Assessing the Feasibility of the Citizens Broadband Radio Service Concept for the Private Industrial Internet of Things Networks

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Abstract. 5G emerges with ultra-dense deployments of small cell networks to serve various vertical sectors' location specific service requirements. While the development of technical solutions for network densification is progressing, less attention is paid to the spectrum models for the new ultra-dense networks and location specific service offerings. This paper examines the problems currently faced by industry in acquiring spectrum to support the Industrial Internet of Things (IIOT). Industrial applications where such spectrum is needed were assessed and their requirements identified. The US Citizens Broadband Radio Service (CBRS) spectrum sharing model to support the IIOT needs is introduced and how it addresses the IIOT requirements were evaluated based on four different real-life use cases. This study developed a view of options for the spectrum supply side, how this could interface with demand from private networks. Results showed that the CBRS model is well suited for several IIOT use cases based on having smaller licensed areas for PALs allowing a low-cost path for acquiring exclusive use spectrum along with a no cost option of using GAA spectrum. The leasing rules defined for CBRS PALs also provides an excellent minimal overhead option for enterprises to lease spectrum to other neighboring enterprises. Furthermore, the CBRS concept was found to leverage all the three forces of the long tail framework: Democratizing the tools of production through access to affordable spectrum, cutting the costs of consumption by democratizing distribution with web-scale automatization and connecting supply and demand via marketplace via SAS.

Keywords: Citizens Broadband Radio Service · Industrial Internet of Things · Spectrum sharing · Use case · 5G

1 Introduction

Digitalization has been transforming and disrupting industries at an unprecedented pace [1] and the diffusion of information technology into the physical industries is poised to revive the economy, create jobs, and boost incomes [2]. New 5th generation wireless network technologies (5G) are foreseen to enable this through wireless services provided at gigabit speeds, millisecond latency, support of wide range of novel applications

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connecting devices and objects, and versatility by virtualization enabling innovative business models across multiple sectors [3]. Present connectivity market has been characterized by incumbent network operators whose business is structured around service mass provisioning with high advance investments in infrastructure and exclusive long-term spectrum licenses [4]. At the same time, the responsibility of delivering resources is being transformed from centralized mobile network operator (MNO) centric system into a more dynamic mode of operation due to the deployment of software defined networks (SDN), network function virtualization (NFV), cloudification, spectrum sharing concepts, and the development of vertical service and application ecosystems [5].

A wide variety of users, machines, industries, public services and organizations will each have their special demands, and the 5G network is expected to fulfill these needs. Furthermore, 5G could be the enabler for new innovative business opportunities and lower the barrier to collaborate across domains. For example, for the industrial control and factory automation 5G can enable fully automated and flexible production and manufacturing systems consisting of sub-processes and subassemblies from several stakeholders. Consequently, this shift to more on-demand and decentralized local network services will require changes in the network's architecture especially in the management and orchestration levels [6] across resources from service integration to spectrum.

The industrial internet of things (IIOT) is a major component for next generation wireless systems and is being studied by many organizations globally. The International Telecommunication Union (ITU) [7] identifies industry automation and smart home/building as key usage scenarios of international mobile telecommunications (IMT) for 2020 and beyond. The European Commission focused on this critical need under the banner of *Industry4.0* [8]: "*Industry 4.0 refers to the intelligent networking of machines and processes for industry with the help of information and communication technology.*" Furthermore, the Industrial Internet Consortium (IIC) was formed to accelerate the development, adoption and widespread use of interconnected machines and devices and intelligent analytics [9], and the 5G Alliance for Connected Industries and Automation (5G-ACIA) was established for addressing, discussing, and evaluating relevant technical, regulatory, and business aspects with respect to 5G for the industrial domain. [10]. Today most of the IIOT equipment is short range devices using unlicensed spectrum. In the future, these short range IoT devices will likely remain a majority of the need, however, there is a significant enterprise need for larger wide-area coverage, supporting mobility, increased security and privacy, and assured certainty and Quality of Service (QoS).

While auctions have resulted in significant income for the governments, their impact on society goes beyond revenues. For example, competition, which will ultimately lead to greater innovation with better and cheaper services, will likely contribute to greater future governmental revenues compared to the sole auction revenues [11]. Future networks are expected to be increasingly locally deployed by new entrant stakeholders, e.g., facility owners or service providers [12]. Furthermore, local high-quality 5G wireless networks are gaining increasing attention as the solution to deliver guaranteed quality of service, particularly concerning the low latency requirements, in various vertical sectors' and enterprises' use cases [13]. Private mobile networks as stand-alone solutions or for collaboratively serving MNOs' customers [14] are particularly envisaged to operate in shared spectrum bands [15].

