which also enables connectivity beyond the plant through its public network."

Ruben Schumacher, Business Analyst at e.GO

Identified benefits:

Innovation **Enhanced Security** **Scale**

ABB Italy

ABB wanted to leverage analytics and automation to improve its plant productivity. A consortium, including ABB and Vodafone, developed the collaborative robot YuMi, which encompasses 5G-powered 3D vision devices and leading-edge analytics for an augmented collaboration.

"For ABB, the collaboration with the MNO was essential in implementing an ultra-low latency connectivity around YuMi, as Vodafone was owning the multi-edge computing processes and infrastructure."

Michele A. Pedretti, Robot Business Development Manager at ABB Italy

Identified benefits:

Innovation **Enhanced Security**

Shell Netherlands

Royal Dutch Shell PLC looked for a solution to better manage product logistics around the Pernis plant while improving asset maintenance and utilisation. The project consortium looked to enable robot inspection, remote machinery control, digital workers and predictive maintenance through 5G solutions.

"The port of Rotterdam is the perfect place for the industrial 5G Field Lab. We can achieve a lot in terms of reliability and efficiency with new digital technologies, helping to improve industry safety performance even more."

Jos Van Winsen, General Manager at Shell Pernis

Identified benefits:

Innovation **Enhanced Security**
Scale **Multi-band**

Vienna International Airport Austria

Vienna International Airport improved its connectivity through a campus network slicing solution to divide the airport's local network into two sub-networks, guaranteeing stable network access, which also increases the safety inside and outside the airport.

"With A1, we have found a competent digitisation partner and developed a solution that meets the requirements of the airport of the future, offers passengers the best possible customer experience and guarantees a high level of reliability of the apron processes."

Günther Ofner, Flughafen Wien AG Executive Board member

Identified benefits

Innovation **Enhanced Security** **Scale** **Coverage**

Deutsche Fußball Liga (DFL) Germany

DFL partnered with Vodafone to equip a section of Wolfsburg's stadium with multiple antennas for 5G connectivity. This offers football fans extensive game-related data and a unique augmented reality (AR) experience, while creating a platform for future commercialisation.

"Technologies are only as good as the application possibilities that emerge from them… we are doing this by connecting 5G and real-time information. A strong 5G infrastructure provides the ideal conditions for partners and clubs too."

Christian Seifert, CEO of DFL

Identified benefits

Innovation **Scale** **Coverage**

Boliden Sweden

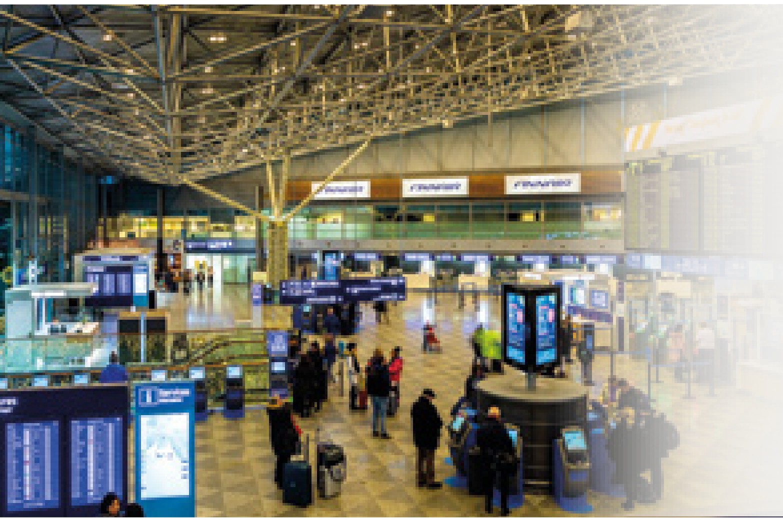
The mining company Boliden needed to switch from a Wi-Fi option to a safe solution fostering automation with ultra-low latency in a remote location. The MNO deployed a public 4G (5G-ready) network-as-a-service solution and network slicing in an open-pit copper mine. This ensured reliability and security, making sure the solution operated constantly regardless of the outside world connection.

"[R]esults delivered to date have been really good, providing very stable operations when it comes to the latency, bandwidth as well as the roaming, compared to other available solutions including Wi-Fi."

Andreas Stenlund, IT Manager at Boliden

Identified benefits

Innovation **Enhanced Security** **Scale** **Coverage**



Finavia Finland

The airport operator Finavia improved the passenger experience and security within Helsinki airport through the introduction of a 5G-powered service robot 'Tellu'. This was the first time 'millimetre waves' were used for 5G in a public use case in Finland.

"The low-latency connection and massive capacity of 5G will serve the airport well with its masses of passengers and data, and with the focus on security and fluency of services."

Janne Koistinen, 5G Program Director at Telia Finland

Identified benefits

Innovation **Enhanced Security** **Multi-band**

The National BVLOS Experimental Centre

(NBEC), UK

The NBEC consortia assisted in the launch of the first 5G-enabled drone beyond visual line of sight (BVLOS) facility in Bedfordshire, UK. Vodafone developed the connectivity infrastructure allowing for ultra-low latency communications necessary for safe and efficient control of the drone flight.

"The network solution deployed in the facility is the first 5G-enabled drone BVLOS of its kind in the UK and will accelerate the uptake of the UK's latent drone technology and infrastructure in global markets."

Ian William-Wynn, Managing Director at Blue Bear

Identified benefits

Innovation **Enhanced Security** **Scale** **Coverage**

Ericsson Estonia

In order to enhance productivity within its Tallinn factory while delivering improved safety and faster connectivity, Ericsson pioneered a new manufacturing environment with automated vehicles, AR, environment monitoring and intelligent automation systems. The dedicated 5G-ready network is a first in Estonia and allows Ericsson to capture the advantages of a private network while leveraging the connectivity expertise of the MNO partner.

"Mobile networks meet the requirements to support diverse smart manufacturing use cases, making it possible to securely and efficiently optimise manufacturing processes. They allow massive real-time data collection and analytics and intelligent automation on the factory floor, solving operational challenges and creating a more sustainable, efficient and safer production environment."

Lars Ottoson, Head of Ericsson Supply at Tallinn

Identified benefits

Innovation **Enhanced Security** **Scale**

Steveco Finland

The port operator Steveco implemented separate long-term evolution (LTE) solution in the port of Mussalo at the same time as Ports of Oulu and Kokkola to improve the digitalisation and automation efforts. They offer any industrial player the possibility of assuming the role of a micro-operator, enhancing the innovation of the sector, bringing reliable mobile broadband connectivity that scales according to the customer's digitalisation strategy.

"At first we considered using Wi-Fi, but an LTE network is superior thanks to its security, reliability and pervasive coverage. At the same time, we can commercialise our network by offering slices to other businesses in the area."

Jyrki Roukala, Development Manager at the Port of Kokkola

Identified benefits

Innovation **Enhanced Security** **Coverage**

Emilio Moro Spain

Emilio Moro has implemented a Narrowband-IoT solution (part of the 5G family of technologies) to help build a smart winery which can transition to 5G New Radio. This enables them to maximise productivity while minimising environmental impact with the support of consortium partners, including Vodafone.

"Thanks to these agreements with Vodafone, we have been able to apply IoT technology to maximise the production and quality of our vineyards. We aim to further scale this partnership with 5G implementation and to extend the solution's geographical scope."

José Moro, Owner of Bodegas Emilio Moro

Identified benefits

Innovation **Scale** **Coverage**

Unlicensed Spectrum Case Study

As set out in Chapter 1, there are technical options other than licensed cellular technology which could in practice be deployed, depending on the use case and the specific requirements of the end-customer. A technical option includes unlicensed spectrum as demonstrated by the case study below:

Ocado UK

In order to gather orders faster and more reliably, the online retailer, in collaboration with Cambridge Consultants, developed a dedicated LTE mobile network over 5 GHz unlicensed spectrum. This sets the ground for ultra-low latency and thus for more reliable automated devices such as robots for grocery collection. As a result, 98.8% of the orders placed are delivered with the correct products, thus enhancing client satisfaction.

"There is no way we could achieve the required throughput if the robots were autonomous, moving around the grid dodging one another. Instead, the swarms of robots are orchestrated by a machine learning-based system that is playing chess many moves ahead. It knows which bins need to be where, and which robots it needs to schedule to complete every order in a perfect pick sequence."

Paul Clarke CBE, Chief Technology Officer at Ocado

Another example in unlicensed spectrum is Wi-Fi 6, which is seen as the next generation of Wi-Fi. The Wi-Fi Alliance states Wi-Fi Certified 6 "... provides the capacity, efficiency, coverage, and performance required by users today in the most demanding Wi-Fi® environments...Wi-Fi CERTIFIED 6 devices bring enhanced performance to emerging applications such as virtual and augmented reality used in e-Learning, telepresence, and healthcare."[xviii]

Spectrum Leasing Case Studies

If full control over spectrum in mobile bands were to be a requirement for some industry uses, spectrum sub-leasing can play an important role. In circumstances where factories are located in areas where MNOs are not making full use of a specific band, then it should be possible and desirable for them to sub-lease the spectrum. Spectrum leasing as a commercial option (where permitted by regulation) is exemplified by the case studies below:

StrattoOpencell UK

StrattoOpencell used underutilised spectrum from UK MNOs through spectrum leasing. Carved out for specific uses, spectrum leasing reduces the cost to the user versus the enterprise owning and deploying the network itself. StrattoOpencell obtained a three-year licence from Ofcom and came to an agreement with Vodafone to leverage its regional and underused 2600 MHz spectrum in a fixed area in Cornwall. This value proposition could be extended to other businesses in underserved rural areas.

"Leveraging the spectrum underused by MNOs in rural areas allows for better service to end-users, lower costs to customers and asset optimisation for the MNO leasing its spectrum locally."

Graham Payne, CEO of StrattoOpencell

Workspace UK

Workspace, a flexible office provider, wanted to provide best-in-class indoor mobile connectivity for tenants and customers. StrattoOpencell offered its expertise in 'neutral host' solutions to enable Workspace to cover all four UK MNOs from a single point of contact.

"The cost is much lower than deploying and managing a high-quality Wi-Fi network which customers still have to log in to. We already see use cases for wider deployment of 5G."

Chris Boultwood, Head of Technology at Workspace group

We will now consider the spectrum policy considerations relevant to spectrum set-aside, followed by an economic analysis of the German 5G spectrum auction.

Chapter 3: Analysis of Spectrum Policy considerations relevant to spectrum set-aside

As set out in Chapter 1, a number of Spectrum Authorities are considering whether to set aside spectrum for localised use, for example to meet the 5G requirements associated with industrial automation. There are a number of policy considerations relevant to the allocation of spectrum in the EU, for example the need for Member State Spectrum Authorities to ensure efficient use of spectrum resources and optimise its use to deliver maximum value for society at large.

Efficient allocation of scarce resources

By setting aside spectrum for localised use, a Spectrum Authority may knowingly or inadvertently undermine fair access to spectrum and therefore distort fair market competition by effectively 'picking winners', leading to inefficient spectrum use resulting from spectrum underutilisation across the country.

In Vodafone's view, spectrum set-aside for localised use is not an efficient use of spectrum, as it can come at the expense of others and can therefore pose several threats to the wider success of 5G. Artificially restricting the amount of spectrum available to be licensed on a nationwide basis creates scarcity among those seeking to offer nationwide services. It can also inflate prices in public spectrum auctions and prevent public network operators offering customers the higher speeds and lower cost services that are only possible when 5G networks can operate across 80-100 MHz of spectrum.

Therefore, spectrum set-aside adversely affects the affordability and quality of services available to users.

Maximum value for society at large

The opportunity cost of spectrum set-aside for localised use is more than just the price of the spectrum licence itself; it includes the broader social value derived from those services relevant to the spectrum in question. Analysys Mason estimated that over just one year (2011) the social value generated by the 3G and 4G spectrum allocated to public network operators in the UK was £30 billion (€25.4 billion)[xix]. The year-over-year social value over the duration of the licences increases significantly when compared to total auction receipts for indefinite licences over the years amounting to just under £25 billion (€21.2 billion)[10].

Conversely, it has yet to be demonstrated that setting aside spectrum for localised use can create similar levels of social value and that this value could not have been delivered through any other technical and/or policy alternatives. Therefore, an industrial policy approach of spectrum set-aside should consider only the benefits of those innovations that could not be delivered through these other technical options.

Analysis of the German 5G spectrum auction

We can now evaluate and test the abovementioned points through empirical evidence gained from the recent German auction, where industrial policy led to spectrum set-aside. The national Spectrum Authority (BNetzA) set aside 100 MHz of the 400 MHz of spectrum in the internationally harmonised 3.5 GHz 5G band for local licences, with the remainder being auctioned among four bidders in 2019.

Along with the set-aside, licence terms were set in a way to encourage the entry of a fourth participant to the auction, resulting in less than 300 MHz of unrestricted spectrum to be divided up between four MNOs[11] and no operator being able to secure the 100 MHz target to fulfil the IMT 2020 vision[12]. As a consequence, more spectrum will be available for local use than will be available to any MNOs, most likely at a fraction of the cost and absent costly nationwide rollout obligations.

In Vodafone's view, it appears that this decision was also found wanting in a number of important respects:

- it was considered important that industry had access to 100 MHz, and not less. However, insufficient evidence was provided as to why the correct amount to set aside was 100 MHz nor why it was acceptable for MNOs to effectively end up with less spectrum than industrial users;
- it was not demonstrated that there was a market failure that justified departing from a market mechanism to award the spectrum;
- there was no examination of whether any costs associated with this decision would be offset by any net benefits; and
- there was no consideration of any policy alternatives, such as spectrum leasing or making other bands available for sharing.

[10] The auction receipts can be broken down by £22.5 billion for 3G, £2.3 billion for 4G and £1.4 billion for the 2018 auction, which was for 2.3 GHz and 3.4-3.6 GHz. It is important to note the £25 billion is an overinflated spectrum cost due to the exceptionally high prices of the 3G auction. Figures converted to Euros using the GBP to EUR exchange rate on January 2011 of €1.18/£.

[11] 20 MHz of which have use restrictions as a result of airborne radar

[12] German auction spectrum allocation: Vodafone obtained 70 MHz (excluding 20 MHz of limited use), Deutsche Telekom obtained 90 MHz, Telefonica obtained 70 MHz and Drillisch obtained 50 MHz.

Analysis of costs to society resulting from spectrum set-aside in Germany

Given the spectrum auction has now concluded, it is now possible to calculate just how much the public network operators valued the spectrum and, therefore, how much value they could have created for national use.

Compass Lexecon's detailed analysis can be found at **Annex B**. This analysis highlights that spectrum has a significant opportunity cost, not only because of its value to MNOs but also because of the value that can be created when the whole of society can make use of this spectrum.

Figure 3 summarises Compass Lexecon's findings of the non-additive categories of costs that were assessed:

Figure 3: Summary of cost resulting from spectrum set-aside in Germany

Direct cost		Assessment of costs (non-additive)
Consumer harm	Scarcity pricing and/or incremental network cost	Compass Lexecon estimates that spectrum set-aside could reduce consumer welfare through higher prices and decrease network quality, in the case of Germany causing consumer losses between €6.2 billion to €15.6 billon for a licence ending in 2040.
	Network quality degradation	Risk of quality degradation when networks reach congestion (expected in 2025). Speeds and network reliability would be adversely affected.
	Competition effects	Risk of a material adverse effect on consumers starting before all networks reach their maximum recommended level of utilisation due to decreased competition.
Wider costs to the economy		Set-aside is likely to cause harm to the wider economy. Compass Lexecon quotes other studies which have estimated the value to the economy of 5G services in the hundreds of billions and even trillions of Euros (see Chapter 4.128 onwards in Annex B). While it's not possible to accurately estimate the impact to the wider economy of spectrum reservation as a result of the reduced capabilities of national mobile networks, it is reasonable to assume that even a small negative impact is likely to create losses in the billions of Euros.
Direct opportunity cost		A loss in value of €1 billion to €1.46 billion based on German auction data.
Risk of reduced incentives to invest due to higher auction prices		Compass Lexecon also estimates that set-aside caused auction prices to increase by around €50 million per block. This means that public network operators had to pay around €2.2 billion more for the amount of spectrum available, with all bidders ending up with less than the optimal amount of spectrum in the band, due to the effect of spectrum-set aside. This increased cost is also likely to have a negative effect on network investment.

Chapter 4: Proposed Policy Approach for Spectrum Authorities considering spectrum set-aside

Chapters 1 and 2 considered the industrial and spectrum policy considerations associated with spectrum set-aside, before highlighting the adverse net effect on social welfare and the wider economy of the German decision to set aside 5G spectrum in Chapter 3. We now set out the policy approach that we believe Spectrum Authorities should adhere to when considering whether to depart from a market-based award for spectrum. This approach sets out Vodafone's policy recommendations based on the detailed analysis carried out by Compass Lexecon.

Policies should aim to maximise the value that spectrum can generate for society. This is critical in relation to spectrum policy given that it is a critical, scarce resource. Spectrum should be allocated to the uses and users who can generate the most value to society from its use. This is particularly important for spectrum that has been earmarked for mobile as it is even scarcer given that mobile equipment is only manufactured for use with internationally harmonised frequency bands.

As a Spectrum Authority's primary goal when setting spectrum policy should be to ensure the efficient use of spectrum, they should favour a market mechanism unless they have identified a potential market failure that could lead to an inefficient outcome.

While Spectrum Authorities have the discretion to intervene when they believe that a market-led approach may not yield the best results, they should demonstrate that there are market failures that would cause a market mechanism to fail and that the social net benefits of departing from such a mechanism outweigh the possible costs and risks of doing so. This is best demonstrated through a detailed and robust analysis and impact assessment where the Spectrum Authority demonstrates that its intervention is likely to maximise net benefits, while considering whether there are other ways of achieving their policy objectives at a lower cost.

Even if there is uncertainty in the estimation of the possible costs and benefits, a formal impact assessment allows the Spectrum Authority to ensure that it has taken into account all relevant factors and at least grasped the order of magnitude of the proposed policy intervention. In addition, consultation with stakeholders is important in this process as the decision-maker might not be aware of potential effects, including what might be the opportunity cost of allocating more spectrum for one purpose in terms of the alternative uses of the spectrum that will be forgone.

This evaluation mechanism is echoed in Recital 136 in relation to Article 55 of the Code, which highlights the need for a transparent procedure to grant spectrum rights based on a thorough assessment of market conditions, giving due weight to the overall benefits for users to ensure it is justified and proportionate[xx].

Ultimately, Spectrum Authorities are likely to need to exercise some regulatory judgement. However, they should do so after collecting as much evidence as possible and assessing it through an appropriate policy framework to minimise the risk of regulatory failure.

We set out the policy framework in Figure 4.

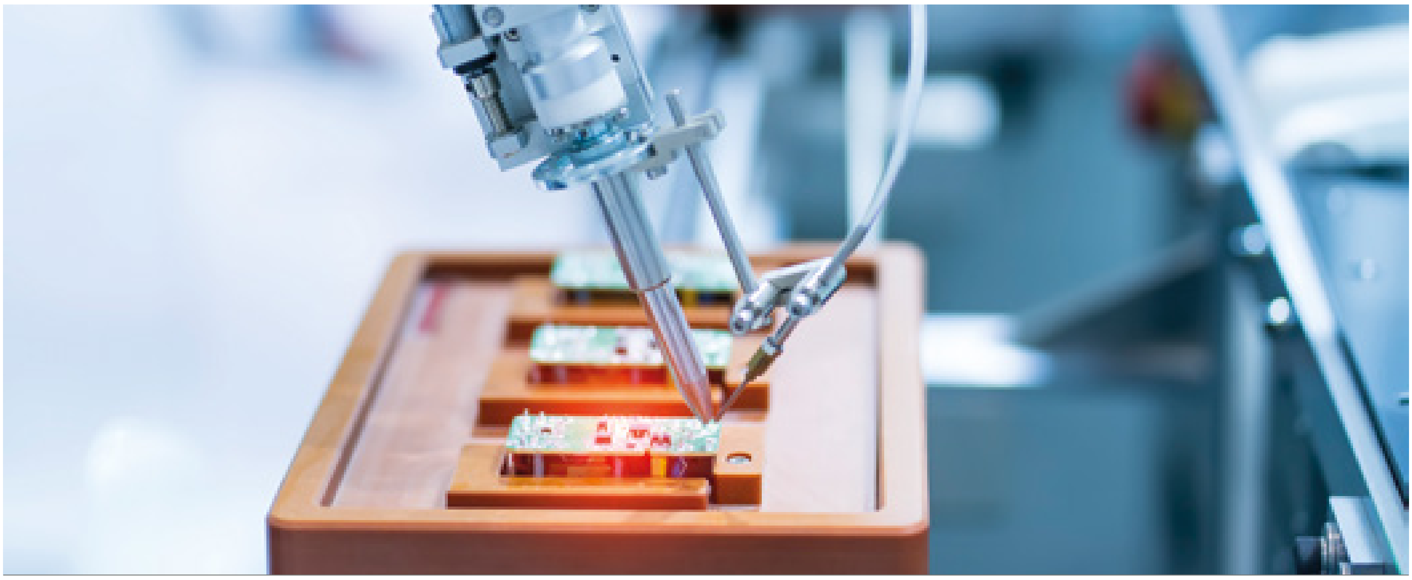


Figure 4: Proposed policy framework for Spectrum Authorities considering spectrum set-aside

Is there a market failure to justify departure from a general auction?	**Identify and assess the relevance of possible justifications for reserving spectrum given the specific market circumstances**
Assessment of costs and benefits of reserving spectrum	**Where a possible justification for departure from a market-based approach exists, there is the need to weigh up the costs and benefits of such an intervention** This requires identifying and evaluating all significant effects of reserving spectrum including: ✓ opportunity cost (both immediately and over time through loss of flexibility) ✓ effects on investment and innovation ✓ effects on competition ✓ effects on the wider economy
Assessment of alternative options	**The costs and benefits of alternative options should also be assessed so as to identify the approach that delivers the greatest net benefit**

This three-stage policy framework to impact assessments lends itself readily to the evaluation of spectrum policy measures.

1. Is there a market failure to justify departure from a general auction?

Generally speaking, a market-based approach works well to allocate spectrum efficiently, while supporting competition and innovation. Therefore, the first question to be asked in our proposed policy framework is whether there is a form of market failure that would justify departure from a market-based mechanism.

A departure from a market-based approach would be warranted where there is a market failure, when a market-based approach on its own would not secure the maximum benefits to society. This could include both direct benefits for users (for example, when consumers can consume more, with better quality, possibly at a lower price) as well as broader benefits to society (for example, widespread coverage which improves access to communication services might be treated as having a wider social value).

There could be a range of reasons as to why intervention is considered necessary, such as if the market-based approach is not expected to lead to the efficient use of spectrum or if it would lead to a competition problem (such as significant spectrum asymmetry leading to lower competition). In its report (Annex B, Chapter 4), Compass Lexecon highlights three types of market failures that might make auctions fail to produce an efficient outcome, but concludes that there is insufficient evidence that there is a market failure that would justify departing from a market-based mechanism to award the spectrum.

These market failures are outlined below:

- **Externalities** – A market failure could arise if alternative users created greater positive externalities than mobile services, or other entities demanding spectrum in an auction, but were not able to express these at auction. However, Compass Lexecon did not discover evidence of such externalities in the mobile markets.
- **Downstream competition problems** – The Spectrum Authority could consider whether the auction could lead to a reduction of downstream competition by gaining/strengthening market power. For example, a dominant operator might try to foreclose rivals because of the expectation that by holding most spectrum in a market they will be able to weaken competition and possibly earn profits above the cost of capital. Compass Lexecon considered that most European mobile markets are effectively competitive and hence do not see a general market failure that would prevent a new entrant from effectively participating in an auction. Furthermore, market failures that could lead to competition issues can generally be addressed through more proportionate measures such as the implementation of spectrum caps in auctions.
- **Coordination** – Spectrum may be of value to a large number of business users each with a demand for a relatively small amount of spectrum. Such users could potentially have a high combined willingness to pay for spectrum although they may face practical difficulties in identifying similar users and being able to successfully coordinate to jointly bid for spectrum. Compass Lexecon found that coordination problems could lead to market failure, although the possibility of entities aggregating bids of local users would mitigate this risk.

Based on the findings from Compass Lexecon, only coordination can cause a plausible market failure and, even then, there is evidence it can be addressed by a firm effectively aggregating the demand of smaller parties[13]. In particular, where there is clear demand from local users and where the combined amount that they would pay is competitive with that of national users, then firms may bid for the spectrum for the purpose of meeting the needs of local users[14].

It is important to note that the existence of a market failure is not a sufficient condition to depart from a market-based mechanism. This only means that Spectrum Authorities should proceed to steps two and three of the framework.

2. Assessment of costs and benefits of spectrum set-aside

As set out above, the existence of a market failure is not in itself a reason to intervene and depart from a market-based award mechanism. Instead, only where a market failure has been demonstrated to be significant should the Spectrum Authority proceed to the next stage of the proposed policy assessment, which would be to determine the possible costs and benefits of intervening.

The benefits and costs should be quantified as much as possible, as placing a monetary value on costs and benefits allows for more objective and direct comparisons of the alternative options. Where it is not practical to quantify particular costs and benefits, qualitative analysis can usually help in estimating the likely order of magnitude of the different effects. This analysis will therefore allow the Spectrum Authority to make an informed decision when using its regulatory judgement.

What are the costs of setting aside spectrum for localised use?

As previously mentioned, spectrum is a scarce resource and setting aside spectrum for one use necessarily denies someone else the right to use it – wider society in the case of set-aside. In turn, this denial generates sizeable social costs from:

- **Consumer harm**: While consumers may not suffer from spectrum set-aside in the short term, congestion will trigger consumer harm in the long term through a combination of increased prices and decline of network quality. These effects could exacerbate due to reductions in network quality and general consumer experience. Furthermore, spectrum reservation could have negative effects on competition as networks approach their maximum capacity.
- **Wider economic effects**: 5G applications are expected to bring benefits across the economy. However, higher prices, less capacity and lower quality will limit these economy-wide benefits. Where licences are acquired for use in one sector, the majority of the potential benefits of 5G could be lost for businesses in other sectors. SMEs may also be negatively impacted, as set-aside favours larger organisations that have the ability to financially justify controlling their own network.
- **Opportunity cost**: If spectrum is not awarded through auction, potential users are prevented from manifesting their value for it, which determines its opportunity cost.
- **Risk of reduced incentives to invest due to higher auction prices**: Losing bids from auctions inform how much entities were willing to pay for spectrum that was not made available. That willingness to pay reflects network cost savings or part of the additional value from better services that the spectrum could help provide.

While there is a certain level of uncertainty about the estimation of the costs, the analysis above at the very least provides a very clear order of magnitude of the costs of implementing such a policy. Specifically, the quantifiable costs to society amount to several billions of Euros, with the unquantifiable benefits potentially larger than this.

What are the benefits of setting aside spectrum for localised use?

