Study on Fixed and Dynamic Spectrum Access Models for Cellular Networks

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Abstract: Radio frequency spectrum is a scarce resource, hence its effective and efficient utilization for contemporary and future technologies is of paramount importance. This paper mainly focuses on analysing conventional models for spectrum management, such as command and control and market-based models, and their inefficacy to serve the upcoming technological demands globally. Generally outlined observations concerning spectrum mismanagement include lesser availability of unassigned spectrum and under-utilization of spectrum allocated to passive users. Due to the considerable urge for flexible spectrum assignment framework models and policies, new spectrum assignment approaches, such as Dynamic Spectrum Access, are investigated. Moreover, models such as Licensed Shared Access (LSA), which evolved from Europe, and Citizen Bands Radio Service (CBRS) from North America are also evaluated in this paper as potential choices for future spectrum management in Pakistan. In the aforesaid models, spectrum is shared among multiple users as per time, place and dimensions, keeping in view the security and priority of incumbent and licensed users. In addition, the efficiency of spectrum utilization and economic advantages of these models have also been analysed. Lastly, LSA and CBRS are studied comparatively, and spectrum management suggestions are made for effective implementation in Pakistan.

Keywords: Command and Control model, Market-based model, Dynamic Spectrum Access (DSA), Licensed Shared Access (LSA), Citizen Bands Radio Service (CBRS)

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Introduction

The radio spectrum is part of the electromagnetic spectrum, ranging from 1 Hz to 3000 GHz (3 THz). Electromagnetic waves in this frequency range, referred to as radio waves, have become widely used in modern technology, particularly in telecommunication. However, this paper is mainly concerned with the radio spectrum for cellular mobile. The International Telecommunication Union Radio Communication Sector (ITU-R) regulates radio spectrum to avoid interference among the radio spectrum users across the globe. Radio bands are typically classified into multiple frequency bands, and each band is reserved for a specific class of use. Within each band, users occupy different frequency ranges, transmitters, and guard bands to avoid interference. The capacity of wireless calls and data connections is all dependent on the available spectrum bandwidth. A small radio spectrum portion, within the available bandwidth, is incorporated in wireless products, such as mobile phones, terrestrial broadcast television and radio, satellite broadcasting, location systems like the Global Positioning System (GPS), Wireless Local Area Network (WLAN), remote control devices, and cordless phones. A major portion of the radio spectrum is allocated to or used by governmental and industrial areas, such as military and national security systems, satellite communication, maritime communication and navigation, aviation systems and weather radar.

Broadly speaking, the radio spectrum is divided into two bands, the licensed band and the unlicensed band. The licensed band refers to the spectrum which has been allocated to operators in a certain amount and for a certain time by a regulatory authority; it is utilized by the operators to provide multiple services to consumers according to the nature and application of the requirement, such as telephony, broadband and Internet Protocol Television (IPTV).

The Cellular Mobile Operators (CMOs) serve users through licensed bands, and hence the users pay for the services provided by the operators. Moreover, the licensed band sold by the regulatory authority to the CMO is deployed to provide multiple services, like voice over IP, broadband and multimedia communications. Through this procedure, the service users pay for the services provided by the CMOs. The unlicensed band is a small portion of spectrum that can be used by operators according to their needs without interfering with other licensed users, keeping in mind that certain regulatory requirements need to be attained, such as channel occupancy time, transmission power, and listen-before-talk mechanism (Saha, 2021). In some countries, the 2.4 GHz Industrial, Scientific, and Medical (ISM) band is used as an unlicensed band, while others use the ISM 5GHz band. The unlicensed band applications include free-to-access wireless technology, such as Wireless-Fidelity (Wi-Fi), Worldwide Interoperability for Microwave Access (WiMAX), Radio and Television.

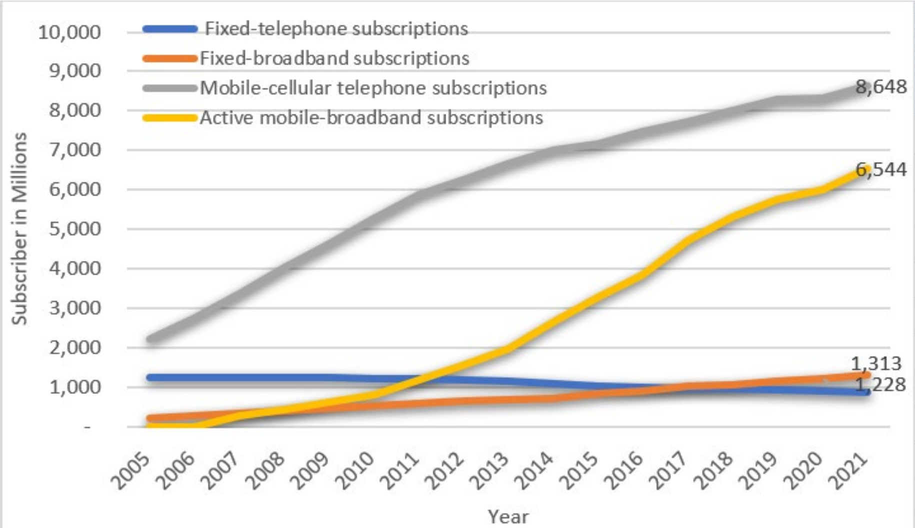

Figure 1. Global Trend of ICT developments, for Mobile cellular against other technologies (ITU, 2022)

Figure 1 illustrates that wireless personal communication has become the most widespread technology nowadays. The global number of active cellular mobile subscriptions reached 8.6 billion by 2021 (ITU, 2022). According to a forecast, there would be 8.7 billion handheld mobile devices worldwide and 4.4 billion machine-to-machine connections by 2023 with new data-hungry multimedia services, real time traffic data and 8K television (Cisco, 2020). Demand for radio spectrum is increasing with the number of wireless devices and bandwidth-consuming content: regulatory management of spectrum needs to ensure maximum social and economic benefit from the use of this finite and scarce resource (Radio Spectrum, 2015).

