TV White Spaces and Licensed Shared Access Applied to the Brazilian Context

Raphael B. Evangelista(✉), Carlos F. M. e Silva, Francisco R. P. Cavalcanti, and Yuri C. B. Silva

Federal University of Ceará, Fortaleza, CE, Brazil
raphael@gtel.ufc.br

Abstract. The spectrum "scarcity" problem can be tackled by promoting a more efficient use of this resource. Spectrum sharing techniques, e.g. TV White Spaces (TVWS) and Licensed Shared Access (LSA), are good solutions for this problem and there are already regulation and standardization efforts worldwide. The Brazilian regulatory scenario is not that advanced regarding spectrum sharing, but there are already some actions towards the adoption of this concept for the Brazilian reality. This paper gives an overview of the spectrum sharing concept and the Brazilian telecommunications regulatory scenario. Case studies regarding the employment of both TVWS and LSA in the Brazilian scenario are also presented as a way to bring more attention to the adoption of those concepts in the country.

Keywords: Spetrum sharing · TVWS · LSA

1 Introduction

There is a considerable increase in mobile data traffic. According to forecasts [8], this traffic will grow sevenfold between 2016 and 2021, and it will reach, by the end of 2021, 49 exabytes per month. This extra boom is mainly due to the popularization and proliferation of devices worldwide, like smartphones and tablets, as well as the development of data-hungry applications.

On one hand it is expected that there will be 29 billion connected devices in the whole world by 2022, thanks to the advancements in technology and development of concepts, like Machine-to-Machine (M2M), Internet of Things (IoT), and Internet of Vehicles (IoV), to name a few [9]. On the other hand, applications which demand high data rate, like video streaming and online gaming, are becoming more common. In order to be capable of dealing with this high traffic, the next generation of communication systems, Fifth Generation (5G), predicted to be launched by 2020, expects to provide a capacity increase of one to ten thousandfold compared to the previous generation, Fourth Generation (4G) technology [24]. As a consequence of this, a huge demand on Radio Frequency (RF) spectrum is also expected. However, this natural resource is limited, and

P. Marques et al. (Eds.): CROWNCOM 2017, LNICST 228, pp. 298–309, 2018.
https://doi.org/10.1007/978-3-319-76207-4_25

currently it is suffering from scarcity. Actually, this is an apparent scarcity, since there are lots of bands (generally high GHz bands) not explored by any service.

The easiest way of trying to solve this “scarcity” problem is to explore the higher frequency bands, in particular cm and mm wave bands, which have a lot of spectrum available [2]. However, this approach does not cover all use cases, since waves in high bands present hostile propagation characteristics, e.g. strong pathloss, atmospheric and rain absorption, low diffraction around obstacles, etc.; and therefore may not always be compatible with all applications, for example, communications where devices are found in a mobile and very dynamic environment.

The massive Multiple Input Multiple Output (MIMO) technique is a very good approach to deal with the propagation characteristics in higher bands. The utilization of large antenna arrays allows a better steering of the signal transmission power towards the direction of interest, enhancing the transmission gain. Furthermore, it allows the interference to be better managed, which also improves the wireless communication in a network [2].

Another solution is to promote a more efficient spectrum use in frequencies which are overused, typically the lower ones. The traditional way the spectrum is managed in most countries, even in Brazil, is through the granting of spectrum licenses for exclusive use on a long-term basis. However, in some cases, a spectrum owner does not use the resource assigned to him during all the time and in all geographical areas. Despite the fact that this static approach is very robust in the avoidance of harmful interference among services, it leads to the underutilization of spectrum.

Spectrum sharing comes out as a very good option to solve this inefficiency problem, enabling a more dynamic access to the RF spectrum and allowing this resource to be shared in a flexible way. This concept should not be confused with the unlicensed use of spectrum, e.g. Industrial, Scientic and Medical (ISM) applications, where the spectrum in specific bands is shared without the need of license and with services being subject to interference of other services.

This work is focused on two concepts of different generations of spectrum sharing: TV White Spaces (TVWS), being part of the first generation, and Licensed Shared Access (LSA), of the following one. Each one having its particularities and well-defined use cases.

Brazil, as a geographically extensive country, has serious problems regarding the digital inclusion, mostly in rural or remote parts of it. In these regions, generally, there is no broadband Internet access or it is expensive and with poor quality.

