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Spectrum access options for vertical network service providers in 5G

Abstract
5G will extend the mobile technology deployment beyond the communications industry, bringing connectivity to the explosively growing number of devices and services. To be able to respond to 5G sectors' different requirements, as well as the spectrum scarcity issue, different spectrum access approaches need to be considered. The aim of this article is to identify substantial properties of spectrum access approaches to assess their suitability to 5G vertical use cases. We have defined five optional spectrum access scenarios for 5G vertical network service providers (VNSPs) in acquiring spectrum access to provide a network service to either end users or other companies. The stakeholders involved in the spectrum awarding process are identified, and their roles and targets are examined. Furthermore, the advantages and drawbacks of each scenario are covered. Following the discussion, we were able to highlight some substantive characteristics in terms of suitability assessment, namely reliability, locality and mobility, mobile network operators (MNOs) involvement, costs and time scale. These characteristics were analysed in terms of each scenario to further the scenario's suitability assessment to VNSPs' purposes.

Key words: 5G communications, spectrum sharing, vertical use cases, radio spectrum access.

1. Introduction
A recent focus of the regulatory bodies, industry and the scientific community relates to finding solutions to a more efficient utilization of the limited spectrum resources. The objective of this trend is to respond to the explosive growth of the use of wireless devices and increased demand for mobile broadband. The current radio spectrum allocation is done by dividing the spectrum among different services. These services are allotted to spectrum bands which are either licensed or unlicensed. Traditionally, spectrum access rights have been granted by defining and awarding dedicated licenses to a spectrum, for example to mobile network operators (MNOs). This ensures security for license holder's network investments for the license period and reliable access to spectrum without harmful interference. However, this has led to rigid spectrum allocations where changing the usage of the spectrum bands between different services is difficult. Following this development, in 2015 the World Radiocommunication Conference (WRC) encountered difficulty identifying International Mobile Telecommunication (IMT) bands bellow 6 GHz. These challenges and trends have motivated a search for spectrum sharing approaches to enable several systems to coexist in the same underutilized spectrum bands.

Many spectrum sharing concepts have been introduced and studied during the past years both within the research community and among regulatory bodies to improve spectrum utilization between the incumbent and additional users (see Kour, Jha, & Jain, 2018). The Federal Communications Commission (FCC) has introduced the Citizens Broadband Radio Service (CBRS) concept in the U.S. (FCC, 2016), while in Europe the Licensed Shared Access (LSA) (ECC, 2014) concept has raised interest. Furthermore, promising trials with both approaches have been carried out and reported in Palola et al. (2014, 2017). Unfortunately, LSA and CBRS for PAL users require a license petition from the national regulatory authority, which is time consuming and involves costs. A somewhat lighter approach is to use the license-exempt operations where different wireless systems operate in the same frequency band under rules and conditions defined by the national regulator. Examples of licensed-exempt access include Wi-Fi and the TV white space devices in some countries. The Industrial, Scientific and Medical band (ISM) is one example of an already existing spectrum sharing solution. It is the most widely used technique for spectrum sharing and currently carries the majority of indoor mobile data. The ISM band offers significant benefits for different stakeholders by allowing them to establish local networks and has a great economic impact on the MNOs in terms of traffic off-loading in homes. In addition, other advanced spectrum sharing approaches, such as spectrum trading and leasing, have been considered (Yang, Guizani, Anpalagan, & Elkashlan, 2016). In the former approach, the license owner trades the rights of its underutilized radio spectrum band directly to other service providers or organizations, whereas in the latter approach, the owner of the spectrum leases part of its spectrum while still possessing the rights.

Currently, a small number of large MNOs dominate the cellular mobile communication markets (Cricelli, Cricelli, Grimaldi, Ghiron, 2011). The small number of high-cost spectrum licenses and related obligations for the spectrum bands allocated for mobile broadband services have made the emergence of new players in the same market challenging. However, 5G and small local cells will open up new possibilities to new entrants such as vertical network service providers (VNSPs). We consider a VNSP as a company building a network in order to provide a network service to either end users or other companies that provide a specific service to the end users. This has been envisaged, e.g., for the CBRS concept, where different stakeholders can apply for a priority access license and provide mobile networks and connectivity to their customers.

Concurrently, the emergence of the fifth generation (5G) mobile communication networks will extend the mobile technology deployment beyond the communications industry leading to the heterogeneity of the future vertical use cases exploiting wireless communications (cf. Kliks, Musznicki, Kowalik, & Kryszkiewicz, 2018; Lemstra, 2018; Zikria, Kim, Afzal, Wang, & Rehmani 2018). This opens up new kinds of spectrum requirements and prepares for situations where the demands and needs vary heavily depending on the users' and service providers' expectations. There are differences in the use case characteristics such as communications reliability, delay and throughput requirements, etc. (see 5GPPP, 2016), which affect the implementation of wireless connection. In 5G, spectrum use will increasingly be customized on a case by case basis to fulfil each user's individual and specific requirements. A onesize-fits-all solution is no longer possible; this, per se, requires new ways of thinking in spectrum access and solutions providing low barriers to access the spectrum for new players.

Spectrum sharing for 5G systems has been studied by, for instance Matinmikko-Blue et al. (2018a), Matinmikko-Blue, Latva-Aho, Ahokangas, & Seppänen (2018b), and Perez Guirao, Wilzeck, Schmidt, Septinus, & Thein (2017). In Perez Guirao et al. (2017), the authors studied local networks and especially the LSA concept for different vertical use cases. In their study, LSA is utilized as a spectrum management solution and local licensing, sub-leasing and MNO hosted wireless network with the addition of an LSA license as mechanisms to achieve spectrum usage rights for the vertical use cases. Matinmikko-Blue et al. (2018a) studied the impact factors for shared spectrum valuation for 5G local networks. Whereas, in Kokkinen, Kokkinen, & Yrjölä, (2019) the authors studied three new valuation methods of private LTE and 5G Networks. The spectrum management approaches and CBRS assessment in the case of the industrial internet of things (IIoT) have been studied in Ojanen & Yrjölä. (2019) and Yrjölä & Jette (2019), respectively. The spectrum sharing criteria for LSA, CBRS and TVWS are considered in Mustonen, Matinmikko, Roberson, & Yrjölä (2014a), Mustonen, Matinmikko, Palola, Yrjölä, Paavola, Kivinen, & Engelberg, (2014b), and Mustonen, Matinmikko, Palola, Yrjölä, & Horneman, (2015). A survey on licensed spectrum sharing concepts and scenarios for mobile network operators is provided in Tehrani, Vahid, Triantafyllopoulou, lee, and Moessner (2016). Application of LSA to support critical communications with a distributed LSA database was studied in Höyhtyä et al. (2018). Finally, spectrum sharing, including satellites and airborne platforms, has been considered, e.g. in Ding, Li, Wang, Wang, and Chen (2018).

The aim of this article is to contribute to the discussion on spectrum opportunities for the 5G VNSPs when acquiring spectrum access. This article identifies five spectrum access scenarios covering already commercialized and mature access approaches as well as those still under the standardization process. We propose vertical use cases to the discussed scenarios taking into consideration the requirements and restrictions. As there can be a vast amount of various vertical use cases each having their own needs, we are not attempting to cover them all in detail. The aim is to show ideas and example use cases of each scenario's applicability. We also discuss the pros and cons of each scenario and identify stakeholders' roles in them. Furthermore, we discuss characteristics which can be considered to have a substantial impact on spectrum access scenario assessment to VNSP.