Multiple conventional approaches have been adopted to manage the scarce radio spectrum resource, such as the administrative Command-and-Control approach, market-based approach, and spectrum commons. The inefficacy of conventional models has led the market and attention of academia to dynamic frequency allocation models, such as Citizens Band Radio Service (CBRS) and Licensed Shared Access (LSA), for future management of radio spectrum and upcoming technologies.

Radio Spectrum Planning, Management and Regulation in Pakistan

Currently, in Pakistan, 189 million mobile users and 108 million Internet users, in mostly all fields of telecommunications, such as radio and television broadcasting, civil aviation, satellites, defence services and mobile communication, depend on radio frequency spectrum and its specified allocations. Under the standard framework, defined by ITU-R, the responsibility of further sharing and managing radio spectrum resources is shifted to the national regulatory bodies. The Pakistan Telecommunication Authority (PTA) is the national regulatory body for establishment, operations, and maintenance of the telecom sector (PTA, 2022a); whereas the Frequency Allocation Board (FAB) is responsible for radio spectrum

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assignment, and management (FAB, 2022a). Moreover, the Ministry of Information Technology (MoIT) is the government entity concerned with information technology and telecommunications for planning, policy making and legislation (MoIT, 2022).

Over the last decade, the usage of, as well as demand for, the radio spectrum has increased dramatically in the whole world. In this regard, Pakistan has faced a similar trend, and sees the same trend ahead, for further usage and demand, driven by growing data transmission rates, and increasing numbers of wireless devices, such as smartphones, laptops, tablet devices, and Internet of Things (GSMA, 2022). The demand for wireless broadband has also soared due to technological innovation, such as Third Generation (3G) and Fourth Generation (4G) mobile services, and now the upcoming Fifth Generation (5G) technology, and the rapid expansion of wireless Internet services that will further push the demand for effective spectrum requirements (Shaukat, 2015). On the administrative side, spectrum management is organized with proper spectrum planning, analysis, allotment, monitoring, and application, and re-enforcement of all rules and regulations of radio waves. The table of allocation is followed and updated by ITU-R, which is further revised at each World Radiocommunication Conference (WRC). National procedures for spectrum allocation can be summarized as:

- A table of frequency allocation maintained by the FAB is the initial draft that has been put in place for reviewing assignment and allocation to users with proper band and channel plans for spectrum management.
- The FAB receives applications (proposals include bandwidth, area of service and transmit power) from various departments, such as the Pakistan Telecommunication Authority (PTA), Pakistan Electronic Media Regulatory Authority (PEMRA) and governmental bodies, for assignment of radio frequencies. It assigns radio frequencies with proper technical parameters after technical evaluation on spectrum management tools and review of the frequency spectrum plan, while fulfilling national obligations, rules and regulations.
- Approval or disallowance of the relevant application in light of the decision by the Board is sent to PTA and PEMRA for license issuance or otherwise.
- While issuing the new bands, spectrum is made available as per Government policy and defined regulations.
- License Exempt spectrum will be made available after conforming with ITU-R radio regulations; devices should be approved and follow international and PTA standards ensuring non-interference (PTA, 2022b).
- Amateur wireless licenses are also issued to users who comply with the standard eligibility criteria defined by PTA (PTA, 2018).

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Pakistan, as situated in Region 3 and as a signatory to International Telecommunication Union (ITU) convention, is also following a conventional administrative and market-based approach for the regulatory framework all over the country. In this regard, the frequency spectrum allocated in Pakistan ranges from 9 kHz to 275 GHz for various applications, such as fixed, mobile, mobile-satellite (earth-to-space), radio astronomy, radio navigation, radio navigation-satellite, and space research, while 275 GHz to 3000 GHz is not allocated (FAB, 2022b).

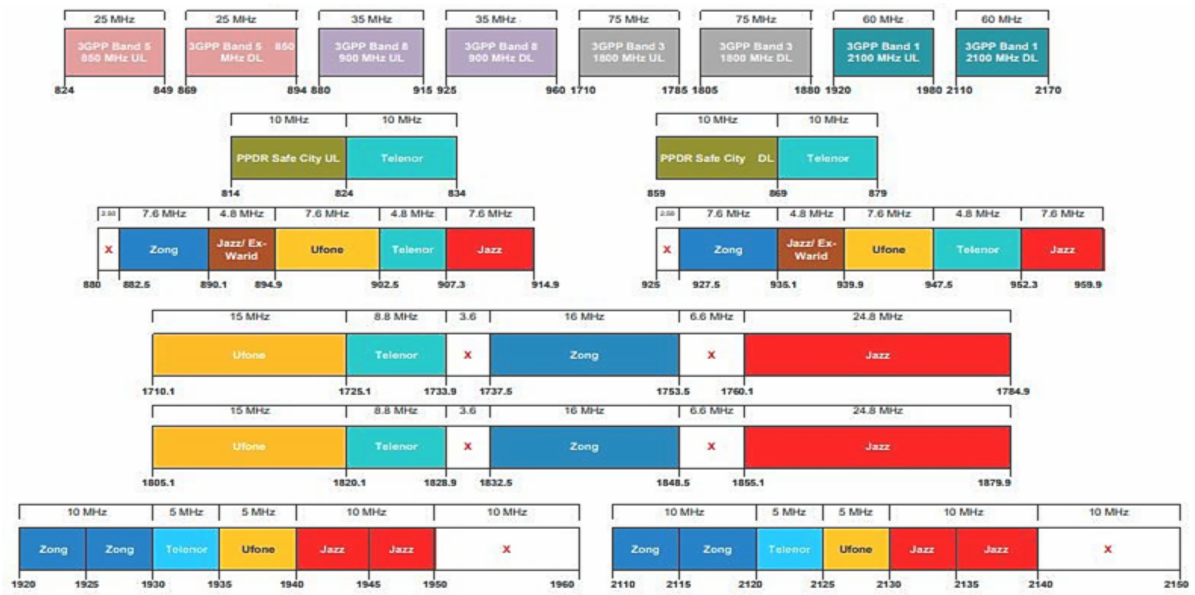

Figure 2. Cellular Assignment in Pakistan (Cellular Assignments in Pakistan, 2022)