In evaluating the benefits of spectrum set-aside, it is important to take into account whether there are alternative technical or commercial options that could effectively deliver the same policy objectives that have been identified by the Spectrum Authority. Such benefits cannot simply be estimated as the social value created by the use of 5G in applications associated with localised use, as most of these benefits can be delivered through the other technical options set out in Chapter 1 (e.g. dedicated licensed spectrum, shared spectrum and unlicensed spectrum).

Instead, a policy approach of spectrum set-aside should correspond only to the benefits of those applications that could not be delivered through these other technical options. For example, if a particular benefit would be attainable through another means, then it should not be included in the benefits specific to the policy measure being considered. This helps ensure that policies are evaluated on the basis of the costs and benefits that they give rise to.

[13] An entity seeking to set up a neutral-host business model could effectively participate in an auction as an agent on behalf of individual users.

[14] For example, Airspan is an independent network operator which has bid on and successfully acquired 3.5 GHz spectrum in several countries, as highlighted by Compass Lexecon (Annex B, Chapter 4).

As set out in Chapter 1, to date Spectrum Authorities have generally stated that spectrum set-aside is necessary in order to promote innovation, ensure security and address issues of limited coverage. Vodafone's view is that licensed cellular technology, as exemplified by cases studies in Annex A, is already addressing these policy objectives.

Vodafone is not aware of any current or envisaged 5G applications that cannot be delivered through any of the existing technical alternatives. Furthermore, while there may be variation in the ease of deployment of some of the technical solutions depending on the specific conditions of each user, we believe it should generally be technically feasible to deploy any application without the need to set aside spectrum.

Given that most (if not all) of the benefits of 5G applications for industry can be provided using the different technical alternatives that currently exist, it is likely that overall benefits of spectrum set-aside will be small and, in any case, will be significantly smaller than the costs that were identified above.

3. Assessment of alternative policy options

Lastly, the Spectrum Authority should assess whether there are alternative policies that it could adopt and that would allow it to deliver the benefits that have been identified at a lower and commensurate cost.

Alternatives to spectrum set-aside include providing for potential users to bid for spectrum without any set-aside[xxi], facilitating sub-lease of mobile spectrum where it's not being used and, where possible, making available other bands for shared or unlicensed use.

One of the key justifications underpinning spectrum set-aside in Germany was that many factories are located in rural areas where MNOs were never going to deploy the spectrum being auctioned. In the UK, Ofcom considered a similar argument but reached a different conclusion, which included the sub-leasing of spectrum by MNOs to local users where the spectrum is not being used.

Furthermore, Ofcom has made available other harmonised but non-mobile bands for sharing such as making available the 3.8-4.2 GHz, 1800 MHz shared spectrum and 2300 MHz shared spectrum bands for new users. The 3.8-4.2 GHz band in particular is currently only used in some areas by satellite and some fixed links and is available for sharing in most of the country.

The spectrum leasing case studies that have been gathered by ADL and which are set out in Chapter 2, further to Ofcom's recent intervention to promote spectrum leasing, highlight the envisaged effectiveness of such an approach.

In assessing the case for spectrum set-aside, authorities should also consider potential alternatives that would allow local users to meet their connectivity requirements, with minimum costs to society as compared to the costs of spectrum aside.

In summary, there is no evidence that a policy of spectrum set-aside is justifiable from a spectrum policy perspective. There is insufficient evidence of market failures that would justify a departure from a market-based award mechanism; the costs of set-aside are significant while the benefits appear to be small. Furthermore, there are less costly policy alternatives that the policymaker could adopt that would deliver most if not all of any identified benefits.

References

i. Identification and quantification of key socio-economic data to support strategic planning for the introduction of 5G in Europe, 2016, available at https://connectcentre.ie/wp-content/uploads/2016/10/EC-Study_5G-in-Europe.pdf

ii. Figure reproduced from Creating a Gigabit Society – the role of 5G, March 2017, available at https://www.vodafone.com/content/dam/vodcom/files/public-policy/gigabit-society-5g-04042017.pdf

iii. 5G Smart Port White Paper, October 2019, available at https://www.huawei.com/ch-en/industry-insights/outlook/mobile-broadband/xlabs/insights-whitepapers/5g-smart-port-whitepaper

iv. Figure reproduced from 5G Smart Port White Paper, October 2019, available at https://www.huawei.com/ch-en/industry-insights/outlook/mobile-broadband/xlabs/insights-whitepapers/5g-smart-port-whitepaper

v. Spectrum Sharing: GSMA Policy Position, November 2018 available at https://www.gsma.com/spectrum/wp-content/uploads/2018/11/Spectrum-Sharing-Positions.pdf

vi. Connectivity for a European Gigabit Society, August 2019, available at https://ec.europa.eu/digital-single-market/en/news/connectivity-european-gigabit-society-brochure

vii. Recommendation ITU-R M.2083-0 (09/2015) IMT Vision – Framework and overall objectives of the future development of IMT for 2020 and beyond, 2015, available at https://www.itu.int/dms_pubrec/itu-r/rec/m/R-REC-M.2083-0-201509-I!!PDF-E.pdf

viii. Directive (EU) 2018/1972 of the European Parliament and of the Council, available at https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv%3AOJ.L_.2018.321.01.0036.01.ENG

ix. Ibid. As mentioned in Recital 102 in relation to Article 42 of the Code.

x. Ibid. As mentioned in Recital 136 in relation to Article 55 of the Code.

xi. Ibid. As mentioned in Recital 32 in relation to Article 4 of the Code

xii. Nota mobiele communicatie 2019, June 2019, available at https://www.rijksoverheid.nl/documenten/beleidsnota-s/2019/06/11/nota-mobiele-communicatie-2019

xiii. Translated quotation that appeared Beleidsvoornemen 3,5 GHz-band, March 2019, https://www.internetconsultatie.nl/beleidsvoornemen_3_5ghz/document/4391, pg. 3

xiv. Preliminary study prior to future assignment of frequencies for 5G, May 2018, available at https://www.pts.se/globalassets/startpage/dokument/icke-legala-dokument/rapporter/2018/radio/preliminary-study-frequencies-5g-pts-er-2018-4.pdf

xv. President's Chamber decision of 14 May 2018 on the order for and choice of proceedings for the award of spectrum in the 2 GHz and 3.6 GHz bands for mobile/fixed communication networks (MFCN), available at https://www.bundesnetzagentur.de/SharedDocs/Downloads/EN/Areas/Telecommunications/Companies/TelecomRegulation/FrequencyManagement/ElectronicCommunicationsServices/FrequencyAward2018/20180613_Decision_I_II.pdf?__blob=publicationFile&v=2

xvi. Paragraph A5.46 – Award of the 700 MHz and 3.6-3.8 GHz spectrum bands, available at https://www.ofcom.org.uk/__data/assets/pdf_file/0021/130737/Annexes-5-18-supporting-information.pdf.

xvii. Ibid.

xviii. Statement: Enabling wireless innovation through local licensing- Shared access to spectrum supporting mobile technology, July 2019, available at https://www.ofcom.org.uk/__data/assets/pdf_file/0033/157884/enabling-wireless-innovation-through-local-licensing.pdf

xix. Wi-Fi CERTIFIED 6, 2019, available at https://www.wi-fi.org/discover-wi-fi/wi-fi-certified-6

xx. Impact of radio spectrum on the UK economy and factors influencing future spectrum demand, November 2012, available at https://www.gov.uk/government/publications/impact-of-radio-spectrum-on-the-uk-economy-and-factors-influencing-future-spectrum-demand

xxi. Directive (EU) 2018/1972 of the European Parliament and of the Council, available at https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv%3AOJ.L_.2018.321.01.0036.01.ENG

xxii. For example, allow them to aggregate their bids as Ofcom did for some 2.6 GHz licenses in the 4G auction as per Statement: Assessment of future mobile competition and award of 800 MHz and 2.6 GHz, July 2012, available at https://www.ofcom.org.uk/__data/assets/pdf_file/0031/46489/statement.pdf

Appendices

Annex A:
Case studies developed by Arthur D. Little

An industrial 5G spectrum policy for Europe

Supporting case studies

Document prepared for Vodafone

Arthur D Little

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Authors: Jonathan Rowan, Enguerran Ripert, Michael Fattori, Catalina Varlan, Lucas Bodrito

The electric car manufacturer e.GO pushes the boundaries of smart manufacturing

Vodafone and Ericsson supporting e.GO car manufacturing innovation

Introduction

e.GO Mobile AG, an electric vehicle company, has partnered with Vodafone and Ericsson to leverage the possibilities of 5G within its factory based in Aachen, Germany. e.GO was founded in 2015 by RWTH Aachen university professor Günther Schuh and currently employs around 500 people.

The project initially focused on the deployment of a private "5G ready" network – to be swiftly followed by 5G – at the 16,000m^2 e.GO factory in Aachen, which is one of the first factories in the world to connect machines using this type of network solution. The solution enables workers, equipment and operations to be interlinked in order to speed-up decision-making, reduce production costs and enhance feedback loops.

Business Need

The company aims to offer more affordable electric vehicles. As a result, the business sought innovation in its main factory to reduce the costs of manufacturing electric vehicles.

As the company is continuously optimising its processes during the ramp-up phase, it needs flexibility across its tools and technology, as well as a reliable coverage with low latency throughout their plant. Available alternatives are not providing for these needs: Wi-Fi generates too much interference and therefore lacks reliability, while Ethernet requires complex cable management, limiting flexibility of the plant layout and increasing upfront capital costs.

MNO Approach

Vodafone addresses the connectivity needs of e.GO enabling them to focus on their core business. In conjunction with the MNO, the factory is currently using spectrum in the 2.1 GHz band but also has the first two 5G radio dots in place. The 4G+ private network allows e.GO to enjoy stable and reliable connectivity across the plant. The absence of cables increases the speed of conducting modifications to the assembly line. RFID chips are placed on vehicles at the start of the assembly process to track them across the end to end manufacturing process. Connecting RFID readers though a mobile network allows flexibility in where the readers can be placed. In addition, cameras are used to run a visual analysis of the assembly process. Connecting the cameras through a 5G mobile network provides the low latency and high bandwidth that enables the use of edge cloud computing for analysis, enabling greater flexibility to adapt the camera setup.

Solution and Use-Cases Enabled

Manufacturing plant connectivity: Vodafone installed 6 smart cells within the factory, 3 across the assembly line and 3 across the logistics line. This connects all the machinery to the IT manufacturing execution system and sends data back to the company's network operations centre. The private mobile network solution deployed is ensuring secure and encrypted communications. Furthermore, mobile network slicing – dedicating a slice of spectrum for the factory – is being used for the first time in Germany to ensure that critical manufacturing processes cannot be interrupted by inadvertent data packet loss.

Ground for process automation: The network offers the possibility of using multi-access edge computing (MEC) to boost the processing power of the Automated Guided Vehicles (AGV), which carry the chassis from station to station, replacing the classic production line. As a breakthrough in manufacturing, the factory contains the world's first AGVs to use 4G+ rather than Wi-Fi. These machines are capable of processing environmental data almost instantaneously, such as unexpected objects in their path. This ensures that machinery in the plant can adapt their routines in real time, highly dynamic environments. In the future, the AGV will be joined by smart forklifts and smart factory trains which will transport material between warehouses and production halls.

Precise control of manufacturing: an electronic database contains a digital twin of the factory such that every component is tagged (using radio frequency identification or RFID tags) with the exact specification for its assembly and disassembly. Parts arrive exactly when they are needed, and the connected tools used by workers automatically adjust to the exact level of torque needed for a task. This ensures future factories can be set up quickly and cost-effectively.

Benefit from Working with MNO and Conclusion

The use of mobile technology provides e.GO's production planning team with the ability to easily analyse network data and automatically adjust factory processes.

The public coverage of the MNO allows for more connectivity between cars, machinery and workers inside and outside the plant as well as across the different company sites. The size and adaptability of the MNO will also enable e.GO to scale their operations in the future and provide access and expertise to the latest technologies such as AR-powered mechanics remotely supporting the repair of cars in the service centres, 5G certification and video analysis of the production process to support predictive maintenance. While the current factory uses a 4G+ network, the increasing trend in digitalisation and demand for systems to process larger volumes of data in real time will require 5G and an upgrade to 5G is currently ongoing in the factory. Working with the MNO allows e.GO to free up time and resources to focus on their core business while deploying the leading edge technologies they require:

> *"e.GO values Vodafone's expertise in setting up such a project from end to end as well as the MNO's large scope, which also enables connectivity beyond the plant through its public network."*
>
> Ruben Schumacher, Business Analyst at e.GO

Source: Arthur D. Little, e.GO

Vienna International Airport deploys a 5G campus network with network slicing

Vienna International Airport partnered with A1 and Nokia

Introduction

Vienna International Airport wanted to improve the connectivity delivered to both airport employees and its 27 million annual travellers. The airport operator Flughafen Wien (FWAG), identified specific cases with strong end-user and operational benefits. These included hyper connectivity (multiple personal devices connected), real-time data analysis, and high bandwidth, ubiquitous data access.

A1, the mobile network operator, enabled the airport to both deploy a fast and stable data infrastructure, and to leverage it to improve customer and operational analytics.

Business Need

Vienna International Airport accounts for more than 27 million passengers and just under 225,000 aircraft movements per year and is one of the most important transport hubs in Central Europe. This critical size is a key driver for best-in-class connectivity demands.

On the one hand, Vienna's airport has a high potential for equipment automation (or partial operator oversight) whilst maintaining efficiency and security. For example, unmanned vehicles are being tested. This requires ultra-low latency, extended connectivity and real-time data analysis, which is not possible within the current Wi-Fi setting.

On the other hand, travellers expect high service quality and fast data rates: the airport places the travellers and their connected devices at the centre of their connectivity strategy. To further enhance the end-to-end customer experience FWAG partners with some airlines.

MNO Approach

MNO partner A1, with the support of the vendor Nokia, deployed small cells across the airport to enable 5G-ready connectivity access across the airport, within the terminal buildings as well as in the aircrafts prior to take-off. The increased connectivity of the small cells allows the airport to cut its number of base stations from around 140 Wi-Fi cells to just 36 5G cells.

Furthermore, A1 developed a campus network slicing solution for Vienna Airport to divide its local network into two sub-networks. It is therefore possible to use a part of the network specifically for airport-internal purposes, such as the check-in processes or for aircraft operations, while the other part of the network is available to passengers as usual. The slicing parameters and attributed bandwidth can be revised depending on needs, bringing in a flexibility aspect to the overall innovation.

Solution and Use-Cases Enabled

Airport devices connectivity: Thanks to the connectivity solution, devices such as luggage scanners, handling equipment or tablets can be integrated into the campus network of the airport. This network of sensors creates a large quantity of data for the airport to leverage operationally. The next steps will include unmanned vehicles for passenger transport.

Sensitive data treated locally: The introduction of a virtualized edge computing platform will enable complex calculations stemming from airport data to be analysed locally and in real-time. This additional computing resource close to the users significantly reduces both the latency and the downtime risk of the applications.

Safer airport operations: The use of a network slicing ensures the security of critical airport processes, regardless of the intensity of passengers' mobile use. Adding 5G will allow personnel (and automated equipment) to remain in contact even in an emergency.

Extended connectivity: Powerful small cells eliminated a significant portion of the network black spots within the airport so that passengers could freely enjoy their connectivity, which is faster than a basic 4G service.

> *"With A1, we have found a competent digitization partner and developed a solution that meets the requirements of the airport of the future, offers passengers the best possible customer experience and guarantees a high level of reliability of the apron processes."*
>
> Günther Ofner, Flughafen Wien AG Executive Board member

Benefit from Working with MNO and Conclusion

Vienna International Airport was able to deploy state-of-the-art connectivity for both airport staff and passengers as well as developing multiple data analytics tools to improve overall monitoring and operational performance. The partner MNO as well as the vendor expertise enabled the airport to focus on its core logistics competencies, yet deliver its ambition within the timetable set at the start of the project.

Believed to be a first in Austria, the solution could be replicated in other airports across Europe and beyond. However, it must be taken into account that given the sensitive nature of airport data, it is subject to different regulatory control in different markets, even across EU member states.

Looking forward, the entire connectivity infrastructure is 5G-ready, prepared for even higher data throughput. Additional data inputs from future devices and sensors planned within the airport will increase the airport's ability for predictive maintenance and self-learning equipment, such as cleaning robots. The MNO will also contribute to the development of unmanned cars transporting passengers across the airport in the near future.

With regards to security, the network slicing guarantees stable network access for airport staff which also increases the safety inside and outside the airport in an emergency. Passengers enjoy extensive connectivity, prior to entering the airport, through to the scheduled take off while on board the airplane.

Source: Arthur D. Little, Halberd Bastion, Shares Magazine, FutureZone, Der Standard

Swedish mining company deploys 4G/5G connectivity to increase productivity through automation

Boliden working together with Telia

Introduction

Telia Company AB, the Swedish telecommunication operator, has deployed both a public 4G (5G ready) network-as-a-service solution and network slicing in the Aitik open-pit copper mine in Sweden. The mine is owned and operated by Boliden AB, a Swedish mining and smelting company focusing on the production of copper, zinc, lead, gold and silver. The network deployed covers an open pit and industrial area of at least 100km^2, which is implemented using 6 LTE cells using 1.8GHz spectrum. The solution went live in February 2019, taking approximately one and a half years to be deployed.

Business Need

Firstly, the enterprise's previous technology in the mine was operated via Wi-Fi; however, this technology was not able to meet all the connectivity needs of the business. The enterprise required a solution which was easily upgradable to 5G, could be integrated with the existing legacy infrastructure and could operate in a relatively large area with extremely low-latency, high predictability and high reliability.

Secondly, the company required more from their existing systems by introducing a solution that was able to increase safety in the mine and drive improved productivity through automation, notably in rig control systems for pit-vipers (as large blast hole drills are commonly known) and bulldozers, as well as for autonomous trucks. For the autonomous machines to work safely, a consistent and stable throughput was required to avoid dangerous spikes in the network that could result in unexpected movements (or lack of movement).

MNO Approach

Boliden approached Telia, its partner MNO, which had proven experience in providing stable network solutions in remote locations in the region. The MNO was responsible for supplying the spectrum, which operates on a 1.8GHz bandwidth, as well as deployment, operation and management of the public 4G network solution.

The MNO leveraged its knowledge and expertise to connect its core infrastructure to the enterprise's and help solve roadblocks and challenges during the implementation of the project. In particular, the MNO assisted Boliden with technical challenges that arose from the integration of the two core infrastructures at the mine.

> *"We had really good help from the MNO in solving most of the issues."*
>
> Andreas Stenlund, IT Manager at Boliden

Solution and Use-Cases Enabled

Real-time location & positioning: Relating to both employees and machines. This enabled the tracking and monitoring of assets at the mine to increase safety by enhancing operational control and reducing intervention times in an emergency.

Improvement of communications tools: The 4G solution enabled the replacement of old communications tools, such as radios, and looking forward to 5G would be able to support sensors and IoT solutions in the future.

Remote control operation & autonomous machines: Applied to the drill rigs at the mine. These became fully autonomous, leveraging the network to boost productivity and free workers' time to focus on more value adding activities.

Processes improvement: The public 4G network solution is capturing performance data to allow the business to better understand which functions would be better outsourced and which to keep in-house.

Following successful trials, Boliden is now considering investing in long-term infrastructure to roll out this solution more widely.

> *"The solution implemented is still in trial so far, together with the testing of the quality of service for the network slicing, have been delivering really good results, providing very stable operations when it comes to the latency, bandwidth as well as the roaming, compared to other available solutions including Wi-Fi."*

Andreas Stenlund, IT Manager at Boliden

Benefit from Working with MNO and Conclusion

The collaboration with the MNO minimised difficulties in the process for the enterprise, as logistics and operations related to the spectrum and the network were handled directly by the partner MNO. Furthermore, the expertise of the MNO ensured cost efficiencies and effectiveness in deploying the solution and solving most of the issues encountered during the implementation phase.

The ownership and management of the spectrum by the partner MNO enabled Boliden to utilise both the public 4G network and the private network, depending on the use case and applications enabled. This provided reliability and security for Boliden, enabling the solution to be operated continuously, independent of the publicly available network.

The use cases developed in partnership with the MNO fit well in the future innovation footprint of the enterprise. In the short-term, Boliden plans to leverage the solution to remotely control its machines, gather, process and store data in the cloud and obtain more granular information on real-time location of both people and machines at the mine. In the long-term, the enterprise plans to add environmental IoT sensors to the network to automatically generate and leverage industrialised data. Besides, completing the transition to 5G will enable more use cases and added functionality, such as wearable devices.

> *"The MNO has good plans for the future when it comes to 5G implementation and collaborates with many companies in the Nordics. Our cooperation has been quite wonderful as they are both very technical and customer focused."*

Andreas Stenlund, IT Manager at Boliden

The MNO network had the advantage of being stable and wide-reaching even in remote locations, offering robust, low-latency connectivity.

> *"When it comes to bringing coverage in remote areas in Sweden, the MNO has the most stable network coverage."*

Andreas Stenlund, IT Manager at Boliden

Source: Enterprise IoT Insights, Boliden, Arthur D. Little

Private LTE solution helps to digitalise Finnish ports

Ports of Mussalo, Oulu & Kokkola together with Operator Ukkoverkot & Technology partner Elisa

Introduction

Ukkoverkot, a Finnish operator, in collaboration with Nokia, is delivering LTE private networks to support industrial innovation and safety in multiple Finnish ports. Separate LTE solutions have been deployed in the Ports of Mussalo, Oulu and Kokkola. The operator's direct access to spectrum allowed the solution to be replicated and scaled across the three ports in less than two years.

The spectrum is owned, managed and deployed by the operator and leverages both 450MHz and 2.6GHz bands. The 2.6GHz band is 5G-ready and will enable new technologies such as edge computing, automation and artificial intelligence (AI).

Business Need

In managed ports, the client, port operator Steveco, wanted to be able to monitor the condition in which containers arrived and departed from the port to improve situational awareness of port logistics and security. This required reliable coverage to ensure operational continuity, improved efficiency and real-time analytics of container handling.

In the Port of Oulu, the client wanted to lay the foundations for its port's digitalisation strategy as part of a five-year deal with the partner MNO Ukkoverkot, whilst improving the communication and interconnectivity within the port. The solution required the capability to connect to Internet of Things (IoT) sensors on the site as well as foster connectivity, automation and intelligence.

In the Port of Kokkola, the client wanted to streamline and improve the efficiencies of its port operations, while acquiring a reliable, secure, pervasive and high-capacity network infrastructure to allow flexibility in its digitalisation and innovation plans.

MNO Approach

Ukkoverkot was also approached to provide lower frequency bandwidth (450MHz) to reinforce the reliability of the solution (at Mussalo, only Ukkoverkot's bandwidth is operating). In all three ports, Ukkoverkot deployed a private LTE solution with indoor and outdoor coverage and low latency.

Solution and Use-Cases Enabled

Port of HaminaKotka: The solution enabled cameras mounted on cranes to stream video and analytics across the network as well as provide proof of container conditions at the entrance and exit of the facility. Steveco was able to embrace IoT and digitalise its processes, enabled by improvements to the network, which brought about efficiencies to container handling, warehouse logistics and security.

"Now we can, if needed, establish the status and state of incoming containers and insurance responsibility thanks to the cameras in the cranes. The connectivity also covers our terminals and the rest of the port area, enabling efficient communication for logistics and asset tracking."

Niko Arola, Steveco's Terminal Manager at Port of HaminaKotka

Port of Oulu: The solution implemented was tailored to the client's capacity, usability and coverage requirements. The use of a private LTE network solution enabled cranes, lifts and other stevedoring machines to be reliably connected, enabling them to receive and transmit data during cargo operations. Furthermore, the 2.6GHz band will enable 5G services as well as new technologies such as edge computing, automation and artificial intelligence (AI).

"By developing the digital infrastructure in the port, we connect the area's network traffic and communication needs into a seamless entity. This was the most technologically advanced and cost-effective solution for our development work that will span many years to come."

Mira Juola, Responsible for Finance and Digitalisation at the Port of Oulu

Port Kokkola: The deployment of a private LTE network enabled the port to become a micro-operator, offering private wireless network connectivity to local companies within the port, as well as run its own operations. Furthermore, the solution enabled a reliable and secure transfer of data within the port, as well as the deployment of new technologies, such as network slicing to improve the commercialisation success.

"It is challenging to create data transfer channels in the vast, 500-hectare port area. At first, we considered using Wi-Fi, but an LTE network is superior thanks to its security, reliability and pervasive coverage. At the same time, we can commercialize our network by offering slices to other companies in the area."

Jyrki Roukala, Development Manager at the Port of Kokkola

In all of the three ports, technology provider Elisa provided a unique solution for dispute resolution via real time video tracking and timestamping. The solution relied on a single base station and three smart cells.

Benefit from Working with MNO and Conclusion

The collaboration with both MNOs has allowed three of the biggest ports in Finland to improve their digitalisation and automation efforts. It also offers any industrial player the possibility of assuming the role of a micro-operator, enhancing the innovation of the sector, bringing reliable mobile broadband connectivity that scales according to the customer's digitalisation strategy.

Steveco reached out to MNOs, because it preferred to concentrate on its core business and valued the technical knowhow and support provided by its MNO partners. The synergies created by the MNOs in owning, managing and deploying the spectrum allowed the innovation process to be spread in a reliable, cost and time efficient way. This is evidenced by rapid roll out of the solution across ports, initiated, as it has been, in less than two years since the first project was carried out in Port of Mussalo.

The private LTE network solution was proven by the operator to be replicable, since the network has been deployed within the same spectrum in three different ports across Finland, all different in size and area. The case study demonstrates a clear future roadmap of innovation, whereby the solution is equipped with the option to support 5G services as well as other new technologies, such as network slicing, edge computing, automation and artificial intelligence (AI).

Source: Arthur D. Little, Steveco

Finavia deploys a private LTE network to digitalise its operations with a 5G-enabled service robot

Finavia is partnering with Telia and Nokia

Introduction

The Finnish airport operator Finavia wanted to improve the passenger experience and security within Helsinki airport. The airport operator leveraged the Tellu robot as an opportunity to develop passenger service and information as well as improve security.

To fully capture value from this experiment, the partner MNO Telia has brought its 5G connectivity expertise when building Tellu, enabling the robot to dynamically interact with its environment.

Business Need

As the Helsinki airport was experiencing increasing traffic, Finnish airport operator Finavia was facing multiple challenges.

On the one hand, Finavia was eager to guarantee a superior passenger experience in an international competition background. This translated into a desire to increase the level of service in the airport, for instance by guiding passengers or providing information relating to flights.

One the other hand, the airport operator wanted to improve the safety within the airport. This meant obtaining real-time information on the current situation in multiple areas of the airport without endangering staff.

MNO Approach

MNO partner Telia leveraged a unique infrastructure for the airport utilizing the 28 GHz frequency band, the highest frequency band allocated for 5G, with a network based on technology by Nokia.

The MNO offered a breakthrough as this is the first time in Finland that so called "millimetre waves" are used for 5G in a public use case.

Solution and Use-Cases Enabled

As a main use case, Finavia and Telia introduced the 1.5m high service robot "Tellu" in the non-Schengen area of T2 terminal. The robot is 5G-powered and fully connected to the 5G-ready existing infrastructure in the airport. The robot is also equipped with a 360 degree camera to better capture the current environment. This innovation is enabling the partners to test different use cases.