Either TVWS or LSA could be used in different use cases, as it is presented in this work, to solve the problems previously exposed. It should be emphasized that the contributions of this work related to both techniques are focused on the Brazilian context.

The rest of the paper is organized as follows. Section 2 discusses about the spectrum sharing concept and describes TVWS and LSA approaches. Section 3 presents the spectrum regulatory scenario in Brazil. A discussion about the application of spectrum sharing concepts in the Brazilian scenario is made in Sect. 4. The paper is finally concluded in Sect. 5.

2 Spectrum Sharing

Spectrum Sharing has different meanings. For a National Regulatory Authority (NRA), it means to provide more spectrum for a service without interfering or bringing harm to the existing users of that resource.

The focus of this work is on Dynamic Spectrum Access (DSA), where the sharing is organized among users and depends on demands of systems that share the resources, with the allocations changing with time in a dynamic manner. This branch of spectrum sharing should not be confused with the co-existence concept, where the shared spectrum is provided in a fixed or static manner, in a way that there is no interference among users using the same or adjacent spectrum [22].

The main problem that comes with the DSA employment is the interference that new users (also called secondary users) of the spectrum can bring to the original users (or primary users) of this resource. For the traditional case where a service has an exclusive license to the spectrum, the unwanted emissions that can cause interference in other services in the same or adjacent bands are regulated through spectral masks, which are generally harmonized across the world regions. For DSA, there is a sharing of spectrum in different radio technologies, then some limits should be established regarding the transmit power and/or the sharing distance, so that one service does not cause interference to the others and vice-versa, compromising the communication.

The two spectrum sharing techniques addressed in this section are TVWS and LSA.

2.1 TVWS

TVWS is a portion of spectrum in the range of Very High Frequency (VHF) and Ultra High Frequency (UHF) that is not in use at a particular time and location and, therefore, it represents a new opportunity for wireless communication systems in a frequency band that has good propagation characteristics. They emerge as a by-product of the Digital Switchover (DSO), also known as the digital television transition; a process in which analog Television (TV) broadcasting is replaced by the digital one. The DSO has been successfully completed in various countries and it is still in progress in some others. In Brazil, for example, the Ministry of Communications established in 2014 a DSO plan, starting in 2015 and gradually to be implemented until December 2018 [25].

The basic principle of TVWS consists of allowing unlicensed, secondary users to access spectrum at specific geographic locations and/or during specific time intervals, not interfering with terrestrial TV transmission or reception, or any other primary service. Importantly, the TVWS regulations require White

Space Devices (WSDs) to obtain authorization before they can transmit, and require those devices to cease operation when they are located within protected areas [26].

Since waves at the frequency range of TVWS have good propagation characteristics, the application of this concept is more envisioned for use cases where there is a need for wireless coverage extension. For example, TVWS can be used to improve the coverage of a 4G network of a mobile operator in rural locations.

The potential uses of TVWS are still being considered by the industry and regulatory bodies, because there are still uncertainties about what sort of TVWS availability is realistic, and the amount of TVWS spectrum available can change significantly from one country to another [17]. Many countries have studied the use of TVWS, but only two of them currently have a proper regulation model that permits the license-exempt use of TVWS: the United States of America (USA) with Federal Communications Commission (FCC), and the United Kingdom (UK) with Office of Communications (Ofcom).

The extension of spectrum occupancy of TVWS has opened up a new dimension for a variety of potential applications. The merit of TVWS exploitation is to provide innovative applications not fully supported by existing technologies, and to offer resource expansion to existing applications for enhanced performance [1]. One company that has begun developing rural broadband equipment using TVWS is Carlson Wireless Technologies[1] from USA. The company has more than a decade of experience in developing effective rural solutions. These wireless radios can provide broadband data rate over much larger distances than the existing Wireless Fidelity (Wi-Fi) routers, and in December 2013, FCC approved its commercial and unlicensed use in the USA.

2.2 LSA

While TVWS is considered a technology of the first generation of spectrum sharing, LSA is the key example of a concept of the next generation [24].

