Overview of Spectrum Sharing Models: A Path Towards 5G Spectrum Toolboxes

Gcina Dludla(✉), Luzango Mfupe, and Fisseha Mekuria

CSIR Meraka Institute, Pretoria 0001, South Africa
{gdludla, lmfupe, fmekuria}@csir.co.za

Abstract. In this paper three spectrum sharing models are studied and their relative merits are outlined to allow dynamic spectrum sharing in all bands of interest. The main criterion is to improve the availability of underutilized spectrum for secondary wireless broadband networks. The three database-assisted spectrum sharing models studied in this paper are the Licensed Shared Access (LSA), Spectrum Access System (SAS) and Television White Space (TVWS). This paper proposes a unified spectrum sharing database-assisted model as solution for improving the broadband connectivity of underserved communities and improving spectrum availability for high bandwidth services in the fifth generation (5G) networks.

Keywords: DSM · Spectrum sharing · LSA · SAS · TVWS
Spectrum database · Interference · 5G spectrum · Broadband

1 Introduction

Radio frequency (RF) spectrum is the superhighway for the wireless communications systems and associated information and communication technology (ICT) services that are exponentially expanding. Spectrum regulators around the world are increasingly becoming aware of the importance to efficiently managing their national RF spectrum resources. They are beginning to adopt flexible spectrum management frameworks that enables opportunistic sharing of spectrum [1]. This trend plays an important role in addressing the demand for broadband connectivity in underserved areas and also in preparation for the gigabits wireless services in the upcoming fifth generation (5G) ICT eco-systems [2–4]. Dynamic spectrum management (DSM) is regarded as a process of regulating the use of RF spectrum to promote efficient utilisation of spectrum resources. The term RF spectrum typically refers to the full frequency range from 3 kHz to 300 GHz that may be used for wireless communication. Increasing demand for services such as mobile telephones and many others has required changes in the philosophy of spectrum management. Demand for wireless broadband has soared due to technological innovation, such as third generation (3G) and fourth generation (4G) mobile services, and the rapid expansion of wireless internet services.

Dynamic spectrum sharing approaches enables third-party users to share spectrum bands licensed to incumbent users while adhering to the interference limitations of the incumbents (i.e., such sharing approaches could be on the secondary or tertiary basis). Database-assisted DSM frameworks such as the Licensed Shared Access (LSA),

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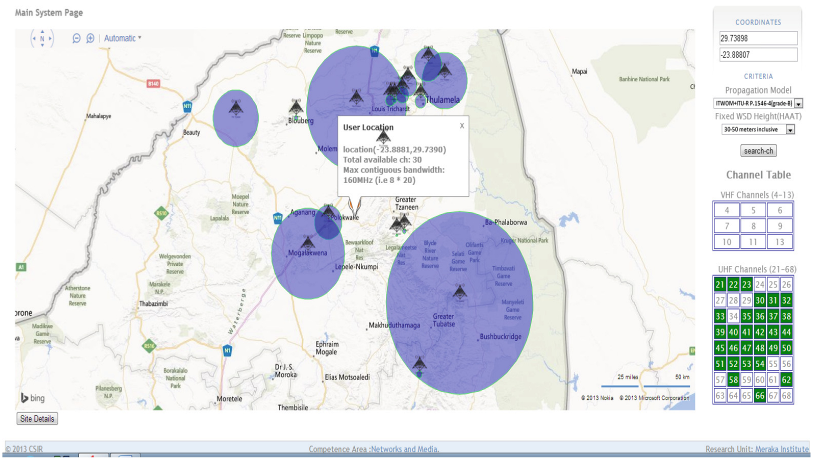
Authorised Shared Access (ASA) and Television white spaces (TVWS) allow spectrum that has been licensed for use by the International mobile telecommunications (IMT), Citizen broadband radio services (CBRS) and TV broadcasting to be shared with unlicensed users. This is said to increase the use of the radio spectrum by allowing shared access when and where the primary licensee is not using its selected frequencies [5–7]. The major drawback of the aforementioned database-assisted spectrum sharing approaches is that they are all band specific (i.e., each model is applicable in a given band of interest). This drawback could be a costly hindrance in the 5G network ecosystem in which heterogeneous wireless access networks are expected, possibly each network operating in different spectrum bands. This paper investigates and compares the LSA, SAS and TVWS frameworks. The key contribution of this paper is a proposed unified spectrum sharing database assisted model that will enable seamless spectrum sharing in many bands of interest for the 5G networks.

1.1 Spectrum Underutilisation

The motivation for research and development in spectrum sharing models comes from the fact that spectrum is grossly underutilized in both time and space domains, by all licensed network services and in all bands of interest. Studies by national regulatory authority such as the Independent Communications Authority of South Africa (ICASA), the Federal Communications Commission (FCC) of USA, and the Office of communications (Ofcom) of UK clearly had shown this [3, 6, 8]. A typical example is shown in Fig. 1 (below). The figure shows the study done using the Council for Scientific and Industrial Research (CSIR) geolocation spectrum database (GLSD), near the city of Polokwane, northern South Africa [9]. The system could identify 30 TVWS channels (This is approximately to 240 MHz of unused bandwidth). The TVWS channels could be shared by broadband network service operators to provide broadband ICT services.