The paper is organized as follows. First, we briefly discuss 5G and cover already existing spectrum sharing schemes. Second, we present the method used in this research to form a collective understanding and broader view on the vertical use cases and spectrum possibilities. Third, the stakeholders related to scenarios are discussed. We introduce the five scenarios for spectrum access, analyse their pros and cons and give examples of use cases for each of them. Fourth, we analyse characteristics of the scenarios. Finally, we conclude the paper in the last section.

2. Key characteristics of 5G

2.1 Vertical applications

The 5G applications are not restricted only to mobile broadband services provided by MNOs. They also cover a number of other service categories and industry fields. Wireless connectivity is required for industry sectors such as manufacturing, transportation, energy, media and entertainment, and health care (5GPPP, 2016), each having its own needs and setting requirements in terms of the data transmission quality and costs. For instance, solutions for short-period spectrum utilization, such as surveillance systems at construction sites or at special events, will require completely different characters from the spectrum band compared to solutions for ultra-reliable and low latency communications (URLLC) in harbour sites or smart grids safety where spectrum access is needed constantly and high QoS certainty is required.

It is envisioned that the single ownership of network infrastructure and frequency spectrum could be potentially decoupled. For example, leveraging the software-defined networking concept, a VNSP can build a programmable small cell network with advanced radio techniques in, e.g., a shopping mall, a stadium, or in a campus area. To generate revenue, an incumbent mobile network operator or other spectrum owners can then dynamically lease a part of the spectrum to the VNSP according to the spatially and temporally varying needs with a pay-per-use model (Kour, Jha, & Jain, 2018). The small-cell network can also belong to an incumbent MNO, which enables several interesting deployment scenarios. For example, a small cell network can easily support multiple VNSPs, which do not own the spectrum or the network infrastructure but pay for the accesses to the network services and serve their subscribers (Liu, Li, Su, Jin, & Zeng, 2013).

2.2 Techniques to enable 5G

The key new enabling techniques in 5G include network slicing and Mobile-Edge computing (MEC). Network slicing in 5G networks enables the creation of a virtual network in order to provide adequate communication resources for different user groups (NGMN Alliance, 2015). A network slice is formed to serve a particular application, or a service, and is set to fulfil service-specific performance, scalability and availability requirements. As such, the same network infrastructure is able to host multiple tenants and VNSPs with diverse quality-of-service and quality-of-experience requirements. The benefits brought by network slicing can be facilitated by a software-defined networking platform (Li, Mao, & Rexford, 2012). At the same time, technical challenges remain in the design of mechanisms that efficiently exploit the decoupling of the control plane from the data plane (Chen Han, Zhang, Xue, Xiao, & Bennis, 2018).

Mobile-edge computing, which provides computing capabilities within the radio access networks in close proximity to mobile users, is envisioned as a promising paradigm to address the tension between resource-constrained mobile devices and computation-intensive applications (Mao, You, Zhang, Huang, & Letaief 2017; Mach, & Becvar, 2017). By offloading computation to a resource-rich mobile-edge computing cloud, the computation qualities of both service and experience can be greatly improved for mobile users (Chen, Zhang, Wu, Mao, Ji, & Bennis, 2019a). In a mobile-edge computing system, offloading the input data of computation tasks involves wireless data transmissions. Under this context, how to allocate the frequency resource among the mobile users, or between the traditional communication and the computation services, has to be carefully designed, which is also a technically challenging problem (Chen, Zhao, Wu, Bennis, Liu, Ji, & Zhang, 2019b).

2.3 5G spectrum

The ITU has in WRC identified a number of spectrum bands for IMT networks over the years. These bands currently used for previous cellular generations will typically be used for 5G overtime as well. For example, WRC-07 identified the 3.4–3.8 GHz band which is now a pioneering 5G band globally (see Matinmikko-Blue et al., 2019). Additionally, new spectrum bands for 5G will be decided upon in WRC-2019. Nevertheless, several national regulatory bodies have already awarded spectrum access rights to deploy 5G networks. In the U.S., the Federal Communication commission has allocated spectrum bands 24.25–24.45, 24.75–25.25 GHz, 27.5–28.35 GHz, 37.6–38.6 GHz, 38.6–40 GHz, and 47.2–48.2 GHz for 5G (FCC, 2019). Correspondingly, the European Commission Radio Spectrum Policy Group has identified three pioneer bands for 5G services in Europe: 700 MHz, 3400–3800 MHz, and 24.25–27.5 GHz (RSPG, 2018). In addition, spectrum bands already allotted to 2G, 3G and/or 4G networks are in the process of being made available also for 5G in many parts of the world in the long run, such as the 900 MHz, 1800 MHz, 2.1 GHz and 2.6 GHz bands in Europe.

3. Existing spectrum sharing concepts

A variety of spectrum sharing approaches exist – we briefly present each of them in order to give the reader an overview of already commercialized sharing models, as well as those still under the standardization process.

3.1 TV white spaces

The bands which are used primarily for TV broadcasting have been studied for spectrum sharing already for over a decade (Kalliovaara, Paavola, Ekman, Kiviniemi, & Talmola, 2016; Mwangoka, Marques, & Rodriguez, 2013; Ojaniemi, Kalliovaara, Alam, Poikonen, & Wichman, 2013; Saeed & Shellhammer, 2017; Stewart, Crawford, & Sterling, 2018;). The studies indicate that there are significantly underutilized frequency bands in which the occupation level can vary either geographically or in time. On the other hand, the TV bands are already utilized on a secondary basis by many devices, such as wireless microphones. TV white spaces technology reuses the TV broadcast spectrum and takes advantage of the fact that broadcast networks are typically configured as high tower, high power. Therefore, the reuse distance of any frequency for the broadcast network is rather long and it is possible to use the same frequency with low power applications in the area, where it cannot be used for broadcasting. The TV white space utilization should protect the higher-priority users from harmful interference while the lower-priority users cannot expect protection against interference. The incumbent TV and other transmissions are protected typically by a database, which the TV white space application contacts before it can start transmissions. Based on the location of the TV white base application, the data base gives maximum transmission power and other possible transmission parameters. In some cases, the TV white space application is also sensing the incumbent, but typically this cannot be used alone. However, the lack of coherent standardization and globally harmonized regulation, as well as the complexity of a geolocation database, impede the utilization of the TV white space approach

(Kalliovaara, 2017). The main interest towards this technology has been in the developing countries in Africa where this approach could provide wireless broadband to remote areas at reasonable costs.

3.2 CBRS concept

The Citizens' Broadband Radio Service (CBRS) (FCC, 2016) is a spectrum sharing concept developed by the FCC for the 3.5 GHz band in the U.S. This concept divides users into three different user types, also known as three tiers. The first-tier users, which comprise the incumbent users, namely military, governmental, and satellite users, enjoy protection against harmful interference and may access the spectrum band whenever required. The second-tier users have to apply for a Priority Access License (PAL) to the spectrum band from the National Regulatory Authority (NRA). The license periods are considered to be 10 years and should be renewable. After the NRA has granted the license to the spectrum, the PAL user can operate on the spectrum channel granted in the license. They are also expected to receive protection against the lower-tier users. The third layer user's operation is quite similar to operation in license-exempt bands, where users share the spectrum under rules and conditions defined by the regulator. These users are referred to as General Authorized Access (GAA) and their operation is not allowed to cause harmful interference to higher-priority users. Nevertheless, they have to be able to tolerate some interference. The operation is restricted in certain geographical areas where incumbent operation is consistent, e.g., on the coastline (naval operation) or next to a satellite ground station. These areas are referred to as exclusion zones. The PAL and GAA base stations register to the Spectrum Access System (SAS) which monitor and coordinate the joint use of the spectrum outside the exclusion zone and grant spectrum access to the PAL and the GAA users according to sent requests. With the aid of the Environmental Spectrum Sensing Capability (ESC) the SAS can retrieve information about the spectrum utilization of the federal radar systems.