Passengers to robot interaction testing: Tellu is an opportunity to study how the passengers and the airport personnel react and interact with an autonomous robot carrying out service tasks. In an attempt to improve servicing, the robot can also guide passengers in the terminal, and the partners aim to try different use cases during the project.

Airport security enhanced by real-time data flows: the ultra-low latency of the 5G-ready connectivity enables data such as video or location to be transmitted in real time to adequate staff. By informing in real-time on any issue occurring within the airport, Tellu enables the airport to guarantee a higher level of safety.

> *"The robot can deliver real-time video stream from the terminal and enable for example monitoring the terminal area through remote or autonomous control and see that everything is running as it should."*
>
> Heikki Koski, Chief Digital Officer, Finavia

Benefit from Working with MNO and Conclusion

The innovation resides in the fact that the robot can fully understand its environment with a 360 degree camera and transmit the information in real-time. The robot also set itself apart with its ability to react to its environment, by answering passengers flight information requests for instance. In addition to bringing the required connectivity skills to connect the robot with the existing infrastructure, Telia is enabling Finavia to keep focusing on its airport logistics expertise.

The robot bases its activity on a fixed infrastructure within the airport as well as on trained staff to leverage the value it is bringing. This configuration could still be reproduced in another airport, given that local authorities accept this breakthrough in the border spaces that airports are.

This project around a service robot is only the beginning of the partnership between the airport operator and the MNO, they both indicated that they were to run other innovative initiatives on 5G applications to airport operations improvement. Among others, next steps could comprise leveraging in real-time the robot data by making the robot or any other device or machinery react automatically.

The overall goal of the robot Tellu was to enhance the level of security & service within the airport. The results of this test will showcase the extent to which this was successful and will constitute a solid learning experiment for service automation in airports.

> *"The low-latency connection and massive capacity of 5G will serve the airport well with its masses of passengers and data, and with the focus on security and fluency of services."*
>
> Janne Koistinen, Telia Finland 5G Program Director

Source: Arthur D. Little, Telia, Mobile Europe, Nokia, Tropical Hainan

VfL Wolfsburg football stadium will benefit from 5G-enabled augmented reality features to enhance fans' in-stadium experience

DFL Deutsche Fußball Liga working with Vodafone

Introduction

Vodafone and Deutsche Fußball Liga (DFL) have embarked on a two-year 5G cooperation to enhance fans' football experience through 5G-enabled augmented reality and real-time data analysis available to fans attending live football matches via the fans' own mobile devices, starting in the 2019 -2020 season

The real-time 5G network will first be available at the Volkswagen Arena of VfL Wolfsburg but is planned for a wider roll-out thereafter.

Business Need

The DFL wants to bring innovation and digitalisation in its stadiums to provide a better and more personalised experience to spectators. In order to achieve this, the league wanted a solution to leverage the increasing amount of data generated during matches, both by DFL analytical tools and by fans themselves.

On the one hand, DFL wants to end the frustration of football fans divided between their desire to attend the game live and their interest in precise data and expert comments, which they can only access when watching the game on television.

On the other hand, DFL is eager to increase its fan base amongst millennials, for whom watching a game is not enough and digital interaction is necessary to stay actively engaged in the game. This entails leveraging leading-edge technology such as augmented reality via a connection between the stadium screen and the mobile screen, with real-time in-match data on the game.

MNO Approach

Vodafone leveraged its recently acquired 3.6Ghz spectrum, which is dedicated to the development of new technologies, including 5G.

The MNO has equipped a section of the stadium with multiple antennas for 5G connectivity to allow comparison of experiences by fans with and without the available technology.

Vodafone partnered with Huawei, the equipment provider, who had an existing relationship with DFL.

Solution and Use-Cases Enabled

Enabling fans to access data already available via other channels: Vodafone, by leveraging its network and spectrum, developed a real-time app that makes commentary and match data available with limited latency to fans on their smartphones. This was made possible thanks to the ultra-low latency of 5G technology. Vodafone supplied part of the 5G infrastructure in the selected Bundesliga stadium, enhancing the mobile communications capacity for fans.

Offering a unique stadium experience including Augmented Reality: Thanks to the solution up to 500 gigabytes of available data – the volume typically produced during televised matches – is safely and rapidly processed and shared with fans. The real-time app makes all additional information immediately available to fans on their smartphones via 5G and using Augmented Reality, thus enhancing the stadium experience. The interface between the user's phone screen and the stadium screen generates new and unique content.

Enabling new and incremental commercialisation opportunities: This aims to help stakeholders capture additional commercial opportunities and test new business models. Several commercial opportunities are currently under consideration, including the digital experience bundled in the ticket price (as is already the case for transport in some cases) and digital contact channels (the app with its content, notifications and access to merchandise and other products) licensed to football clubs.

> *"Technologies are only as good as the application possibilities that emerge from them. As a leader of innovation, the DFL is continuously advancing new technologies concerning sport and media to provide additional possibilities to spectators in the stadium and in front of screens. We are doing this by connecting 5G and real-time information. A strong 5G infrastructure provides the ideal conditions for partners and clubs too."*
>
> Christian Seifert, DFL CEO

Benefit from Working with MNO and Conclusions

The project showcases an innovative application of 5G in the sports/entertainment industry. Augmented Reality, deployed thanks to a real-time 5G network solution, is enhancing engagement and increasing loyalty, with fans and spectators now able to obtain data and analyses in real-time within the stadium.

The app presents the data visually with live graphs, statistics and analyses, usually only available during or after the match on TV. For fans, this means accurate real-time analysis instead of replays, and it enhances the post-match analysis discussions. From the DFL perspective, it augments the viewing experience, adds potential added revenue and commercialisation opportunities and reinforces the value proposition of live sports to an elusive millennial segment.

Relying on Vodafone's expertise allowed DFL to keep focusing on their core business. Outsourcing to the MNO ensures DFL keeps up with technological developments without the need to invest further in technology research and development in house. DFL is thereby keeping pace with technology with limited Capex spend, while improving its commercial flexibility, as it is not constrained by the need to amortise technology it owns.

The network infrastructure embedded in the stadium by Vodafone in collaboration with Huawei guarantees a stable throughput for the high quantities of data shared by different sources within the stadium, while protecting fans' personal data and the stadium's own data centre from cyber security threats.

The deployment and management of the real-time 5G network can be replicated in other stadiums as well, with a plan already in place to bring augmented reality to spectators in different stadiums across Germany. DFL is currently working on a roadmap to expand this usage across its partner stadiums.

Source: Arthur D. Little, DFL Deutsche Fußball Liga, Interviews, Vodafone

The National BVLOS Experimental Centre (NBEC) has launched a 5G-enabled “Beyond Visual Line Of Sight” drone test facility in the UK

The NBEC consortium pioneers drone technology and sets the first regulatory framework overviewing it

Introduction

The National BVLOS Experimental Centre (NBEC) consortium assisted in the launch of the first 5G-enabled drone Beyond Visual Line of Sight (BVLOS) facility in Bedfordshire, UK. The MNO partner, Vodafone, is responsible for the 5G connectivity linking the drones and other infrastructure and assets.

Other key members of the consortium include unmanned systems developer Blue Bear Systems Research, aerospace equipment specialist SAAB, world-leading scientists from the University of Cranfield, and public governance institutions such as the Civil Aviation Authority (CAA) and the European Space Agency (ESA).

Business Need

NBEC, a research organisation, has a mission to evaluate drone flight safety in different environments to optimise combinations of technology and partnership requirements. This overarching mission resulted in two main sub-goals for the consortium. Firstly, NBEC wanted to crash test the use of drones in semi-urban areas in an environment closely approximating to future real situations. This was aimed at evaluating technology needs, developing appropriate regulatory frameworks and gauging societal impact of drone activity. Secondly, the consortium was looking to develop resilient drone systems. All stakeholders' various systems had to function together and to be able to adapt to changes such as an unexpected critical failure of a sub-system. Overall, the most critical connectivity need was to enable the real time tracking and monitoring of the precise position, altitude, direction of travel and velocity of each drone, with an extremely high level of accuracy.

MNO Approach

As the MNO within the NBEC consortium, Vodafone developed a connectivity infrastructure allowing ultra-low latency communications necessary for safe and efficient control of drone flight, but also to test the regulatory framework. The MNO shared insights from experience to advance the maturity of drone flights, working closely with the CAA and the technology partners to understand the pros and cons of each set of technology options, including 5G. Connectivity stakeholders such as Thales and Blue Bear (part of the 5G Rural Integration Test-bed “5GRIT” consortium) are also relying on Vodafone to test interference between each other and enable further assessment of innovative uses of 5G technology.

Solution and Use-Cases Enabled

The MNO's supply, management and deployment in Oakley, UK of 5G solutions enabled scientists to track and identify drones along the NBEC air corridor that connects Blue Bear's Twinwoods Flight Test Centre and Cranfield University's Airport. Work to date has identified several potential use cases, although many more are expected as tests continue.

Active monitoring of the health of livestock: Drones could survey crops and/or livestock in remote rural regions, such as Cumbria in the UK.

> *"We are flying drones in agricultural regions of Cumbria to monitor the health of livestock and to survey crops and investigating how 5G can help transport large volumes of 'Big Data' to anywhere in the world. In the future farmers will be able to remotely task the drones to carry out routine tasks and analyse results from the breakfast table."*
>
> David Walters, Blue Bear's Operations Manager

Sensitive healthcare-related drone delivery in rural areas: Until now, drone delivery of pharmaceuticals or blood samples was only done in disaster cases in Europe. However, in this case, drug companies and retailers as well as public healthcare bodies will aim at establishing regular direct deliveries to individual's home or other convenient locations. Easing the delivery of pharmaceuticals will increase the quality and efficacy of healthcare for rural inhabitants but may also have benefits for mobility impaired patients in urban areas, for example.

> *"Showing the public benefit of drone applications would pave the way for further business applications by increasing societal support."*
>
> Adrian Cole, Cranfield U. NBEC lead

Drone delivery as part of Ocado's delivery automation strategy: The company has developed its forward-looking subsidiary Ocado Technology to look at how highly automated systems could enable autonomous delivery across the country. Ocado would like to build on the NBEC consortium air corridor leveraging its insights from the company's automated facility.

Benefit from Working with MNO and Conclusion

The 5G solutions deployed by the partner MNO represent a first step in unlocking nationwide economic benefits. For these to be fully captured, several challenges lay ahead for stakeholders including MNOs: Guaranteeing technical resilience and cyber security, developing workable legal and insurance frameworks and establishing social trust in the delivery and logistics technology.

> *"The economic benefit for future drone use in the UK is predicted to be multi-billion so this facility is a great catalyst for the emergent industry in Bedfordshire, which has been a hub for the Aerospace industry since the 1940's."*
>
> David Hodgson, Mayor of Bedford

The MNO role is crucial in establishing the current position, speed and direction of the drone at any point in time. Deep connectivity expertise enables the consortium to leverage the full potential of 5G and achieve real-time data updates, which will ease the realization of all use cases in a cost-efficient manner.

> *"The network solution deployed in the facility is the first 5G enabled drone BVLOS of its kind in the UK and will accelerate the uptake of the UK's latent drone technology and infrastructure in global markets."*
>
> Ian William-Wynn, Managing Director of Blue Bear

Source: Arthur D. Little, Blue Bear Systems Research, University of Cranfield

StrattoOpencell's spectrum leasing business model enhances wireless connectivity in remote areas with dedicated local network

StrattoOpencell leases spectrum from Vodafone

Introduction

StrattoOpencell's value proposition is to leverage underused spectrum from any of the four UK MNOs in a specific area (typically a rural area with poor network coverage). The partner MNO's expertise and existing infrastructure will help to enable an optimised 5G coverage in those selected areas.

When carved out for specific uses, spectrum leasing from incumbent mobile operators dramatically reduces the cost to the user versus the enterprise owning and deploying the network itself. StrattoOpencell is demonstrating this concept through a planned deployment for a Caravan Park in Cornwall.

Business Need

StrattoOpencell developed a host neutral model, in other words a technology solution that is agnostic in terms of which MNO it supports, to cover the needs of various stakeholders in rural and poorly served areas. These areas are typically economically unattractive for MNOs on their own due to the limited or seasonal demand profile in the area. StrattoOpencell is able to deploy a cost-effective model working with one or more operators to cost effectively solve localised problems.

First of all, rural enterprises – such as a remote caravan park in this case – can benefit from stable connectivity with ultra-low latency for their end customers. This means that local end-users benefit from a better connectivity in remote rural areas through an Enterprise's contract with StrattoOpencell. From the perspective of Ofcom (UK communication regulator), enabling sub-licensing increases coverage in remote geographies and supports an innovative model. Eventually, StrattoOpencell, through its collaborative approach with MNOs, will offer this service to small and medium local businesses unable to support a direct relationship with MNOs or build a network of their own. For all MNOs, it represents an additional source of revenues, hence the incentive to provide this solution where feasible.

MNO Approach

Enterprise customers often fail to find suitable solutions when looking for high throughput in a remote location or on a temporary basis (e.g. for festivals, caravan parks).

StrattoOpencell aims at solving this problem via a collaborative model and its own leasing approach. StrattoOpencell first looks for underused spectrum across MNOs to cater for the need of end-users in fixed areas and then packages the solution for specific end-uses. Advice, expertise and an attractive business case can be developed directly with StrattoOpencell prior to deployment of the equipment.

Solution and Use-Cases Enabled

An example of StrattoOpencell's business model is showcased in a planned deployment of a caravan park in Cornwall. StrattoOpencell obtained a 3-year licence from Ofcom and came to an agreement with Vodafone to leverage its regional and underused 2600Mhz spectrum in a fixed geographical area in Cornwall. The licensed area covers a 500m radius, which is more than adequate to cover the entire caravan park. StrattoOpencell's infrastructure will comprise one or two smart cells to connect residents of the park to a 5G network using a 1Gb fibre connection base station.

This solution will bring several unique advantages for the caravan park:

Stable output for residents: All of the caravan park's residents will be able to access a stable network at all times throughout the park with 2 to 5Gbps data connectivity guaranteed. Additionally, the caravan park will have a fixed cost to provide the service, but has complete flexibility in terms of how it prices the service(s) to its end customers, delivering, as it does, all the commercial advantages of a personalised network offer.

Much lower cost to serve its customers: there will only be 2 fixed base stations required instead of 20+ in a Wi-Fi setting. This will allow for lower power cost, lower upfront investment, lower cost to maintain while offering a higher and more reliable level of service to customers. Furthermore, Wi-Fi interferences can also imply costly maintenance and configuration issues.

Flexibility of the connectivity partner: 2600Mhz spectrum will be used at first, but the smart cells implemented can switch to 1800Mhz in order to be leveraged by Vodafone for general local service. This also negates the need to deploy ethernet cables in many fixed locations.

> *"Leveraging the spectrum underused by MNOs in rural areas allows for better service to end-users, lower costs to customers and asset optimization for the MNO leasing its spectrum locally."*
>
> Graham Payne, CEO of StrattoOpencell

Benefit from Working with MNO and Conclusion

StrattoOpencell is able to leverage underused spectrum from an MNO in a given area – which often is in a rural area where only poor or patchy service is otherwise available to end-users. As a result, MNOs are offered a new value proposition for existing underused spectrum which is valued through a collaborative host neutral model.

This value proposition could be extended to other businesses in underserved rural areas with limited infrastructure costs, although Ofcom and the MNOs would currently have to agree on a similar licensing agreement in each case. StrattoOpencell is currently working to expand its offer by putting in place the roaming agreements required for international calls in order to offer voice connectivity to its rural clients in the future.

The solution enables local businesses based in rural areas to guarantee customers greater stability and faster connectivity, while decreasing the inherent cost of offering such a high-end service, to the benefit of all stakeholders.

Source: Arthur D. Little, StrattoOpencell

Workspace, a flexible office provider, requires excellent in-building host neutral connectivity to enhance its value proposition

Workspace leverages StrattoOpencell expertise in host neutral connectivity

Introduction

Workspace, a coworking and business space rental company, worked closely with StrattoOpencell to provide best-in-class indoor mobile connectivity for its tenants and customers. To address its client's connectivity needs, StrattoOpencell leases spectrum from all 4 UK MNOs (Vodafone, EE, O2 and Three) and then represents a single point of contact for Workspace mobile coverage.

Workspace first launched this solution in their Ladbroke Grove site in London, which successfully led to a Gold WiredScore – highlighting the connectivity quality on offer in the office space. Building on this a deeper partnership has been developed between Workspace and StrattoOpencell, and the intention is to further expand their collaboration to many other sites in the UK and to keep improving the indoor connectivity using a host neutral platform.

Business Need

Workspace was facing indoor connectivity issues in their Ladbroke Grove building (and in many other locations across their 200+ sites).

The main issues were significant latency and a limited reliability due to interference. When looking for a solution, Workspace wanted to appeal to a large share of its current and potential customers. Therefore, compatibility with all MNOs was required so that all customers could benefit from this service with no friction or bias. In addition, the co-working company was looking for a flexible, low capex, solution to their needs – thus ruling out the complex and expensive mobile private network option in a busy city centre location.

> *"We want to reduce connectivity friction for our customers in the environment we provide"*
>
> Chris Boultwood, Head of Technology, Workspace group

As a leading-edge real estate stakeholder, Workspace wanted to offer a high level of service to its customers with no switching costs, loss of service or poor wireless connectivity, particularly given a highly connected customer base with over 60% of users connecting more than 3 devices daily.

MNO Approach

StrattoOpencell acted as a proxy for an MNO by offering its expertise in neutral host solutions to enable Workspace to cover all 4 UK MNOs from a single point of contact and advise on hardware deployment. The host neutral technology consisted of deploying 4 smart cells inside the Workspace building, each dedicated to an MNO, so that Workspace customers could connect multiple devices regardless of their MNO with seamless sign on.

Apart from its technical expertise in implementing this solution, a key challenge was to build a consensus across all 4 UK MNOs – which StrattoOpencell successfully achieved to the benefit of the enterprise.

Solution and Use-Cases Enabled

Seamless, high quality connectivity: This solution delivers ultra-low latency with 10Gb fibre connectivity to the building and speeds of up to 100Mb/s for individual devices inside the building. Connectivity extends across the building (including communal areas and outdoor spaces) for a seamless customer experience. The building has also achieved a 'Gold' WiredScore, awarded in recognition of reliable and diverse internet connectivity and preparedness for the future connectivity needs of customers.

Meeting the growing connectivity needs of co-working spaces: As more and more workers share spaces, there is a growing need for co-working spaces to be able to provide high quality indoor mobile connectivity to all workers. There is a challenge posed by the fact that these workers bring a diversity of devices to the work space while at the same time using different MNOs. Having a solution involving all four MNOs for best-in-class indoor connectivity is becoming more and more important to keep attracting customers.

Cost-effective solution: The host neutral option offers the advantage of being fast to implement with light infrastructure required – just 4 smart cells were deployed in this instance (and in future the solution will be able to delivered on a single 'multi-host' cell). This results in costs being approximately one tenth of an equivalent DAS (Distributed Antenna System) solution. The scale required for such a solution to break-even is small for Workspace's site, offering the coworking company an opportunity to differentiate among competitors.

> *"We have always championed small cells, and there is a growing industry consensus that they will be a crucial component in delivering mobile coverage, both inside and outdoors, for today's networks and even more so as we enter the 5G era."*
>
> Graham Payne, CEO of StrattoOpencell

Benefit from Working with Partner and Conclusion

The innovative business model from StrattoOpencell leverages the collaborative agreement between the four UK MNOs to better serve Workspace's business residents. The ability to lease spectrum for specific use cases allows for a lower cost model compared to Enterprise-owned networks while bringing additional benefits. Workspace can offer frictionless connectivity for customers who carry and use multiple devices (possibly connected to multiple networks) in their work environment.

This solution can easily be replicated since Workspace and StrattoOpencell already collaborate across multiple sites with the same or very similar technology architecture. This model could be further extended to other customers (e.g. airports, shopping centres, and many public spaces as well as other European countries, subject to agreement being realised with MNOs in those countries).

End-users benefit from greater stability and faster connectivity, enabling the supported companies to focus on their core business. The disruptive business model offers high quality connectivity at a reduced cost.

> *"The cost is much lower than deploying and managing a high quality Wi-Fi network which customers still have to log in to. We already see use cases for wider deployment of 5G."*
>
> Chris Boultwood, Head of Technology, Workspace group

Source: Arthur D. Little, StrattoOpencell

Shell's Pernis (Rotterdam) facility uses 5G-ready and 5G solutions to improve the safety and performance of its operations

Shell formed a consortium including all logistics and connectivity stakeholders to deliver improved safety and performance

Introduction

Royal Dutch Shell PLC required a solution to better manage its logistics around its Pernis plant near Rotterdam port and to improve asset maintenance and utilisation. To achieve its goal, Shell formed the Industrial 5G Field Lab consortium, made up of Accenture, Huawei, KPN, ABB and ExRobotics, to enable robot inspection, remote machinery control, digital workers and predictive maintenance, through 5G solutions.

As the MNO, KPN's connectivity expertise and consortium contributions enabled Shell to ramp up capabilities quickly, despite deployment complexity. Using a model of close collaboration with consortium partners ensured a short delivery and payback timeline.

Business Need

Shell was keen to improve its operations within the Pernis plant near Rotterdam port. The plant is involved in the transportation of Oil & Gas and associated products such as containers, pipeline and refinery equipment.

Prioritisation of the connectivity efforts revolved around multiple considerations. Firstly, Shell wanted to gain a better understanding of the location and quality of sensitive products via cargo and asset tracking. Secondly, predictive maintenance capabilities were required to support this function, as the nature of goods moved necessitates strict quality control over transportation facilities and equipment within the harbour. Finally, Shell was interested in increasing its asset utilisation by analysing the data gathered in real-time to optimise infrastructure and help to drive a short payback period.

The consortium "Industrial 5G Field Lab – Shell Pernis" built up all the necessary skills to implement 5G applications within a port and a refinery.

MNO Approach

Beyond its connectivity expertise, the partner MNO KPN supported the deployment architecture with 5G-ready consistent coverage in the area with three antennas. In terms of 5G, one antenna is already live in the Pernis plant, with more due to be deployed. Overall, the MNO deployed services using 3 frequencies: LTE 700Mhz for coverage, LTE 2300Mhz for capacity and 5G 3.7Ghz for accelerated data transfer.

In addition to physical infrastructure, KPN offered both centralised processing of the radio signal to optimise network performance and increase reliability, as well as a virtual private network set-up to support secure data processing.

Solution and Use-Cases Enabled

Faster gas leak detection with mobile inspection robot: The inspection process for gas leaks is crucial to the continuity and safety of the Shell Pernis operation. The solution allowed for a robot to run daily on a fixed route across key process installations and search for potential leaks with gas detection cameras and sensors. This created greater visibility of potential gas leaks in comparison to checks every 2 to 3 months, which was the case before the solution was deployed.

Monitoring production assets with wireless sensors: Shell had encountered issues with the vibration data collection process for rotating equipment. The data was collected manually and prone to errors which led to counter-productive rescheduling of measurement tasks. To resolve the issue, key production assets were equipped with a wireless sensor which monitored measurements such as vibrations. This solution enabled the engineer to download the data via Bluetooth, which was also made available in Shell's central asset management system via 4G, resulting in a more precise and less labour-intensive control and maintenance planning process.

Connected workers: Vessel controls require inspectors to physically check the vessels and agree on a diagnosis. To speed up the remote communication process across junior and senior inspectors, a smart helmet solution is connecting junior inspectors directly to their more experienced colleagues to diagnose the issue and agree on the repair, through connected audio and video, instead of waiting for a meeting potentially several days later. For industrial maintenance, the former intensive paper procedure is digitalised via a tablet showing asset data to engineers, which will improve "time on tools" when preparing and executing maintenance activities. Furthermore, the maintenance is recorded step by step and progress is visible to relevant parties in real time.

Predictive maintenance of pipe racks: Sections of pipe rack were inspected periodically by building a scaffold and taking photographs. The solution enables Shell to use a jib crane with an ultra-high definition camera, which allows the inspector to decide what is photographed. Photographs can subsequently be downloaded and analysed by inspectors which is creating a smoother process and provides improved anticipation for maintenance, which is generating savings.

Benefit from Working with MNO and Conclusion

Most of the value created in this initiative stems from the successful gathering of the right stakeholders and their commitment to the project. Furthermore, the partner MNO provided a unique infrastructure (and deployment process) with 3 smart cell antennas (one handling 5G), 3 different spectrum frequencies to be leveraged as a private network and an infrastructure managing the significant flows of data across the port, refinery, pipelines and many other pieces of key equipment.

The final solution is devoid of interference, and delivers ultra-low latency, and high consistency of data throughput, enabling real-time operations and low payback timeline. The MNO programme management allowed each of the stakeholders to focus on their core skills. Besides, the stability of the network is ensured by a robust infrastructure, with strong cyber security protection.

Looking forward, several improvements to the use cases are already scheduled, all of which will be supported by the MNO. They include equipping all the production assets in the plants with 5G sensors and building a car with an integrated ultra HD camera to record the state of pipes at the Shell Pernis plant, allowing automatic analysis to further improve preventive maintenance.

> *"The port of Rotterdam is the perfect place for the industrial 5G Field Lab. We can achieve a lot in terms of reliability and efficiency with new digital technologies, helping to improve industry safety performance even more. Shell, KPN and other partners are therefore pleased to be at the forefront with this industrial 5G Field Lab in the Netherlands."*
>
> Jos Van Winsen, General Manager of Shell Pernis

Source: Arthur D. Little, KPN, Shell, Accenture, Huawei, Industrial 5G Field Lab

Ericsson developed its smart manufacturing and industry IoT capabilities via a dedicated cellular network in its Tallinn factory

Ericsson partnered with Telia and ABB to build a smart factory

Introduction

As a manufacturer, Ericsson wanted to enhance productivity within its Tallinn factory while delivering improved safety and faster connectivity. To deliver on this goal, Ericsson is pioneering a new manufacturing environment with automated vehicles, augmented reality, environment monitoring and intelligent automation systems.

However, it was the connectivity speed and expertise brought by the MNO partner, Telia, that unlocked the potential for breakthrough manufacturing use cases.

Business Need

Ericsson's Tallinn factory produces complex radio and baseband products for the Ericsson Radio System. Ericsson wanted to digitally enable its 23,000 m^2 factory, which required fast and secure wireless connectivity within the factory enabling real-time communications and data gathering and analysis.

The manufacturer was eager to scale up capacity, speed and control of the manufacturing process while improving the flexibility and customisation of regularly changing production lines by removing physical cabling. The manufacturer also required over 20,000 devices to be connected with real time data flows across the factory.

MNO Approach

To support those needs, Telia developed a holistic solution for Ericsson's factory. The partner MNO implemented a dedicated 5G-ready network, with high density of coverage within the factory.

The MNO collaboration was not limited to infrastructure supply, and included supporting Ericsson in implementing connectivity of a broad array of sensors across the whole plant. The partnership also included state-of-the-art servicing with customised data systems, allowing for prioritisation of some data flows in the dedicated network.