These trends are expected to result in defining spectrum access rights increasingly over appropriate geographical areas, e.g., national, regional, city or hyper-local, like for use in a factory [16]. The regulators foresee the need for more flexibility in 5G spectrum authorization approaches including the commons approach (general authorization, unlicensed), licensed shared use between different users, geographical sharing, or more dynamic approaches to spectrum sharing in time and space, with the help of geolocation databases [16]. Sharing-based spectrum management approaches facilitate more efficient spectrum use by allowing two or more radio systems to operate in the same frequency band. Prominent sharing concepts under standardization and pre-commercial trials are the US based Citizens Broadband Radio Service (CBRS) [17] and the European Licensed Shared Access (LSA) [18].

While the spectrum sharing models and CBRS concept have been widely studied in the technology, trial validation, regulation and business contexts, e.g., [19–22], to the best knowledge of the author, IIoT real life use case assessment and the options for related business model antecedents that could potentially develop has not been proposed in the literature. This paper will examine four selected IIoT use cases where such spectrum is needed, identify their requirements in the context of spectrum allocation, and assess the applicability of the CBRS spectrum sharing concept [17].

The rest of the paper is organized as follows. In Sect. 2, the economic drivers behind IIOT, its application characteristics and selected use cases are shortly reviewed. Next, an overview of the spectrum options for IIoT applications is given and the CBRS spectrum sharing systems presented. Section 4 presents and discusses the results of the use case assessment. Finally, the conclusions are drawn in Sect. 5.

2 Industrial Internet of Things (IIoT)

Productivity growth in the digital industries covering technology, content, finance & insurance, professional & technical services over the last 15 years has been strong, e.g., 2.7% in U.S. At the same time, productivity in the physical industries consisting of manufacturing, construction, mining, utilities, healthcare, hotels, restaurants, transportation, wholesale and retail trade grew just 0.7% annually, leading to weak overall economic growth over the last decade [23]. Companies and countries that provide spectrum and resources to support digital automation needs of industry verticals have been predicted to gain a significant financial benefit. For example, [24, 25] estimated that in 2025 the value creation potential of the IIoT can be between 1.2 B$ and 3.7 B$ in the factory segment only. The European 5G-PPP organization [3] is also focused on the economic benefits of IIOT in the manufacturing sector as a pivotal driver for economic growth: *The manufacturing sector is a pivotal driver for growth of the economy. In fact, it accounted in the period 2010–2012 for about 60% of productivity growth and 67% of exports in Europe.* At the same time, China has put in place a *Made in China 2025* action plan to future-proof their manufacturing industry to handle information technology highlighting *Manufacturing is the main body of the national economy* [26].

2.1 IIOT Application and Use Case Characterization

To analyze which use cases are best supported by the spectrum sharing solution and CBRS concept, it is necessary to first characterize the applications by the properties of the network that are required to deliver them [27]. The key dimensions considered in this study are depicted in Fig. 1.

Fig. 1. Characterization of IIOT applications.

Data transmitted for industrial applications may need to be protected due the *sensitivity* of the data for commercial or *security* reasons whereas the other dimensions by which the applications are characterized relate to technical requirements. Indoor and outdoor *coverage* relates to the setting in which the application is deployed as well as the requirements for mobility on the devices used for the application. Industrial applications can include the use of wireless connectivity in wide outdoor area such as on mines or in indoor spaces such as logistic hubs. *Bandwidth* requirements refer to the throughput level necessary to enable the application. Remote, tandem operation of machinery in a factory through virtual/augmented reality not only requires high QoS but also very high data transmission rate. This is particularly the case where the processing of a vast amount of information is done in the cloud. *QoS* refers to the application's requirement in terms of the network speed and consistency as well as requirements on latency and resilience. High QoS is needed for applications that are mission-critical such as process automation control or safety measures in industrial setting, where human and robots may come into close collaboration. QoS "dependability" is a key dimension that distinguishes a private network from a public or license-exempt network solution and can be broken down into five properties: reliability, availability, maintainability, safety, and integrity [28]. In some applications, there can be a significant *transmission asymmetry* between bandwidth required for uplink and downlink transmissions, e.g., high-definition monitoring and analytics will require a very high bandwidth in the uplink direction.