Figure 2 presents the complete assignment of allocation frequencies for cellular services in Pakistan (Cellular Assignments in Pakistan, 2022). From this figure, it is clear that the assigned frequency bands allocated to the Pakistan-based Cellular Mobile Operators for downlink and uplink frequencies are: for 2G (850 MHz, 900 MHz); 3G (1900 MHz, 2100 MHz); and 4G (1700 MHz, 1800 MHz). It can be observed that most of the spectrum band is already occupied with the conventional spread spectrum techniques, and very little spectrum is left unconsumed to facilitate new technologies in the market, such as 5G, and, thereby, to allocate new spectrum bands, such as 2.3 GHz, 2.6 GHz, 3.5 GHz, and 700 MHz, to old and new service operators.

Conventional Spectrum Management

The need for new radio spectrum bands is ever increasing, which highlights the dire need for an innovative spectrum management model, as traditional approaches of spectrum management do not meet the futuristic requirements of upcoming technologies. The revenue generated by radio spectrum utilization is considered to be a strategic resource for the national economy worldwide. While surveying the introduction as presented in section 1 of this paper,

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it has been analysed that implementation of conventional spectrum management models for policy management, as well as in the technical domain, are not robust enough to cater for the demand of upcoming technologies, such as 5G services. The national and international bodies responsible for spectrum management are continuously making serious efforts to find a better way of handling the scarce spectrum resource (GSMA, 2017). Critically, if the spectrum resources are not properly managed, within the existing spectrum bands, the resources are going to become a pitfall for meeting the future demand of existing users and that of upcoming technologies and, due to this unforeseen situation, the old users may create a monopoly in the market. Therefore, policy management requires efficient and effective updates in the methods and approaches to re-assign the spectrum. In that sense, Pakistan is facing the same global issue of not adequately employing a robust framework for dynamic spectrum management and relying heavily on the conventional fixed assignment model that has resulted in spectrum scarcity with inefficient spectrum utilization, thus rendering minimal economic benefits.

Command and Control approach

The administrative approach, traditionally referred to as the command-and-control approach, is traditionally one of the dominant methods that regulators have used to manage the radio spectrum and is still effectively employed in some parts of the world today. The spectrum management is done through direct awards of radio spectrum licenses. In the authoritative control and command approach, the regulator will decide upon allocation and assignment of fixed frequency band usage rights for a specific use with respect to time, place and frequency. In this model, a user applies for a specific frequency spectrum range and the regulator assigns a non-overlapping frequency band to the user after performing legal procedures. If there is only one applicant, the services would be licensed on first come, first served basis; but, for more than one contender, the regulator will hold a public hearing or auction, which will determine the rights transfer to the successful applicant. However, obtaining the license does not provide property rights of the spectrum to the licensee, but confers enforceable rights with respect to fixed usage about purpose, frequency band, transmission power, and location. Command-and-control approaches generally do not permit license trading, which may produce better economic results and usage of the spectrum (Freyens, 2007). From the administrative point of view, there is neither a proper way for licensed users to observe and adopt market changes, and thus get more spectrum from regulators; nor do the regulators have unassigned bands to provide to the user and serve their robust demands (Matheson & Morris, 2012).

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Market-Based approach

The inherent limitation in the command-and-control approach paved way to the market-based approach, which replaced the administrative assignment in many countries. Through the idea of the newly introduced mechanism, a license is provided to those limited number of competitive market users who are eligible to own the license, for a specified period of time, and are capable of exploiting effective and efficient use of spectrum bands provided with the license. This approach weighs the radio spectrum more and takes into account the efficient use of spectrum bands held through license. Some countries and their regulatory bodies also managed to introduce secondary users and markets for spectrum trading, where the spectrum rights can be furthered via vending and leasing, concerning, particularly, about geography, bandwidth, and time. Trading and leasing of spectrum in secondary markets generally refer to the idea of an increase in efficient utilization of spectrum with scope for new entrants, working for social welfare and coping with the spectrum demands across different geographical areas, to the market (Kalliovaara *et al.*, 2018). The success of spectrum bargaining mainly depends on its trading cost that will justify economic efficiency as a parametric objective. Consequently, this pre-condition upscales complexity in spectrum management and technical prerequisites of spectrum management. This would ultimately create enough space for buyers and sellers to make the market competitive and, thereby, produce best public interest. Secondly, the complexity of spectrum utilization, such as assignment and handling spectrum among different users with no harmful interference, is adequately managed (Matheson & Morris, 2012).

Command and Control vs Market-Based approach

Table 1. Comparative Analysis of Command and Control and Licensed Shared Access

Aspect	Command and Control Approach	Market-Based Approach
Spectrum availability	With the fixed assignment of spectrum to CMOs, the scarcity issue arises with time in this approach. Spectrum sharing has been suggested to Spectrum shortcoming. (Shaukat, 2015)	Spectrum will be available to more users through market sharing and leasing (Prasad & Sridhar, 2013).
Spectrum usage	Assignment of large band spectrum to number of operators for fixed term is not reasonable due to underutilization because every operator cannot use spectrum efficiently due to a smaller number of subscribers (Kibria *et al.*, 2016).	Being even effective and economically industrious, but this approach cannot fully optimize underutilization due to minimal control of regulatory oversight.
Spectrum assignment	Spectrum assignment on unjustified prices with exclusive rights to use, which is clear example of injustice in the market (Prasad & Sridhar, 2013).	This approach applies auction and leasing to market users and sub-users for trading of spectrum at a fixed long interval (Prasad & Sridhar, 2013).