3.3 Licensed Shared Access

The Licensed Shared Access (LSA) (ECC, 2014) concept in 2.3 GHz, introduced in Europe, is a fully controlled sharing scheme that enables additional use of spectrum on bands already allocated to incumbent users. In this concept, two additional management units, namely LSA repository and LSA controller, are used to coordinate spectrum licenses, spectrum availability, policies, and permitting access to the spectrum. The main idea is for the national regulatory authorities to grant a finite number of licensees to a spectrum band allocated to an incumbent user (RSPG, 2013). This authorizes the licensed users to operate at the same spectrum band with the incumbent user and with guaranteed Quality of Service (QoS). In some cases, spectrum utilization is highly dependent on time and geographical location. For example, in some countries Program Making and Special Events (PMSE) usage (wireless video cameras) on the 2.3 GHz band is focused mainly on specific locations (for example TV studios). These areas could be excluded from secondary licensing. More occasional usage appears during report making at special events such as sports events and music festivals or in an area where a traffic accident has happened. Cellular networks have been studied as the entrant systems in LSA, but the concept itself is not restricted to mobile communication systems (cf. Palola et al., 2014; Mustonen et al., 2014b; Mustonen et al., 2015).

3.4 License-exempt operations

One of the most successful technologies operating in the license-exempt bands is Wi-Fi (wireless fidelity), which is a communication solution based on the IEEE 802.11 standards and primarily used in indoor environments. MNOs use it to offload traffic from cellular networks. In the easiest approach, data services are moved onto a Wi-Fi network when the user is inside the Wi-Fi coverage area while voice services are still being delivered via a cellular operator's network. The challenge with this approach is that the network operator loses control of its subscribers when they are using the Wi-Fi network. If the operator wants more or complete control over the subscribers when they are in the range of a Wi-Fi network, the cellular and the Wi-Fi networks can be connected using different coupling architectures (Aijaz, Aghvami, & Amani, 2013). Another communication technology generally operating in a non-licensed band (e.g. 868 MHz in Europe and 915 MHz in

U.S.) is low-power wide-area networks (LPWAN). This is targeted for IoT, providing inexpensive and energy-efficient operation as well as an operation range up to 40 km in rural areas and 5 km in urban areas (Centenaro, Vangelista, Zanella, & Zorzi, 2016). There are several LPWAN technologies, of which Sigfox, LoRA and NB-IoT are the most successful.

A competing technology attempting to access the license-exempt bands comes from the cellular domain. Both Long Term Evolution (LTE) and 5G are being pushed by the network vendors and operators to operate also in the license-exempt bands, such as the unlicensed LTE (LTE-U). Coexistence of LTE and Wi-Fi in the same unlicensed 5 GHz band is a challenging issue and has been only recently studied (Chen et al., 2016). Utilization of LTE-U can increase MNOs' capacity and alleviate congestions by enabling offloading of the cellular network data to unlicensed spectrum bands similar to Wi-Fi. The LTE-U has evolved to standardized License Assisted Access (LAA) version (Zinno, Di Stasi, Avallon, & Ventre, 2018; Ajami & Artail, 2017a) which covers only downlink and further to enhanced LAA covering both uplink and downlink (Ajami & Artail, 2017b; Grønsund, Grøndalen, & Lähteenoja 2013). Another version of the approach is MulteFire that focuses only on small cells. Both LTE-U and LAA require licensed spectrum to be used as an anchor channel, as opposed to MulteFire which utilizes only unlicensed spectrum. 3GPP is also studying the deployment of the 5G New Radio in unlicensed bands both by using the anchor channel and the standalone versions.

4. Research methodology

The data for this article on spectrum access options for vertical networks service providers in 5G commenced by reviewing the literature including scientific publications and regulatory and standardization bodies resolutions. In addition, one expert workshop was held in order to access large-scale views and ideas. Using workshop with representatives from different actors engaged in the development of mobile communications leads to a profound and joint understanding of the crucial factors of different 5G vertical use cases related to spectrum access requirements and different scenarios' suitability to them. Workshop participants included partners of a Finnish nationally funded project, namely Wireless for Verticals (WiVe), representing industry, media, regulatory, and research organizations. The workshop was organized as follows: First, a short introduction of four spectrum management scenarios and the stakeholders was provided to the participants. The scenarios were unlicensed, secondary licensing, spectrum leasing and trading and virtual network provided by MNO. A more detailed description of the scenarios used as a base for the workshop as well as local licensing scenario is provided in section 5. Second, the participants were divided into four groups rotating from table to table. At each table, each group discussed one scenario at a time for approximately 15 minutes. The discussions where moderated by a facilitator, who directed the conversation by asking questions according to a predetermined scheme and also took notes based on the discussions of each group. A total of four facilitators participated and stayed at the tables, while the smaller discussion groups moved further to discuss the next scenario at the next table. Thus, each group discussed each of the four scenarios. All conversations were recorded, and the comments and thoughts provided by the workshop participants were used in this article.

5. Identified spectrum access scenarios

In defining spectrum access scenarios for VNSPs in 5G, four key stakeholders can be identified: the NRA, the current owner of the spectrum usage rights (incumbent spectrum user), MNO and the VNSP.

The exact role of each of the three main stakeholders depends on the considered spectrum scenario. On a high level, spectrum utilization options for VNSPs are here divided into five categories:

1. Unlicensed: no license required by the regulators (example: ISM bands)
2. Secondary licensing: the NRA issues a license to the VNSP in a band already used by an incumbent spectrum user (example: LSA and CBRS)
3. Spectrum trading or leasing: an MNO that owns the license trades or leases spectrum to the VNSP

4. Virtual network provided by MNO: MNO provides a dedicated virtual network for the VNSP
5. Local licensing: NRA issues a local license to the VNSP

The applicability of these scenarios depends on the characteristic and the requirements placed by the vertical use cases. In this article, we describe and evaluate these five options, their main advantages, limitations, and requirements. In addition, the suitability of the spectrum access scenarios for different vertical use cases is considered depending on their characteristics as well as the effect on the roles of the involved stakeholders.

5.1 Spectrum scenario 1: unlicensed

This scenario consists of three stakeholders, namely an NRA, a VNSP and possible incumbent user. The VNSP utilizes the unlicensed spectrum opportunities, e.g., ISM bands or TV white spaces, to provide wireless connectivity. For example, in the U.S. 3.5 GHz spectrum with GAA level of CBRS and the 5 GHz unlicensed spectrum are currently two prevailing spectrum examples of unlicensed use for private networks. (RCR Wireless News, 2018). This procedure does not require any licensing by the regulatory authority. However, general authorization rules must be defined on a band-by-band basis, e.g., Regulation 15 on collective frequencies for license-exempt radio transmitters and their use in Finland (Traficom, 2019). While it enables fast, low barrier access to the spectrum, there is no guarantee of interference-free operations for all users in the same geographical area. In the CBRS, 5 GHz ISM band (the interference avoidance mechanism for radar) and the TV white space concept, there are also higher-priority users that limit the availability of spectrum. If an incumbent exists, additional equipment provided by a third party to control and monitor spectrum access is required (e.g., SAS, ESC, geolocation database). The coverage area in this scenario is typically considered rather small and local because of the maximum transmission power limitations typically imposed on unlicensed bands. However LPWAN technologies are able to provide much wider operation areas but with a much lower data rate. Global access outside the network could be provided but requires a contract with an Internet Service Provider (ISP). Figure 1 represents spectrum awarding in the ISM bands and Figure 2 shows spectrum awarding for the CBRS and the TV white space cases. The role of each stakeholder is depicted in Table 1.