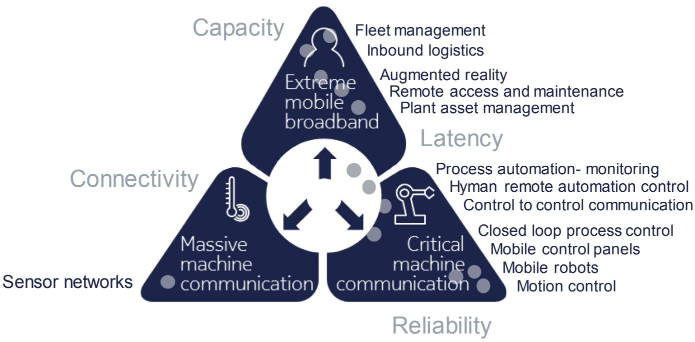

Fig. 2. Key network characteristics and IIoT applications.

Based on the 3GPP [28] and 5G-ACIA [10] use case categorization and the introduced characterization, the following IIoT application types were found optimal for *private network solution,* as depicted in Fig. 2: mobile robotics that require cloud computing access; remote operation of mobile machinery including augmented reality; sensors on machinery for personnel safety; remote operation of stationary machinery and high definition monitoring and tracking. The current use of private networks and IIoT is characterized by narrowband sensor networks and driven by simple functional requirements. The trend is to greater use of broadband sensors, while narrowband sensors keep a role, with enhanced downlink and uplink transmission capacity and latency shown in Fig. 2. Network performance needs for industrial automation are evolving and going towards [10]: higher reliability and availability of communication service; lower latency with higher synchronicity between devices; higher data rates with extended coverage; enhanced mobility and device density with high localization accuracy; and improved security. These evolutions are likely to be slow, because of implementation constraints and related costs. Potential for integration into systems and processes is increasing, while it is still limited, as well as network adaptability to configuration changes.

2.2 Use Cases

The characteristics of the selected real-life use cases, a mine, a harbor, a windmill park and a logistic hub, of this study are summarized in Table 1. While there are many common characteristics across the cases there are differences that may accentuate over time as the requirement for increased broadband capability develops. As previously noted, this is likely to place a significant data requirement in the uplink, which in turn creates more demanding transmission conditions and will increase bandwidth requirements and decrease the size of cells.

Table 1. Use case characteristics.

	Mine	Harbor	Windmill park	Hub
Activity	Extraction of ore, On-site processing, loadout facilities	Ship docks for goods and passengers	Turbines and substations generating and collecting power	Logistics facilities: collection, storage and sorting
Specificities	High QoS for critical operations and safety	High QoS for safety, multi-tenant	High QoS for safety	Fast pace process
Dimension	Extra wide area × 100 km^2	Wide area × 10 km^2	Extra wide area	Local × 1 km^2
Area spec.	Open pit + Underground	Water + land		Airports, Military bases
Environment	Outdoor LOS (+Indoor)	Outdoor NLOS (+Indoor)	Outdoor LOS (+Indoor)	Indoor + (Outdoor)
Specificities	High temperature + moisture	Marine env.		Cold chain center
Term	Twenty-four hours a day, seven days a week			

The purpose of the study was not to undertake a detailed network planning on each use case but to give a sense of what would be the requirements and differences in terms of spectrum between the use cases. For this, a set of common assumptions were made for the deployment of indoor and outdoor environments as depicted in Table 2. Device parameters would give a traffic density per km^2 of 200 Mbps for broadband devices and 7.5 Mbps for narrowband devices. Using 12 Mbps per sector, this would require 16 sectors to be deployed per km^2, assuming a relatively uniform geographic distribution of devices.

Table 2. Assumptions for line-of-sight (LOS) and non-LOS LTE sectors and device density in outdoor site scenarios.