Aspect	Command and Control Approach	Market-Based Approach
Spectrum license duration	Licenses are assigned for long period of time, such as 10 to 15 years. During this time period, no other user can use this spectrum band even if underutilized.	Spectrum license is awarded for 10 to 15 years of interval, which cannot be retained back after duration completion, but can be renewed.
Market competition	Market competition is not appreciated due to small number of operators, all with exclusive rights, and with no opportunity for new operators to get into the market (Prasad & Sridhar, 2013).	All market users are invited to compete for spectrum auction and trading (Shaukat, 2015).
Spectrum price	Government uses the spectrum auctions to boost revenue. However, due to non-realistic prices of spectrum trading, social welfare and public interest cannot be guaranteed; therefore, causing the firms to overbid the actual value of national assets. This is detrimental to the growth of industry (GSMA, 2014).	Spectrum price depends on the number of buyers and sellers in the market in addition to impact of price on spectrum availability (GSMA, 2014).
Spectrum access	Command and control approach gives exclusive rights to users, resulting in effective technical and allocation efficiency. In addition, regulatory bodies cannot maintain transparent information about the utilization of spectrum by the users (Prasad & Sridhar, 2013).	This approach renders exclusive rights to users, resulting in non-effective technical and allocative efficiency. In addition, regulatory bodies cannot maintain transparent information about the utilization of spectrum by the users (Mueck *et al.*, 2020).
Spectrum trading	The authoritative command and control approach does not allow spectrum trading to secondary firms; consequently, making the entry of small firms difficult in the sector, and the higher likelihood of suboptimal use of spectrum is disregarded (Prasad & Sridhar, 2013).	This approach allows spectrum trading to secondary firms; consequently, making the entry of small firms easy in the sector, and thus the chances of suboptimal use of spectrum are enhanced (Prasad & Sridhar, 2013).
Industrial growth	Government is mostly focused on accumulating high prices and revenues from operators. This becomes a trade-off for fast infrastructure growth of the industry.	This approach is mainly focused for a large number of operators, thus adding support to competitive and productive industrial growth.

Technical and economic impact of administrative and market-based model

Due to limited vacant spectrum availability, economic viability of administrative and market-based approaches is challenged progressively with time. These models do not provide adequate solutions to facilitate the required services for new applicants and users. It has been observed that the spectrum allocation, performed via conventional models, has resulted in the inefficiency and scarcity of available spectrum (Prasad, Sridhar & Bunel, 2016). Moreover, the radio spectrum bands, issued to users for long-term periods, cannot be recalled from the primary users within the allocated period. In comparison, the administrative approach is more biased towards monopoly of incumbents, while the market-based model inhibits monopolization of the spectrum market, and, hence, cannot be recommended as an efficient approach among the service providers due to lack of control in terms of effective utilization of the allocated spectrum. In both the models, spectrum is assigned for a long period of time with static assignment; however, spectrum trading mitigates that in the market approach. Furthermore, in the administrator-controlled model, users have limited rights over the spectrum, while in the market-based model, there is inadequacy of transparent information of spectrum usage flow to regulators, and therefore making it less administrable.

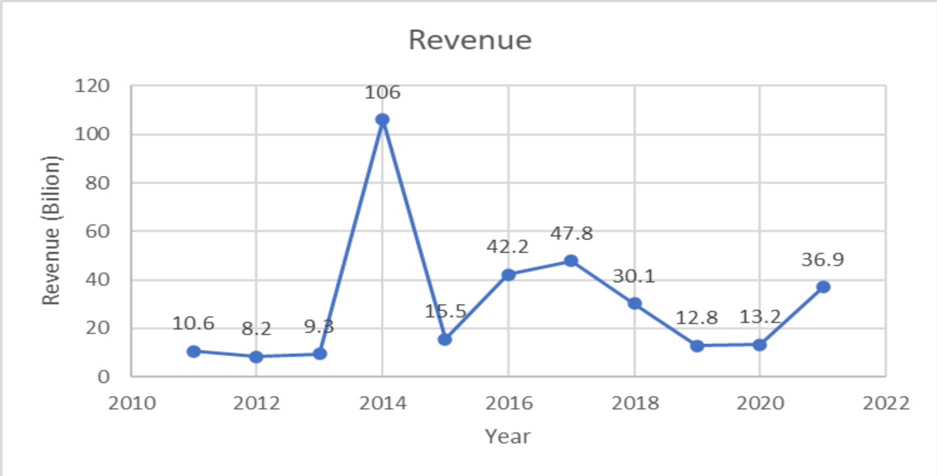

Figure 3. PTA Statistics of Revenue Generated within the Last Decade

Consequently, when there is not much to sell, in terms of spectrum allocation, in the market, there would be less revenue generated in return. Pakistan's National Regulatory Authorities (NRAs) are also facing the same issue — the problem to generate revenue by using spectrum efficiently and paving way for new market entities — for decades. Figure 3 depicts the decline in spectrum revenue generated after the auction of 3G and 4G licenses in Pakistan in 2014. A well-functioning spectrum market with a large number of frequencies available for allocation will be contingent for economic growth (Prasad, Sridhar & Bunel, 2016).

Therefore, policymakers must choose an appropriate administrative management policy, in future planning for effective deployment of 5G technology, that can be pivotal for minimizing interference issues and maximizing spectrum utilization, providing preferred economic incentives, and, thereby, introducing new opportunities for unlicensed uses. In addition, the administrative management policy must be able to productively confront the legal and political challenges that may arise from incumbent users and government regulations. Moreover, the management policy must profitably cater for dynamic assignment, easy access to all the classes, and be economically beneficial to the partner stakeholders (Hannabuss, 2006). In the authors' opinion, these factors will contribute enormously for more cognitive and dynamic spectrum access policies for the effective deployment and instalment of next generation wireless technologies.