LSA, firstly known as Authorized Shared Access (ASA), is defined as a new complementary regulatory framework which was developed in Europe as a joint effort of the Electronic Communications Committee (ECC), the European Conference of Postal and Telecommunications (*Conférence Européenne des administrations des Postes et des Télécommunications*, CEPT) and the European Telecommunications Standards Institute (ETSI). This framework allows the so-called LSA licensee (secondary user) to access additional spectrum resources, which are underutilized by its incumbent user. It is based on an agreement called sharing framework which is defined by three stakeholders: incumbent user (primary user), LSA licensee, and NRA. The sharing framework includes technical and operational conditions which the users are subject to, aiming at the protection from harmful interference for both incumbent and LSA licensee.

The main feature which differentiates LSA from the other spectrum sharing techniques is its individual licensing regime, which means that the licensee in

[1] http://www.carlsonwireless.com/.

order to use the spectrum needs an individual authorization that contains its rights and obligations. The advantage of this regime is that these sharing rules, which the licensees must follow, guarantee that the interference might be managed, enabling protection from interference and predictable Quality of Service (QoS) for both primary and secondary users [15].

Differently from TVWS, LSA is not expected to be applied to enhance wireless coverage. The application of this concept is more related to the provision of additional spectrum access and predictable QoS for services. The first use case of LSA is the application of the concept to provide additional spectrum for mobile broadband services in the 2300 MHz to 2400 MHz band. This band is defined by the Generation Partnership Project (3GPP) as Long-Term Evolution (LTE) Band 40, allocated to mobile services and identified for International Mobile Telecommunications (IMT) globally in the International Telecommunication Union (ITU) Radio Regulations [11]. It should be mentioned that the basic principles for the LSA operation are not dependent on the frequency, allowing it to be applied to other bands [24].

The system components are standardized by ETSI and described in [11]. The system requirements and architecture are specified in [10,12].

The basic architecture of the LSA system is composed by a database called LSA repository, which manages the LSA spectrum. Besides that entity, there is the LSA controller, which communicates directly with the LSA repository and, according to the information in the last entity, it grants access or requests the evacuation of the band by an LSA licensee through a control mechanism.

3 Brazilian Regulation Scenario

The NRA in charge of the regulation of telecommunications in Brazil is the National Telecommunications Agency (*Agncia Nacional de TelecomuniÇões*, Anatel) which was created in 1997 by the (*Lei Geral de TelecomunicaÇões*, LGT), a very important law for the regulation of this sector, providing the ground rules for the telecommunications market and contributing to the development of the country [4].

Anatel is an independent agency linked to the former Ministry of Communications (currently Ministry of Science, Technology, Innovation and Communications), which is in charge of establishing the public policy of the telecommunications sector in Brazil.

Among the attributions of the Brazilian NRA, can be highlighted, the management of the RF spectrum, being Anatel responsible for its rules and regulation. Anatel designs and updates the RF spectrum allocation, distribution and destination plan. The attributions follow the ITU recommendations defined for region 2. The distribution and destinations of RF bands for the services and telecommunications activities consider the present needs and future expansion [28].

According to the LGT and established by Anatel, as previously mentioned, RF bands are designated to specific telecommunications services, and, hence, companies exploiting a service using a given band can only be granted license for a spectrum designated for that band. Furthermore, as the RF spectrum is a limited resource and a public property, its economic exploitation is only allowed by Anatel grant through concession, permit, or authorization [4], obtained generally through bidding processes, so that there is fairness in the competition among stakeholders.

Still, according to the LGT, there are two exceptions where the exploitation of the RF spectrum is allowed without the need of authorization: the use of this resource by the army and by restricted radiation equipment.

Regulation for the use of the RF spectrum went through recent modifications in 2016 under an Anatel Resolution [5]. From that time on there are some possibilities for a kind of secondary market of spectrum, since it enables the spectrum that was licensed to a primary user to be explored in a secondary basis by another player upon a prior authorization of Anatel, if the incumbent is not yet utilizing the resource properly.

Another step towards spectrum sharing was recently taken by Anatel, when two mobile operators were allowed to perform an agreement in the sharing of a Radio Access Network (RAN) of the 450 MHz band in order to improve rural coverage. With that, Anatel considered the benefits, like price reductions, and gain in QoS, that the sharing of infrastructure and spectrum could bring to the telecommunications sector through efficient resources usage [28].