Parameter	LOS	NLOS
Equivalent radius (km)	1.0	0.4
Coverage (omni antenna) (km^2)	3.1	0.5
Spectrum carrier (MHz)	10	10
Spectral efficiency (b/sec/Hz)	1.5	1.5
Maximum capacity loading (%)	80%	80%
Plan sector throughput (Mbps)	12	12
Narrowband devices (10 Kbps) per km^2	750	
Broadband devices (5 Mbps) per km^2	40	

3 Spectrum Models for IIoT

Industry seeks standardized solutions for IIOT to avoid expensive proprietary equipment. Standards have worked well to provide low cost devices for wireless local area networks (Wi-Fi) and LTE equipment where global low-cost devices have allowed for the technology to become universally prevalent. On the other hand, spectrum regulation has created a gap for industry to acquire spectrum which may require power and QoS levels above those of unlicensed spectrum for usage within an enterprise at a reasonable cost. There is an immense global effort to provide additional spectrum to meet the growing IIOT demand, and the following allocation approaches has been considered as depicted in Fig. 3: sub-licensing, leasing or trading of MNO spectrum; auction spectrum in smaller areas via regional micro-licensing, e.g., in Germany [29]; and shared spectrum approaches in particular CBRS and LSA.

Spectrum allocation decisions have major impact on the connectivity service model, as depicted in Fig. 3. Historically, self-provision has been the norm for private networks involving entities having access to licensed spectrum and buying, installing and operating the infrastructure themselves or using it through a lease/rental agreement with a third-party supplier that also facilitates access to the necessary frequencies. Being unable acquire appropriate spectrum would be a barrier to such an approach. On the other hand, technologies like LTE or 5G form a key part of public mobile networks and these platforms could provide private services utilizing an existing MNO's network and its spectrum portfolio and operating the private network as a virtual instance.

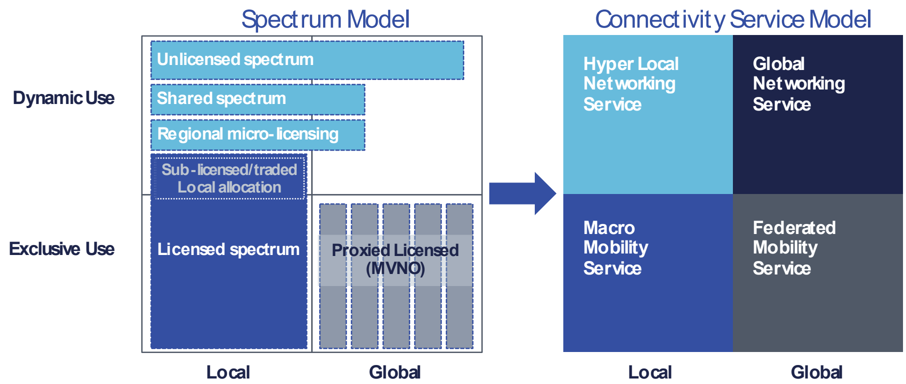

Fig. 3. Spectrum allocation model options determines the solution and the opportunity.

Alternatively, the private LTE network could be supplied by a third-party federated mobility managed service provider, wholesaler not generally providing public mobile services. Under this model, a wholesale mobile network could offer the private LTE service as a virtual instance on dedicated network infrastructure using its own spectrum. The spectrum would be dedicated for the private LTE service. The wholesaler would manage coverage and capacity related spectrum issues to ensure that its wholesale network meets the QoS requirements of the industrial sites it serves.

3.1 Citizens Broadband Radio Service

The US regulator FCC proposed a novel CBRS approach in the 3.5 GHz band to allocate up to 150 MHz low-cost shared spectrum in the 3550–3700 MHz band [17]. The spectrum currently has existing tier 1 incumbents who are given priority and protection from interference within the band from lower tiers, as depicted in Fig. 4. Besides incumbents, the FCC has setup two additional tiers of users: tier 2 priority access license (PAL) users and tier 3 general authorized access (GAA) users.

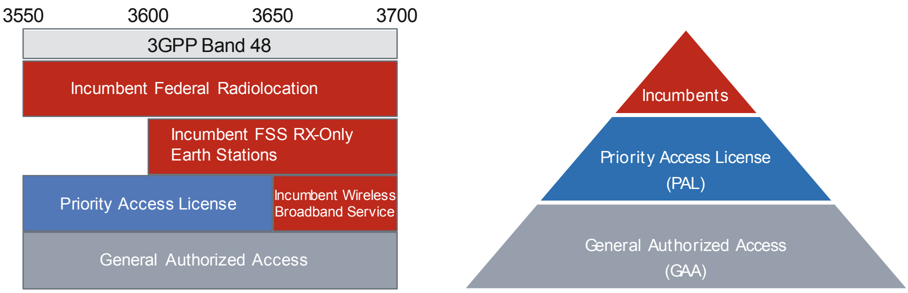

Fig. 4. CBRS spectrum sharing model.