Solution and Use-Cases Enabled

Automated guided vehicles (AGVs): As part of the solution, AGVs are delivering product components from warehouses to production lines. They can communicate with the control system, provide a live stream of data and video, as well as use the dedicated network to open doors. Transporting components is a labour-intensive, costly and repetitive task where AGVs can save time, reduce the risk of damaging components, and cut waste.

Augmented reality: Ericsson developed an interactive method for quality control and testing of electronics components. By using AR enabled glasses the technician gets an overlay with all manuals, instructions and collective knowledge of other technicians, allowing them to quickly resolve potential problems. Field tests have shown a 50% reduction in time spent on troubleshooting circuit boards.

Environmental monitoring: This consists of monitoring the environment using mobile sensors to measure moisture, temperature, noise, light, and carbon dioxide. Employees benefit from a safe and healthy work environment while minimizing the risk of production defects. The dedicated cellular network has the capacity to handle thousands of sensors in a factory, allowing them to be relocated as the layout of the factory evolves.

Intelligent automation system: In partnership with ABB, Ericsson will combine this analytics system with multiple existing data points. This will bring machine learning and artificial intelligence capabilities to its production, enabling real-time data analytics and an end-to-end predictive automated manufacturing chain. ABB will also provide a fully automated flexible robot cell solution for final assembly of 5G radios.

> *"Mobile networks meet the requirements to support diverse smart manufacturing use cases, making it possible to securely and efficiently optimize manufacturing processes. They allow massive real-time data collection and analytics and intelligent automation on the factory floor, solving operational challenges and creating a more sustainable, efficient and safer production environment."*
>
> Lars Ottoson, Head of Ericsson Supply, Tallinn

Benefit from Working with MNO and Conclusion

As a direct result of the use cases, Ericsson's Tallinn plant benefits from lower costs, higher productivity, increased capacity and additional flexibility. These improvements can already be assessed quantitatively. This first in Estonia allows Ericsson to capture the advantages of a private network while leveraging the connectivity expertise of the MNO partner, thus incurring lower costs upfront.

The partner MNO Telia empowered Ericsson to process large amounts of data and to react upon it in real-time, which was required for all of the use cases described. Consequently, Ericsson was able to focus on its manufacturing core expertise while relying on a preferred connectivity partner for network and data transmission.

The solution used in this "Smart Factory" can be replicated to other manufacturing sites that require physical flexibility in terms of the plant's layout, and high data throughput from both machine and human inputs. Several factories could also be connected to further enhance lessons learned and operational productivity across multiple sites within Ericsson.

Source: Arthur D. Little, Ericsson, Mobile World Live, Telia, Mobile Europe, GSMA

ABB develops leading-edge collaborative robots to further connect human and automated machines in the future

ABB partnered with Vodafone, Politecnico di Milano and SmartRobots

Introduction

ABB wanted to leverage the latest developments in analytics and automation to improve its plant productivity while keeping local workers involved. As an answer, the collaborative robot YuMi encompasses 5G-powered 3D vision devices and leading-edge analytics for an augmented partnership between the robot and the human.

The real-time 5G ready connectivity offered by the MNO enabled ABB to synchronise in real-time the robot, the vision device and the analytics capabilities.

Business Need

ABB had a challenging goal to improve productivity in its valve plant near Milan. The manufacturer wanted to improve the capacity and control of its plant via analytics and automated processes, while keeping its local operating staff involved.

ABB gathered the relevant skills through a 5G consortium including several stakeholders: MNO partner Vodafone, elite national technical university Politecnico di Milano and robotics specialist start-up SmartRobot – which is part of the E-Novia group. The consortium engaged in a competition at a national level to be granted the authorisation to leverage 5G technologies around Milan, which they subsequently won. The consortium was also required to collaborate with both Nokia and Huawei whose mobile network equipment covers the Milan area.

MNO Approach

Vodafone leveraged its network expertise to propose how to best capture the potential of the 5G technology. This was completed by diligent project management as the MNO delivered against an extended timeline and overcame issues identified along the way.

Vodafone also adapted to the change of focus of the project: from an ultra-low latency focus at first to new possibilities involving data flow optimization and edge computing functionalities later on.

Solution and Use-Cases Enabled

Collaborative robot "Cobot" YuMi: YuMi is a two-armed robot designed to work side by side with an operator located in its immediate surroundings to assemble valves. The robot's value lies in its ability to master the value chain tasks and to adapt to the human movements in real-time. The robot instantaneously transfers data gathered by its activity to a data centre in the facility. SmartRobot equipped YuMi with a vision device which enables it to capture its environment in 3D. The robot can consequently picture what the human is doing and adapt to it. In order to facilitate the real-time capabilities, the data flows with an ultra-low latency and edge cloud computing capabilities which are integrated into the connectivity equipment. AI software from Politecnico di Milano recognizes and predicts human movements and actions so that the robot safely coordinates with the operator. The robot is equipped with machine learning capabilities which has enables it to learn and better adapt to each situation it encounters.

Improved control & flexibility over manufacturing process: The stable connectivity provides ABB with real-time visibility over robot and worker movements. The absence of cables associated with 5G allows for greater flexibility in organising machinery in the future, making production lines much easier to change.

Augmented collaboration: Workers will soon be able to further leverage the Cobot capabilities via 5G-powered IoT wearables displaying Augmented Reality holograms of what the robot tasks consist of at all times. As a result the worker will be able to focus on the most value-adding tasks in a safer work environment.

> *"The collaborative robot is able to modify its work cycle and dynamically adapt to the operator. This results in the optimization of the production process in terms of time and quality of the production cycle, with benefits also for ergonomics and operator safety."*
>
> Andrea Zanchettin, professor at Politecnico Di Milano & founder of Smart Robots

Benefit from Working with MNO and Conclusion

The consortium is in the process of bringing to life the first 5G manufacturing case in Italy. The unique innovation resides in the collaboration between the robot and the worker. This requires the ability to understand the environment, but also to adapt to it and to learn from it. All these steps must occur in real-time with an ultra-low latency as the data is critical – the worker could be severely harmed in the event of an error. This use case would not have been possible without the safe and real-time connectivity between the robot, the vision device and the analytics capabilities.

Plant operators can now work safely, knowing that the robot will adapt to their actions. For instance, if the worker gets their hand in the way of the robot arms, the robot would recognise this and stop instantly.

Furthermore, the robot focuses on manual, repetitive tasks including heavy lifting, which improves the quality of life of the worker, allowing them to focus on tasks which add value.

This project is currently limited to a part of the ABB plant with one robot and one worker leveraging those capabilities, but is targeted to expand to full production in the future.

> *"For ABB, the collaboration with the MNO was essential in implementing an ultra-low latency connectivity around YuMi, as Vodafone was owning the multi-edge computing processes and infrastructure."*
>
> Michele A. Pedretti, Robot Business Development Manager at ABB Italy

Source: Arthur D. Little, Innovation Post IT, SmartRobot, E-Novia, Industria Italiana, ABB, interviews

Emilio Moro embraced NB-IoT to build a smart winery with the support of a connectivity and data management consortium which can transition to 5GNR

Emilio Moro with Vodafone and DigitalGlobe, Qampo, Abaco and GMV build a smart winery

Introduction

Bodegas Emilio Moro was looking for a way forward, balancing productivity improvements with a more sustainable environmental footprint. As a result of the use case, the winery is able to better monitor its environment via IoT sensors and satellite imagery, and act upon the data through advanced analytics.

Vodafone's digital platform enabled Emilio Moro to capture the value from different sources of data and various analytics techniques.

Business Need

Emilio Moro has existed as a wine producer in Spain for more than 3 generations, owning more than 200 hectares of vineyard in the Ribera del Duero wine region in Northern Spain. As part of its development, the renowned winery was facing the dual challenge of improving productivity and control of the vineyards and facilities while preserving the local environment – by reducing the quantity of water and pesticides used.

The goals might appear conflicting, however Bodegas Emilio Moro believed it was possible to embrace both via the latest connectivity technologies. To address the challenge the MNO Vodafone was engaged along with its multiple consortium partners – DigitalGlobe from the US, Abaco from Italy, GMV from Spain and Qampo from Denmark .

MNO Approach

Vodafone developed a full range of services for Bodegas Emilio Moro's connectivity needs. The MNO provided its narrowband Internet of Thing capability (NB-IoT) to the winery using its existing 800MHz spectrum. NB-IoT is a 3GPP standard which is part of the 5G family of technologies as it is designed to co-exist with other 3GPP 5G standards. NB-IoT allows the sensors to combine industrial-grade connectivity with low costs and a long battery life – ten years or more on a single charge complemented with solar panels. This low-power wide-area technology brings a stable connectivity in comparison to the interferences and black spots in coverage inherent to the formerly used local rural cellular networks.

With regards to analytics, the MNO launched a new programme "Sensing4Farming" to leverage IoT and AI across the winery. This service allows for the winery to incorporate a broad array of data and analytics from external stakeholders into its decision-making processes in real-time.

Solution and Use-Cases Enabled

IoT sensors providing a more accurate view of what is happening: Ground sensors supplied by Qampo bring in data about soil and leaf moisture, temperature and humidity. The sensors provide information in real-time, such as about a potential irrigation leak. This is replacing the formerly highly labour-intensive inspection tasks across the whole vineyard. Sensors have been extended to the cellar room, where they monitor and control the humidity and temperature required, which provides improved quality control over the wine processing.

Satellite data imagery going beyond the human eye: DigitalGlobe provides high resolution satellite data imagery. It distinguishes objects to just 30cm in size and operates in spectra not visible to the human eye. This informs the winery on the vines' health via their concentration of chlorophyll, which can limit the plant's growth if insufficient.

AI algorithms turning all sources of data into action lists: Abaco software processes ground-based data via its cloud-based platform "SITI4farmer". GMV then combines Abaco's data with the satellite data and external meteorological data with its "WineEO" dedicated service. The resulting analytics inform when and where to water plants, fertilise and harvest as well as enabling and supporting best-in-class methodologies to avoid diseases – which destroy 13% of wine production. GMV's AI software estimates production costs can be cut by between 4 to 6%, by anticipating the appearance of mildew for instance.

> *"Thanks to these agreements with Vodafone, we have been able to apply IoT technology to maximise the production and quality of our vineyards We aim to further scale this partnership with 5G implementation and to extend the solution's geographical scope."*
>
> José Moro, grandson of Emilio Moro and current owner of Bodegas Emilio Moro

Benefit from Working with MNO and Conclusion

Bodegas Emilio Moro successfully brought IoT sensors, satellite data and AI analytics to its field so that they could maximise productivity while minimising environmental impact. The winery now enjoys precise data in real-time about each sub-part of their vineyard as well as the conclusions derived from it. They are now able to reduce their spending, anticipate diseases and other issues and better target their harvesting efforts in terms of time and location.

Vodafone provided an edge thanks to its connectivity expertise and to its analytics platform Sensing4farming. The infrastructure included an IoT dedicated spectrum and ground sensors to lay the foundations of a sustainable monitoring process. Sensing4farming enabled Emilio Moro to leverage the local data combining it with external inputs and running real-time AI-based analysis. This immediate processing would not have been possible without the network coverage and stability from the MNO.

Vodafone's farming platform can easily be extended to any other complex rural environment. This is possible thanks to the scope of the selected data providers and to the availability of the 800 MHz spectrum throughout the country, combined with the enhanced functionality of NB-IoT (e.g. the improved outdoor coverage compared with existing wide area technologies). One of the 5G deployment scenarios supported in 3GPP will be to allow NB-IoT transmissions to be placed directly into a 5G NR frequency band. Therefore it is expected that the MNO will be able to further evolve the solution to 5G-New Radio (NR), including private network capability, as and when required.

Source: Arthur D. Little, GigaLife, Enterprise IoT Insights

Ocado leads the way for online retail by leveraging unlicensed spectrum in its logistics centres to capture value from technology and automation

Ocado used unlicensed spectrum to develop its own mobile network via as well as network slicing solutions

Introduction

Ocado has been developing a new type of business model, rooting its online retail activity onto technology with automated robots handling a significant share of the value chain. In order to gather orders faster and more reliably, the online retailer developed its own connectivity solutions for its automated robots. This solution involves a dedicated network, using a radio access scheme similar to that used in LTE, and which is sliced for enhanced control over the data flows.

As a result, Ocado can offer a broader product portfolio, more precise orders and generate higher client satisfaction for a limited cost.

Business Need

Ocado is a leading online retailer, with several Customer Fulfilment Centres (CFC) preparing customers' commands within minutes capitalising on technology and automation. Ocado's belief is that these elements are necessary as they only have 60p of average gross margin per product to efficiently handle the whole logistics from product reception in their CFC to orders gathering and finally customers delivery.

Ocado thus faces a financial push to smoothly roll out operations at a limited cost. The online retailer also experiments a pull from customers, who want more diversified product offering and faster delivery. Their latest facility in Erith in the UK was thus set to push the efficiency boundary further ahead.

The online retailer needed to develop a radio system matching its warehouses connectivity that could guarantee a stable connection within 150m with ultra-low latency and that offered 10Hz update for their thousands of autonomous robots. This solution also had to be scalable technology-wise via free spectrum and geography-wise with presence in several areas such as Europe, North America and Canada.

Connectivity Approach

In collaboration with Cambridge Consultants, Ocado developed a dedicated LTE mobile network over 5GHz unlicensed spectrum. This sets the ground for ultra-low latency and thus for more reliable automated devices such as robots for grocery collection in the CFC. This system includes a base station communicating with robots' radios and processing the robots' data into a cloud via a base station controller. The robots also have their own PC to execute calculations locally, which reduces latency as well as the quantity of data that need to be flown.

To further capture value from this network, Ocado sliced in a thousands of “cells”. Each robot is allocated at least one cell, so that its connectivity is guaranteed. If needed, a robot can be flexibly allocated more cells to enhance its communication abilities for a short period of time.

Solution and Use-Cases Enabled

3D logistics centre powered by robots: in its Erith centre, Ocado developed two “hives”, each leveraging 1700 intelligent robots. Each hive is similar to a chess plate the size of 3 football pitches: it is a rectangle with a large number of slots, each slot having 21 bins vertically stored with one type of product only in each bin. Bidirectional robots move across the top of this chess plate and stop by the most relevant slots to pick the right items from a specific bin. Robots then gather the items collected into orders for customers.

Collaborative robots: the ultra-low latency allows robots to communicate in real-time so that they do not run into each other. A machine-learning software optimises robots’ journeys to avoid collisions but also to limit the time for each order to be processed. This can involve gathering several robots to complete a single order, based on each robot location.

Data analysis: the reliability offered by this network brings the possibility to analyse in real-time significant amounts of data. Robots have their own calculation tools, but also transmit instantaneously the data gathered to a data lake in a Google-powered cloud. Ocado thus gathers 1Gigabyte of data per robot per day. This data is also used to run tests for further innovation via a digital twin of the factory.

> *“There is no way we could achieve the required throughput if the robots were autonomous, moving around the grid dodging one another. Instead, the swarms of robots are orchestrated by a machine learning-based system that is playing chess many moves ahead. It knows which bins need to be where, and which robots it needs to schedule to complete every order in a perfect pick sequence.”*
>
> Paul Clarke CBE, Chief Technology Officer at Ocado

Benefit from Developing this Solution and Conclusion

This connectivity solution enables Ocado to improve its logistics efficiency in various ways. First, 98.8% of the orders placed are delivered with the correct products, thus enhancing client satisfaction. Ocado also leverages the fact that it only has a limited amount of CFC where the products are stocked – in comparison to thousands of shops for classic retailers. This translates into a much broader diversity of products, for which availability to customers is known in real-time thanks to the data gathered by robots. As a result, the total number of different products available amounts to 54,000. The robots’ precision in gathering orders and collecting data allows to have an almost non-existent amount of products thrown away, with only 1 in 6000 items going into waste in comparison to 3% for classic retailers.

The fact that Ocado developed this connectivity solution allows for a greater control over further innovation. As regards to technological innovation, the online retailer currently researches how its robots can better grasp irregular items such as fruits or vegetables, in order to further progress collection speed and precision. This development involves equipping the robot with 3D cameras and more complex arms, thus increasing the need for higher throughput and reliability of the connectivity. Ocado also considers business model innovation, such as leasing its hardware and software technology – which could include the connectivity setting – to traditional retailers eager to follow their lead.

Source: Arthur D. Little, Ingenia, Financial Times, Cambridge Consultants

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Arthur D. Little has been at the forefront of innovation since 1886. We are an acknowledged thought leader in linking strategy, innovation and transformation in technology-intensive and converging industries. We navigate our clients through changing business ecosystems to uncover new growth opportunities. We enable our clients to build innovation capabilities and transform their organisations.

Annex B: Economic study by Compass Lexecon

When are departures from a market-based approach to spectrum licensing warranted?

4 November 2019

Paul Reynolds, Alejandro Lombardi

Contents

Section 1

Introduction and summary

1.1 5G technology offers large improvements over earlier mobile technology including much faster and better-quality mobile broadband as well as a host of innovative uses in industry and the public sector including massive machine-to-machine communications, enhanced mobile broadband and ultra-reliable low latency applications. Critical to the success of 5G is spectrum policy. Without adequate spectrum, mobile operators will not be able to meet the rapidly growing demand for mobile data nor be able to supply the higher quality services required to fully realise 5G's transformative potential.

1.2 Countries are at different stages in the assignment of spectrum to support 5G services. Various approaches to spectrum licensing are being considered including auctions, national versus regional licensing, reservation of spectrum for particular purposes, spectrum leasing, light-licensing[1] and unlicensed spectrum. The choice of approach will shape the future development of 5G with significant implications for investment in services and quality of service as well as prices for end-users.

1.3 Vodafone has requested Compass Lexecon to set out a framework to help policy-makers determine which licensing approach would work best for end-users given the market conditions in their country.

1.1. Framework for assessing whether to depart from a market-based approach

1.4 The original 'command and control' approach to spectrum management relied heavily on regulators determining what services and technologies would be used with each frequency band. Over the last two decades, there has been a major change in spectrum management with leading authorities recognising that spectrum can be used more efficiently and deliver greater benefits to society if the market rather than regulators determine how spectrum is used. A key element of a market-based approach is the use of auctions to allocate spectrum to the users that can generate the greatest value from its use. Auctions are now routinely used to allocate spectrum to new uses in many countries.

1 Light licensing is where licences are required but the rules on use allow for the band to be effectively shared.

1.5 In the context of 5G, some industry players have argued that some spectrum should be reserved for their needs or licensed on a local basis. The German regulator accepted these arguments and reserved 100 MHz for local licences of the 400 MHz of 3.5 GHz spectrum earmarked for 5G with the remainder being auctioned earlier in 2019.

1.6 Reserving spectrum for some purposes, however, can come at the expense of others. Efficiency and benefits to society will be reduced if spectrum is not allocated to its highest value use. Further, local licences can result in spectrum being used in some locations while remaining idle in others. Local network deployments may also be costlier because they are not able to realise the efficiencies of national deployment.

1.7 In deciding on their licensing approach, authorities should consider potential costs as well as benefits of particular approaches and whether there are other ways of achieving their objectives at lower cost. We propose a three-step approach for authorities to decide whether to reserve spectrum:

1. Is there a market failure to justify considering departing from a market-based approach?

2. What are the benefits and costs (including opportunity costs) of reserving spectrum?

3. How do these costs and benefits compare with those of alternative options?

1.8 We examine the matters relevant to considering each of these steps in the context of 5G spectrum.

1.2. Are potential justifications for departing from a general auction relevant to 5G?

1.9 In evaluating whether to depart from allocating spectrum via a general auction, a threshold question is whether there is likely to be a market failure that would prevent an auction from achieving the socially optimal allocation of spectrum. In the absense of a market failure, auctions would be expected to allocate the spectrum to the users able to generate the greatest benefits to society from its use.

1.10 One type of market failure that could arise is where spectrum is of value to a large number of business users, each with a demand for a relatively small amount of spectrum. Such users could potentially have a high combined willingness-to-pay for spectrum although they may face practical difficulties in identifying similar users and being able to successfully coordinate to jointly bid for spectrum. That said, coordination might be resolved by operators who are able to customise quality of service to meet the demand of multiple individual users and/or the participation of third party aggregators who acquire the spectrum on a national basis and sub-license the spectrum to individual users. The provision of some spectrum on a licence-exempt basis could also address the needs of multiple, small users provided that interference issues are manageable.

1.11 Another potential type of market failure is where externalities create a difference between the private value and the social value from the use of the spectrum. The provision of widespread

5G coverage might create a social value beyond the commercial value able to be generated by the use of spectrum. If that is the case, it would be important to examine whether national or regional licensing would be more likely to achieve widespread coverage noting that there can be efficiencies in deploying a network nationally compared with multiple local networks. A market failure would arise only where a market-based approach would not lead to spectrum being allocated to the use which delivers the highest society value, noting that mobile services can also deliver social benefits greater than private benefits. The merits of specific measures such as coverage obligations or allowing for spectrum to be sub-licensed in particular areas should also be considered.

1.12 A third key type of market failure is where downstream competition problems lead to bids by some auction participants being inflated by the opportunity to earn excess profits. However, given that most mobile markets are effectively competitive, we expect that such a market failure to be relevant to only a small number of markets. Even then, caps on the amount of spectrum able to be acquired by a single firm are likely to better address the competition problem with less risk to the efficient use of spectrum.

1.3. What are the benefits and costs of reserving spectrum?

1.13 Any benefit from reserving spectrum compared with auctioning the spectrum depends on a market failure that would lead to the spectrum being assigned to a less valuable use under an auction. The benefit would then be the difference between the value in the reserved use and the value in the use that would have resulted from the auction.

1.14 The benefit should also be assessed taking into account the extent to which technical solutions would otherwise have addressed that demand. For example, network slicing, the use of alternative licensed or unlicensed spectrum and sub-leasing of spectrum may meet the need for spectrum for particular uses without spectrum being reserved.

1.15 Authorities should also assess the expected cost of spectrum set-asides. There can be significant costs to society from not making spectrum available through a general auction particularly in the absence of any market failure.

1.16 When spectrum is licensed for one use, it is not available for other uses. If the other uses would generate greater benefits for society then spectrum set-asides would carry a loss to society. This loss can be estimated by reference to the value that would otherwise have been paid for the spectrum in an auction as well as taking into account the harm for downstream users of the services that would have been supplied with that spectrum.

a. Conservative estimates based on the recent German 5G auction indicate that €1 billion to €1.5 billion of value to society was lost due to reservation of 100 MHz of the 400 MHz of mid-band spectrum that would otherwise have been assigned by auction.[2]

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[2] *See* Table 2.

b. In addition, spectrum set-asides are likely result in less capacity for mobile services leading to higher prices and/or lower quality. Our illustrative calculations based on conservative assumptions suggest that reservation of 100 MHz of 400 MHz of mid-band spectrum could cause consumer losses in net present value terms (as of 2020) in the range of £5 billion to £12.6 billion (or €6.2 to €15.6 billon in a German-sized market[3]) for a licence ending in 2040.[4] Such a range arises from different ways in which spectrum scarcity could translate into higher consumer prices. The higher end of the range occurs when prices are increased to limit traffic to the available capacity. The lower end corresponds to a scenario where congestion is managed through a combination of capacity expansion (*i.e.* additional network sites) and increase in service prices. Estimated losses would be much higher under less conservative assumptions on key parameters, such as demand elasticity. There are alternative ways in which consumers may be affected as well. Consumers may suffer a loss in service quality or a combination of this and higher service prices. There may also be additional losses to dynamic efficiency through competitive distortions and reduced investment.

Table 1: Potential costs and risks of spectrum set-asides

Cost	Assessment of Costs (non-additive)
Direct opportunity cost	Opportunity cost of €1 billion to €1.5 billion based on German auction data.
Consumer Harm: Higher consumer prices	NPV of costs in the range of £5 billion to £12.6 billion as of 2020 based on UK data, which risks being much higher with a lower assumed elasticity of demand. Extrapolating these figures to a market the size of Germany's results in an NPV of costs in the range of €6.2 billion to €15.6 billion.
Network quality degradation	Risk of quality degradation when networks reach congestion (expected in 2025). Speeds and network reliability, among the highest valued attributes of networks, risk being adversely affected.
Harm to competition	Risk of material adverse effect on consumers starting before all networks reach their maximum recommended level of utilisation due to decreased competition
Increased auction prices reducing investment	Auction prices are likely to increase substantially. We estimate operators paid €2.2 billion extra in the German 5G auction because of the set-asides. These higher costs can be expected to reduce investments in mobile services to the detriment of consumers.

3 In this report, we have generally used Germany as a base to illustrate the potential effects of spectrum set-asides drawing on data from the German 5G auction. However, some of our analysis relies on certain data which was available for the UK. Our results can be readily extended to other countries using the approach described at paragraph 4.111.

4 Net present value calculated using UK Treasury Green Book's (real) Social Time Preference Rate of 3.5%.

1.17 5G services are also estimated to have the potential to bring substantial wider economic benefits, potentially 1.8 times the value of direct benefits. However, the wider benefits of 5G will be reduced if spectrum set-asides leads to less capacity, higher prices, less investment and reduced quality.

1.4. Are there ways of achieving the benefits at lower cost?

1.18 We believe that, to the extent that the needs of specific industry users would not be met through a general auction, there are a range of alternatives that could meet those needs without incurring the costs of reserving prime 5G spectrum. These alternatives include:

a. Allowing other spectrum, not identified for geographic wide-area 5G coverage, to be able to be used without a licence. In particular, certain higher frequency spectrum such as at 66 GHz and possibly 6 GHz is likely to be suitable for local uses as such spectrum can provide for substantial capacity over short ranges. There is likely to be sufficient spectrum available in higher frequency bands to support some unlicensed spectrum as well as the licensing of mmWave spectrum for mobile broadband (IMT).

b. Licensing spectrum available in other bands on a shared basis: other spectrum bands than prime 5G spectrum are less critical for nationally licensed networks while being able to meet local users' needs.

c. Sub-leasing: Spectrum sub-leasing by operators can play an important role in meeting the needs of local users where it is allowed.

d. A regulator managed process to provide access to licensed spectrum where there are not plans for that spectrum to be used in the short term, as set out in recent proposals by the UK regulator, Ofcom.

1.19 5G has the potential to deliver transformative change across the economy and large benefits to society. The extent to which this potential would be realised will depend on the licensing approach adopted by authorities. Auctions are likely to generally be the best approach to assign 5G spectrum. However, in some cases, there could be a justification for departing from a general auction. Whether such a departure is warranted will depend on weighing up the costs as well as the benefits of spectrum set-asides and considering whether alternative policies could deliver the benefits at lower cost.

Section 2

The general benefits of a market-based approach to spectrum allocation

2.1 Radio spectrum is an essential input in the provision of mobile services. The amount, frequency and cost of available spectrum is a key determinant of the traffic, variety, quality and price of services supplied to end-users. Ensuring that spectrum is licensed effectively is critical to meet rapidly growing demand for mobile data services. Licensing choices being faced by decision-makers at the current time will help determine how quickly and how successfully 5G services will be rolled out. 5G technology, in turn, holds the potential to transform not only the services available to consumers but to have a far-reaching impact across industry and public services.