These efforts show a certain progress towards a more efficient RF spectrum management in Brazil, and it places both TVWS and LSA in the Brazilian regulation horizon, since these concepts are very good options for more efficiency in the utilization of the spectrum.

4 Spectrum Sharing Trends in Brazil

The access to information and knowledge are essential for a country to be competitive in a globalized economy. In this sense, broadband Internet becomes a very important element for the country infrastructure nowadays [14]. Hence, the economic, social and political development of Brazil can be accelerated by improving the broadband access, speed, quality and decreasing its cost. This enhancement can be translated into technological advances, cost reduction and service quality improvements in various areas, e.g. health, education, and public security. Furthermore, it can be considered an investment in the research field.

Brazil has achieved considerable advances in broadband, but in comparison with other countries, it is still expensive, slow and usually of poor quality. In [13] the rank of Brazil in 2015 with regard to other countries can be seen for different categories, like fixed broadband Internet prices, fixed and mobile broadband Internet subscriptions, mobile network coverage, etc. The status of broadband in Brazil is shown in [20], comparing some statistics from 2006 to 2014. It can be noticed a certain progress in digital inclusion but at a slow pace, and the situation in rural and remote regions and for poor people is still far from being acceptable. While there is Internet access in 54% of urban households, this percentage is just

22% in rural ones. Furthermore, in households of economically disadvantaged individuals, there is Internet access in just 14% of cases.

For rural or remote areas, a critical reason that makes the broadband access very difficult is the lack of interest from service providers in such areas. Brazil is a geographically extensive country, hence, an investment on providing such service in various regions (mostly rural or remote) would imply in an enormous expenditure on telecommunications infrastructure, what makes this practice very unattractive. As it can be seen in [25], there is poor coverage of Third Generation (3G) and 4G services of a Brazilian mobile operator in an important state of the country.

One way to increase the provision of wireless broadband in general is the employment of techniques or technologies to allow the RF spectrum to be used more dynamically and efficiently, so a broader range of stakeholders could have access to and explore wireless broadband. Either TVWS or LSA are very good tools for reaching this efficiency and dynamism of spectrum use.

At the moment, it seems that Anatel is particularly interested in fostering the development of telecommunications/broadband in rural and remote areas. This can be attested in the Anatel regulatory agenda, which indicates a movement towards the regulation of the use of TVWS for the development of broadband of Brazilian rural areas, as a regulatory impact analysis on the use of white spaces in VHF and UHF bands is expected to happen by the second semester of 2018 [30].

In Brazil, there is still no ongoing regulatory actions related to LSA, but there is already research regarding the application of this concept in the Brazilian scenario. In [27] there is a spectrum sharing proposal based on the LSA concept with its specificities, in order for it to be more appropriate to the Brazilian reality. The candidate frequency bands for LSA in Brazil are: 1.4 GHz (L-Band), 2.7 GHz (2500 MHz to 2690 MHz) and 3.5 GHz (3565 MHz to 3650 MHz). Furthermore, the effort in the direction of TVWS regulation is the first step towards the use of the spectrum sharing concept, hence there is some hope in the Brazilian regulatory scenario for LSA implementation in the near future.

4.1 TVWS Case Study

As previously mentioned, Brazil presents some problems related to Internet access in rural and remote areas. With the DSO in Brazil happening and expected to be concluded by the end of 2018, the opportunity for reallocating the TV spectrum is a reality, which opens opportunities to introduce new business models, players and technologies like TVWS into the Brazilian market [25]. One of the major obstacles to providing mobile broadband connectivity in semi-urban and rural areas of Brazil is the weak economic appeal of such areas for operators to deploy their telecommunications infrastructure.

This case study idealizes the use of TVWS to address the challenge in providing mobile broadband to rural or remote areas in the Ceará state in the regions around the Digital Belt of Ceará (*Cinturão Digital do Ceará*, CDC), since there are many white space channels available in such areas [25]. The good propagation characteristics at the TVWS band compared with the current band used in LTE in Brazil means less base stations covering larger spaces, which is a better scenario to attract the attention of mobile operators to invest in such areas.