The rules provide two paths for IIOT spectrum, PAL and GAA. According to the recent final FCC rules [30], the PAL spectrum will be auctioned off in smaller regional areas, in roughly 3200 counties, for ten years licenses with possibility of renewal. In comparison, to date many spectrum auctions in the US are done over 416 Partial Economic Areas that has made it expensive and not viable for an enterprise to acquire. The cost to acquire a single 10 MHz PAL will be determined by a spectrum auction but should be reasonably priced compared to other cellular spectrum auctions. Furthermore, the rules allow for a single PAL licensee to hold up to four channels in any licensed area at any given time, providing up to 40 MHz of spectrum protected from interference [30].

The final rules also allow the PAL holder to lease their PAL spectrum beyond their deployment coverage but within their PAL area. Moreover, PAL may be partitioned and disaggregated. Thus, in an industrial area a PAL holder may lease to other neighboring enterprises within their PAL area use of their PAL spectrum. A second path for IIOT spectrum in the CBRS band is to use 80 GHz of opportunistic, licensed by the rule GAA spectrum. Additionally, spectrum not currently used by an incumbent or by a PAL holder is available for GAA users on a shared basis. For both GAA and PAL, the base stations (CBSDs) must register with a SAS (Spectrum Access System) and request a spectrum grant. The SAS will attempt to find suitable spectrum for the CBSD and ensures higher tier users are protected by lower tier users, thought the unprotected GAA spectrum may have significant interference from other GAA users.

4 CBRS Use Case Analysis

CBRS suitability to selected use cases is assessed below based on interference risks, PAL/sub-leasing/GAA use of spectrum, initial network planning simulations (bandwidth, CBSDs), and use case specific limitations and is summarized in Table 3.

4.1 Mine

Private LTE networks in mines are almost unique in that they are completely separated from any potential public LTE network, not just by geographic distance but also by natural barriers, and as such there is unlikely to be any interference caused by using spectrum which is otherwise used by these networks. There would be very limited scope for any interference or alternative use of the spectrum, meaning that GAA licensing would be sufficient to ensure that the private LTE network could operate with sufficient reliability and consistency. Furthermore, in case needed a PAL sublicense could be obtained cheaply since it would present a very low opportunity cost for the PAL holder.

Some remote location of private LTE equipment may suffer from difficulties in receiving the heartbeat that appears to be a limitation of the CBRS framework. Under these conditions private network operator will require a sublease of alternative LTE spectrum from mobile network operators, or operate using unlicensed spectrum, again because the location will restrict the potential interference. Utilization of alternative spectrum layer will additionally offer resiliency needed in operating critical application.

4.2 Harbor

The networks to be deployed will be dense and require large bandwidths, particularly given the streaming video applications, future automated vehicles and high reliability. As they are also in areas open to the public, particularly surrounding the cruise ship terminals and marinas, it is likely that MNOs have deployed their own networks to cover at least part of the port area. This mix of requirements from private LTE operators and MNOs will mean that the only spectrum that could be used for the private LTE network would be that covered by CBRS: MNOs will not be willing to sublease their spectrum since they will either be using it or have a reasonable belief they will use it in the near future; while unlicensed spectrum would not have sufficient reliability and security to support the applications needed.

Given the need for greater reliability, private LTE operators would need access to PAL, but given the county-wide licensing regime, it would likely be unprofitable for them to buy a PAL themselves. Therefore, we would expect a PAL leasing arrangement would be most suitable. The case where the port elects to acquire a PAL itself at a low price may be limited by the bandwidth available as it may be necessary for multiple licenses to be used to meet the demands of various networks. This is a fairly significant drawback to the use of CBRS for this licensing.

4.3 Windmill Park

Unlike ports, most large windmill parks are situated away from built-up and populated areas. This means that higher frequency spectrum is unlikely to either cause interference or suffer from interference from other sources, given the short propagation distance. The lack of interference will in turn lead to a low opportunity cost associated with the use of CBRS spectrum; PAL holders may be unlikely to be inconvenienced if they allow the windmill parks to sublease their spectrum. This may not be true for other potential LTE bands; the wider propagation of these could lead to surrounding villages suffering interference.