2.2 Society can obtain maximum benefit from the use of spectrum by ensuring that it is allocated efficiently, i.e. that it is allocated to the uses and users who can generate the most value to society from its use. This is particularly important given that the amount of spectrum suitable for mobile services is scarce relative to demand, including that equipment is manufactured for use with certain internationally harmonised frequency bands.

2.3 Well-designed auctions generally lead to spectrum being allocated to the best use. This is because bids for spectrum reflect the value that can be obtained by supplying services using that spectrum to end-users. A bidder in an auction that expects to earn more from the supply of services than other bidders should be willing to outbid rivals and obtain the spectrum licence.

2.4 Administrative approaches to spectrum allocation, such as ‘beauty contests’, are instead often inefficient and can generate wasteful expenditure in ‘rent-seeking’ efforts to try to influence the outcome of the administrative process in favour of one firm over others. Administrative processes also tend to be inflexible and can lead to spectrum being retained for a particular use even when it would generate value in an alternative use. A report for the European Commission estimated that spectrum trading and liberalisation (i.e. the flexibility of a licence-holder to change the use of the spectrum) would lead to benefits to society of billions of euros per year.[5]

2.5 A review of spectrum management in the UK identified the rigidity of the traditional command and control approach to spectrum management:

> *"But with a sharp acceleration in demand in recent years, change in the market place is outpacing the ability of the national and international regulatory regime to respond. Fundamentally, the spectrum manager is called upon to devise procedures to ration current and future demand for radio spectrum between competing commercial and public service users. To do so centrally would require a detailed knowledge of supply and demand trends, technology developments, and the relative value to society of alternative services. This represents a mammoth central planning task, which is now beyond the scope of any regulatory body, no matter how well staffed and managed. The central regulator is becoming less able to accumulate and assimilate sufficient information to make a correct assignment of spectrum to optimise use over time."*[6]

2.6 Recognition of the efficiency of market-based approaches to spectrum management have led to greater reliance on auctions and the introduction of spectrum trading and a liberalisation measures across Europe and in many other markets.[7]

2.7 While auctions can generally be expected to assign spectrum to its best use, policymakers should nonetheless be aware of when alternative or modified approaches might be warranted. One exception is where auction outcomes could be distorted by the existence or creation of market power. For example, a firm might outbid rivals if it could obtain a dominant position through acquiring most of the available spectrum. Where there is such a risk, policymakers may impose rules such as spectrum caps to limit how much spectrum can be obtained by a single firm. Another exception is where the firms that could generate the highest value to society from the use of the spectrum do not bid higher than other firms. This could result where the particular use generates social value which is much higher than the private value able to be realised by the firm (what economists call 'positive externalities'). It could also result where

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5 *See* Analysis and Dotecon. May 2004. "*Study on conditions and options in introducing secondary trading of radio spectrum in the European Commission*".

6 *See* Cave, M. "*An independent review for the Department of Trade and Industry and HM Treasury*", 2002, para.12-13.

7 For example, *see* European Commission. 2005. "*Communication from the Commission to the Council, the European Parliament and the European Economic and Social Committee and the Committee of the Regions: A market-based approach to spectrum management in the European Union*".

the highest value use requires many individual firms to bid and there are coordination problems that, instead, lead to the spectrum going to larger firms.[8]

2.8 In this report, we take into account the general efficiency of market-based approaches. However, we will also examine whether any exceptions to this principle are likely to be relevant for licensing spectrum suitable for 5G services. In particular, we ask whether there is a case for departing from auctioning the available spectrum and, if so, in what circumstances.

8 One type of coordination problem could arise where shared bids are allowed but individual parties limit their bids in the hope that they will still gain access to the shared spectrum because of bids made by other parties. The incentive to free-ride could lead to the shared bids failing to secure the spectrum at all. That said, this problem might be overcome by aggregators acquiring the spectrum for later use by individual parties.

Section 3

Framework for evaluating whether spectrum should be set aside for particular uses

3.1 When evaluating any policy proposal, it is important to consider not only the policy's objective but also what wider effects it might have. Ultimately, policies should be chosen that are expected to best achieve their objective while minimising costs. This is critical in relation to spectrum policy because the scarcity of spectrum means that spectrum allocated to one use is not available for other purposes.

3.2 The practice of undertaking impact assessments and cost benefit analysis of policy proposals is now well established in many countries.[9] A regulatory cost benefit analysis, also called a Regulatory Impact Assessment (RIA), is a tool that is designed to ensure that regulatory changes are consistent with the regulator's statutory duties, particularly by leading decision-makers to routinely consider and balance the likely benefits and costs of alternative regulatory options. A cost benefit analysis provides an objective framework for comparing the overall effects of alternative options. The ultimate goal is to ensure that decisions are soundly based.

3.3 The Organisation for Economic Cooperation and Development summarises the purpose and use of RIAs as:

> *"As a tool supporting decision making, RIA systematically examines the potential impacts of governments actions by asking questions about the costs and benefits; how effective will the action be achieving its policy goals and; whether there are superior alternative approaches available to governments… As a governance process RIA now forms a core component of the regulatory management strategy of all governments throughout the OECD."*[10]

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9 For instance, *see* the European Union. 2015. "*Better Regulation Guidelines*" and Ofcom. 2005. "*Better policy making – Ofcom's approach to Impact Assessment*".

10 OECD. 2009. *Regulatory Impact Analysis – A tool for policy coherence.*

3.1. Proposed decision framework

3.4 The general approach to impact assessments lends itself readily to the evaluation of spectrum policy measures.

3.5 First, it is important to identify the nature of the problem that the policy is being developed to address. A spectrum policy measure could be put forward where it is believed to be necessary to achieve the policymaker's objectives, such as a statutory duty of a licensing authority. As noted in the previous section, market-based approaches work well in allocating spectrum efficiently and in supporting competition and innovation.

3.6 A departure from a market-based approach should be considered where there is a market failure, i.e. that the market-based approach on its own would not secure the maximum benefits to society. The relevant benefits are both direct benefits for users (particularly the consumer surplus where consumers obtain value from services that exceed the price they pay for them) as well as broader benefits to society (for example, widespread coverage which improves access to communication services might have a wider social value). There could be a range of reasons as to why intervention is considered necessary, such as if the market-based approach is not expected to lead to optimal (i.e. efficient) use of spectrum or if it would lead to a competition problem or fail to best promote investment and innovation. We will consider potential arguments for market failure with respect to spectrum allocation in Section 4.1.

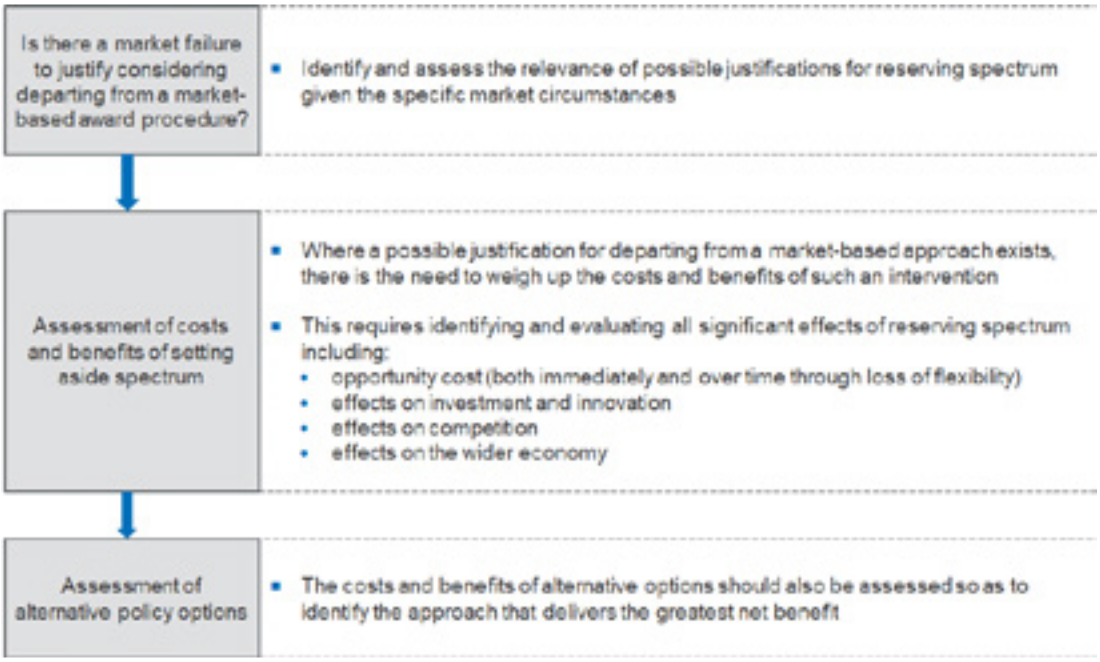
3.7 Second, all significant benefits and costs of the policy measure should be identified and evaluated. Consultation with stakeholders is important in this process as the decision-maker might not be aware of some potential effects, including what might be the opportunity cost of allocating more spectrum for one purpose in terms of the alternative uses of the spectrum that will be forgone. Indeed, one of the benefits of market-based mechanisms is that they enable market participants to reveal information on the value of spectrum in a particular use.

3.8 The benefits and costs should be quantified as much as possible, as placing a monetary value on costs and benefits allows for a more objective and direct comparisons of the alternative options. Where it is not practical to quantify particular costs and benefits, detailed analysis can usually help in estimating the likely order of magnitude of the different effects. The assessment of potential effects (such as on efficiency, investment and competition) needs to be undertaken on the basis of the relevant market circumstances. Uncertainty in relation to the costs and benefits and the risks of unintended consequences should also be taken into account by using expected (i.e. probability-weighted) costs and benefits. This is significant in relation to 5G as it is difficult to predict how applications will develop. More rigid approaches may entail large costs if they prevent valuable new applications from being deployed.

3.9 Third, alternative policy options to address the identified problem should also be evaluated so that the ultimate decision takes into account the costs and benefits of the available alternatives. Alternatives to reserving particular spectrum for one use include providing for potential users to bid for spectrum without any reservation, allowing for, or requiring licence holders to support particular uses (potentially through sub-leasing such as proposed by Ofcom) and making available other spectrum for that use. Again, consultation can be important to help identify alternatives and to provide information to evaluate their effects. When evaluating expected costs and benefits of particular measures, it is important to only take into account the extent to which costs and/or benefits result from the measure being taken. For example, if a particular benefit would be achieved anyway through other means, then it should not be included in the benefits specific to the policy measure being considered. This helps ensure that policies are evaluated on the basis of the costs and benefits that they give rise to. This comparative assessment can then enable the option to be selected that best achieves the policymaker's objectives taking into account its expected costs and benefits.

3.10 Figure 1 summarises the proposed analytical framework for assessing the case for spectrum set-asides.

Figure 1: Proposed analytical framework to evaluate spectrum set-asides



3.11 The UK regulator, Ofcom, followed a similar approach in assessing proposals in relation to awarding the digital dividend.[11]

3.12 In the next section, we discuss how this analytical framework can be applied in practice to assess the case for spectrum set-asides in a particular country.

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11 *See* Ofcom. 13 December 2007. "*Digital Dividend Review – Statement*", Section 5.

Section 4

Assessing the case for spectrum set-asides

4.1 In this section, we first consider to what extent potential justifications for departing from a market-based approach might be relevant for 5G. We then focus on the assessment of the costs and benefits of spectrum set-asides and how these might vary given differences in market conditions. Finally, we compare the costs and benefits of spectrum set-asides with those of alternative measures that could also be used to achieve the same objectives.

4.1. Are potential justifications for setting aside 5G spectrum relevant?

4.2 To assess the best licensing arrangements to support 5G services, it is useful to first review expected 5G use cases. While doing so, it is also important to bear in mind that future valuable applications for 5G may not be known at this time. As such, flexible licensing approaches which enable spectrum uses to be changed may be needed to ensure that spectrum remains efficiently used over time.

4.3 In the initial years, the major use of 5G is likely to be in the provision of enhanced mobile broadband supported by much greater capacity and faster speeds. Such services can be expected to be efficiently delivered by national networks in the same way that mobile broadband services are delivered today.

4.4 Looking forward, 5G is also expected to bring new applications, particularly in uses by industry and a range of services. In particular, one of the major benefits of 5G is that it is expected to be a key enabler of businesses of the future - what has been called the fourth industrial revolution or 'Industries 4.0'. The term Industries 4.0 involves the integration of the Internet of Things (machine-to-machine communications) and computation, networking and physical processes to support greater factory and process automation. Industries 4.0 include technologies such as device automation, automatic guided vehicles, augmented reality among others.[12]

4.5 The future business applications expected to be supported by 5G require a large number of devices to be monitored and controlled in a way that ensures fast and precise coordination.

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12 *See* Rao and Prasad. 2018. "Requirements of 5G Technologies on Industry 4.0", *Wireless Personal Communications*.

Such applications require communications services, which have ultra-low latency, very high reliability, very high bandwidth and high data rates. Box 1 presents the expected major groups of industry applications.

Box 1: 5G industry applications

5G technology is expected to bring innovative future business applications across a wide range of industries including:

a. Automotive: autonomous and connected cars, remote driving as well as information and entertainment services for passengers;

b. Media and entertainment: high quality video and virtual and augmented reality services;

c. Energy and utilities: real-time monitoring and control of networks;

d. Public transport: monitoring and optimisation of services, increased safety and passenger information and entertainment services;

e. Agriculture: remotely connect and control farm equipment, advanced imagery and use of drones;

f. Healthcare: remote patient care, wearable and implantable devices and smart sensing inhouse devices for monitoring and treatment;

g. Manufacturing: time-critical, reliable process optimisation inside 'digital factories', vision-controlled robot arms or mobile robots requiring reliable high-bandwidth, low latency connections;

h. Security: remote monitoring and detection.

4.6 A key question that has emerged is whether the 5G business applications will be able to be successfully provided by mobile operators or whether, at least for some uses, the need for customised network solutions requires dedicated spectrum and self-provision by industry uses. This has led to policy discussions of whether certain spectrum should be reserved for businesses and organisations which might have local demand for spectrum.

Assessment of potential market failures

4.7 In assessing whether there could be a case for departing from a market-based approach to awarding spectrum, an initial threshold question is whether there is a market failure. In particular, would a market-based approach prevent business or local users from obtaining spectrum where they would generate the greatest benefits to society from its use?

4.8 The use of spectrum for industry applications is likely to bring substantial benefits to society. However, this does not on its own provide a sound basis for reserving spectrum for specific industry use. There are many applications for 5G and limited spectrum available in frequency bands that are internationally harmonised for 5G services, particularly with respect to low and mid-band spectrum. Auctions can generally be expected to lead to spectrum being allocated to the most valuable uses. In the absence of a market failure, some bidders may fail to acquire spectrum in an auction simply because their use of the spectrum is less valuable than the use of winning bidders. However, there is nothing wrong with such an outcome unless the allocation resulting from the auction is not the allocation which maximise overall benefits to society, *i.e.* if there is a market failure.

4.9 In this section, we assess the relevance of three potential types of market failures that could lead to an auction failing to allocate spectrum on a socially optimal basis:

a. Externalities;

b. Downstream competition problems; and

c. Coordination.

4.10 We also then explain why an argument that setting aside spectrum to increase the bargaining power of industry users does not constitute a market failure which warrants spectrum set-asides.

Externalities

4.11 A positive externality arises where an activity has benefits to parties other than those directly involved in the transaction. It should be noted that many benefits of 5G applications are likely to be shared between business owners and their customers. However, if they do not also benefit other parties, these would not create a positive externality.

4.12 An example of a business application that could create positive externalities is in relation to transport[13] where there might be reductions in accidents, pollution and congestion.

4.13 Another example is where local licensing is put forward as a way to achieve widespread coverage and where that coverage is expected to bring wider benefits such as the development of an economically deprived area.

4.14 A market failure could arise if particular business applications create greater positive externalities than the use of the spectrum for other services. This could lead to spectrum being allocated sub-optimally in an auction where the allocation is based on bids which reflect private values.

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13 *See* "*Identification and Quantification of Key Socio-Economic Data to Support Strategic Planning for the Introduction of 5G in Europe*", a study prepared for the European Commission.

4.15 In this regard, it should be recognised that general mobile services could also give rise to positive externalities in enabling people to be better connected and having improved access to information and public services. Mobile and other services can also give rise to consumer surplus which is not captured by operators and hence leads to social benefits than exceed the commercial value of a service to an operator. The existence of externalities would only provide a justification for reserving spectrum where the particular use was expected to generate greater social value relative to private value than other uses (as otherwise, an auction would still lead to the socially optimal allocation of spectrum).

4.16 It is also necessary to consider whether spectrum would be allocated sub-optimally in practice. For example, many transport applications are likely to need national solutions which are best supported by national licences. There are also efficiencies in rolling out a network nationally including in sourcing equipment and being able to draw on a larger team of experienced engineers. Regional licences which prevent those efficiencies from being realised can result in higher service costs and may lead to less coverage.

4.17 While we believe that externalities could, in principle, justify spectrum set-asides for a particular use, we are not aware of externalities that create a general case for reserving spectrum for local use.

4.18 There is also no reason in general to expect that local licensing will achieve more widespread coverage than national licensing. Where licences are issued on a national basis, there could be solutions to address the need for timely coverage in particular areas:

a. Operators tend to be responsive to business customers seeking specific solutions such as the provision of coverage at a particular site where the revenues are expected to cover the cost of deploying equipment and backhaul to that site[14];

b. If an operator has no plans to use the spectrum in an area, then it should be willing to sub-license the spectrum in that area (assuming that the licensing framework allows for sub-licensing);

c. High frequency spectrum and/or unlicensed spectrum might be suitable for use by a business user at their site in a regional area (although it would again be important to assess the value of this spectrum under alternative uses); and

d. National licences also often include particular coverage obligations.

Cost of coordination

4.19 Spectrum may be of value to a large number of business users, each with a demand for a relatively small amount of spectrum. Such users could potentially have a high combined

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14 For example, Vodafone UK developed a mini mast solution to provide connectivity for two JCB's quarries in rural Staffordshire. *See* https://mediacentre.vodafone.co.uk/news/mini-masts-jcb-staffordshire-quarries/.

willingness-to-pay for spectrum although they may face practical difficulties in identifying similar users and being able to successfully coordinate to jointly bid for spectrum. For example, as noted earlier, an auction might fail to lead to spectrum being assigned for shared use if each potential user reduces their bids because they expect the bids of other parties to be sufficient to obtain the spectrum for shared use. Regulatory authorities have recognised that coordination problems may need to be taken into account in determining how to allocate spectrum.[15]

4.20 This type of market failure could be relevant for 5G. There is likely to be a large number of vertical users with a demand for spectrum confined to a very small geographic territory who might not participate individually in an auction for national licences.

4.21 Coordination problems may, however, be addressed by a firm effectively aggregating the demand of smaller parties. In particular, where there is clear demand from local users and where the combined amount that they would pay is competitive with that of national users, then firms may bid for the spectrum for the purpose of meeting the needs of local users. Such firms have been successful in acquiring spectrum in auctions. For example, Airspan is an independent network operator, which has bid and successfully acquired 3.5 GHz spectrum in several countries.[16] Airspan's business model targets solving local network densification needs and addressing non-mobile carrier and private network deployments, including the needs of vertical market segments.[17]

4.22 While aggregating firms may solve coordination problems in some cases, there may not always be effective private market solutions.[18]

4.23 In sum, we believe that coordination problems could lead to market failure, although the possibility of entities aggregating bids of local users would mitigate this risk.

Downstream competition problems

4.24 A further potential justification for reserving spectrum is where the outcome of an auction is expected to be distorted by bidders' seeking to reduce downstream competitive pressure by gaining market power. For example, a dominant operator might outbid rivals because of the

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15 For instance, *see* Ofcom. 2007. *Digital Dividend Review - Statement*, para. 5.42f.

16 Airspan's subsidiary Dense Air, has acquired 3.5 GHz spectrum in Australia, Ireland and Portugal and has acquired 2.6 GHz spectrum in Belgium and New Zealand.

17 *See* https://www.airspan.com/about-airspan/

18 The risk of inefficiencies associated with bilateral trade are illustrated in the classical work by Myerson and Satterthwaite (Journal of Economic Theory, 1989), which poses that there is no bargaining protocol that guarantees efficient trade in bilateral negotiations. The FCC considered this argument in evaluating the possibility of the secondary spectrum market of achieving efficient outcomes (*See* page 80 of "Putting Auction Theory to Work" by Paul Milgrom). However, such reasoning does not apply where there are several parties competing to provide access in secondary markets.

expectation that by holding most of the spectrum in a market they will be able to earn monopoly profits.

4.25 Foreclosure or strategic investment bidding entails significant costs for operators, as it implies buying more spectrum than necessary, and potentially raising auction prices significantly.

4.26 Whether an operator has an incentive to bid to foreclose rivals will depend on:

a. the level of competition in the downstream market,

b. the degree of overlap of business models, and

c. alternatives to develop vertical or local applications.

4.27 Where the outcome of the auction is unlikely to materially impact downstream competition then bids in the auction are unlikely to be distorted by the prospect of an operator foreclosing the market.

4.28 Bids are also unlikely to be distorted by foreclosure effects where other bidders for the spectrum are not targeting the same customers or market segment.

4.29 A firm would also not expect to acquire spectrum to foreclose rivals where the rivals would be able to supply services by other means, potentially such as using unlicensed spectrum.

4.30 Most European mobile markets are effectively competitive and hence we do not see a general market failure that would prevent a new entrant with a competitive business case from succeeding in an auction.[19] We also note that entrants have been able to enter even in the absence of spectrum set-asides, such as the successful acquisition of spectrum by 1&1 in Germany's 3.5 GHz auction.

4.31 Overall, we do not believe that there is market failure that would create a general need for intervention to prevent downstream foreclosure. Regulators should nevertheless consider the particular circumstances of each market to identify whether set-asides or other measures are warranted to protect competition.

Improving bargaining power with respect to operators does not constitute a general market failure

4.32 Another possible argument is that business users may face higher prices, poorer quality or no access at all to the 5G services they require if they are forced to rely only on operator services. For example, a business user might want access to some service components and not others

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19 In Ireland, Airspan succeeded in acquiring 60 MHz of 3.6 GHz spectrum in the cities and 25 MHz in rural areas without any particular spectrum set-aside. In the UK, Airspan did not succeed in acquiring 3.4 GHz spectrum but was outbid at a price of around £5.5m, much lower than the final price of £39.7m. Given that the demand for spectrum of other players in the UK led to the auction continuing for several rounds after Airspan dropped out, it is unlikely that their bids were inflated to foreclose Airspan.

whereas operators might only offer full end-to-end managed services. Spectrum set-asides could then be seen as a way to ensure access to local users and provide them with leverage with operators in negotiating services that better suit their needs. A representative of Bosch Rexroth has stated that "*We think having our own license is very beneficial because this gives us the freedom to either deploy the network alone or with a telecom operator*".[20]

4.33 Where there is effectively competition between operators, wholesale access to downstream users is likely to be provided on commercial terms.

4.34 Vertical access problems tend to arise when a vertically integrated entity (*e.g.*, an operator) risks losing a downstream source of profits (*e.g.* the managed services margin) because of granting upstream access to a client (*i.e.*, a business user seeking to build its self-managed network based on network slicing). Without effective competition, the business user which is denied access might not have a reasonable alternative to relying on the operator's managed services. An operator which does not face competition might sometimes have an incentive to deny access or offer uncompetitive access terms.

4.35 Effective competition solves such access problems. If there are rival operators, a business user that is denied access by one operator could obtain access from competing operators.[21] Recognising this, each operator with available capacity will have the incentive to try to earn wholesale revenues by offering access itself. Indeed, in most European countries, there is a healthy MVNO sector based on commercial wholesale access agreements (*i.e.* without the need of mandated access). Access seekers might still seek regulatory intervention if they expect the regulator to impose low access prices, however, the public policy case for such regulation is weak where there is competition between operators.

4.36 On this basis, we do not believe there is a general case for setting aside spectrum to ensure access on competitive terms. Only if the market is not expected to be effectively competitive would there by a case for measures to increase competition. Even then, setting aside spectrum for a particular use might not be suitable as it effectively leads to less spectrum being available for operators and might reduce rather than increase overall competition. Given that we do not expect there to generally be market failures in relation to the allocation of 5G spectrum, business users would also be able to compete effectively in an auction.

Conclusions on market failures

4.37 We conclude that there is not a general market failure warranting departures from auctioning spectrum. Nonetheless, regulators should evaluate whether externalities, coordination problems or downstream competition problems are relevant to their specific market circumstances.

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20 A statement of Gunther May, Bosch Rexroth AG, reported in Cap Gemini. 2019. "*5G in industrial organisations – how telcos and industrial companies stand to benefit*".

21 Other factors could also reduce the risk of access problems for local users such as the availability of other spectrum suitable for the business user.

4.2. Benefits of spectrum set-asides

4.38 In this section, we consider how to assess the benefits of setting aside spectrum in specific market circumstances.

4.39 As noted in the previous section, the main benefit of spectrum set-asides arises where it would lead to spectrum being allocated to the use with the highest social value if a market failure would otherwise cause a sub-optimal allocation of spectrum. The benefit of spectrum set-asides would then be the additional value to society compared with the value that would have been generated from the alternative use of the spectrum.

4.40 It should be noted that where spectrum set-asides do not lead to a different allocation of spectrum than what would have been achieved under an auction it would generate no benefit compared with an auction.

4.41 As we discuss in the next section, where setting aside spectrum leads to spectrum being assigned to a use which has a lower value than its opportunity cost, then society will be made worse off by the difference between its value in the reserved use and the opportunity cost. In Box 2, we consider evidence on the expected value of the 100 MHz of 3.5 GHz spectrum set aside in Germany had it been assigned by auction instead. We estimate that an entity would have needed to pay €1.46 billion to acquire the spectrum that was ultimately reserved for local users. If the sum of local users' willingness to pay for that spectrum is below that value, then setting aside spectrum would not have been socially beneficial (assuming that there were no relevant externalities and/or competition problems).

Box 2: The price that a hypothetical bidder would have paid for the spectrum set-aside in Germany

Suppose that instead of having reserved 100 MHz for local use, the German Regulatory Authority (BnetzA) auctioned all 400 MHz of the 3.5 GHz band. In this context, what is the price that a hypothetical entity buying all the additional 100 MHz would have paid for the auction allocation to have been efficent?

The German 3.5 GHz auction had an SMRA format, which is a popular ascending format for multiple units. The auction allowed bidders to substitute among different blocks of 10 MHz spectrum. From the publicly available round information, one can infer that the highest losing bid was a €145.9 million bid for a 10 MHz block by 1&1.

Absent the set-aside, an additional 100 MHz (10 blocks) would have been auctioned. If any of the lots held by the hypothetical bidder was priced below €145.9 million, then 1&1 would have had incentives to bid for it. As a consequence, for the auction allocation to be efficient each of the additional 10MHz blocks would need to be priced at least at €145.9 million, making the hypothetical bidder's total expenditure to be €1.46 billion. Thus whether the 3.5 GHz spectrum set-asides in the Germany would have led to greater benefits than had all the spectrum been auction would depend on whether local licensees would have been willing to collectively pay €1.46 billion for their spectrum.