The CDC was implemented in 2010 and the investments in such infrastructure were about R$ 70 million. The project managed to reach 48% reduction in expenditures with Ceará state Operational Expenditure (OPEX), attending, at the beginning, Governing bodies, schools, hospitals and police departments. The "excess" of fibers enabled partnerships with the private sector, which brought financial and technological development to some rural and suburban regions of the state. The CDC infrastructure is made of redundant fiber optic ring and ramifications comprising more than 3000 km, with 24 optical fiber cables and branches with 12 fibers; and the access in the last mile is made through Worldwide Interoperability for Microwave Access (WiMAX) technology [29]. The use case consists in using the CDC infrastructure to provide LTE services using the white space channels available in each location (LTE over TVWS scenario). This case serves as a basis to be implemented in any other region with similar characteristics.

Since the locations of licensed Digital TV (DTV) transmitters and their corresponding service areas are known, it is reasonable to assume that a database with maps of possible locations for TVWS networks could be implemented (Geolocation Database (GLDB)). In this scenario, the WSDs obtain the available TV channels via querying a certified GLDB, instead of sensing the local spectrum environment. Due to this fact, the GLDB needs to have updated information about the TVWS availability.

The TVWS applied along with the CDC infrastructure opens up a new dimension for a variety of potential applications. Another possibility to provide digital inclusion in such regions could be the deployment of a Super Wi-Fi scenario using the TVWS as backhaul, following the idea implemented in India [21]. This solution could use modems in indoor environments to receive TVWS signal sent by Internet service providers. The receiving equipment would process this signal and forward it to 2.4 GHz or 5.8 GHz, providing wireless Internet services to the end users.

4.2 LSA Case Study

Brazil is very rich in natural resources, holding a very large mineral repository. The Brazilian mining industry has a great importance worldwide, producing and exporting high quality ores, which makes mining a very important activity for the Brazilian economy. Brazil is very well ranked in the world for different minerals regarding its production and reserves. Forecasts show excellent perspectives for this economic activity for the next decades [23].

The importance of the mining industry makes the development of this activity crucial for Brazilian economy growth. In the current globalized world, to face competition, the industry must be in constant development so that the productivity is maximized. The Industry 4.0 is the concept used for the following industrial revolution that is about to happen and which was defined in Germany, one of the world top competitive manufacturing industries. This concept is expected to improve the "industrial processes involved in manufacturing, engineering, material usage and supply chain and life cycle management" [19].

The key feature of Industry 4.0 and the enabler of such improvements is what has been called the smart factory, which is a factory that assists people and machines in performing their tasks through the awareness of the physical and virtual world. This awareness is allowed thanks to a network compatible equipment called Cyber-Physical Systems (CPS) supplied with sensors and actuators, which monitor physical industrial processes, helping to decentralize decisions. In the smart factories, these CPSs are interconnected using the concept of IoT, so the industry is a network of automated machines and people, with the possibility of some activities being controlled remotely by the latter [16].

Regarding the automation process envisioned by Industry 4.0, the wireless factory automation is recently drawing more interest than the wired one, since the former presents attractive advantages, e.g. low installation and maintenance cost, higher flexibility.

One main challenge of wireless factory automation is its requirements regarding communications latency and reliability. Industrial applications like packaging machines need very strict requirements (latency less than 1 ms and block error probability around 10^{-8} or 10^{-9}) [3]. Such services with very rigorous requirements, mainly in respect to latency and reliability, were defined by ITU as Ultra-Reliable and Low-Latency Communications (uRLLC) [18].

In recent years, there were some advances in wireless technologies for factory applications, e.g. WirelessHART, ISA 100.11a, Industrial WLAN [7]. However, these solutions together with other proprietary ones operate mostly on unlicensed RF spectrum, and, hence, there are no QoS guarantees, since there is interference from other services using the shared band.

The employment of the Industry 4.0 concept to the mining industry in Brazil is a process that needs to occur in order to keep this sector competitive in the world market [6], and the application of the LSA framework concept is a good approach to address the challenges mentioned previously. The LSA band would be made available to the mining companies with QoS guarantees, since this is a key feature of the exclusive licensing basis of this concept. Despite that, this solution facilitates the granting of spectrum license to the companies, in comparison with the traditional bidding process, which happens not so often and has quite expensive bids.

The flexibility of LSA is another advantage for this case study. The definition of the sharing framework by the stakeholders facilitates that the conditions of the parts are met. For example, a mining company would require the spectrum just for a specific part of the country, for a certain time and with a particular bandwidth size.