Dynamic Spectrum Access

To overcome the challenges offered due to spectrum scarcity and non-effective utilization of frequency bands, new communication techniques, i.e., Cognitive Radio (CR) and Dynamic Spectrum Access (DSA), were introduced. CR network provides efficient utilization of the limited radio spectrum with an added advantage of highly reliable communication to users through efficient energy and resource utilization (Nurelmadina *et al.*, 2021). On the other hand, DSA technique may allow unlicensed secondary systems to share the radio spectrum when not in use by licensed primary systems (Garhwal & Bhattacharya, 2012). However, this paper mainly focuses on the DSA technique and its impact on effective policy making for spectrum management.

From the core technical point of view, DSA capitalizes on the advantages offered with the utility of radio frequencies in an efficient manner where multiple users can access the radio band simultaneously. Moreover, DSA has the capability to share the radio frequency spectrum among multiple users or service providers at the same time without causing any interference among them and without degrading the quality of service. In relative terms, DSA is a set of techniques based on provisioning of frequency spectrum services with optimum use by the users. In addition, DSA defines a mechanism platform that allows accessibility of spectrum to multiple users. Furthermore, in the absence of primary users, the abundant white spaces in the radio spectrum can be accessed by secondary users to take technical and economic advantage of the capital resource (Song *et al.*, 2012). By converting the unutilized spectrum bands, economic advantages of dynamic spectrum access, as a flexible radio access policy that can replace the current fixed radio spectrum allocation policy without compromising the performance of the existing radio regulation governed by the conventional fixed spectrum allocation policy, can be achieved. Moreover, DSA, also referred to as Opportunistic Spectrum Access (OSA), specifies a new spectrum sharing paradigm that allows unlicensed or Secondary Users (SUs) to access the idle or unused spectrum, otherwise referred to as spectrum holes or white spaces in the licensed spectrum band (Singh *et al.*, 2020). Importantly, it is a flexible radio spectrum access policy to alleviate the current problems of spectrum scarcity and spectrum underutilization in order to increase spectrum utilization. The concept of DSA is to find a means of accessing the unused portion of already assigned licensed spectrum without interfering with the transmission of the Primary Users, as illustrated in Figure 4 (Popoola *et al.*, 2016). The type of radio that enables Secondary Users to operate in an idle portion of the licensed spectrum in this opportunistic manner works on the principal of cognitive radio.

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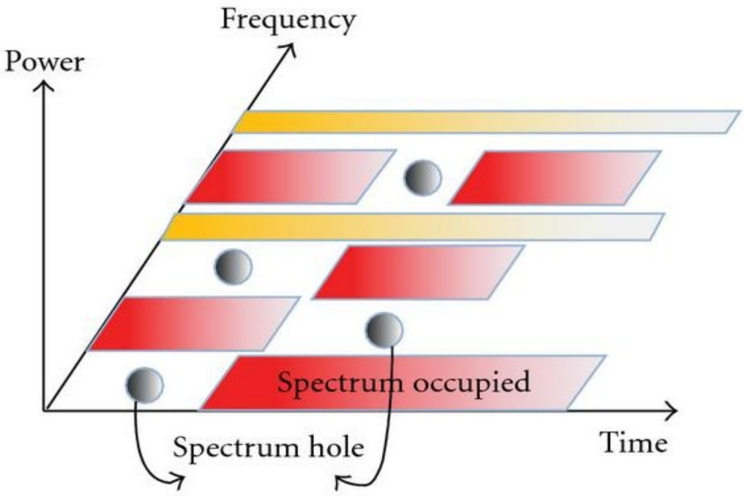

Figure 4. Spectrum Hole concept is showed and how these holes can be made usable through DSA (Popoola *et al.*, 2016)

CBRS

CBRS was initiated in 2012 by the FCC to enable spectrum sharing among multiple users; the rules were outlined in 2014 and officially adopted in 2015 (FCC, 2020b). Citizens Band Radio Services (CBRS), also known as Spectrum Access System (SAS), is a 150 MHz-wide band arranged on 3.5 GHz band (3550-3700 MHz). This is a valuable band that is chosen because of its ability to penetrate walls, go up to medium distances and transfer large amounts of data, which is a reasonable requirement of LTE and 5G.

The CBRS band is specially designed for spectrum sharing among tiers of different users: incumbent users; Priority Access Licensees; and Generally Authorized Access users. They all can use with conditions of priority to user plus no interference with each other. All tiers' detail is given (Kułacz *et al.*, 2019) with proper graphical representation in Figure 5.

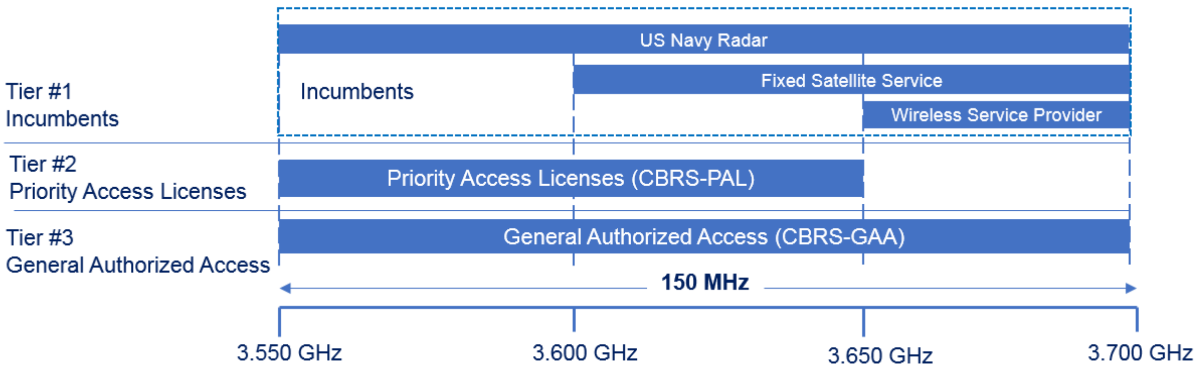

Figure 5. CBRS layer model provides information of three different users and their relevant uses (Kułacz *et al.*, 2019)

- Incumbents are old exclusive users of this band, such as satellite. An incumbent user shall not be interfered with by Priority Access Licenses and General Authorized Access users; its rights will be protected under rules defined by the authority. The existing band range defined formally for incumbents is 3650-3700 MHz. Priority is given to incumbent users over Priority Access Licenses and General Authorized Access users. Incumbents can acquire the license for a finite term.