Regulators often apply this reasoning to set licence fees for spectrum holdings which were not obtained through market mechanisms. For example, Ofcom has recently proposed this approach for setting the licence fees of 3.5. GHz spectrum previously held by UK Broadband, using market clearing prices in the PSSR auction as the relevant framework.

4.42 In evaluating the benefits of setting aside spectrum, it is important to recognise that there are often technical alternatives or other solutions available to meet industry needs, and benefits should be assessed net of what would otherwise be achieved anyway.[22] Such technical solutions involve different parties and ways to meet those needs.

4.43 In term of what parties are involved in providing the solutions, there are different options ranging from full MNO provision of services to fully self-managed networks. These include the following:

a. Mobile operator provision – business users take services from operators. A major innovation of 5G technology is that it provides for network slicing, i.e. that a common network infrastructure is used to provide for multiple virtually independent business

22 This can either be undertaken in an integrated way by considering benefits and costs net of alternatives or by assessing the net benefit of alternative options and adopting the policy that is expected to lead to the highest net benefits.

operations in which each operation is able to be customised to the service quality required by each business customer or specialised industry ('vertical') including in relation to data speeds, quality, latency, reliability, security and the services offered. This solution is expected to be available across the EU, wherever 5G spectrum has been licensed nationally.

b. Self-managed networks – Operational Technology companies and/or business end users fully manage the 5G connectivity solution.

c. Hybrid solutions - business users delegate some aspects of the solution to MNOs and take responsibility of other aspects. The user could manage its 5G network but rely on the MNO to offer localised access to its nationally licensed spectrum, or could seek its own spectrum and rely on the MNO to operate the 5G network.

4.44 There are also different ways in which access to spectrum can be provided including:

a. Acquisition of dedicated licenced spectrum – in the majority of EU countries, spectrum is made available in open auctions, generally on a nationwide basis. Dedicated licence spectrum might also be acquired in secondary markets.

b. Leased spectrum – business users lease spectrum in a particular area from the holder of a national licence. This would be available if the licensing authority allows for leasing. Regulators may or may not intermediate in this process

c. Shared spectrum – a licensed band that can be used by different users. Such use is subject to technical limitations and also depends on favourable regulatory and commercial conditions.

d. Unlicensed spectrum – business users deploy devices allowed to be used with particular unlicensed spectrum. This might be a viable solution for many applications with specific requirements. For example, Ocado developed a solution based on unlicensed spectrum in the 5 GHz band to control over 1,800 robots in warehouses, a very high device density which exceeds LTE network capabilities.[23]

4.45 There may be regulatory barriers to the adoption of some of these solutions in particular markets. If so, authorities should consider whether removal of these barriers might create a more efficient way to securing spectrum for particular uses compared with spectrum set-asides.

4.46 Where spectrum set-asides are put forward based on a market failure (and we argue that market failures provide the only case for considering departures from market-based

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23 *See* Cambridge Consultants. 23 April 2018. "*Why LTE didn't cut it for Ocado*".

mechanisms), it would be important to also assess how well reservation would work to address that market failure.

4.47 Spectrum set-asides could lead to more spectrum being allocated to a use with significant positive externalities. One challenge would be to ensure that the amount of spectrum allocated to that use is socially optimal as only a proportion of the available spectrum may need to be allocated to a particular use to achieve the social benefits. Allocating a large amount of spectrum to one use may prevent other valuable uses from being realised. Further, there may be other ways of achieving a particular objective, such as widespread coverage, which carry less costs. For instance, one licence could be issued with a coverage obligation which would enable the market participant to acquire the licence who can meet that coverage obligation at lowest cost. An expansion of general mobile coverage would benefit all potential services users in the area rather than only a specific user.

4.48 Local licences could help overcome coordination problems associated with national licences. However, they also carry the risk of stranding an amount of spectrum which national networks will not be able to use even if they turn out to be the highest social value users. Local licences allocated to a specific user might also deprive other users from benefiting from the use of the spectrum. It is also important to assess the relevance of coordination problems given alternative solutions such as:

a. unlicensed spectrum can provide an effective solution to the problem of many potential users and where individual use is not expected to interfere with other users; and

b. secondary licencing would allow for local users to sublease spectrum acquired by aggregators or national operators where operators have the capacity available (noting that operators also need capacity to meet the needs of general mobile customers).

4.49 Spectrum set-asides might lead to greater competition in markets where a dominant player might otherwise seek to acquire licences for most of the available spectrum. However, spectrum set-asides might only solve a competition problem for some uses whereas a spectrum cap could potentially support greater competition more widely and provide for greater flexibility in the use of the spectrum.

Conclusions on benefits of spectrum set-asides

4.50 An auction will generally facilitate spectrum being allocated efficiently, i.e. to the use that delivers the greatest benefits to society. Setting aside spectrum can, however, create a benefit to society where a market failure would otherwise lead to spectrum being allocated sub-optimally. In particular, the benefit from spectrum set-asides would be the value of the spectrum in its reserved use compared with its value in the use of the spectrum that would have occurred absent the reservation.

4.51 In considering how spectrum might have been used without a spectrum set-aside, the range of potential technical solutions to address particular demand should be taken into account. Solutions might be provided by mobile network operators, particular users or a combination of both parties. These alternative technical solutions require spectrum, which can be accessed through open auctions, leased spectrum or shared spectrum, and through the use of unlicensed spectrum. Insofar as there are any benefits to be gained as a result of reservation, these will depend on the existence of efficient use cases that can only be delivered through reserved spectrum and not through any of the technical alternatives. At this moment, we are not aware of any application that could not be systematically delivered through technical alternatives (even if there may be specific cases where some options might not be available). Therefore, we believe that there would be marginal benefits through setting aside spectrum.

4.52 In addition, even where spectrum set-asides could help address a market failure, they may be only partly effective in doing so. There is also the risk that too much spectrum might be reserved for a particular use, depriving other valuable uses of adequate spectrum.

4.53 Even where spectrum set-asides lead to a benefit, they can also be expected to create costs. We address the potential costs of spectrum set-asides next.

4.3. Potential costs associated with spectrum set-asides

4.54 In the previous sub-section, we examined a range of arguments for and benefits of spectrum set-asides. We found that while there is not a general case for setting aside 5G spectrum for particular uses, certain market failures may provide potential justifications for reserving spectrum in some market circumstances.

4.55 Where a potential benefit from spectrum set-asides is identified, it would be important to weigh the expected benefit against the costs that reservation might give rise to and to consider whether alternative policy options are available that might be able to achieve the benefit at lower cost. This is the third step in our recommended framework set out in Figure 1.

4.56 A key advantage of an auction is that it provides for potential users of spectrum to effectively ‘put their money where their mouth is’ by bidding to acquire spectrum for their use against other bidders. A risk of an administrative process in which spectrum is instead licensed in a more restricted way is that it encourages potential spectrum users to seek to influence the rules and process to favour their use over others. The outcome of the process can then be determined by which presentation from players is found most attractive by authorities. Authorities are unlikely to be as well placed as market participants to assess the assumptions underlying rival business plans. Further, if licences are issued based on plans put forward, it can be difficult for authorities to then enforce those plans as technologies and market conditions might change and make the original plan no longer achievable or the best use of the spectrum.

4.57 The licensing approach can also create costs to society through a wide range of effects.

4.58 Most directly, where spectrum is employed for one use, it is not available for another use. The benefit that society obtains from its spectrum resources will be lower where spectrum is not assigned to its highest value use. As we explore further in the next sub-section, this loss of benefit can impact consumers in a number of ways, including higher prices and lower service quality as well as limiting the benefits of innovative new uses. There is not a net cost to society where spectrum is set-aside to address a market failure that would otherwise lead to spectrum being assigned to a lower value use. However, as we discuss, the loss to society can be substantial where spectrum is reserved without regard to its value in alternative uses.

4.59 Where spectrum is assigned on a regional basis rather than nationally, the licensing approach can prevent the realisation of economies of scale with fixed costs being recovered over smaller customer numbers. Networks might be deployed in some areas and not others. Regional licences may also lead to other inefficiencies in the use of spectrum such as restrictions on use to avoid interference with other uses in neighbouring licensing areas. Where services are more efficiently delivered on a national basis, operators may accumulate significant debt in needing to merge with operators holding regional licences.[24] Some regional licence-holders might refuse to sell their licences at a price commensurate with the value of the regional licence, creating a barrier to the national delivery of services.

4.60 There can also be significant indirect effects of the licensing approach. If there are major differences between mobile operators in their access to spectrum, particularly if individual operators have very little spectrum suitable for key services, competition in the retail mobile market may be distorted. There could also be distortions among users of spectrum if some industry players have been able to obtain access to spectrum at below market rates whereas other players need to rely on services from mobile operators which have paid market rates for their spectrum. Most perniciously, licensing restrictions could prevent some innovative uses from being deployed at all with the consequence that users do not have access to the benefits they would generate.

4.61 We examine the range of effects further in the rest of this section.

Direct costs to society from spectrum set-asides

4.62 In this section, we set out our analysis of the direct costs to society of spectrum set-asides. Generally speaking, spectrum set-asides imply less capacity for general mobile services.

4.63 Such a reduction in capacity will cause demand and supply side effects which we analyse below. Regarding the supply side, we use bidding data to analyse bidders' lost surplus from not having access to an additional 100 MHz of spectrum (i.e. the amount of spectrum set aside in Germany). With regard to the demand side, we analyse several scenarios which may lead to consumer harm. These scenarios depend on precisely how operators respond to limited spectrum such as by raising prices, reducing quality, seeking to obtain additional sites or by combination of these measures. We assess each of these alternatives to show the full range of harmful effects that can arise (although, as we explain, the individual quantitative estimates of different effects should not simply be added to estimate the overall loss to society).

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24 For example, this was the case with the cable TV industry in the UK where cable franchises were initially issued on city-by-city basis. The model proved uneconomic resulting in a long period of financial problems and high debt levels before eventual consolidation.

Direct opportunity cost to society of spectrum set-asides

4.64 Bidders seek to buy spectrum in auctions because it allows them to create value. Additional spectrum would enable additional value to society to be created from the services which use spectrum as input. This value can arise from various factors, including avoiding incremental network costs (such as additional sites), or making available more or better services to customers. Where all the available spectrum is auctioned, absent market failures, the spectrum is likely to be acquired by the bidders which expect to create the highest value. However, where spectrum is set aside, some of the highest value use may not be realised.

4.65 In this section we describe how the losing bids in an auction reflect bidders' unrealised value from spectrum set-asides. This lost value can be understood as part of the social benefits forgone by setting aside spectrum, or, equivalently, as a part of the opportunity cost of setting aside spectrum. We quantify this effect using data from the recent 3.5 GHz auction in Germany.

4.66 In quantifying the opportunity cost of reserved spectrum, we use two different approaches:

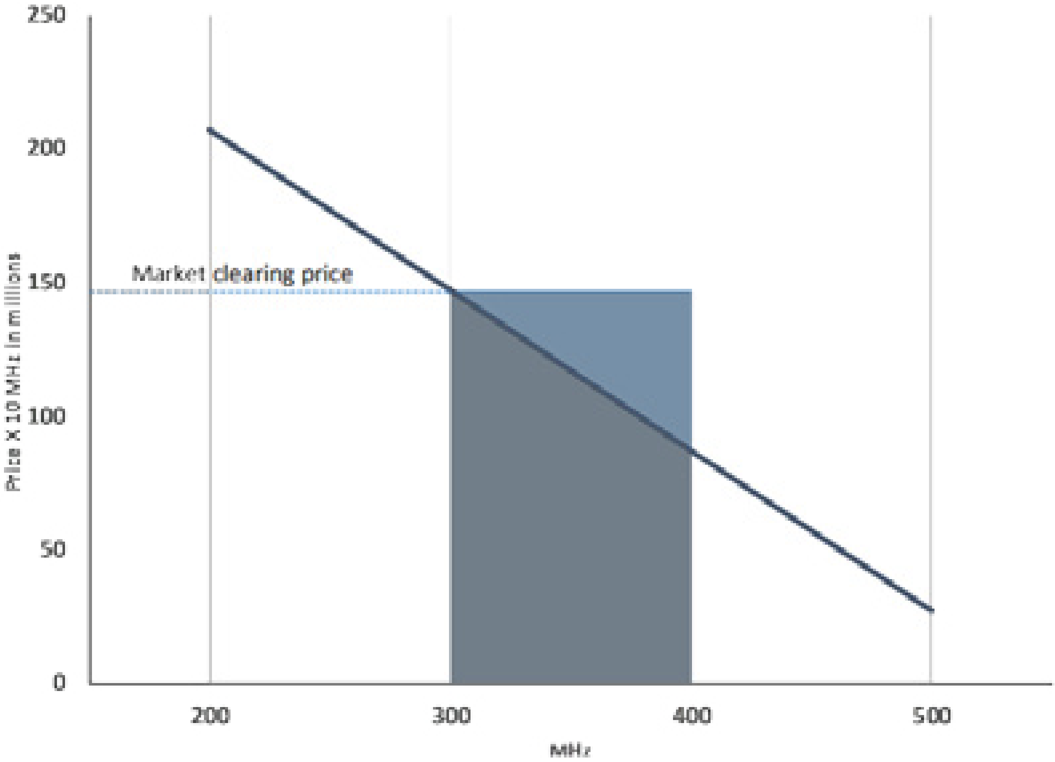
a. Pure opportunity cost (Option A): bidders' lost surplus from setting-aside a given amount of spectrum can be derived from the highest losing bids for that given amount of spectrum. In other words, this approach takes the value reflected in unsuccessful bids as the relevant opportunity cost.

b. Marginal opportunity cost or market price (Option B): In a well-functioning market, the "market price" for a marginal block (*i.e.* a 10 MHz block) of spectrum would be expected to reflect the valuation of the best alternative use of the spectrum.

4.67 Both approaches have been put forward as ways of measuring opportunity cost. The latter coincides with what beneficiaries from spectrum set-asides would need to pay for the spectrum had the spectrum been assigned as part of the general auction, as discussed in Box 2. The former reflects what bidders participating in the auction would have been willing to pay for an amount of additional spectrum equivalent to the reserved amount. The pure opportunity cost (option A) is in general a more conservative estimate.

4.68 Figure 2 shows the relationship between both methodologies. The black line is the aggregate demand for spectrum of bidders in the auction, as captured by bids. The grey area below the demand curve is what methodology A estimates, whereas methodology B is the sum of both the blue and the grey areas.

Figure 2: Bidders' opportunity cost vs. marginal opportunity cost



The relation between bids and bidders' value of the spectrum

4.69 Operators and entities interested in acquiring spectrum regularly compete in open auctions to obtain a portion of the spectrum available. In these auctions, bidders are allowed to express demand for different amounts of spectrum. Auctions start with a low price, for which bidders often demand a large amount of spectrum, and demand tends to fall as auction prices rise.

4.70 Conceptually, a bidder's valuation of spectrum may reflect the intrinsic or use value of the spectrum to the bidder and/or a foreclosure (or strategic investment) value.[25] The former reflects the value that bidders place on the use that they can make of the spectrum. The latter reflects the value that bidders may obtain by denying spectrum to competitors so as to weaken rivals' competitive positions. In European markets, regulators design auctions to reduce the risk of bids being driven by the interest of foreclosing or weakening rivals. Hence, in most recent auctions, bids are unlikely to be heavily influenced by this motive.[26] For example, in the

25 *See*, for example, fn. 140 of "*FCC Report and Order In the Matter of Policies Regarding Mobile Spectrum Holdings*" dated June 2, 2014.

26 For instance, in 2014 Ofcom reviewed the results of 19 European auctions. In this assessment, Ofcom only identify some risk of foreclosure bidding playing a potentially relevant role in four auctions, with the risk in two of them being only limited. *See* Tables 8.1 and 8.2 of Annex 8 the Statement on the Annual licence fees for 900 MHz and 1800 MHz spectrum, 2015.

German auction under consideration, BNetzA considered that the relatively large amount of spectrum being made available would make acquisition of spectrum to foreclose rivals too costly.[27] All eligible bidders, including a new entrant, were able to acquire spectrum.

4.71 As such, bids in well-designed auctions will generally be based on bidders' intrinsic value of the spectrum. Bidders would be expected to be willing to pay up to the incremental value they can generate from additional spectrum in order to secure an additional amount of spectrum. Bids thus provide information about the incremental use value of the spectrum in particular uses.

4.72 While in general one would expect bidders with a higher use value of spectrum to place higher bids for the spectrum, there are particular issues arising from auction design aspects that may distort this relationship. In particular, some recent auctions of 3.5 GHz spectrum in Europe (including the 3.5 GHz German auction) adopted variations of an SMRA (*i.e.* 'Simultaneous Multiple Round Ascending') auction format. This format has two features that tend to make observed losing bids underestimate bidders' true demand curve for spectrum:

a. **Demand reduction:** This format penalises high bids for large amounts of spectrum and induces bidders to engage in a phenomenon called "demand reduction".[28] This phenomenon has the effect of understating bidders demand, in particular as to bids for several blocks of spectrum (see Box 3).

b. **Activity Rules:** SMRA auctions often allow bidders to leave part of their demand dormant, with so-called "activity rules". These rules may permit bidders to not reveal their demand for large blocks in the auction.

4.73 Both features mean that the opportunity cost of spectrum can be underestimated when it is based on observed bids. The demand reduction phenomenon may also bias downwards estimates of the marginal opportunity cost of spectrum.[29] These features imply that our estimates of the opportunity cost of spectrum set-asides based on the German 3.5 GHz auction's bids will be conservative.

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27 President's Chamber decision of 14 May 2018 on the order for and choice of proceedings for the award of spectrum in the 2 GHz and 3.6 GHz bands for mobile/fixed communication networks, paragraph 304.

28 *See*, for example, "Multi-unit auctions with uniform prices", Economic Theory, Engelbrecht-Wiggans and Kahn (1998).

29 In general, demand reduction will tend to depress market clearing prices, and thus affect the marginal opportunity cost.

Box 3: **Demand reduction in uniform price multi-unit auctions**

In certain types of auctions for multiple units, prices tend to be uniform for similar units. For example, final prices paid for 10 MHz lots of 3.5 GHz in the German 5G auction ranged between €146 million - €148 million for 27 of the 28 lots available, and the remaining one had a price of €158 million. This is because bidders can substitute across different lots, and switch demand to cheaper lots until the prices of all similar lots are similar.

Bidders, on the other hand, tend to have a decreasing valuation for additional lots. This means, for instance, that an additional lot is more valuable for a bidder when they have no lots, than when they have existing lots.

These aspects create incentives for bidders to avoid fighting for a large number of lots in an auction. For example, suppose that at some point of an auction, lots are priced at around €100 million each. At those prices, bidder A may be willing to acquire up to 12 lots. However, bidder A may realise that if it instead demands 10 units, the auction will come to an end. This is because, given rival bidders' expected demand, there would no longer be excess demand in the auction. On the other hand, if Bidder A pursues 12 lots, prices could continue to bid up. By demanding 2 extra units (*i.e.* 12 instead of 10), Bidder A could increase the price of not only those two units, but also the price it pays for the other 10 units. In this case, bidder A might instead choose to settle for 10 units.

Not all types of auctions create these type of incentives. Other popular formats for spectrum auctions (like CCA) do not lead to uniform prices and tend to not generate as clear incentives for demand reduction. In SMRA auctions, however, this effect can lead to bidders refraining from expressing demand for a large number of units. For example, in the German 5G auction, bids in initial rounds were not so different from bids in final rounds, and in most rounds, there was only one lot of excess demand. This does not necessarily mean that the bidders did not value additional lots. Instead it may reflect that they preferred to avoid the risk of raising auction prices further.

Methodology and Results

4.74 We estimate the lost value of 100 MHz of spectrum using both approaches described by using bidding data from the German 5G auction. The approach relating to the marginal opportunity cost coincides with what was described in Box 2, and it is a straightforward calculation arising from the highest losing bid.

4.75 Computing bidders' full opportunity cost is more complex and requires additional assumptions. We set out these assumptions below.

4.76 First, we note that in the German 5G auction, not all bid history information is available. The regulator disclosed the provisionally winning bids at the end of each round (497 rounds in total), but losing bids were not disclosed. Hence, we base our calculations on accepted bids.

We recognise that this may underestimate our figures, as some losing bids may not be considered (for instance, if there were tied bids for a block in a given round).

4.77 Second, we make two conventional technical assumptions. First, we assume that bidders have a decreasing (or more specifically a non-increasing) demand curve for spectrum and that they generally adopted straightforward bidding strategies. [30] The first of these assumptions means that bidders' value for additional 10 MHz does not increase as bidders hold a greater amount of spectrum. The second, coupled with the first one, implies that bidders will be willing to bid for an additional block of spectrum until the price reaches the value of this additional unit.

4.78 Based on these assumptions, the opportunity cost of 100 MHz equals the sum of the highest losing bids for 10 extra 10 MHz blocks. The value of the highest losing bids can be derived from the rounds where bidders dropped demand. These bids are the following:

a. 1&1 dropped demand from 6 to 5 blocks in round 493 at the price of €146 million, and three additional blocks from 9 to 6 blocks in rounds 157 to 163, at a price which ranges from €71 million to €100 million.

b. Telefonica dropped demand from 12 to 7 blocks in round 226, at a price of circa €104 million.[31]

c. Vodafone dropped demand from 10 to 8 blocks between rounds 177-182, at a price of around €98 million.[32]

4.79 Table 2 shows the results of both approaches estimating the lost value to bidders from setting aside 100 MHz of spectrum. In either case, estimates exceed one billion euros. However, as expected, Option A estimates are more conservative, and can be considered as a lower bound for bidders' lost value. To put these figures in perspective, the amounts involved represent 25%-35% of what bidders paid for the spectrum available.

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30 We recognise that given activity rules, there are several instances where one could infer that bidders did not adopted strict straightforward bidding strategies. For example, several bidders have increased their demand for lots as auction prices increased. However, our analysis builds on the fact that the highest bid for the n^{th} lot (say, the 10^{th}) informs about its marginal value (*i.e.* the marginal value for the 10^{th} lot).

31 Telefonica also placed smaller bids in earlier rounds for 80, 90 and 110 MHz. However, given our assumptions on non-increasing demand for spectrum, the only relevant bid for the analysis is the 120 MHz bid.

32 This 20 MHz of spectrum has limited utility because of interference issues. For the purposes of our analysis, we have assumed that this restricted spectrum is equivalent to 10 MHz of unrestricted spectrum. Based on the price differential of this block and other blocks in the auction end results, we think this is a conservative assumption.

Table 2: Opportunity cost of 100 MHz reservation in Germany

	€ million
Option A	1,040
Option B	1,459

Higher spectrum costs lead to less investment and higher consumer prices

4.80 Our analysis in the previous section shows that there was a significant drop in total demand for spectrum at a price of around €70 million - €100 million per block. Based on this, and making the same assumptions as before, we can estimate by how much the spectrum set-asides caused the auction price to increase.

4.81 In a SMRA auction, the highest losing bidder is the one that sets the price of the lots. As discussed, the highest losing bid was placed by 1&1. If the regulator had made available an extra 10 MHz lot, based on our straightforward bidding assumption, 1&1 would have acquired that lot. The price for that lot (and all other lots) would have been set by the next losing bid. This bid was Telefonica's bid for €105 million. This means that adding a 10 MHz lot could cause prices to decrease from almost €150 million per 10 MHz lot to €105 million.

4.82 If the auction had included an additional 100 MHz, based on the history of demand described in paragraph 4.78, then the highest losing bid (that is, the 10th highest losing bid in the actual auction) would then have been the €71 million bid by 1&1. This means that setting aside 100 MHz of spectrum could have caused auction prices to more than double. Table 3 shows how this increase in price translated into additional costs of spectrum.[33] This illustrative calculation shows that bidders had to pay an extra €2.2bn for the 300 MHz because of the effect of spectrum set aside.[34]

Table 3: Estimated effect of set-asides on spectrum costs in the German 5G Auction

	€ million
Actual 3.5 GHz spectrum cost for 300 MHz	4,176
Counterfactual 3.5 GHz spectrum cost for 300 MHz without reservation	2,021
Estimated additional spectrum costs	2,155

4.83 We note that the estimated price, had an additional 100 MHz been auctioned in Germany, of €71.4m per 10 MHz block is in line with the recent auction prices in UK. In the 2.3 GHz and

33 We assume that the 20 MHz block price would have reduced in a similar proportion to other blocks.

34 We note that, on top of the assumptions set out in paragraphs 4.76 4.78, this calculations also assume that additional spectrum available would have not caused additional bidders to participate in the auction.

3.4 GHz auction in the UK, final prices were about £78m (€89m[35]) per 10 MHz of 3.4 GHz spectrum. While the UK auction involved auctioning only 150 MHz, 390 MHz of the 3.5 GHz will be available soon for mobile use.[36] Hence, UK prices are less likely to reflect artificial scarcity then German prices, although there was some uncertainty about the availability of additional 3.5 GHz spectrum at the time of the UK auction.[37] Given population differences, adjusted UK prices (€0.14/MHz pop) in MHz per head of population are in the middle of German actual prices (€0.18/MHz pop) and counterfactual prices (€0.09/MHz pop).

4.84 The effect of spectrum scarcity on spectrum prices can also be illustrated by looking at the results of the recent Italian spectrum auction. In Italy, a market with four mobile operators, 200 MHz of 3.5 GHz (100 MHz less than in Germany) was auctioned. This resulted in very high prices, of about €0.36/MHz pop, about twice the price paid in Germany (€0.18/MHz pop). In other countries, such as Austria, auctions for 3.5 GHz spectrum ended with considerably lower prices (in Austria, final prices were €0.055/MHz pop).[38] In Austria, all three national operators were able to win at least 100 MHz of spectrum each, and the rest of the spectrum available was split between regional operators. While there are other conditions that are also likely to have affected prices (such as packaging, different licence duration and macroeconomic factors), spectrum scarcity is likely to have played an important role in these auctions.

4.85 While operators should be expected to pay a price for spectrum reflecting its opportunity cost, spectrum set-asides can create artificial that can drive up auction prices and ultimately end up hurting consumers through lower investment and/or higher service prices.

4.86 Higher prices for spectrum mean that operators have less internal funds available for investment. The economics literature shows that when firms have less cash flow and are forced to rely more on external finance this reduces their level of investment.[39] Fundamentally, this arises from internal funds being a lower cost source of capital than having to raise external finance. Raising equity externally is costly because outside investors with less information on a firm's prospects demand a discount on the price that they pay for shares which harms current equity holders by reducing the value of their equity.[40] Raising new debt may affect the credit

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35 We use an exchange rate of 1.14€/£ as of April 2018, when the UK auction ended.

36 H3G, one of UK's operators, held part of the band not auctioned, and the rest of the band is going to be auctioned in the upcoming 700 MHz and 3.6 GHz award.

37 At the time of the UK auction, there was uncertainty about the availability and usability of 3.6-3.8 MHz band in all regions of the country in a similar timescale than the 3.4-3.6 GHz band.

38 Switzerland and Ireland are other examples of low spectrum scarcity.

39 *See*, for example, R.G. Hubbard. 1996. "Capital-market imperfections and investment", Journal of Economic Literature, 36.