The interference that one service could generate on another is an issue that needs to be considered carefully, since the interference management is made using data that is present at the LSA repository (e.g., incumbent location, maximum Effective Isotropic Radiated Power (EIRP)) together with a propagation model. Since the mining sites are very particular, with a irregular relief and big depressions, the propagation model is very different from the ones already studied and available in the literature. Therefore, it represents a critical part for which a certain importance must be given.

Using this approach, all the stakeholders are contemplated. The financial investment of the mining company would be addressed to the incumbent. The LSA licensee would have the access to the licensed spectrum with the QoS guarantees that it needs. The advantage for Anatel would be a more efficient use of the spectrum, alleviating, in this sense, the spectrum "scarcity" problem.

The same idea could also be employed to other industrial activities in which the application of the concept of Industry 4.0 is envisioned, e.g. agriculture and metallurgy.

5 Conclusions

Significantly more spectrum and much wider bandwidth than what is available today will be needed in order to reach the targets of future mobile broadband systems. It is visible that the fixed allocation scheme of frequency has resulted in an underutilization of the spectrum both spatially and temporally.

The spectrum sharing concept is an innovative option to solve the spectrum "scarcity" problem by promoting a more efficient use of this resource.

Brazil still has a lot to advance in the adoption of the spectrum sharing concept, as there were very few regulatory actions in that direction. The modifications in the regulation for the use of RF spectrum demonstrates a modest progress towards the secondary market, and TVWS regulation studies are already expected to happen by 2018. Nevertheless, there is still no visible effort related to the employment of the LSA concept in the Brazilian scenario.

This paper presents two case studies about the application of TVWS and LSA concepts for the Brazilian context. It is expected that this work brings the attention of Anatel and other Brazilian stakeholders to the application of those concepts and the benefits they could bring not only for the telecommunications sector, but also for the whole country economy.

As a future work, it can be performed a more quantitative approach, evaluating the case studies presented in this paper in terms of Capital Expenditure (CAPEX) and OPEX. Similar studies could not be found in literature, what makes such work of relevant importance for the development of spectrum sharing concept in the country.

Acknowledgment. The research leading to these results received funding from the European Commission H2020 programme under grant agreement no. 688941 (FUTEBOL), as well from the Brazilian Ministry of Science, Technology, Innovation, and Communication (MCTIC) through RNP and CTIC.

References

1. Alemseged, Y.D., et al.: TV White Space Spectrum Technologies: Regulations, Standards, and Applications. Ed. by Saeed, R.A., Shellhammer, S.J. CRC Press, Boca Raton (2012). ISBN 978-1-4398-4880-7
2. Andrews, J.G., et al.: What will 5G be? IEEE J. Sel. Areas Commun. **32**(6), 1065–1082 (2014). https://doi.org/10.1109/JSAC.2014.2328098. ISSN 0733-8716
3. Ashraf, S.A., et al.: Ultra-reliable and low-latency communication for wireless factory automation: from LTE to 5G. In: 2016 IEEE 21st International Conference on Emerging Technologies and Factory Automation (ETFA), pp. 1–8, September 2016. https://doi.org/10.1109/ETFA.2016.7733543. ISBN 978-1-5090-1314-2
4. República Federativa do Brasil - Imprensa Nacional, ed. DOU - Seção 1 135, July 1997. Lei no 9.472, de 16 de julho de 1997
5. República Federativa do Brasil - Imprensa Nacional, ed. DOU - Seção 1 213, November 2016. Resolução no 671, de 03 de novembro de 2016. ISSN 1677-7042
6. Agência Brasil.: Brazil: innovation key to mining and metallurgical industry to compete abroad, September 2016. https://goo.gl/EZELV2. Accessed July 2017
7. Christin, D., Mogre, P.S., Hollick, M.: Survey on wireless sensor network technologies for industrial automation: the security and quality of service perspectives. In: Future Internet 2010, pp. 96–125, 2 April 2010. ISSN 1999-5903. https://doi.org/10.3390/fi2020096
8. Cisco.: Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2016–2021, White paper. Cisco, February 2017
9. Ericsson.: Ericsson Mobility Report. Ericsson, June 2017
10. ETSI.: System architecture and high level procedures for operation of Licensed Shared Access (LSA) in the 2 300 MHz–2 400 MHz band, TS 103 235, October 2015
11. ETSI.: System Reference document (SRdoc); Mobile Broadband Systems in the 2300 MHz–2400 MHz band under Licensed Shared Access (LSA), TR 103 113, July 2013
12. ETSI.: System requirements for operation of Mobile Broadband Systems in the 2300 MHz–2400 MHz band under Licensed Shared Access (LSA), TS 103 154, October 2014
13. World Economic Forum.: The Global Information Technology Report 2015: ICTs for Inclusive Growth. Insight report (2015)
14. World Bank Group.: World Development Report 2016: Digital Dividends (2016). https://doi.org/10.1596/978-1-4648-0728-2
15. Gundlach, M., et al.: Recent advances on LSA in standardization, regulation, research and architecture design. In: 2014 1st International Workshop on Cognitive Cellular Systems (CCS), pp. 1–5. IEEE, September 2014. https://doi.org/10.1109/CCS.2014.6933807. ISBN 978-1-4799-4139-1
16. Hermann, M., Pentek, T., Otto, B.: Design principles for industrie 4.0 scenarios. In: 2016 49th Hawaii International Conference on System Sciences, pp. 3928–3937 (2016). https://doi.org/10.1109/HICSS.2016.488
17. Horvitz, R., et al.: TV White Spaces. A Pragmatic Approach. Ed. by Pietrosemoli, E., Zennaro, M. 1st edn. ICTP-The Abdus Salam International Centre for Teoretical Physics, December 2013. ISBN 978-9295003-50-7
18. Ji, H., et al.: Introduction to ultra reliable and low latency communications in 5G. In: Computing Research Repository (CoRR) abs/1704.05565, April 2017. http://arxiv.org/abs/1704.05565