The location of a windmill park is an enabler and a framer. To be at their most efficient, wind turbines tend to be tall buildings located high on hills, which means that any signals sent by transmitters placed on the turbines themselves are ideally located to achieve maximum range. This will reduce the willingness of mobile operators to allow for subleasing of their spectrum and may also reduce the possibilities for PAL leasing as well, depending on how PAL holders plan to use the spectrum in surrounding areas. Windmill parks can be very large and spread over a large geographic area, particularly where the geography requires straight lines of turbines. Where this lies in two different counties, it will require multiple agreements to sublease PAL for CBRS spectrum, and it may not be possible to obtain compatible licenses in the two different counties. Given this, while windmill parks appear to be an ideal case for CBRS spectrum sharing, given the lack of interference and likely low opportunity cost, there are several logistical issues to overcome before the benefits can be realized.

4.4 Hub

The use of CBRS spectrum in the logistics hub considers indoor and outdoor use cases. Within the fulfilment centers and sorting buildings, CBRS spectrum can be used indoors with minor risk of interference to the surrounding region. However, the outdoor usage has the same issues as described for harbor use case above; logistics hubs are likely to be in built-up areas, with many other potential uses for the spectrum, and as a result the opportunity cost of PAL leasing may be very high. Unlike the case of harbor, however, the use of spectrum outdoors at the logistics hub is likely to be restricted to fixed point-to-point links, and this further reduced the likelihood of CBRS spectrum being used, since higher frequencies, such as 26 GHz can be used instead with little loss in quality.

The spectrum needs of a logistics hub are therefore most likely to be met with a mix of CBRS and other bands. The relevant mix will depend on the usage of CBRS in surrounding regions, derived from the demand for fixed wireless access or other services. Indeed, this demand will affect CBRS in two ways: will interference clash with high demand (preventing PAL leasing or GAA at all) or will low demand mean there is no PAL sublicensing at all?

Table 3. CBRS suitability to use cases.

	Mine	Harbor	Windmill park	Hub
CBRS suitability	++	−	++	Indoor: +++ Outdoor: −
Interference risks	Low	High	Low	Indoor: low Outdoor: high
Use of spectrum	GAA sufficient PAL license in some cases	PAL necessary depends on other services in the county	GAA PAL sub-license	GAA PAL outdoor
Sub-leasing	Very low opportunity cost for PAL holder	High opportunity cost	Low opportunity cost for PAL holder	High opportunity cost
Bandwidth (10 MHz carrier)	2 or 3	2 or 3	2 or 3	3
CBSD sites (3 sectors)	18/12	Land 45/32 Water 8/5	19/13	14
Limitations	Reception of heartbeat in some cases	County-level PAL awards unfeasible	Wide coverage from masts	Other spectrum usage on site

4.5 Discussions

The heterogeneity of industrial use cases, applications and requirements leads to a flexibility requirement in spectrum award and use, which makes CBRS relevant and suitable for small-cell deployments and private LTE applications in industry. In its latest regulatory updates, CBRS appears as a favorable license scheme to industry as it responds to a growing need to bridge the gap between very large projects with direct mobile operator involvements and large numbers of smaller projects that are too small for mobile operators to consider, but too complex for enterprises to handle on their own. Flexibility of spectrum use and license periods of 10 years with renewal possibility are an incentive to investment. Furthermore, the CBRS concept was found to leverage all the three forces of the long tail framework [31]: *Democratizing the tools of production* through access to "free" spectrum, *cutting the costs of consumption* by democratizing distribution with web-scale automatization and *connecting supply and demand* via marketplace via SAS.

On the other hand, CBRS displays certain characteristics that appear to be unfavorable to some IIoT use cases. Using CBRS spectrum incurs incremental costs, while providing a low incremental reliability. In this way, the value of CBRS spectrum is based on the operator' willingness to pay and thus largely based on the value put in the incremental reliability and flexibility compared to unlicensed spectrum options. Another CBRS constraint is the mandatory heartbeat mechanism that makes its application unreliable or not feasible in some use cases. Furthermore, FCC policy decisions may make PAL-leasing unrealistic for the some IIoT use cases. Counties are appropriate for rural ISP type operators but not for micro-operators serving distinct local facility.