40 A leading finance textbook refers to the pecking-order theory of financing in which firms prefer to rely on internal funds over raising debt and prefer raising debt to raising equity and states: "*The pecking-order theory stresses the value of financial slack. Without sufficient slack, the firm may be caught at the bottom*

rating for a company resulting in higher interest rates or requiring greater collateral. Raising new debt and equity also carries legal, accounting and underwriting costs.[41]

4.87 A firm that can rely more on its own cash flows to fund investment and avoid raising costly external finance can be expected to invest more because its lower cost of funds makes a larger number of investments economic. A number of studies confirm that there is a statistically significant relationship between higher cash flows and higher investment.[42] A recent study by Lewellen and Lewellen found that an extra dollar of cash flow is associated with between \$0.32 and \$0.63 of additional investment varying with the extent to which the firms were constrained in raising external funds.[43] The higher cost of funding additional investment can be expected to lead to operators not undertaking investments where the expected return is less than the cost of the additional capital.

4.88 Lower levels of network investment can in turn result in poorer quality services and/or more limited coverage. For example, 5G coverage might not be extended beyond densely populated urban areas. In addition, with less investment in expanding capacity and in deploying new technology more widely, operators are less able to offer higher data allowances, effectively increasing the price per unit of data. A study by NERA confirms that there is a statistically significant link between:[44]

a. high spectrum costs and higher consumer prices; and

b. high spectrum costs and a lower wireless score being a measure of 3G/4G coverage, average data speeds and 4G subscriber shares.

Consumer harm relating to existing mobile services

4.89 Spectrum scarcity not only affects mobile operators or other potential entities willing to purchase spectrum. Ultimately, spectrum is a means to provide services to consumers, and spectrum scarcity will translate into consumer losses.

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of the pecking order and be forced to choose between issuing undervalued shares, borrowing and risking financial distress, or passing up positive-NPV investment opportunities" (Brealey, Myers, Allen, *Principles of corporate finance*, 2011, p.466).

41 For example, Moody's has recently downgraded Vodafone, citing a "slower growth and higher leverage owing to spectrum investments" as one of the reasons for the downgrade. *See* February 2019. "Rating Action: Moody's downgrades Vodafone to Baa2; negative outlook".

42 *See*, for example, N. Bloom, S. Bond, and J. van Reenen. 2007. "*Uncertainty and investment dynamics*", Review of Economic Studies 74.

43 *See* J. Lewellen and K. Lewellen. Aug. 2016. "*Investment and Cash Flow: New Evidence*", Journal of Financial and Quantitative Analysis, Vol. 51, No. 4, pp. 1135–1164.

44 *See* NERA. May 2017. "The Impact of High Spectrum Costs on Mobile Network Investment and Consumer Prices".

4.90 An academic study by Hazlett and Muñoz (2009)[45] supports the view that releasing additional spectrum reduces consumer prices and increases overall welfare. The study, which uses cross country information for the period 1991-2003, finds that an increase of 80 MHz of spectrum in a country like the UK in the early 2000s would cause significant welfare gains, mostly driven by an increase in consumer's surplus of about US$28 billion in net present value for perpetual licences.

4.91 Hazlett and Muñoz's results only measure the welfare effects associated with data and text services. Spectrum has become scarcer with the rapid growth in demand for mobile data and the uses for mobile services have grown since the time of the study particularly with the take-up of smartphones.

4.92 There are a number of ways in which consumers can be harmed due to spectrum scarcity. In the consultation of the future use of the 700 MHz band, Ofcom has considered two mechanisms through which an increase in spectrum could reduce consumer prices: (1) a reduction on marginal costs of providing services (noting that changes in marginal costs can be expected to lead to changes in customer prices) and (2) an easing of network capacity constraints.[46]

4.93 In addition to these direct effects, less spectrum available can distort competition in the market potentially leading to even higher consumer prices. Consumers can also be harmed due to a loss in network quality.

4.94 In this section, we discuss the potential magnitude of effects on consumers of setting aside 100 MHz of 3.5 GHz spectrum. We illustrate the potential size of these effects with respect to the UK market given the availability of data for the UK. We also provide an indicative way of extrapolating the results to other markets.

Capacity constraints affecting consumer prices through scarcity pricing

4.95 The 3.5 GHz band together with the introduction of 5G are expected to ease the pressure on network capacity for some years. However, the rate at which data consumption grows has been and is expected to continue to be very steep. According to Ofcom, over the period from 2011 to the second quarter of 2018, the average yearly growth of traffic in the UK was around 60%.[47] Cisco forecasts an average 39% compound annual growth in traffic in the UK until 2022.[48] At this growth rate, the pressure on network capacity is likely to reappear soon.

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45 *See* T. W. Hazlett and R. E. Muñoz. 2009. "*A welfare analysis of spectrum allocation policies*", RAND Journal of Economics, Vol. 40, No. 3, pp. 424–454.

46 *See* Ofcom. May 2014. "*Consultation of the future use of the 700 MHz band*".

47 *See* paragraph A.7.4 of Annex 7 to the Consultation of the Award of the 700 MHz and 3.6-3.8 GHz spectrum bands.

48 *See* "*Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2017-2022 White Paper*".

4.96 In the face of capacity constraints, operators may increase prices to adapt traffic to the levels that the network can tolerate, rather than allow network quality to deteriorate substantially. For example, in 2016 Three UK substantially increased the price for unlimited data plans (i.e. from £17 to £30; or, equivalently, from €22 to €39 at the exchange rate of the date of the announcement) in response to growing data usage by customers.[49] Whether operators respond to capacity constraints by setting prices higher than otherwise and/or reducing quality will depend on the impact on profits of each approach taking into account the pricing and quality of rivals. We also consider the impact of quality degradation later in this section.

4.97 We illustrate the effect that prices being higher than otherwise can have on consumers by reference to a simple model.

4.98 Our model builds on the fact that making available 300 MHz for mobile services instead of 400 MHz of 3.5 GHz spectrum is likely to create two effects (see Box 4):

a. Capacity constraints will appear earlier on, and lead to prices being higher than otherwise.

b. At some point even if all 400 MHz of spectrum is released, networks will reach capacity. However, releasing 100 MHz less will create greater pressure on network capacity. The required increase in prices to manage traffic will be lower with 400 MHz available than with 300 MHz available.

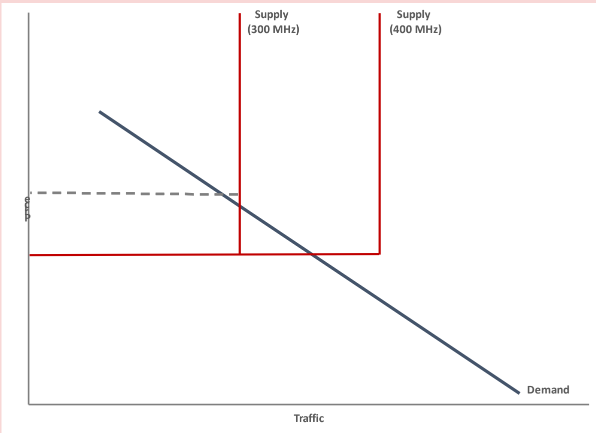
4.99 We quantify consumer losses arising from the extent to which prices would need to be raised if 100 MHz of spectrum are withheld from the auction.

4.100 We set-out the assumptions of our modelling exercise below.

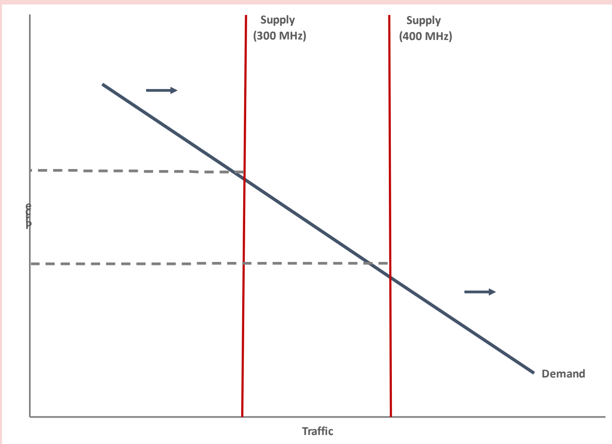
49 *See* https://www.bbc.co.uk/news/technology-35441452.

Box 4: Capacity Constraints and Price Dynamics

In the figure below, the red lines represent the supply curve with 300 MHz and 400 MHz of 3.5 GHz respectively, and the blue line is the demand curve at a given moment of time. In the horizontal portion of the supply curve, operators can meet increases in traffic demand using the available spectrum without needing to increase prices. Once traffic reaches a critical utilisation threshold, networks are no longer able to meet traffic needs, and must increase prices to be able to ration capacity (the supply curve becomes vertical). The following figure illustrates a situation where networks are capacity constrained with 300 MHz but would be able to handle traffic if 400 MHz were made available to MNOs.



As time progresses, users demand for mobile data increases at each price point leading to the demand curve for mobile broadband to shift upward and to the right. At some point in time capacity constraints will bind both with 300 MHz and 400Mhz of 3.5 GHz spectrum available and prices would need to increase in both scenarios. Nevertheless, the prices would higher when only 300 MHz is made available.



4.101 **Demand.** We use GSMA intelligence traffic data for 2018 and assume that traffic will grow by 57% in 2019, and then traffic growth will reduce gradually to a rate of 13% by 2031.[50] The conclusions of our analysis are not materially altered if we use alternative forecasts such as CISCO's Mobility Report for the UK.

4.102 We assume a price demand elasticity parameter for mobile broadband of -1.42 based on a recent study by Grzybowski et al. (2014). Based on our literature review, we think this is a conservative assumption for our illustrative exercise.[51]

4.103 **Network capacity.[52]** Total network capacity can be modelled according to the following formula:

$$Capacity = Spectrum \times Spectral\ Efficiency \times Cell\ sectors$$

4.104 We populate this formula by considering operators spectrum holdings as of 2019, and the incremental capacity to be added to the average network both with 300 MHz and 400 MHz of 3.5 GHz available for mobile services. We rely on Ofcom's Mobile Termination Rates model's assumptions on the total number of cells sectors, and we further assume that 3.5 GHz spectrum will only be deployed in urban/suburban areas. We use a spectral efficiency factor that varies across bands and technologies (4G and 5G).[53]

4.105 To simplify our exercise, we model the capacity of an "average" network, instead of modelling the expected capacity of each of the four UK networks separately. We assume that networks start facing capacity constraints when the total traffic of the network reaches 50% of available capacity. A recent report by Enders Analysis considers this parameter as the relevant threshold for recommended network utilisation, "*beyond which capacity issues begin to cause very notable degradation in service*".[54] Given that we are looking at the utilisation of the

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50 Forecasts are based on Vodafone's projections.

51 The estimates available on mobile broadband elasticity presents values which are in a wide range. Silva et al. (2013) studied the Portuguese broadband market and concluded that mobile broadband own price elasticity was between -3.45 and -4.14, depending on the model specification. Srinuan et al. (2011) estimated mobile broadband own price elasticity at -0.88 in Sweden. However, Srinuan et al. (2012) estimated the same elasticity between -0.48 and -3.62, with different models. Grzybowski et al. (2014) estimated the price elasticities of demand for Internet access in Slovakia and concluded that mobile Internet own price elasticity was of -1.42 at country-level. We relied on Grzybowski et al. (2014) estimation, since it is the most recent estimation. Additionally, we believe that this is a conservative figure, since the general adoption of mobile broadband is likely to make its demand less elastic over time.

52 Our estimation of network capacity is further explained in Appendix A.

53 For further details, see paragraph A.4b in the Appendix. *See* presentation of New T-Mobile's Network to the FCC dated August 16, 2108, by T-Mobile US in the context of the proposed merger of T-Mobile and Sprint.

54 See Enders Analysis. April 2019. "*5G to Change the Shape of UK Mobile*".

"average" network rather than the most constrained network, in practice we are assuming a higher utilisation threshold, which is likely to result in conservative estimates.[55]

4.106 **Market Data.** We assume an average ARPU of £15 per connection per month, based on GSMA forecast for 2025, and 75 million connections in the UK.[56] We take as a simplifying assumption that subscriber numbers remain constant, and ARPUs would not change except for the effect of capacity constraints on data consumption. This is a highly conservative assumption, as it implies that revenues will not grow from an increased subscriber base.

4.107 **Results.** Our modelling exercise predicts that networks will reach their capacity in 2025 both if all 400 MHz are made available to operators, and if 100 MHz are reserved for local use.[57] Yet, the difference in capacity in each scenario (capacity is about 19% higher with an extra 100 MHz available for mobile services) will translate into a need for operators to further increase prices (or not decrease prices) by an extra 13.1%.[58]

4.108 We estimate that, as a result, consumers will lose around £1.4 billion a year in consumer surplus during the first 5 years of constraints (2025-2029). This is because they would need to pay higher prices for data, and also because they will have to reduce their data consumption. In 2020 net present value terms for a licence ending in 2040 (such as that of Germany), these losses to consumers represents around £12.6 billion.[59] Table 4 summarises our findings.

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55 For example, Enders Analysis considers that in 2018 in the UK, O2 and Three were slightly above that threshold. One could argue that this could be already a situation where prices would face an upward pressure. However, our approach is more conservative and considers the average utilization of all 4 networks, which was below the 50% threshold in 2018.

56 We use 2025 because it is the closest year with GSMA forecast to the moment in time that is relevant to our analysis. See next section.

57 This result is consistent with Enders Analysis forecasts of network utilisation. A recent report by Enders Analysis forecasts that one UK operator may become capacity constrained in 2025, and two other operators would be close to the threshold of recommended utilisation. According to this forecast, and a modest assumption of traffic growth rate, the average utilisation of the networks would exceed the recommended threshold in 2026.

58 Depending on the elasticity of demand, prices might fall anyway, so this can also be interpreted as an inability to decrease prices.

59 Net present value is calculated using UK Treasury Green Book's (real) Social Time Preference Rate of 3.5%.

Table 4: Consumer harm due to higher prices as a result of capacity constraints

	£ million
Average annual losses first 5 years of constraints	1,424
NPV of losses as of 2020	12,601

4.109 We note, however, that our results are highly sensitive to the assumption on the price elasticity of mobile broadband, which is an uncertain parameter in the face of rapidly changing consumer habits. For example, considering an elasticity of -1 (which is within the range of elasticities surveyed) can cause estimated average consumers losses to more than double, reaching £25 billion in present value terms. Consumer losses also increase even with a modest increase in the assumed number of subscribers.

4.110 It is worth noting that not only do consumers lose in this scenario, but also mobile operators. Increasing prices causes customer demand for traffic to fall, which can reduce operators' revenues. In fact, if demand elasticity does not affect the number of users of mobile services but rather the data consumption per user, we could expect ARPUs to be lower with 300 MHz available than with 400 MHz available with elasticities greater than 1.

4.111 Finally, our results can be extrapolated to other countries by multiplying by the ratio of ARPUs and subscribers of each country. This method is equivalent to adjusting demand assumptions as specified in paragraph 4.106. For example, for Germany, GSMA data forecasts an ARPU of €13 per month, and 108 million subscriptions. Based on this market data, consumer losses due to set-asides in Germany are estimated at €1,759 million per year on average during the first five years of constraints or a NPV of losses to 2040 of €15,568 million (these results can be compared to those presented in Table 4).[60]

Capacity constraints affects data incremental costs

4.112 In the previous section, we assumed operators would handle capacity constraints by increasing prices. Instead, operators might resort to alternative ways of expanding capacity to overcome the spectrum shortage.

4.113 We extended our stylised model presented in the previous section to illustrate how consumers could be impacted if operators decide to expand sites and related network capacity to meet data demand.

60 We recognise that this extrapolation has some limitations, as different supply conditions could also affect the extent of expected losses. The amount of spectrum available, the number of operators in the market, and the amount of cell sites in each country, among other things, will also affect the likelihood and severity of capacity constraints. On the other hand, some supply side network aspects are, to some extent endogenous to demand conditions. Overall, we consider that extrapolations may be useful for illustrative purposes, but regulators should consider the specific supply side conditions in each market.

4.114 Operators might seek to offset the impact of having too little spectrum by trying to acquire additional sites (albeit operators may face practical problems in gaining additional sites). For a given number of 5G sites, having 300 MHz of spectrum means more 5G sites would be needed to match the capacity of a network with 400 MHz of spectrum.[61]

4.115 We use Ofcom's Mobile Termination Rates model to estimate the effect that incremental sites have on the long run incremental cost (LRIC) of 4G data. Using this information, we find that increasing the number of sites by 10% would cause the LRIC for 4G data to increase by 2.6% to 4.33%, depending on whether the incremental sites are new builds or upgrades from existing sites.[62]

4.116 We assume that the incremental cost of providing data services will be passed on to consumers by charging a mark-up which is proportional to the incremental cost of provision. Hence, incremental costs will cause prices to increase in a similar proportion. This is a simplification as the precise extent to which costs will be passed on to consumers depends on various factors, including the nature of competition in the market although even with a monopoly there would be substantial cost pass-through. [63]

4.117 In this scenario, increasing the number of sites eases capacity constraints in two different ways. First, it causes capacity to increase (supply expansion) to be able to handle a greater amount of traffic. Second, as operators pass through incremental costs to consumers, they reduce their traffic demand (demand contraction).[64]

4.118 Our illustrative calculations show that consumers' surplus could be reduced by up to £0.8 billion a year on average due to higher incremental costs of providing mobile data services. Such an increase in prices would cause consumers to lose £5 billion to £6.5 billion in net present value (over a period to 2040). These figures can be extrapolated to the German market using the method explained in paragraph 4.111. In this case, the estimated NPV of consumers losses is in the range of €6.2 billion to €8 billion. Again, the estimates would be substantially larger if less conservative demand assumptions were adopted.

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61 For simplicity, this assumes that spectrum is evenly split among operators in both scenarios and that traffic is spread uniformly geographically.

62 This is based on Ofcom's LRIC model showing that site costs account for 26% of the incremental cost of 4G data (i.e. 0.208 pence of 0.8 pence per MB) so that if 10% additional sites are required the incremental cost of 4G data would be 2.6% higher. The 4.33% estimate reflects information from Vodafone on the relative cost of new sites compared with existing sites. Incremental costs are relevant to pricing in long term investment decisions. If the prices were not expected to exceed the incremental cost of associated with an investment, then such investment will not be materialised.

63 Constant proportional markups over cost can be derived from standard competition models with a demand with constant price elasticity parameter.

64 Note that overcoming a capacity shortfall of a given amount of traffic can be resolved by expanding capacity by less than that amount. This is because demand contraction resolves part of the shortfall.

Spectrum availability affects quality of services

4.119 Withholding spectrum can also hurt consumers by degrading network quality.

4.120 The European Commission's Implementing Decision for the 3.4 – 3.8 GHz band recommends that operators be assigned 80 MHz to 100 MHz of contiguous spectrum in mid-band frequencies each to efficiently deploy 5G services with high throughput, high reliability and low latency.[65]

4.121 Less spectrum can result in customers having slower download and upload speeds.

4.122 As networks become congested, operators may opt to tolerate higher than optimal levels of congestion, creating serious restrictions on the ability of users to benefit from bandwidth-intensive applications, like high quality video. This way of managing traffic constraints would reduce the reliability of the services and lead to a significantly worse consumer experience.

4.123 Quality degradation poses risks to the value that consumers can realise from mobile services. In a recent consultation document, Ofcom referred to a survey identifying network reliability as the most important factor of network quality, and data speeds as the third most important factor.[66] A recent study by Brunell University for the UK has also identified speeds as a key parameter determining network quality from the point of view of users.[67]

Spectrum availability distorts competition between operators

4.124 We have discussed the various ways that spectrum scarcity can directly harm consumers. A further source of harm can result where spectrum set-asides lead to some networks reaching capacity constraints earlier than their competitors.

4.125 Where one or more operators come close to their maximum utilisation threshold, competition may become weaker, particularly in segments where customers have a high valuation of quality, with the risk of higher prices. This can arise from a number of effects.

a. Networks close to their utilisation threshold will have less incentive to compete vigorously for new subscribers and may need to raise prices to reduce traffic demand so as to maintain a reasonable quality of service as customers' underlying preference for higher usage rises.

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65 *See* "*Commission Implementing Decision (2019/235) of 24 January 2019 as regards an update of relevant technical conditions applicable to the 3 400-3 800 MHz frequency band*".

66 *See* paragraph 5.34 of the Consultation of the Award of the 700 MHz and 3.6-3.8 GHz spectrum bands, December 2018.

67 *See* Al-Al- Raweshidy et al. 2016. "*Factors Influencing Customer Satisfaction and Switching Intention, a study of the UK mobile telecom market*".

b. Networks close to capacity will also be less likely to effectively constrain other operators because they are not able to accommodate customers switching to them should rivals' raise their prices.

c. Should some networks be unable to match the quality or data allowances of others, they will become increasingly marginalised. As they lose scale relative to other operators, they can face higher average costs and potentially become loss-making. In the extreme, one or more operators may cease to be credible competitors and be at risk of leaving the market.

4.126 Features of 5G technology make these issues particularly relevant. There are clear benefits for national operators of having contiguous channels of mid frequency spectrum of 80-100 MHz each. This is because the network equipment requirements do not materially change with narrower bandwidths, i.e. the cost of deploying 100 MHz is not significantly higher than the cost of deploying 40 MHz, for example. Thus, there are economies of scale from having large contiguous blocks. Operators which fail to secure channels of that width will be disadvantaged. In other words, by withholdings spectrum, some operators may not be able to acquire the amount of spectrum that would enable an efficient use of spectrum and affect their ability to compete.

4.127 Releasing additional spectrum would reduce this risk. In the absence of externalities – or when regulators take measures to prevent them - firms with a higher need for spectrum are likely to be those with the highest willingness-to-pay for additional spectrum. Hence, making more spectrum available is likely to address the problems faced by operators with the greatest need for additional spectrum.

Potential costs to society associated with the development of new services and wider economic effects

4.128 In the previous section, we set out the direct effects that can be expected to result from setting aside spectrum for some uses rather than the spectrum being assigned via a general auction. These effects include higher prices for 5G services (resulting from operators rationing limited available capacity and from higher costs due to the need for more sites) as well as lower quality of service. We also noted how high spectrum licence fees can reduce the level of investment in deploying new technologies potentially limiting the extent of 5G coverage. In this sub-section, we investigate the risks of wider economic harm from spectrum set-asides. We do this by first reviewing estimates of 5G's potential and then considering the extent to which spectrum set-asides could prevent this potential from being realised. We show that the expected benefits of 5G are widespread both in terms of having many general applications as well as specific applications in sectors across the economy. If spectrum is instead licensed in a way that results in the spectrum being used disproportionately for a specific industry use, it would reduce the extent to which the majority of the benefits of 5G are able to be realised.

Estimates of the potential economic benefits of 5G

4.129 A number of studies have sought to estimate the economic potential of 5G. Fundamentally, these arise from the ability of 5G to deliver much faster speeds, increased capacity, lower latency, reduced energy consumption and to offer specialised quality of service. The

Radiocommunication Sector of the International Telecommunications Union (ITU-R), an agency of the United Nations, has defined the following three groups of 5G applications:

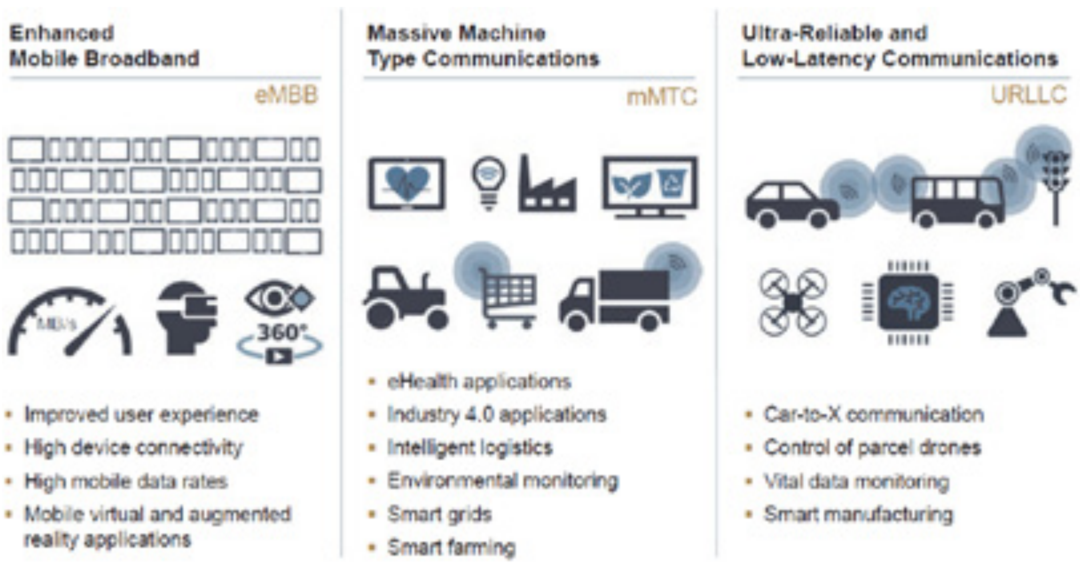
a. **Enhanced mobile broadband** – the spectral efficiency of 5G technology together with the allocation of sufficient spectrum to general 5G mobile services will be able to deliver high data rates (potentially up to 20 Gbit/s) and increased capacity and quality. This would enable higher quality mobile broadband which can support services such as high definition video, virtual and augmented reality applications as well as provide for a greater competitive constraint on fixed broadband;

b. **Massive machine type communications** – the connection of a very large number of devices (potentially 1 million per square kilometre) so as to realise large-scale Internet of Things deployments across sectors supported by scalable connectivity and the use of network slicing to provide customer-specific quality of service; and

c. **Ultra-reliable low latency communication** - 5G is also expected to support a host of new applications where safety, security and low latency are critical.

4.130 Figure 3 illustrates how these three main application groups can lead to a diverse range of services and uses. While some services, such as mobile broadband, will be used by consumers and in businesses across the economy, other applications will be specific to particular industries such as health, farming and transport. As with other major technological advances, there may also be innovative new uses that deliver substantial benefits which are not known or predicted at this stage.