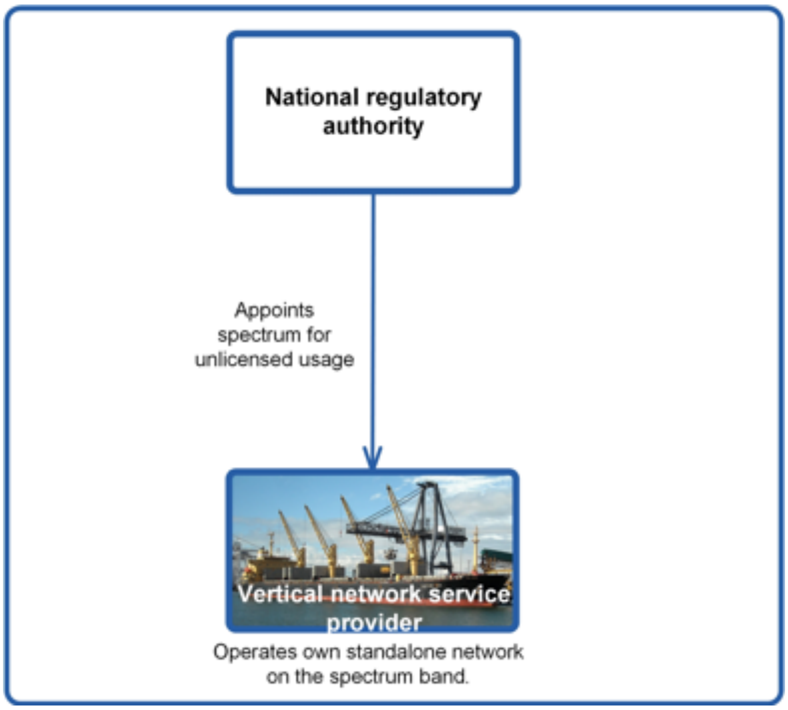

Figure 1. Unlicensed access in ISM bands.

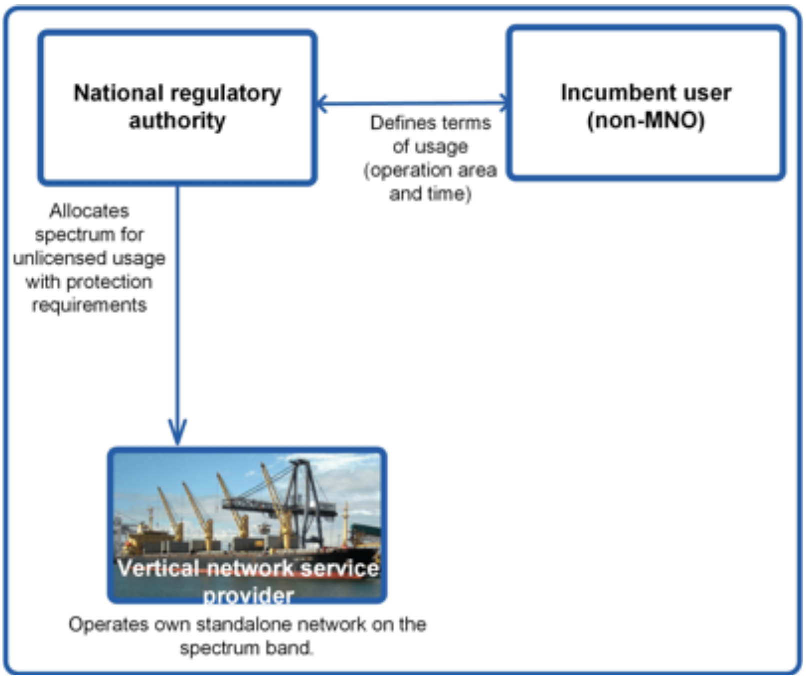

Figure 2. Unlicensed access in the CBRS (GAA users) and the TV white space bands.

5.1.1 Example use case

This scenario is suitable for services requiring high or low data rates using different technologies. For example, with Wi-Fi the data rates are not limited for any approach used in this scenario. The limitations occur more with access, but as the access is obtained, the data speeds can be rather high. Thus, the services and applications need to tolerate latency if the spectrum is congested. This scenario could be used to push down the cost, e.g., for the MNO. Another high data rate example use case relates to drones. Hospitals are also a good example, as they are already actively using Wi-Fi.

Other types of potential use cases include low data rate IoT with technologies such as LoRa, since the spectrum availability is not the issue in this case; rather low cost is considered more important. This kind of spectrum suits non-time-critical applications such as sensor reading, animal tracking in national parks, monitoring street conditions or traffic amounts, or sensoring moisture and weather in acrigulture. These are examples where data must be sent only a few times per hour or day. Typically, it is not important that the data transmission instantly succeeds, it can be enough that data transmission is completed within some longer period of time, e.g., within a day, etc.

Table 1: Roles and targets of the stakeholders in the unlicensed scenario, with its advantages and limitations from each stakeholder's perspective.

	NRA	**VNSP**	**Incumbent owner (not an MNO)**
Stakeholder's role	Allocates the spectrum band for unlicensed usage and defines the rules of use for the spectrum, e.g. which coexistence mechanisms need to be used.	Builds, operates and maintains a standalone network.	Defines its usage area and time. This sets the boundaries for the VNSP operation.
Advantages	This approach is favourable due to efficient spectrum utilization. This scenario also provides easy access to spectrum for new players	Low cost to access spectrum and maintain network.	Guaranteed access to spectrum on primary bases without harmful interference.

	and spurs innovations and competition.		
Limitations	Protection from interference might be problematic in some cases. In the CBRS concept, the SAS controller takes care of the traffic orchestration to mitigate interference toward incumbent and between other users. The TV white space concept utilizes either database or spectrum sensing mechanisms to avoid interfering with primary users.	Traffic congestions and possible delays might cause trouble for some services. If incumbent exist, operation of required spectrum control and monitoring units and databases operated by the third party (e.g. SAS, ESC and geolocation database) will bring cost which might increase VNSP service fees.	The incumbent usage is protected against harmful interference and there is no limitation to their spectrum usage.
Target	Foster innovation, efficient spectrum use, spur competition	Easy and low-cost access to spectrum.	Maintain its current spectrum allocation and guaranteed QoS

5.2 Spectrum scenario 2: secondary licensing

This scenario defines the spectrum sharing between the incumbent user and the VNSP. Examples of this spectrum scenario are the LSA and the CBRS (as PAL user) concepts. In this scenario, a VNSP applies for a license from the NRA to a spectrum band already utilized by an incumbent user. This license guarantees some certainty in the spectrum availability. The VNSP needs to obey the conditions given in the license in order to protect the incumbent user from interference, but there is no need to share the given spectrum portion between other users with equal priority. License costs will depend on the amount of use: a stable need, e.g., 10 years for a factory or a more dynamic use for an event. The access outside the network requires extensions to equipment and a contract with an ISP. In addition, the VNSP equipment must support the given rules to ensure that all users with higher priority are protected from harmful interference (e.g. LSA requires deployment of an LSA controller unit on VNSP infrastructure). Additional equipment to control and monitor spectrum access is required (e.g., SAS, ESC, LSA repository). This scenario is suitable for local as well as nationwide usage. This scenario is illustrated in Figure 3 and stakeholder roles in Table 2.