19. Recommendations for implementing the strategic initiative Industrie 4.0. Final report of the Industrie 4.0 Working Group, April 2013
20. Knight, P., Feferman, F., Fodistch, N. (eds.) Broadband in Brazil. past, present and future. Novo Século Editora (2016)
21. Kumar, A., et al.: Toward enabling broadband for a billion plus population with TV white spaces. IEEE Commun. Mag. **54**(7), 28–34 (2016). https://doi.org/10.1109/MCOM.2016.7509375. ISSN 0163-6804
22. Matyjas, J.D., Kumar, S., Hu, F. (eds.) Spectrum Sharing in Wireless Networks. Fairness, Efficiency, and Security. CRC Press, Boca Raton (2017). ISBN 978-1-4987-2635-1
23. Ministério de Minas e Energia.: Plano Nacional de Mineração 2030. Geologia Mineração e Transformação Mineral, April 2011
24. Mueck, M.D., Srikanteswara, S., Badic, B.: White paper: Spectrum Sharing: Licensed Shared Access (LSA) and Spectrum Access System (SAS), White paper. Intel (2015)
25. do Nascimento, M.F.S., et al.: TV white spaces for digital inclusions in Brazil. In: Revista de Tecnologia da Informação e Comunicação, **6**(2), 6–15 (2016). ISSN 2237-5104
26. Noguet, D., Gautier, M., Berg, V.: Advances in opportunistic radio technologies for TVWS. EURASIP J. Wirel. Commun. Netw. **2011**(1), 170 (2011). https://doi.org/10.1186/1687-1499-2011-170. ISSN 1687-1499
27. Ron, C.V.R., de Silva Mello, L.A.R., de Almeida, M.P.C.: A spectrum sharing proposal based on LSA/ASA for the Brazilian regulatory framework. In: 2017 IEEE Wireless Communications and Networking Conference (WCNC), pp. 1–6, March 2017. https://doi.org/10.1109/WCNC.2017.7925440
28. da Silva, R.B.F., da Silva, C.T.R.: Spectrum regulation in Brazil. IEEE Wireless Commun. **23**(3), 2–3 (2016). https://doi.org/10.1109/MWC.2016.7498067. ISSN 1536-1284
29. Empresa de Tecnologia da Informaço do Ceará (ETICE).: Impacto socioeconomico do Cintur ao Digital do Ceará (2016). https://goo.gl/5c2cMJ. Accessed July 2017
30. Agencia Nacional de Telecomunicações.: Portaria No 491, de 10 de Abril de 2017. April 2017