Figure 3: Three main application groups for 5G



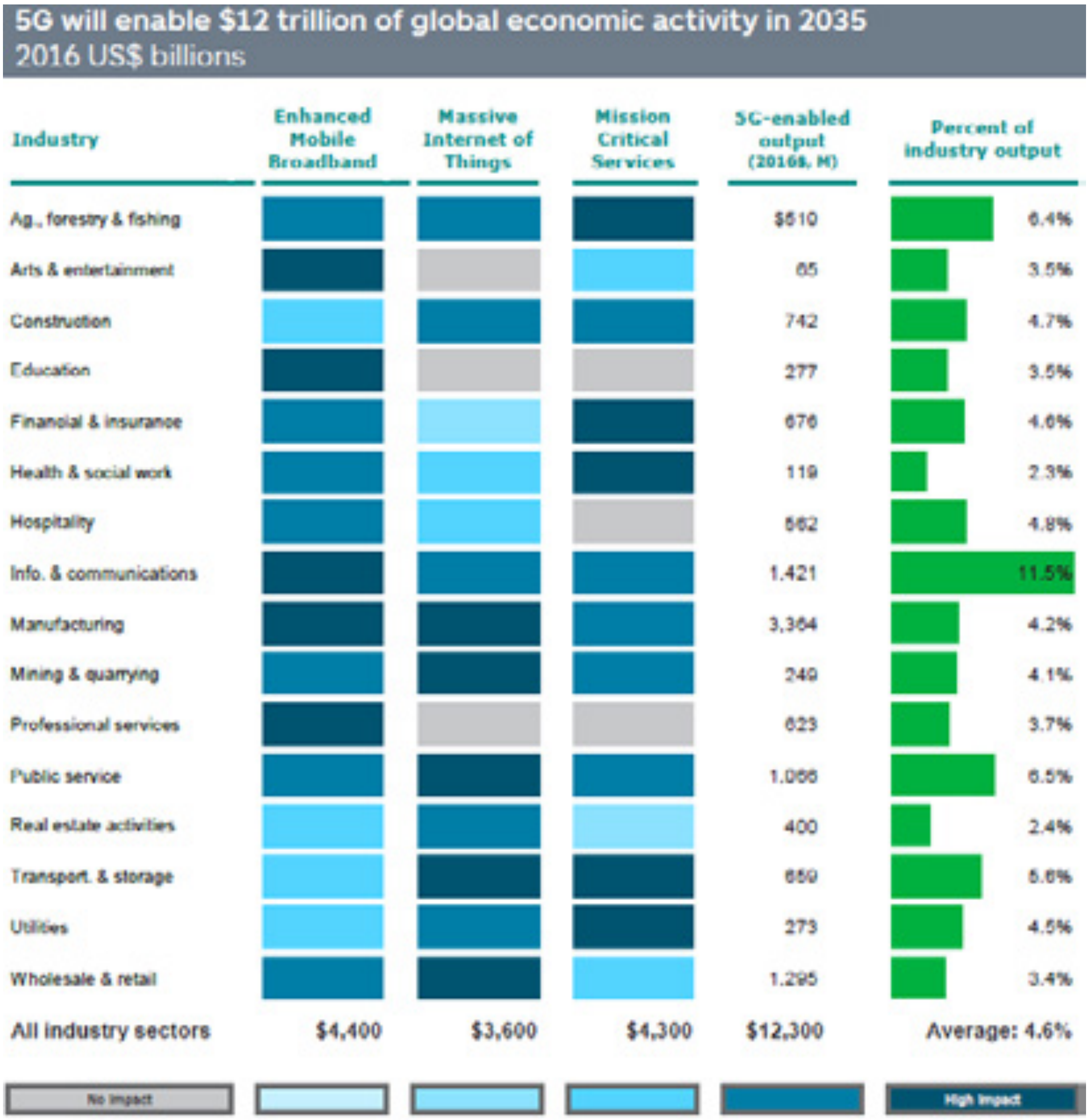
Source: German Federal Government, 5G Strategy for Germany, p.5.

4.131 IHS Markit undertook a study to estimate the potential economic benefits of 5G by studying the three main groups of applications for 5G.[68] With respect to enhanced mobile broadband, they estimated the impact of 5G on the basis of the extension of mobile coverage into a broader range of structures (including office buildings, industrial parks and shopping centres) as well as improved capacity. Benefits from massive machine type communications were expected to depend on improved low-power requirements, the ability to operate across a range of licensed and unlicensed spectrum and improved coverage. The benefits of ultra-reliable and low latency communications will depend on the capacity being made available and the extent of 5G deployment. Figure 4 shows the study estimates of the global value of 5G services reaching $12.3 trillion by 2035, equivalent to around 4.6% of all global output. Assuming a value proportional to the GDP, the value of 5G services would be €153 billion for a country with Germany's GDP in 2018.[69] These results show that 5G is expected to bring benefits across the economy, albeit with the amount of benefits and the significance of particular applications varying between industries. No one industry accounted for more than 28% of the economy-wide benefits. The study also estimated that the net contribution to global GDP of 5G would be to increase the growth rate by 7%, i.e. from an annual average of 2.7% to 2.9%.

68 *See* IHS. 2017. "*The 5G economy: how technology will contribute to the global economy*".

69 Eurostat reports Germany's GDP of €3,344 billion euros in 2018.

Figure 4: Forecast global economic impact of 5G by industry



Source: IHS, The 5G economy: how technology will contribute to the global economy, 2017.

4.132 A study for the European Commission focused on the use of 5G in four sectors of the economy: automotive, healthcare, transport and utilities.[70] The study estimates that 5G would deliver benefits in these sectors of €62.5 billion per annum in 2025 and total economy-wide benefits from its use in these sectors of €113.1 billion. This suggests that the total economy-wide benefits of 5G may be 1.8 times the direct value of 5G.

4.133 Where spectrum is assigned in way that effectively reserves spectrum for one sector, it deprives other sectors of the use of that spectrum. The IHS Markit and European Commission

70 *See* Tech4i2 et al. 2016. "*Identification and quantification of key socio-economic data to support strategic planning for the introduction of 5G in Europe*".

studies show that 5G is expected to deliver value across multiple sectors. A restrictive licensing approach may prevent this full value of 5G from being realised.

4.134 The study also estimated the spectrum requirements for these sectors and noted that "*the multi gigabit connectivity environment such as the motorway use case, there is not enough spectrum available in any of the ranges for service providers to hold dedicated spectrum and meet the needs of users*."[71]

How would spectrum set-asides impact realisation of the wider economic benefits of 5G?

4.135 In the section 4.3, we estimated the direct impact if one quarter less spectrum was to be made available for 5G services. We found that this would lead to higher prices, less capacity, lower quality and less network investment. We now explore how these effects would act to limit the realisation of the wider economic benefits of 5G.

4.136 The major benefit of 5G in the short-to-medium term is expected to arise from enhanced mobile broadband. Mobile broadband is used by both consumers and businesses. Demand for mobile broadband is highly price elastic. The study by Grzybowski referenced earlier found a price elasticity of demand for mobile broadband of -1.42. With less capacity available, mobile operators could also be expected to be less likely to offer unlimited or large data allowances except at higher price points than would otherwise be the case. These effects could deter customers from making use of bandwidth-intensive applications such as high definition video or augmented reality applications. If less network investment leads to less 5G coverage then some customers might not have access to the specific benefits of 5G at all.

4.137 Limits to the quality of mobile broadband would, in turn, reduce its potential to develop as a competitive constraint on fibre broadband services. In particular, customers will only regard mobile broadband as a close substitute to fixed broadband where its speed and reliability is available at a similar quality-adjusted price (including with respect to data allowances). The potential benefits of infrastructure competition between different technologies are substantial, not only in terms of delivering lower prices but in creating competitive pressure for operators to continue to deploy technological advancements over time. A number of studies have found that inter-platform competition (i.e. between different technologies) has been the major driver of broadband penetration.[72] For similar reasons, inter-platform competition can be expected to drive consumer benefits and take-up of ultra-fast broadband.

4.138 The impact of spectrum set-asides on industry uses is harder to predict because applications are at an earlier stage of development. Less coverage and higher prices would be expected to limit take-up with the extent of the impact of higher prices depending on the expected benefits of each use. Limited quality may mean that some applications are not able to be offered at all. These risks could be greater for applications with large bandwidth requirements).

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71 Ibid, p.12-13.

72 For example, *see* J. Bouckaert. 2010. "*Access regulation, competition, and broadband penetration: an international study"*.

For example, the study for the European Commission estimated that 56.1 GHz of spectrum could be needed just to support vehicles travelling on motorways.[73] Figure 5 identifies the bandwidth requirements of various 5G applications.

Figure 5: Bandwidth and latency requirements of potential 5G use cases

Applications	Communication Range	Bandwidth Capacity	Latency	Link Reliability	Energy	Security Privacy
Smart buildings	short range	10 - 1000 Mbps	Median	Median	Low	High
Smart devices	short range	10 - 1000 Mbps	Median	Median	Low	High
Smart farming	long range	1 - 100 Mbps	Tolerant	Median	Low	Median
Urban monitoring	long range	1 - 100 Mbps	Tolerant	Median	Low	Median
Autonomous driving	long range	10 - 5000 Mbps	Critical	High	High	Critical
AR/VR services	short range	100 - 5000 Mbps	Critical	Median	High	Median
Smart energy	median range	10 - 1000 Mbps	Median	High	Median	High
Smart mobility	long range	10 - 1000 Mbps	Median	High	Median	Median

Source: A. Ding and M. Janssen, 5G Applications: Requirements, challenges and outlook, December 2014, Table 1.

4.139 While licensing of spectrum to particular industry uses could address the needs of those users, there are two key drawbacks.

4.140 First, where spectrum is acquired by a user in one industry, it would not be available for use in other industries. However, the IHS study discussed above shows that 5G is expected to have applications in industries across the economy. A licensing approach which results in the benefits of 5G only being realised (or fully realised) in one industry, would reduce the extent to which the majority of the economy-wide benefits of 5G are able to be realised. Even manufacturing where 5G is expected to have a greater impact than in other sectors, only accounts for 27% of the economy-wide benefits of 5G estimated by IHS. A general auction and flexible licensing approach would be expected to lead to spectrum being used where it generates the greatest value to society which is likely to be in a range of general and industry uses (e.g. manufacturing as well as other industry uses).

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73 *See* Tech4i2 et al. 2016. "*Identification and quantification of key socio-economic data to support strategic planning for the introduction of 5G in Europe",* p.93.

4.141 Where setting aside spectrum leads to spectrum instead being used for a lower value use then society would receive lower benefit from the spectrum.[74] By way of illustration, if spectrum set-asides led to spectrum not being available for the five industries with the smallest amount of 5G-enabled output estimated in the IHS Markit study then that would lead to a loss in value of global output of $1.1 trillion or 9% of estimated total global 5G output.[75] The net loss to society would then be the difference between this loss and the value generated by that spectrum instead being used for a lower value use. If we assume that the spectrum is set aside for a use that is only half the value of the use of the spectrum in these five industries[76] then potentially $553 billion or 4.5% of the estimated total global 5G output would be lost. At best, spectrum might be set aside for the highest value use (leading to no loss compared with an auction). However, set-asides risk spectrum being reserved for a much lower value use leading to a substantial loss to society as illustrated in this example.

4.142 Second, where set-aside spectrum is acquired by a particular industry user, there is a risk of undermining competition between that user and its competitors. In particular, other competitors may be reliant on services supplied by mobile operators. If operators are required to pay a higher price for the spectrum than the particular industry user, this could lead to higher prices for mobile operator-supplied services disadvantaging their customers.

4.143 In short, we believe that there are substantial risks to the realisation of the economy-wide benefits of 5G through spectrum set-asides. The risks would be greatest in relation to general uses that require significant bandwidth as well as to specific industry uses which are deprived of spectrum because of its reservation for other uses. While it difficult to estimate the potential losses from spectrum set-asides, given the expected large value of 5G to the economy (potentially over €150 billion per year for an economy the size of Germany's as derived earlier) even a failure to realise 5% of this potential would represent a significant loss to society (i.e. a 5% loss of 5G's potential would translate to a loss of around €7.6 billion per year for an economy the size of Germany's).

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74 Spectrum set-asides could still result in spectrum being used in the highest value use but this would depend on the authority being able to identify the highest value use rather than for this to be determined in an auction. Further, if this is the case then there would be no reason to reserve spectrum instead allocating it all by auction.

75 In practice, where some spectrum is reserved for a particular use, it is likely to lead to spectrum not being available for the most marginal uses. For the purposes of illustration, we have use the value of spectrum to the industries expecting to obtain the smallest value from 5G services. However, in practice, the marginal uses of spectrum may be spread across industries.

76 If spectrum is reserved for a use with a greater value than these commercial uses of spectrum then there would be no need for spectrum set-asides as an auction should instead lead to it being used for that purpose.

4.4. Overall assessment of spectrum set-asides

4.144 We have analysed potential costs and benefits associated with setting aside spectrum for local use.

4.145 In analysing benefits, we have reviewed potential reasons that could justify departing from a market-based solution to allocate all 3.5 GHz spectrum available. The following table summarises potential benefits.

Table 5: Potential market failures and the assessment of the likely benefits from addressing them for 5G services

Reason to reserve spectrum		Assessment of benefits in relation to reserving spectrum for 5G services to address market failure
Reasons unrelated with market failures in the auction (coverage, access, etc.)		Absent a market failure, reserving spectrum can at best match the value created by an auction. However, spectrum set-asides would carry a large risk of leading to spectrum being used sub-optimally generating a lower value than its opportunity cost.
Market failures	Externalities	No general benefits identified.
Market failures	Downstream competition	No general benefits identified in competitive mobile markets, although regulators should consider the particular circumstances of each market.
Market failures	Coordination	Limited benefits at most in competitive mobile markets, as similar benefits can be achieved with available technical alternatives (like network slicing), market solutions (*e.g.*, demand aggregators) or alternative options where these are available (such as subleasing).

4.146 In sum, we did not identify any market failure as being generally relevant in most mobile markets although there may be justifications for setting aside some spectrum in some markets (although the precise amount to be reserved should also be carefully assessed given its high opportunity cost). Other reasons to reserve spectrum are unlikely to involve any general benefit to society. Where there are no market failures, auctions are likely to lead to spectrum being allocated to its highest social value use, and thus reserving spectrum can, at best, achieve the same allocation although with a high risk of leading to an allocation that leads to lower benefits to society.

4.147 The costs of set-asides, on the other hand, are expected to be high, where the reserved amount of spectrum is as large as 100 MHz. Table 5 summarises our assessment of the expected direct costs including the opportunity cost. Specific consumer harms may arise in different ways, such as increased prices or degraded network quality. The extent to which one or other scenario (or a combination of scenarios) is relevant will depend on the particular circumstances of each market, but each scenario is associated with significant costs.

4.148 Costs to bidders in Table 6 are not directly additive with cost to consumers, as part of the consumer harm may be absorbed by bidders in the form of higher prices.[77] We have estimated different categories of costs drawing on available data from different markets. In order to show comparable figures, we provide figures based on the UK auction adapted to German market conditions, to normalize the results for a market the size of Germany's.

Table 6: Summary of Direct Costs

Direct cost		**Assessment of Costs (non-additive)**
Direct opportunity cost		A loss in value of €1 billion to €1.46 billion based on German auction data.
Consumer harm	Scenario 1: Scarcity pricing	NPV of losses of £12.6 billion as of 2020 based on UK data, which would be much higher with a lower assumed elasticity of demand. Extrapolating these figures to the German market results in an NPV of losses of €15.6 billion.
Consumer harm	Scenario 2: Incremental network costs	NPV of costs in the range of £5 billion to £6.5 billion based on UK data. Extrapolating these figures to the German market results in an NPV of costs of €6.2 billion to €8 billion. These estimates would also increase with a lower assumed elasticity of demand.
Consumer harm	Scenario 3: Network quality degradation	Risk of quality degradation when networks reach congestion (expected in 2025). Speeds and network reliability would be adversely affected.
Consumer harm	Competition effects	Risk of a material adverse effect on consumers starting before all networks reach their maximum recommended level of utilisation due to decreased competition.
Bidders and Consumers	Increased auction prices	Auction prices are likely to increase substantially (we estimated €2.2 billion based on the German 5G auction). Higher spectrum prices risks lower investments in mobile services to the detriment of consumers.

4.149 We have also identified relevant risks of wider economic effects associated with spectrum set-asides. Table 7 summarises these risks.

77 For scenario 1 (scarcity pricing) we can compute the total harm. We estimate that adding both components results in total cost of approximately €16.5 -17 billion.

Table 7: Potential Risk of Wider Economic Effects

Application type	IHS estimated potential global value of 5G services in 2035	Risks to realisation of the value from spectrum set-asides
Enhanced mobile broadband	US$4.4 trillion (€4.2 trillion)	Higher prices and limited capacity would limit use and reduce quality of service particularly for bandwidth-intensive applications and inhibit mobile broadband developing as a competitive constraint to fibre broadband. Less extensive roll-out of 5G equipment would limit availability.
Massive machine type communications	US$3.6 trillion (€3.4 trillion)	Limited capacity would impact bandwidth-intensive applications and less extensive roll-out would limit availability.
Ultra-reliable low latency communication	US$4.3 trillion (€4.1 trillion)	Such communication could be particularly at risk from limited capacity. Less extensive roll-out would also restrict availability.

Note: The original values in US$ were converted to euros at the exchange rate of December 30, 2016.

4.150 Given the significant costs to society and the expected limited benefits, there is not a general case for reserving spectrum for particular uses. However, we do not exclude that there might be a case for reserving some spectrum in some markets on the basis of market failures given the specific market circumstances.

4.5. Evaluation of alternative policy options

4.151 As discussed throughout this report, there are a number of potential alternatives that would allow local users to meet their connectivity requirements if 3.5 GHz spectrum is not reserved for local use.

4.152 Before considering various policy intervention, authorities should first consider the extent to which the market can be expected to deliver technical solutions to meet the needs of particular users. As discussed in paragraph 4.42, a range of technical solutions exist including customised supply by mobile operators, leased or shared spectrum, managed spectrum and licensed exempt spectrum. These solutions could potentially meet the needs of industry without carrying the cost of setting aside a large amount of spectrum for the exclusive use of one enterprise or industry.

a. National operators are likely to be able to provide viable solutions to local users through their networks. This could include managed services and **network slicing**. Network slicing enables a common network infrastructure to be used to provide for multiple virtually independent business operations in which service quality is customised to each business customer or specialised industry including in relation to data speeds, quality, latency, reliability, security and the services offered. Where regulatory authorities consider that there are regulatory impediments for the implementation of network slicing, consideration should be given to whether those impediments should be retained.

b. Spectrum **sub-leasing** can play an important role in meeting the needs of local users.

   i. A significant portion of verticals users are likely to be located in non-urban areas where mobile operators may not have a high use value of mid to high frequency spectrum. In this context, operators could benefit by leasing their spectrum, and local demand for spectrum is likely to be supplied on a commercial basis. Regulators should ensure that there are not unnecessary barriers to leasing.

   ii. Sub-leasing can also facilitate the emergence of firms aggregating demands for local spectrum needs.

c. **Licence exempt spectrum** may be a viable solution for many applications. Licence exempt frequencies are subject to a higher risk of interference, and it is unlikely that these frequencies will be an alternative that suits all local needs. However, there are concrete examples of successful use cases based on licence exempt spectrum, and its role cannot be ignored. Problems with licence exempt spectrum are less likely to arise in remote or non-urban areas, where industries might be located. In evaluating the need for alternative policies for local use, regulators should consider the extent of licence exempt spectrum available.

4.153 Policy changes may be needed to enable some of these solutions to be implemented. For example, sub-leasing might require changes to rules governing spectrum use in some countries. The bands and amount of spectrum made available for licence exempt use will continue to be an important policy decision which requires authorities to weigh the costs and benefits of alternative uses.

4.154 Authorities can also consider **licensing spectrum in other bands for industry use:** The 3.5 GHz band has a huge value for mobile use, as it has the potential to provide a large amount of contiguous spectrum, and efforts are being made to make it a globally harmonised band, with benefits in terms of handset costs, roaming, among others. Other bands, however, may be less critical for mobile operators (and thus less likely to cause adverse effect on mobile users) and yet be able to meet local users' needs.

4.155 Ofcom's recent proposals to make available 3.8-4.2 GHz, the 1800 MHz DECT guard band and 10 MHz of 2.3 GHz spectrum available for local use are an example of a potential alternative.[78] Other options include alternative spectrum bands such as higher frequency spectrum that can provide large capacity in local areas. There is likely to be sufficient higher frequency available to support some unlicensed spectrum as well as the licensing of mmWave spectrum for mobile broadband (IMT).

4.156 Ofcom's recent proposal to allow **local access to mobile operators' spectrum if there are no plans to use it within the next three years** provide an alternative to sub-leasing where

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78 *See* Ofcom. 2019 "*Enabling wireless innovation through local licensing*", Section 3.

the regulator keeps greater control of the process.[79] Ofcom's proposals involve issuing local access licences for a default period of three years (longer or shorter periods may be considered) at a fixed price. Operators are given the opportunity to raise a reasonable objection to issuing the licence, based on the extent to which granting such licence could impact their deployment plans. Ofcom believes that this proposal can achieve the same benefits that sub-leasing can achieve.[80]

1.1 The alternatives set-out above provide solutions for local users and entail a much lower risk of regulatory failure than setting aside 3.5GHz spectrum for mobile use.

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79 See Ofcom. 2019. "*Enabling wireless innovation through local licensing*", Section 4.

80 See Ofcom. 2019. "*Enabling wireless innovation through local licensing"*, para 4.14.

Section 5

Conclusions

5.1 This report sets out a framework to assist authorities in deciding whether licensing spectrum for 5G warrants departing from a general auction.

5.2 We propose a three-step approach for authorities:

a. Is there a market failure to justify considering departing from a general auction?

b. What are the costs and benefits of setting aside spectrum?

c. How do these costs and benefits compare with those of alternative options?

5.3 We did not identify any generally applicable market failure for departing from a general auction. However, in particular circumstances, coordination problems, positive externalities and downstream competition problems could create a justification for considering spectrum set-asides. We have also reviewed and dismissed the relevance of other arguments for reserving spectrum which are not associated with market failures. If no market failure prevents an auction from allocating spectrum to the highest value use for society there would be no benefit of setting aside spectrum for specific uses compared with auctioning the spectrum.

5.4 The benefit of spectrum set-asides thus depends on whether it would lead to spectrum being assigned to a higher value use than an auction. The benefit should also be evaluated taking into account the potential for technical solutions to meet the demand for spectrum in particular uses including network slicing, the use of alternative spectrum and sub-licensing.

5.5 Spectrum set-asides carry the potential to cause substantial harm to consumers and efficiency, particularly in the absence of a market failure. This harm includes depriving spectrum from higher value uses as well as limiting capacity for general services requiring higher consumer prices and/or leading to lower quality services. High spectrum prices created by making less spectrum available may also lead to lower network investment. Higher prices, less capacity and lower quality would also limit the wider economic benefits of 5G from being realised.

5.6 In assessing the case for spectrum set-asides, authorities should also consider potential alternatives that would allow local users to meet their connectivity requirements, with minimum costs to society as compared with the costs of spectrum set-asides.

Appendix A

Calculation of capacity and utilization

Capacity

A.1 The starting point of the capacity calculation is the formula to calculate the downlink capacity in any geographical area.

$$Capacity = Spectrum * Spectral\ Efficiency * Sectors$$

A.2 Where *Capacity* is measured in megabits per second (mbps), *Spectrum* is the amount of spectrum holdings employed on the network in MHz, *Spectral Efficiency* is measured in bits per second per Hz (bps/Hz). *Sectors* is the number of sectors deployed on the cell site network in the area of interest. We assume average values for *Spectral Efficiency* and *Spectrum* across all operators and their cell sectors. Thus, our calculations estimate the capacity of the average network given an average operator's spectrum holding.

A.3 For the purpose of these calculations we assume that downlink represents 80% of the total data traffic.[81]

A.4 We have made the following parameter assumptions in calculating capacity.

a. For *Spectrum* we use the average spectrum holdings of operators in the 800MHz, 900MHz, 1800MHz, 2300MHz and 2600MHz bands in the United Kingdom, published by Ofcom.[82] Furthermore, we only consider spectrum used for downlink, so FDD spectrum will count with a factor of 0.5 and TDD spectrum will count with a factor of 0.8. We assume two cases of spectrum holdings in the 3.6GHz bands. Overall, the assumptions in detail are:

i. Spectrum scenarios for 5G:

81 International Telecommunication Union, IMT traffic estimates for the years 2020 to 2030, 2015.

82 See Ofcom. 2019. "*Mobile and Wireless Broadband below 5GH*"and Ofcom. 2017. "*Award of the 2.3 and 3.4 GHz spectrum bands*".

– Our assumptions mimic the BNetzA's decision, to only attribute 300MHz among four MNOs versus 400MHz in the counterfactual. This results in an average holding of 75MHz (with 300MHz in total), and of 100MHz (with 400MHz in total).

– We also assume that 5G will not be deployed using 3.5 GHz in rural areas.

ii. For 4G we assume the following spectrum usage:

– Only 800MHz and 1800MHz is available for use in 2018. We assume all other bands become available from 2019. We exclude the 1400MHz band from 4G usage.

– In rural areas, we assume only 800MHz and 900MHz to be used in all years.

b. For *Spectral Efficiency*, we use the following assumptions: For 4G 2.1 bps/Hz for low bands and 2.5 for mid bands. For 5G 2.5 bps/Hz for low bands and 3.8 for mid bands.[83] We assume bands below 1GHz to be low bands and all other bands considered as mid bands.

c. For *Sectors*, we use estimates of Ofcom in the framework of its LRIC cost model for the calculation of mobile call termination rates. According to the model around 28,000 are in urban areas and close to 6,000 in rural areas. We assume the number of sectors in 2020/21 for all time periods.[84]

A.5 This results in the theoretical national urban capacity in mbps being based on the following periods:

a. In 2018, only 4G capacity, with limited spectrum availability.

b. From 2019 on, 4G capacity with extra spectrum bands becoming available.

c. 5G capacity becoming available from 2021.

A.6 The capacity in mbps for rural areas is:

a. For all time periods the capacity of 4G with 800MHz and 900MHz spectrum.

A.7 The total capacity is the sum of urban capacity and rural capacity. We multiply the results in mpbs with the seconds per year, which leads to megabits per year, which are then converted to megabyte and to petabyte. We use the two capacity cases (see A.4a.i): one where there are 300MHz of the 3.6GHz band available and the other case where 400MHz are available.

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83 *See* presentation of New T-Mobile's Network to the FCC dated August 16, 2108, by T-Mobile US in the context of the proposed merger of T-Mobile and Sprint.

84 *See* Ofcom. 2018. "*Mobile call termination rate cost model*".

Traffic

A.8 Traffic is based on Cisco data on the UK telecoms market.[85] The total data traffic in the UK stood at 152 petabyte per month in 2017, this figure is annualised and then assumed to grow at a rate of 38% (Ericsson, Cisco) until 2018.[86] We then assume data growth rates as supplied by Vodafone. Additionally, we multiply the traffic with 0.8 to estimate annual downlink traffic.

Table 8: Assumed rate of growth in total mobile data volumes

Year	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Growth rate	57%	54%	48%	41%	39%	37%	35%	26%	21%	17%	15%	13%

Source: Vodafone.

Utilisation

A.9 To calculate the *Utilisation rate*, *data traffic* is compared with the *capacity* in every individual year:

$$Utilisation\ rate = \frac{data\ traffic}{capacity},$$

where *data traffic* is calculated as in A.8, *capacity* as calculated in A.5. We separately identify utilisation for the 300MHz and for the 400MHz case (see paragraph A.4a.i).

85 *See* Cisco. 2017. “*Virtual networking index, Mobile Forecast Highlights Tool – United Kingdom*”.

86 Ibid. and Ericsson, Mobility report, 2017. Cisco estimates a compound annual growth rate 2016 to 2021 of 38% and Ericsson estimates a rate of 37% between 2017 and 2023.

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