The cost of using CBRS consists of the *licensing* cost of spectrum, where PAL holders must consider the opportunity cost of not having access to the subleased spectrum to assess this cost, and so this is not driven directly by the private LTE network; and the cost of additional *spectrum control and monitoring equipment*. Environmental Sensing Capability (ESC) [17] is mandatory to detect military radar operations before operating CBRS. This may be provided by the SAS operator, or by a third-party ESC operator, and these costs will be passed on to end users through higher service fees. Although these costs may be small, they will still be non-zero, meaning that private network operators must receive a clear benefit from using CBRS spectrum. Users should consider how to quantify the benefits by thinking of willingness to pay in terms of QoS and reliability through business continuity insurance, existing investment in failsafe and security and the cost of loss of productivity These benefits are going to differ for every specific case, and in almost every example deriving a robust estimate of benefits will be impossible for a third party given the need for confidential operating information and business decisions. Required spectrum monitoring and controlling equipment may present a barrier to entry and know-how cost is also high, even if supplied by the SAS: If costs and related SAS fees become too high, alternative technologies will be used instead.

5 Conclusions

Current spectrum regulation forces vertical business to mostly rely on the MNOs. Direct services to verticals are possible only through shared spectrum or unlicensed bands, and spectrum brokering emerging as an alternative. Main stream spectrum regulation for 5G promotes 100% spectrum assignment to MNOs. The growing need for regional quality spectrum by vertical IIOT application is creating a conflict between verticals and traditional operators.

Verticals' IIOT use case specific applications differs from mobile broadband use case in several ways. Local private network deployments are typically in distinct limited coverage areas. Dedicated spectrum resources of 10–30 MHz bandwidth are needed. Leased or shared use of bands may be possible as access to spectrum through auctions is not considered feasible. Timely access to free/low cost spectrum with variable license period are requirements driven by business needs. IIOT applications have distinct application specific technical performance requirements (e.g., throughput, latency, transmission symmetry), and several IIOT applications set also high requirements for local data security and privacy.

The heterogeneity of industrial use cases, applications and requirements leads to a flexibility requirement in spectrum award and use, which makes CBRS relevant and suitable for small-cell deployments and private LTE applications in industry. In its latest regulatory updates, CBRS appears as a favorable license scheme to industry. Flexibility of spectrum use and license periods of 10 years with renewal possibility are an incentive to investment. This paper studied four industry Internet of things use cases: a mine, a harbor, a windmill park and a logistics hub. The results show that use case that appear to make the most of CBRS spectrum use is the logistics hub in indoor environment. There may be a good availability of spectrum in mines and windmill park areas with low interference risks, but these use cases may face an issue by not being able to access the heartbeat signal. Both the harbor use case and the outdoor environment of the logistics hub appear as being less likely to make the most of CBRS spectrum.

In addition to access to affordable quality spectrum, there could be other regulatory issues to address when operating private networks, including: other licensing requirements for operation of telecommunications systems and any non-spectrum license or authorization fees payable. Policy makers should try to keep the overall complexity and costs as low as possible, and PAL holders should be incentivized to price PALs just above opportunity cost to encourage as much use as possible.

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References

1. Downes, L., Nunes, P.: Big Bang Disruption: Strategy in the Age of Devastating Innovation Big-bang disruption, vol. 91. Penguin Group, New York (2014)
2. Mandel, M., Swanson, B.: The coming productivity boom. The Technology CEO Council (2017)
3. 5GPPP: 5G empowering vertical industries: Roadmap paper. The 5G Infrastructure Public Private Partnership, Brussels (2016)