5.2.1 Example use cases

This scenario is suitable for verticals with high data rate demand and willingness to pay for license rights. The service should accept some delays or there has to be an alternative method for data transmission (an MNO network or a Wi-Fi as a backup system), if the incumbent appears. The scenario supports mobility inside the coverage area; for fixed services or for services within limited areas, this would be a very stable and reliable solution. Example cases relate to reliable emergency communications, logistics, remote operations, ad hoc video surveillance at public events or at construction sites, factories or harbours, and data offloading for MNOs.

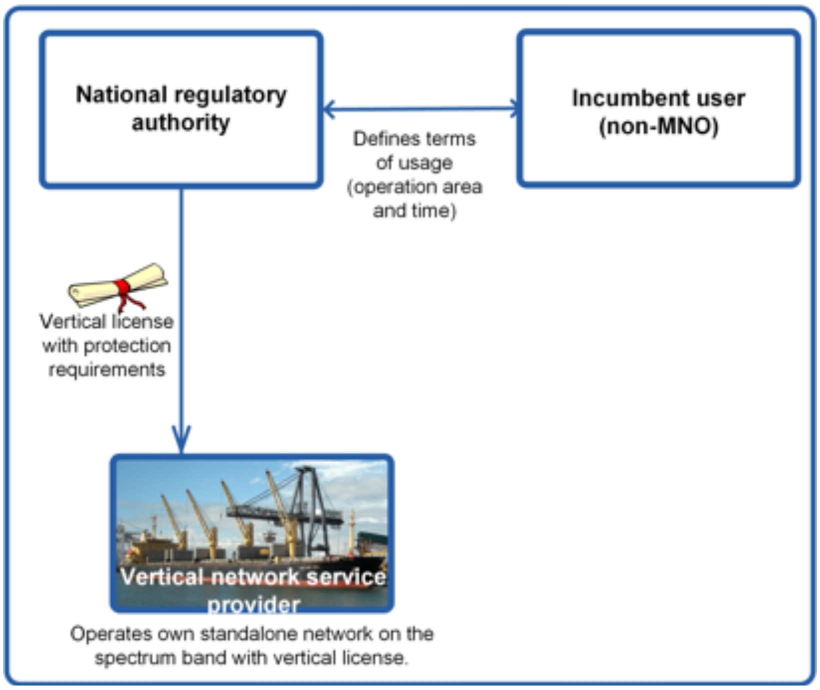

Figure 3. Secondary licensing.

Table 2: Roles of the stakeholders in the secondary licensing scenario, with its advantages and limitations from each stakeholder's perspective.

	NRA	VNSP	Incumbent owner (not an MNO)
Stakeholder's role	Grants additional individual rights of use (i.e., radio licenses) and defines boundary conditions for spectrum use in such a way that incumbent user is protected.	Applies for a local license for a specific area (e.g. PAL or LSA license), builds a standalone network. VNSP takes care of additional equipment deployment and costs, e.g., LSA controller unit.	Defines its protection requirements and reports its own spectrum usage.
Advantages	Opens spectrum market to additional players and supports innovation. This approach could offer a reasonable price access to spectrum and some level of certainty in spectrum availability.	Provides autonomy and full control to the VNSP. Increases the possibilities for small operators to utilize spectrum with reasonable costs.	Guaranteed access to spectrum on primary bases without harmful interference.
Limitations	Risk for fragmented use of spectrum.	Building up the infrastructure and its maintenance are high investment. Guaranteed access to spectrum may not be possible in all cases, depending on the characteristics of the incumbent usage. Operation of	This scenario should not cause any limitations to incumbent users.

		interference coordination mechanisms (e.g. databases) will bring cost which might increase VNSP service fees.	
Target	Foster innovation, Eeficient spectrum use, spur competition guarantee fairness, transparency and pro-competition with national procedures for licensing.	Additional spectrum to cover VNSP's spectrum needs, moderate price spectrum for occasional or longer spectrum use.	Maintains its current spectrum allocation and guaranteed QoS.

5.3 Spectrum scenario 3: spectrum trading or leasing

In this scenario, an NRA has granted exclusive license to an MNO, who can then lease or trade part or parts of the licensed spectrum to one or more VNSPs. The terms of the agreement between the MNO and the VNSP are negotiated on a case-by-case basis. Since, many vertical service providers have identified their willingness to operate their own network and be less reliant on MNOs, this scenario enables VNSPs to establish and operate a standalone network, where both the equipment and its maintenance are the VNSP's responsibility. The NRA grants exclusive license to the VNSP based on the agreement between the MNO and the VNSP. The access outside the network is not provided inherent and it requires extension to the equipment and a contract with an ISP. The scenario can support versatile operation area depending on the VNSP's needs and agreement between the parties. This scenario is shown in Figure 4 and stakeholder roles in Table 3.

This type of spectrum sharing mechanism is already utilized in Europe, where the trend seems to be that small operators specialising in the small private network market segment implement the private networks in frequency bands for which they typically own or lease the license. An example of such a company is Ukkoverkot (Ukkoverkot, 2019a; 2019b). Typically, these operators collaborate closely with the network equipment manufacturers. In some cases the major mobile operators also provide private mobile networks.

5.3.1 Example use cases

As this scenario provides the VNSP with an exclusive spectrum band, the access and the service level are highly guaranteed. This scenario is best suited for mission critical machine type communication, where ultra-reliable and low latency connectivity is required. It can be used for applications with high performance (reliability, capacity, latency) or security requirements. The price paid for the connectivity is not the main criteria; a VNSP might be willing to pay additional costs for a designated spectrum band that guarantees a high service level.

The application areas are related to factory automation, remote control, or transportation, e.g., a port operator who runs transportation services inside a port area (but may not own the port). In the energy domain, a transmission system operator could lease or buy a chunk of spectrum and lease it to distribution system operators or aggregators for smart grid operation. Specific sites are, e.g., airports, very large shopping centres, hospitals, or large automated factories where the VNSP could build their own network and maintain it. Thus, the VNSP gets full control of the local network. In communication systems, this approach is suitable for the island concept, where a local MNO is not able to offer acceptable network performance. Thus, the members of the island lease a frequency to upgrade the network in their area to fulfil the additional needs.

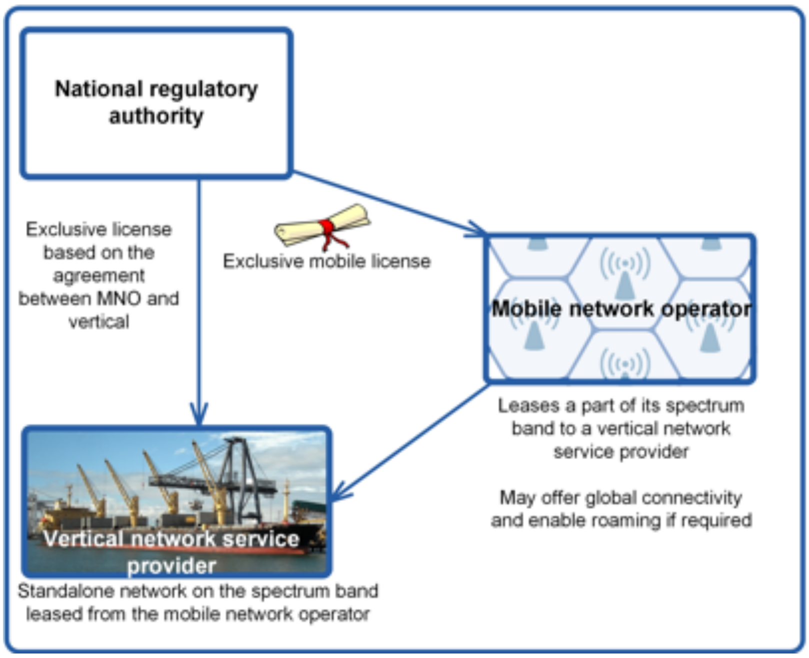

Figure 4. Spectrum leasing.