- Priority Access Licenses belong to users who will pay for this license via auction. Through competitive auctions, the band of 3550-3650 MHz will be assigned to users with a maximum of 10 MHz on a single Priority Access License to a single applicant. A single applicant can take up to four bands of 10 MHz and can acquire the license for two consecutive terms. The PAL users shall not be interfered with by General Authorized Access users (GAA) as they will be prioritized over General Authorized Users.
- A GAA can use these bands when no-one from PAL or incumbent is using these bands. These users have freedom to use the 150 MHz (3550-3700) band, when it is not in use by incumbent or PAL users. In the presence of incumbent and PAL users, the band usage rights will be reverted from the General Authorized User. The priority of GAA is always less than PAL and incumbents.

CBRS/SAS is composed of multiple functions to become a complete system of spectrum sharing, as illustrated in Figure 6, where functional components are indicated for better understanding (Mueck *et al.*, 2020).

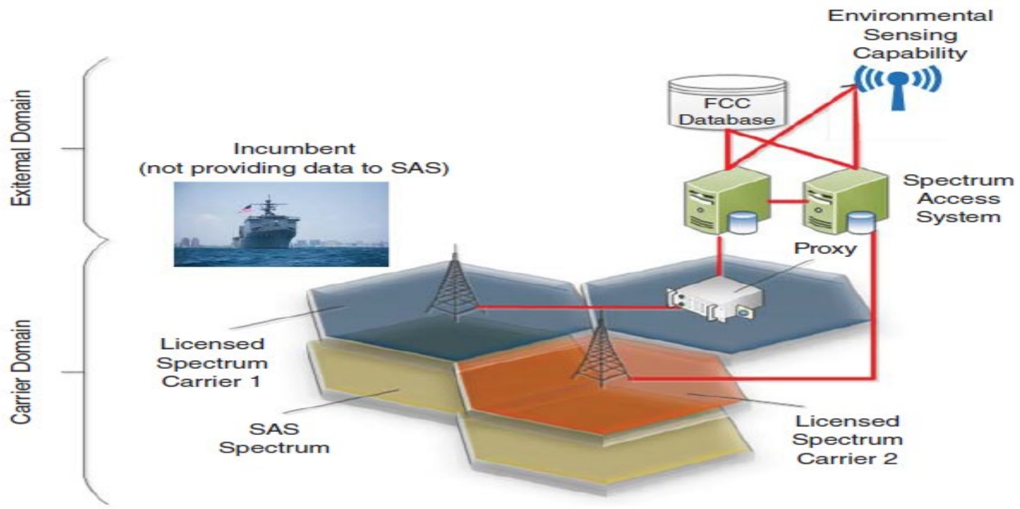

Figure 6. CBRS/SAS layer functional model (Mueck *et al.*, 2020)

- **Environment Sensing capability:** The environment sensing capability (ESC) senses the band operations by the incumbents and shares it with SAS to facilitate the protection of band operation and information in it. ESC works under the command and regulation set in the spectrum repository and sends alerts to SAS.
- **SAS Repository:** The FCC database, generally known as SAS repository, simultaneously collects the spectrum usage information from each node, including Citizen Band Service Device (CBSD) parameters, such as identification of spectrum, spectrum location,

parameters of antenna, transmission power, and channel usage. The repository keeps updated with information for further channel allocations and interference management.

- **Domain Proxy**: An entity engaging in network management and aggregate communications with the SAS on behalf of multiple individual CBSD nodes or networks of such nodes. Those CBSDs, which are not directly controlled by SAS, get controlled and managed by a domain proxy on behalf of SAS under SAS-CBSD protocol. It intercuts the NMS function of other networks to configure CBSDs' frequency, bandwidth, transmit power, and operational state. NMS returns the collected CBSD information to Domain Proxy, which further sends it to SAS. Domain Proxy contains advanced functions for flexible self-control, interference reduction, and optimizing the coverage of cells (Swamy, Srinivasan &, Rashmi, 2020).

LSA

With the rise for new technology in the market, the need for spectrum sharing has also been highlighted in recent decades. In spectrum sharing, the frequency band that has been an exclusive property of an incumbent will be shared with other users for a specific time and location, when the band is underutilized or not efficiently utilized. The vacant spectrum will be utilized through Dynamic Spectrum Access methods, such as Licensed Shared Access (LSA), where vacant spectrum resources will be licensed or leased to users with proper guarantee of protection from harmful interference to incumbent users and vice versa. The incumbent's rights will be protected, plus they will be given a monetary share on leasing their underutilized spectrum. The development of LSA began in Europe for spectrum sharing between Mobile Network Operators (MNOs) for mobile broadband and an incumbent for its fixed conventional use, via proper agreement between both. The European Commission's Radio Spectrum Policy Group (RSPG) defines LSA as follows:

> "A regulatory approach aiming to facilitate the introduction of radio communication systems operated by a limited number of licensees under an individual licensing regime in a frequency band already assigned or expected to be assigned to one or more incumbent users. Under LSA framework, the additional users are allowed to use the spectrum (or part of spectrum) in accordance with sharing rules included in their rights of use of spectrum, thereby allowing all the authorized users, including incumbents, to provide a certain QoS" (Medeisis & Holland, 2014).

Also, Figure 7 shows the major stakeholders of LSA sharing framework, such as Incumbent, LSA licensee, and NRA.

- Incumbents are the old exclusive users in the 2.3-2.4 GHz band, who have the individual rights of use of the band.