4. Ahokangas, P., Matinmikko, M., Yrjölä, S., Okkonen, H., Casey, T.: "Simple rules" for mobile network operators' strategic choices in future cognitive spectrum sharing networks. IEEE Wirel. Commun. **20**(2), 20–26 (2013)
5. Yrjölä, S., Ahokangas, P., Matinmikko-Blue, M.: Novel context and platform driven business models via 5G networks. In: The 2018 IEEE PIMRC Proceedings, Genova, Italy (2018)
6. NGMN Alliance: NGMN 5G White Paper (2015)
7. ITU-R: M.2083, IMT Vision - Framework and overall objectives of the future development of IMT for 2020 and beyond. https://www.itu.int/rec/R-REC-M.2083-0-201509-I/en. Accessed 02 Jan 2019
8. Federal Ministry for Economic Affairs and Energy: Platform Industrie 4.0. https://www.plattform-i40.de/I40/Navigation/EN/Industrie40/WhatIsIndustrie40/what-is-industrie40.html. Accessed 02 Jan 2019
9. Industrial Internet Consortium (IIC). https://www.iiconsortium.org/members.htm. Accessed 02 Jan 2019
10. 5G Alliance for Connected Industries and Automation (5G-ACIA): White Paper, 5G for Connected Industries and Automation (2018)
11. Cramton, P.: Spectrum auction design. Rev. Ind. Organ. **42**(2), 161–190 (2013)
12. Zander, J.: Beyond the ultra-dense barrier: Paradigm shifts on the road beyond 1000x wireless capacity. IEEE Wirel. Commun. **24**(3), 96–102 (2017)
13. Guirao, M.D.P., Wilzeck, A., Schmidt, A., Septinus, K., Thein, C.: Locally and temporary shared spectrum as opportunity for vertical sectors in 5G. IEEE Netw. **31**(6), 24–31 (2017)
14. Ahmed, A.A.W., Markendahl, J., Ghanbari, A.: Evaluation of spectrum access options for indoor mobile network deployment. In: IEEE 24th International Symposium on Personal, Indoor and Mobile Radio Communications Proceedings, London, pp. 138–142 (2013)
15. ETSI: TR 103 588 Feasibility study on temporary spectrum access for local high-quality wireless networks (2018)
16. European Commission: RSPG18-005 Strategic spectrum roadmap towards 5G for Europe: RSPG second opinion on 5G networks. Radio Spectrum Policy Group (2018)
17. FCC: Part 96 - Citizens Broadband Radio Service (2015)
18. ECC: Report 205 Licensed Shared Access (LSA). European Conference of Postal and Telecommunications Administrations, Electronic Communications Committee (2014)
19. Sohul, M., Yao, M., Yang, T., Reed, J.: Spectrum access system for the citizen broadband radio service. IEEE Commun. Mag. Year **53**(7), 18–25 (2015)
20. Palola, M., et al.: Field trial of the 3.5 GHz citizens broadband radio service governed by a spectrum access system (SAS). In: IEEE International Symposium on Dynamic Spectrum Access Networks Proceedings, pp. 1–9 (2017)
21. Mustonen, M., Matinmikko, M., Palola, M., Rautio, T., Yrjölä, S.: Analysis of requirements from standardization for Licensed Shared Access (LSA) system implementation. In: IEEE International Symposium on Dynamic Spectrum Access Networks Proceedings, pp. 71–81 (2015)
22. Yrjölä, S., Ahokangas, P., Matinmikko, M.: Evaluation of recent spectrum sharing concepts from business model scalability point of view. In: IEEE International Symposium on Dynamic Spectrum Access Networks Proceedings, pp. 241–250 (2015)
23. Mandel, M.: Long-Term U.S. Productivity Growth and Mobile Broadband: The Road Ahead. Progressive Policy Institute (2016)
24. McKinsey Global Institute: The internet of things: mapping the value beyond the hype (2015)

25. McKinsey: Manufacturing the future: The next era of global growth and innovation. https://www.mckinsey.com/~/media/McKinsey/Business%20Functions/Operations/Our%20Insights/The%20future%20of%20manufacturing/MGI_Manufacturing%20the%20future_Executive%20summary_Nov%202012.ashxa. Accessed 02 Jan 2019
26. The State Council People's Republic of China: Made in China 2025. http://www.gov.cn/zhengce/content/2015-05/19/content_9784.htm. Accessed 02 Jan 2019
27. Lavender, T., et al.: Use cases, spectrum requirements and valuation of spectrum for private LTE. PLUM Consulting (2018)
28. 3GPP: TR 22.804 Vl.0.0 Study on Communication for Automation in Vertical Domains (2017)
29. Bundesnetzagentur (BNetzA), German National Regulatory Authority: Electronic Communications Services, Spectrum for wireless access for the provision of telecommunications services. https://www.bundesnetzagentur.de/EN/Areas/Telecommunications/Companies/FrequencyManagement/ElectronicCommunicationsServices/ElectronicCommunicationServices_node.html. Accessed 02 Jan 2019
30. FCC: Increasing Incentives for Investment and Innovation in 3.5 GHz Band. https://www.fcc.gov/document/increasing-incentives-investment-and-innovation-35-ghz-band. Accessed 02 Jan 2019
31. Anderson, C: The Long Tail: Why the Future of Business Is Selling Less of More. Hyperion (2006)