Table 3: Roles of the stakeholders in the spectrum trading or leasing scenario, with its advantages and limitations from each stakeholder's perspective.

	NRA	VNSP	Incumbent owner (MNO)
Stakeholder's role	Grants an exclusive mobile license with leasing rights to the MNO. The NRA grants license to a vertical user after the MNO and the VNSP have completed the leasing agreement. The NRA may also set conditions for lease or not issue the license for the VNSP. The NRA handles interventions if needed to foster an equitable situation for competition and requisite network broadband in the area.	Negotiates a contract with a specific MNO to use a part of its spectrum band locally or nationwide. Possibility to build and operate a standalone network.	An MNO negotiates a contract with a VNSP on the use of its spectrum band locally or nationwide. MNO may offer global connectivity, establish a network and enable roaming to the VNSP if required.
Advantages	Increases efficient spectrum utilization. Does not require time-consuming re-farming process to get spectrum for new vertical services and applications.	Custom-made networks for dedicated services.	Opportunity to gain profit by leasing or trading unused spectrum bands.

Limitations	How to guarantee transparency and fairness of the leasing and trading process. National regulation needs to be transparent and comparable between parties. Risk of fragmented spectrum use.	Deployment is fully dependent on MNO's willingness to lease or trade the band. The leasing and trading contracts need to be agreed nation by nation, which can be too large a burden in some vertical use cases. It requires relatively high investment in the local network equipment for the VNSP. There should be an easy way to re-configure the network to other frequency bands when the leasing expires.	If VNSP establishes the network, this scenario is quite safe for the MNO, as it does not require high investments in network equipment.
Target	Efficient spectrum use, spur competition.	Acquire suitable spectrum for vertical use with good QoS.	Economical profit making.

5.4 Spectrum scenario 4: virtual network provided by MNO

In this scenario, the NRA grants an exclusive license to the MNO, who offers connectivity services to meet the VNSP's needs. In this case, the full-service package offered to the VNSP includes establishing and maintaining the network equipment. Although this scenario is not directly related to spectrum sharing, it is included here as an alternative method to allow vertical service providers to emerge. The VNSP negotiates a contract with an operator to fulfil its service demands and pays an agreed fee for the service. In addition, the VNSP and the MNO agree in their negotiations on an expiry date for the contract. The service may be provided either locally or nationwide and is based on a commercial agreement between the MNO and the VNSP. Typically, the Virtual Network Operator (VNO) utilizes this approach. A VNO may have a database and manage its subscribers, compete for subscribers, collect money and serve customers. The network infrastructure is shared between the MNO and the VNO. This scenario is shown in Figure 5 and stakeholder roles in Table 4.

One early example of this infrastructure model is the Mexican shared LTE infrastructure network for MVNOs. In Mexico the communication service providers, MVNOs, public safety, finance, manufacturing, transport and health verticals can use a shared network infrastructure (Red Compartida) operated on the 700 MHz frequency band. The network is a 'wholesale only' network, where the builder and operator of the network are not involved in providing mobile services to consumers. The idea is that the operator sells the mobile service providers access to the network and thus facilitates the entrance of new entrants to the Mexican consumer market, as they do not need to build their own mobile network (TeleGeography, 2019). Another example MVNO is Google, which leases wireless radio resources (spectrum and base stations) from infrastructure providers (e.g., AT&T) to serve its own subscribers.

5.4.1 Example use cases

As an example, the VNSP could be a dedicated service provider, which specializes in factories and other sites requiring special expertise. The scenario provides a VNSP with a stable and reliable connection and security for service continuation at least to the due date of the contract. This would be favourable for mission critical Industrial internet of Things applications such as remote monitoring and control, and process automation. For example, a railway operator could be a VNSP themselves. In this case, the area in which a train operates is specified. The less local the vertical service site is, the more expensive the service package will be. Other examples of use cases relate to the Public Protection and Disaster Relief (PPDR) services and applications, where MVNO can provide the required reliable and high quality mobile connectivity.

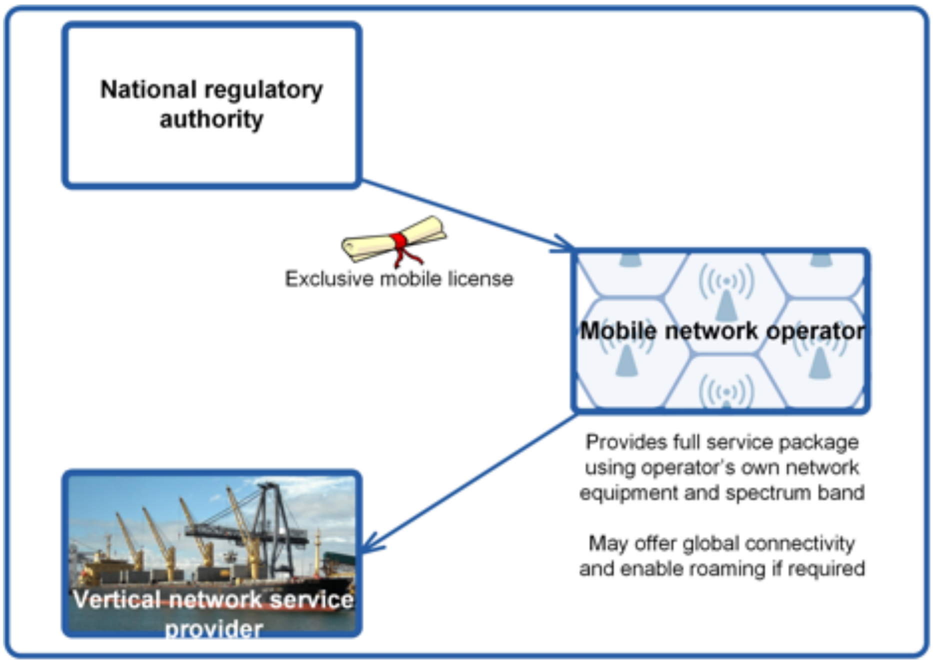

Figure 5. Virtual network provided by MNO.

Table 4: Roles of the stakeholders in scenario 4, with its advantages and limitations from each stakeholder's perspective.