- LSA licensees, who have mutual sharing agreement with the incumbent to use the band; the protection against interference will be guaranteed for both the licensee and incumbent.
- NRA, which is responsible to supervise the agreed negotiation and sharing agreements between incumbent and Licensee. The licensing process and assurance to agreement from all stakeholders are also done by the NRA, under European Telecommunications Standards Institute (ETSI) and 3rd Generation Partnership Project (3GPP) specification.

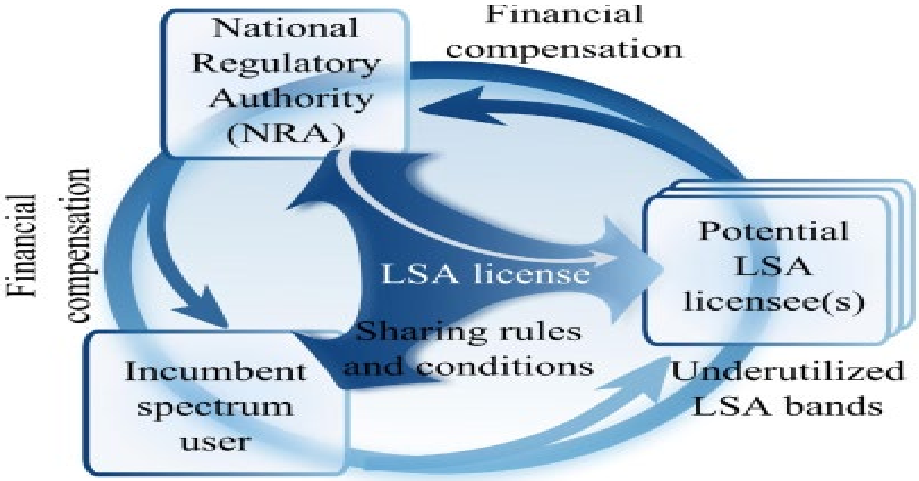

Figure 7. LSA Sharing framework between Tiers and Regulatory

LSA is composed of multiple functions to become a complete system for spectrum sharing, as illustrated in Figure 8, where functional components are described for better understanding (Mueck *et al.*, 2020).

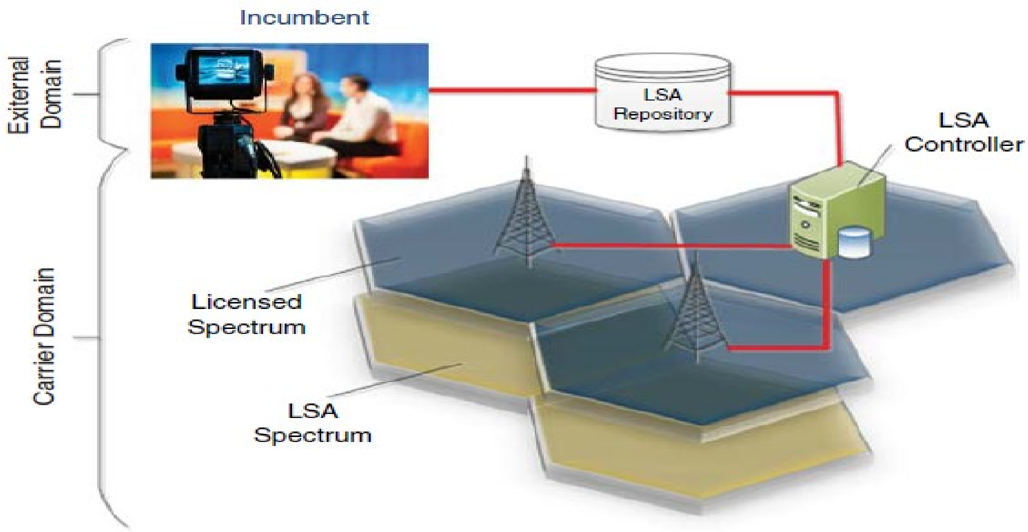

Figure 8. LSA Functional model

- **LSA repository:** LSA Repository will be the main spectrum database, that will contain proper spectrum data, policy, agreements on sharing, rules, and regulations. It will also monitor the users in real-time for interference avoidance.

- **LSA controller**: LSA controller will manage the spectrum and LSA licensees under the information retrieved from the LSA repository; it will allocate and shut down the channel transmission as directed by the LSA repository.
- **Incumbent:** Incumbent will continuously inform the LSA licensee about the vacant spectrum and its availability.

The International Telecommunication Union (ITU-R) has globally allocated the band range of 2.3-2.4 GHz to mobile broadband services and International Mobile Telecommunication (IMT) (Moghaddam, 2018). The European Commission started to develop standards for the launch of LSA in Europe on 2.3-2.4 GHz band. In Europe, within this band range of 2.3-2.4 GHz, countries and regulators are using the band for PMSE (Program Making and Special Events), such as cordless cameras and video links, while some others are using it for fixed satellite, government use including military, and mobile applications, such that it would not require additional features in infrastructure with implementation of LSA. As compared to Europe, it would be difficult for North America to vacate this band from incumbent usage and protection (Yrjölä, Ahokangas & Matinmikko, 2015).

LSA framework does not provide subleasing opportunities to additional frequency bands. The next stage of LSA framework is evolved Licensed Shared Access (eLSA), which enables spectrum access to local high quality or Vertical Sector Players' (VSP) wireless networks under NRA decision. Additional resources will be leased/subleased to local wireless operators. These local operators will be dealt with directly by the NRA under standard agreements and sharing agreements, which will define an allowance zone and frequency range, keeping interference low and QoS high (ETSI, 2020).