	NRA	VNSP	Incumbent owner (MNO)
Stakeholder's role	Grants an exclusive mobile license to the MNO.	Negotiates a contract with a specific MNO for a full-service package based on a commercial agreement.	Negotiates a contract with a VNSP on a full-service package including a network and benefits of a full mobile ecosystem and connectivity services.
Advantages	No need for time-consuming re-farming process to get spectrum for new vertical services and applications.	Locality and stability depends on the agreement between the participants. The access and service level are highly guaranteed with required security and mobility. The VNSP can concentrate on its own core competence and does not need to have network expertise.	This scenario opens up new business opportunities for the MNOs.
Limitations	Does not increase spectrum sharing.	Costs might be high.	The MNO needs to build the whole network infrastructure. This is an expensive solution for

		Restricted control over network, since the MNO takes care of it.	the MNO, especially when the MNO does not consider the use case attractive enough for heavy investments. The attractiveness depends on expected utilization rate of infrastructure during its life span.
Target	Spur competition, innovation and new services.	Acquire suitable spectrum and infrastructure fulfilling the anticipated QoS levels for case-specific needs.	Economical profit making

5.5 Spectrum scenario 5: local licensing

In the local licensing scenario, the NRA grants a local license to the VNSP to be able to operate on the pre-defined spectrum portion in a pre-defined area stated in the license (Matinmikko, Latva-aho, Ahokangas, Yrjölä, & Koivumäki, 2017). The license expiration date is set by the NRA and can be significantly shorter time periods than present exclusive licenses. With local licensing the VNSP can establish and maintain its own network within the specific area to serve the verticals in that area. Network slicing and network function virtualization could be deployed in the scenario. The access outside the network requires extensions to equipment and a contract with an ISP. The difference compared to a secondary license is that incumbent users are not involved. National regulators in several countries are currently considering local licensing for vertical-specific networks in 5G bands such as 3.5 GHz and 26/28 GHz, but the actual example deployments are still rare. This is particularly feasibly at higher carrier frequencies where the signal attenuation limits the interference distances, which allows local licensing. The actual awarding methods for issuing local licenses to the applicants are currently under discussions by several NRAs and there is no common model. This scenario is shown in Figure 6 and stakeholder roles in Table 5.

5.5.1 Example use cases

Factories of the future are increasingly interested in deploying and operating their own private networks. In this scenario, the VNSP is able to offer a licensed spectrum to end users. This ensures stable and reliable operation and supports high data rates and mobility inside the coverage area. The scenario is suitable for factories, harbours, and data offloading for MNOs. Possible use cases are, e.g., hospitals, and mission critical Industrial internet of Things applications such as remote monitoring and control, and process automation in restricted operation area.

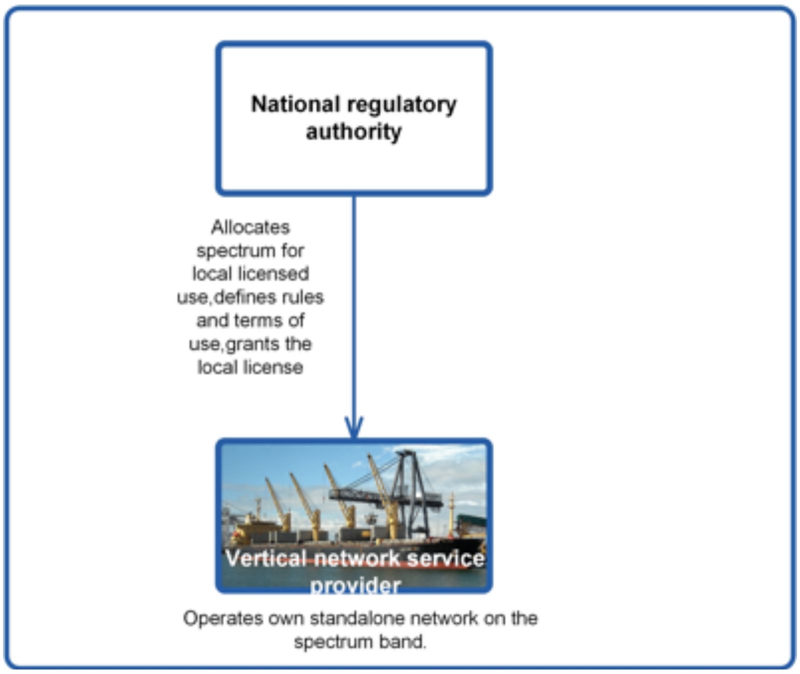

Figure 6. Local licensing.

Table 5: Roles of the stakeholders in the local licensing scenario, with its advantages and limitations from each stakeholder's perspective.

	NRA	VNSP
Stakeholder's role	Grants a local license to the VNSP and defines the boundary for the spectrum use.	Applies for license from NRA and establishes its own network in local area.
Advantages	Opens spectrum market to additional players and supports innovation. Fairness, transparency, and pro-competition are guaranteed with national procedures for licensing.	The access and predefined service level is highly guaranteed. Increases the possibilities for small operators to utilize the spectrum with reasonable costs.
Limitations	Risk of fragmented spectrum use.	Requires relatively high investment in local network equipment. In use cases of long-lasting spectrum demand, the investment risks depend on the availability of other spectrum bands, if required, or license renewal possibility after license expiration.
Target	Spur competition, innovation, and new services.	Acquire suitable spectrum and infrastructure fulfilling the anticipated QoS levels for case-specific needs.

6. Analysis of spectrum access scenarios for 5G verticals

In this section, we define the key features of spectrum access scenarios to enhance suitability assessment of scenarios to the VNSP. The intention of the analysis is not to undertake an exhaustive description of all possible properties, but to consider some eminent features to give a view of what would be the differences in terms of the selected characteristics between scenarios.

The characteristics are reliability, locality and mobility, MNO involvement, time scale issues, cost and investment security. In Table 6, we depict the relation of the features to the scenarios.

Reliability requirement: Reliability is defined as the probability of delivering a packet successfully and without error within a pre-defined time scale. Spectrum availability and interference possibility greatly impact reliability, as congestion may cause eminent delays and packet errors. This is a very important aspect for the VNSPs and the MNOs. The suitability of the scenario is deeply tied to how reliable, stable, and foreseeable the access to the spectrum and the service quality is. Therefore, the main question for a VNSP is: What is the required reliability for spectrum access?. It is evident that a more reliable spectrum availability requires some sort of license to a part of the spectrum, as it is in the secondary and the spectrum leasing concepts. These are of course more expensive solutions and they require case-specific consideration beforehand to decide the cost-effectiveness for a VNSP or an MNO.

Locality and mobility: In this article, we consider locality as a restricted geographical area either indoors (e.g., an office building, hospital or factory) or outdoors (e.g., a harbour). A vertical use case might require a relatively wide operation area. Not all of the scenarios are able to support a wide area and achieving nationwide designated spectrum may be too expensive. This can be a crucial criterion for some use cases. Locality is closely related to mobility. For instance, in some use cases, such as harbour sites, the crane operation area is restricted. However, use cases such as automated driving or remote control of trains require vast operation area.

Time scale: Time scale indicates the duration of gaining access to the spectrum, including negotiation and granting processes. It depends on with whom the VNSP has to negotiate the access grant. Time scale also retains the time period the network is maintained for one VNSP. Different vertical use cases have highly distinct demands for spectrum availability. The network requirement can be quite occasional, e.g., sending small amounts of sensor information once or twice a day, however over several years. In the case of a special public event, the need for spectrum access can be a few days only.

Costs and investment security: Costs involve the investments needed for constructing and building the network, the maintenance costs, as well as the possible spectrum license fee. The costs vary heavily in each scenario; even within one scenario the costs may vary depending on the use case. In some of the scenarios, the costs for spectrum leasing or a full-service package can be negotiated. On the other hand, in scenarios where unlicensed spectrum bands are used, the costs may remain reasonably low, meaning that the investments are needed only in the network equipment and its maintenance. The network provider can be an MNO or a VNSP, depending on the scenario. In both cases, the network provider will need assurance that the built network will cover the investments. This requires the planned spectrum to remain usable for a sufficient period of time. Another aspect is the certainty of the service continuation. From the perspective of the VNSP, they have to be certain that the technologies and the spectrum bands supported by their devices are available, and that the network service is continued for a sufficient amount of time to cover the planned life span of the devices and the service. For instance, in case of IoT, the customer may have invested in hundreds or thousands of devices with a long life span.

Level of MNO involvement: The level of MNO involvement comprises contract making with an MNO, and VNSPs´ dependency on MNO infrastructure. Many vertical service providers have identified the willingness to operate their own network and be less dependent on MNOs. Instead of acquiring an MNO´s services or establishing a WLAN network, verticals have other options to access wireless spectrum bands. In Table 6 we identify the MNO involvement level in each scenario. In some cases, MNO involvement is needed to guarantee backup wireless access and increase reliability if the primary spectrum option is congested. Nonetheless, in some use cases the MNO can bring clear assets to the VNSP and thus the MNO involvement cannot be identified solely as a burden to the VNSP.

While the economic conditions, advantages, and risks vary according to the needs and requirements of the stakeholders in each scenario, it is evident that the MNO gains business advantages in scenario 3, where MNO involvement is the highest in the negotiation phase with the

NRA, and then considerably lower after entering contracts with VNSPs. From the VNSP's point of view, scenarios 2 and 5 provide the greatest business potential, while scenarios 3 and 4 allow for a revenue model in which the MNO takes a share (but is responsible for negotiating the leasing contract, which lowers the risk and involvement costs for the VNSP). Also, network setup and maintenance in scenario 3 involve risks and higher investment costs for the VNSP. From the VNSP's point of view, scenarios 2, 3 and 5 involve the highest risk and investment, as operating a local network may not be the core competence of the VNSP. However, the scenarios allow for independence and agile development according to the needs of the VNSP.

Table 6: The named characteristics and their relation to the identified scenarios.

Characteristic	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Reliability requirement	Reliability and operation conditions may fluctuate and depend heavily on other traffic at the same band.	The secondary licenses give certainty but some additional spectrum, such as an MNO's spectrum, is needed in the case of evacuation requirement.	Fully reliable access and operational conditions during the term of contract.	Fully reliable access and operational conditions during the term of contract.	Predefined service level and operational conditions during the term of contract should be guaranteed.
Locality and mobility	Local and long-range operation area depending on used technology. Mobility can be supported within coverage area.	May offer local or nationwide area even though the nation-wide spectrum availability is rather unlike. Mobility can be supported.	Local or nationwide operation area can be negotiated. Mobility can be supported.	Local or nationwide operation area can be negotiated with MNO. Mobility can be supported.	Local operation area. Operation is however targeted for indoors. Outdoors mobility is restricted to small area.
Time scale					
Access to spectrum	Fast access to network	Moderate access to network. Requires license application from NRA.	Moderate access to network. Depends on negotiations.	Moderate access to network. Depends on negotiations.	Moderate access to network. Needs license application from NRA.
With whom the access is negotiate	No need for negotiation.	Negotiation with NRA (MNO	Negotiation with MNO needed.	Negotiation with MNO needed.	Negotiation with NRA.

		network might be needed for backup).			
Time period	Works well for both short and long operation periods.	The contracts may vary from short periods, such as some days to a yearly basis.	Stable use for years.	Stable use for years.	Operation period of some years.
Costs and investment security	No license costs. The equipment and the maintenance costs depend on the selected technology. If incumbent exist, operation of required spectrum control and monitoring units and databases operated by the third party (e.g. SAS, ESC and geolocation database) will bring cost which might increase VNSP service fees. Investments are quite secure, and spectrum can be utilized as long as is required.	Relatively low costs for licensing. Investments in the infrastructure required to enable operation. Operation of interference coordination (e.g. databases) will bring cost which might increase VNSP service fees. High infrastructure investment costs might be problem for short period of use. The possibility to renew license would give security to infrastructure investments.	Costs for spectrum lease may vary. Requires investments from VNSP to put up and maintain network infrastructure. VNSP investment security is related to infrastructure exploitability after leasing contract expiration. Possibility to renew leasing contract and re-configure network infrastructure to other frequency bands would increase VNSP investment security.	Costs for VNSP may vary depending on agreement negotiated by VNSP and MNO. No investments in the infrastructure required from VNSP. MNO investments risks are related to utilization rate of infrastructure during its life span in particular area.	Relatively low costs for licensing. Investments in the infrastructure required to enable operation. In case of long-lasting spectrum demand use cases, the investment risks depend on the availability of other spectrum bands if required or license renewal possibility after license expiration.
Level of MNO involvement	No MNO involvement when operating	No MNO involvement needed. If backup	High MNO involvement when negotiating	High MNO involvement both in negotiating	No MNO involvement.

	only on unlicensed bands. If backup network is required and provided by MNO, its role is considerable.	network is required and provided by MNO, its role is considerable.	the leasing contract. Low after the contract is approved.	the contract and dependency on MNO infrastructure.	

7. Conclusions

The aim of this article is to respond to the long-range 5G vertical spectrum needs as well as spectrum scarcity issue by analysing five spectrum access frameworks for vertical-specific 5G networks. Four of the frameworks allow VNSPs to use the 5G spectrum on a shared basis with flexible spectrum awarding mechanisms. However, all the scenarios promote new entrants to enter wireless connectivity markets. We draw attention to the scenarios' properties which seem relevant to suitability assessment of the scenario to the VNSP. The versatility of access options allows the VNSP to ponder which spectrum access method suits best its operation logic and customers' needs. From the 5G vertical sectors' perspective, spectrum access scenarios are not mutually exclusive, but rather complimentary by jointly responding to different 5G vertical sector requirements.

Even though the focus of this article is on spectrum options for VNSP, we have elucidated the requisites and objectives of MNO, incumbent user and NRA as well and identified their roles. Further, we have discussed each scenario's advantages and disadvantages from the stakeholder perspective. The roles and targets of the stakeholders vary depending on the used spectrum access approach. For example, the efforts required from the VNSP and MNO for building and maintaining the infrastructure depend on the scenario, which also influences the investment costs and risks. The scenarios enabling VNSP to operate a standalone network are appealing business opportunities for VNSPs, especially if the access fees are moderate or free and the spectrum awarding process is flexible and expeditious like in scenarios 1, 2 and 5. While scenarios 2 and 5 allow access to the local spectrum for the VNSPs, the license costs should offset the uncertainty for spectrum availability to encourage the VNSPs to utilize this option.

MNO involvement has its own advantages, such as alleviation of the risks and investments needed on the VNSP side by managing the network infrastructure-related issues. This is favourable especially in case network operation is not among the VNSP's core competences. Under these conditions, scenario 4 is, on the VNSP side, the most carefree option but more costly as well. Scenario 3 is favourable in use case conditions acquiring high QoS and continuous spectrum availability, but it also places requirements on VNSP to have some expertise to operate and bear the risks of a dedicated network. In addition, the leasing fee or trade price for their own spectrum is higher than in scenarios 2 and 5.

All sharing scenarios are able to support mobility; however the differences are more related to operation area. Scenarios 3 and 4 are most suitable if nationwide operation is required, whereas scenarios 1, 2 and 5 are suitable for more local and indoor operation.

To be able to exploit the full potential of this kind of assessment, further elaboration on the economic advantages and risks linked to the different scenarios and predominantly the business opportunities and potential, as well as revenue logic, is required. The assessment features considered in this article are not an exhaustive description of possible characteristics, but rather an overview of some prominent ones. Another important aspect could be, e.g., required privacy and security of the transmitted data which might be imposed by the organizations related to vertical use cases. Since all sharing schemes may not be able to respond to strict security requirements, this aspect should be further considered.

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