CBRS vs LSA model

The concept of CBRS is deployed in America, while Europe has foreseen LSA for commercial deployment in order to achieve spectrum sharing (Massaro & Beltrán, 2020). Although both have multiple layer similarities, such as that both models are comprised of incumbent users and licensed users, however, they are not completely similar. Table 2 illustrates the comparative analysis of CBRS vs LSA. In LSA, shared access users are known as Licensed Shared Access Licensees, whereas in CBRS they are known as Priority Access Licensed users. LSA does not provide opportunistic access to general users, but CBRS/SAS came up with an additional third tier known as General Authorized Access to give spectrum band access to unlicensed users in the absence of incumbent and PAL users, so the PAL user is protected from GAA interference and incumbents are protected from both PAL and GAA users (Yrjölä & Kokkinen, 2017). We can say SAS gives priority to incumbents and they are not required to share prior spectrum usage information due to secrecy with central data. Therefore, SAS uses

Environment Sensing Capability (ESC) to sense spectrum usage and sends the information to the central database for decision making, but the LSA repository takes spectrum utilization information from incumbents as well (Moghaddam, 2018). The mentioned frequency band for LSA is 2.3-2.4 GHz, while CBRS is being deployed on 3.55-3.70 GHz.

Table 2. Comparative Analysis of CBRS and LSA

Aspects	LSA	SAS/CBRS
Released by	Released by ETSI	Released by FCC
Tiers	Two tiers with individual Access	Three tiers; two tiers for individual access and one for general opportunistic access
3GPP Band	LTE TDD Band 40 (2.3-2.4 GHz) applicable for other countries (The Global Solution for Unpaired Spectrum, 2014)	LTE TDD Band 42 and 43 (3.55 GHz - 3.7 GHz) applicable for other countries (The Global Solution for Unpaired Spectrum, 2014)
Database	Centralized Geolocation database on static a priori information of the incumbents (Kalliovaara, Jokela & Kokkinen, 2018)	Centralized Geolocation database based on spectrum sensing (Kalliovaara, Jokela & Kokkinen, 2018)
Spectral Efficiency	Less efficient with individual access	More efficient with individual and General access
Complexity	Less complex with a static framework for long term	Much more complex due to sensing and of GAA users
Adaptability	Initiated from Europe but easily can be adapted by other regions (Massaro & Beltrán, 2020)	Initiated by USA, but can be adapted to other regions (Massaro & Beltrán, 2020)
Revenue Expectations	With more users, there will be more expected revenue	With more users, there will be more expected revenue
Extensions	CBRS is a potential LSA extension with three tiers with individual and general tiers	Already have three tiers with individual and general access
Incumbent Access	No direct access for SAS to Incumbent; ESC just detects incumbent usage information (Kułacz *et al.*, 2019)	LSA have partial access to incumbent information for usage sharing, agreement and usage information
Interoperability	Defined enabling standardized interoperability	General level requirements and frameworks furthered with agreements
Sub licensing	Sublicensing supported to PAL users	Sublicensing is not supported in LSA; however, eLSA will support (ETSI, 2020)
QoS Assurance	Through a standardized framework, QoS is assured for incumbent and PAL access but GAA users are not guaranteed with QoS (Parvini *et al.*, 2022)	QoS is assured to incumbent and licensees through LSA framework and sharing work (Parvini *et al.*, 2022)
New users	Does not allow new users to be in framework	CBRS provides advantage to new inexperienced MNOs
Practical Deployment	Scarce interest of European countries towards deployment (Massaro & Beltrán, 2020)	Already deployed by FCC in United States (FCC, 2020a)

ETSI has already standardized LSA for Europe, while CBRS is being standardized by Federal Communication Commission (FCC) for America. Licensing will be initiated soon in these

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regions and they will become the model example for the rest of the world. The CBRS-based approach appears to be more acceptable, with an innovative initiative of serving individual and general users. However, opportunistic general access is not a priority, though QoS could be envisioned for individual users, such as PALs, as LSA seems to be moving itself to evolved Licensed Shared Access (eLSA). The eLSA is almost giving the same concepts as CBRS, with the addition of a local vertical sector (local wireless networks) beside the main licensed users and incumbent (Moghaddam, 2018). CBRS is facilitating a diverse range of wireless ISPs, enterprises and, moreover, rural ISPs. Opportunistic access to rural areas for ISPs will likely improve the capacity and quality of networks (Calabrese, 2021).

Comparative analysis provides more edge to Citizens Band Radio Service, as it provides more flexibility and is a better model to be deployed in Pakistan as the national framework for spectrum sharing. It provides more tiers and user options to serve national cellular mobile operators, incumbents and general users. With the launch of 5G, regulators will be under great pressure to provide radio bands to all users in a balanced manner. Therefore, the need for dynamically accessible spectrum and sharing frameworks would indeed be a great opportunity to facilitate radio spectrum services to existing as well as new market users.

Conclusion

The traditional spectrum assignment frameworks, such as CCA and MBA, have been in use from a long time, but their efficacy has become low with the passage of time and the rise of innovative technology, especially cellular mobile technology. As a resultant, the traditional framework has failed to provide reasonable economic and technological advantage. Like other countries of the world, Pakistan is also facing the issue of non-availability of enough spectrum for meeting technological and economic requirements of the nation. The NRA has not yet decided on which framework or policy it is going to deploy for spectrum management in Pakistan. DSA suggests the innovative way to utilize spectrum and improve its technical and economic advantage with more users and vacant space in the spectrum domain.

In this research work, Europe-based LSA with two tiers and US-based CBRS with three tiers were briefly compared with each other on multiple aspects, to sort out a better framework to be deployed in Pakistan. Both approaches provide a clear solution for dynamic frequency allocation and will provide a solid platform for the launch of 5G services. However, these approaches may be used as complimentary solutions for operators having ownership of bands through traditional methods, keeping in mind that CBRS provides more flexibility to the users and a management framework to operate and entertain every tier, including incumbent, priority licensed and non-licensed general access users. With a more flexible architecture for all-purpose users, CBRS proved to be a better option to be adapted by Pakistan for cellular mobile network operators. There is no restriction to deploying the CBRS band in Pakistan, as this band is already under refarming for future allocations. Hence, CBRS will not only utilize the scarce resource efficiently but also paves the way for inclusion of new technologies in the upcoming future.

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