CSIR GL-DSA System Output for Limpopo TVWS trial: (http://whitespaces.meraka.org.za)

Fig. 1. GLSD based spectrum underutilisation study in the UHF band.

Regulators all over the globe are now scrambling to enable new models of spectrum sharing, using modern technologies such as GLSD, spectrum sensing, advanced spectrum sharing algorithms, cloud computing and artificial intelligence.

2 Spectrum Sharing Models Overview

Spectrum sharing models such as the LSA, SAS and TVWS enable regulators to manage spectrum sharing between existing licensed and unlicensed secondary networks. The spectrum sharing models aim 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 [10, 11].

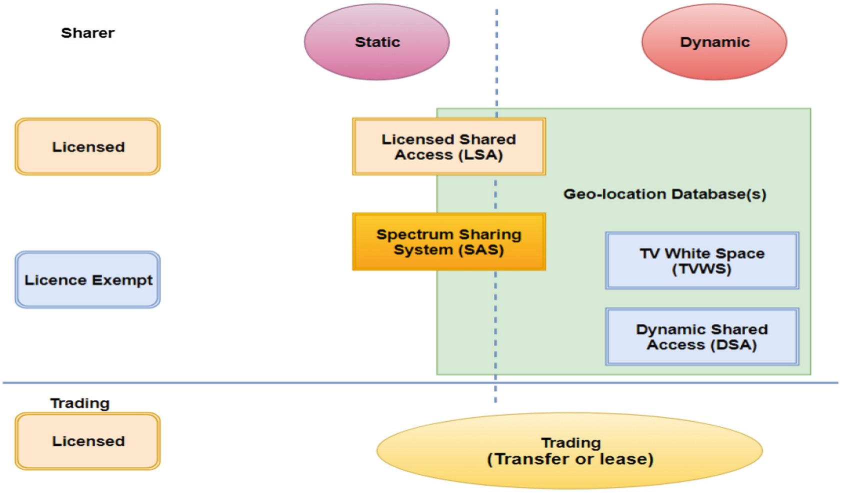


Fig. 2. Spectrum sharing mechanisms and spectrum trading [4].

Figure 2 illustrates different spectrum sharing mechanisms namely; LSA, SAS, and TVWS in the context of DSA. Important observations are twofold (i) the close connections between spectrum sharing in licensed and unlicensed (license exempt) modes (ii) spectrum trading which opens the gates of business and commercialisation opportunities for database-enabled white space networks.

2.1 Licensed Shared Access (LSA) Sharing Model

LSA model enables harmonization of spectrum sharing between the incumbents (primary users) and the LSA licensees (secondary users) of the band [7]. The LSA licensee are authorised to use the spectrum (or part of the 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 Quality of Service (QoS) [7, 10, 12].

The LSA spectrum sharing approach is intended to ensure immediate access to the spectrum to commercial operators, without binding their investments to the times of the traditional process of refarming. The generic LSA concept encompasses sharing between any types of radio systems, most activities in standardization and regulation are concentrating on the application of LSA to the IMT bands [7]. This could enable mobile communication systems to access the bands available on a shared basis that are currently not available for them on an exclusive basis.

The 2.3–2.4 GHz band is under study as the first use case for LSA. In the regulatory domain, European Conference of Postal and Telecommunications (CEPT) has considered harmonised implementation measures and introduced cross border coordination procedures for this band [11, 12].

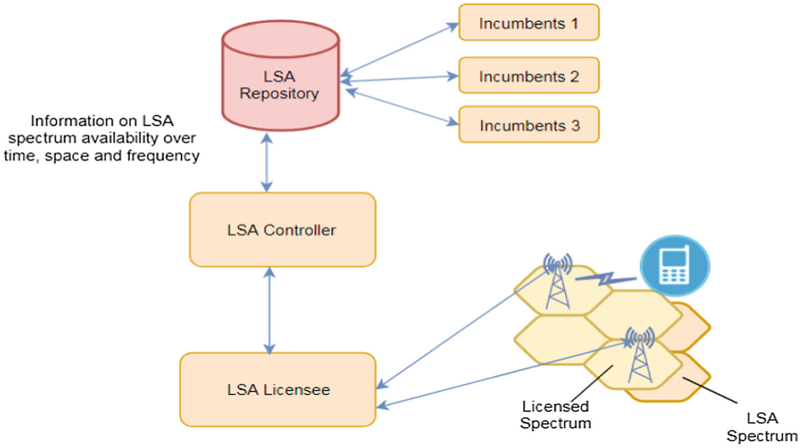


Fig. 3. LSA architecture.

Figure 3 demonstrate the LSA model architecture as defined by the European Telecommunications Standards Institute (ESTI) [13]. The spectrum is managed through a centralized database; LSA Repository. The incumbents are required to provide their spectrum usage information to the database over time and space. Based on the provided information by the incumbents, the LSA licensee will be given a permission to use or vacate the band through LSA controller.

2.2 Spectrum Access System (SAS) Sharing Model

SAS is a model used for enabling sharing of the CBRS in the 3.5 GHz, currently this model has attracted interest in USA [5, 7]. SAS supports spectrum sharing with three levels of hierarchy in spectrum usage.

Figure 4 illustrates the architecture of SAS. The incumbent Access are given the highest level of usage rights including exclusive spectrum access and guaranteed protection from harmful interference when and where they deploy their networks [5, 7]. Secondary licensees occupy the middle level and are generally expected to be a

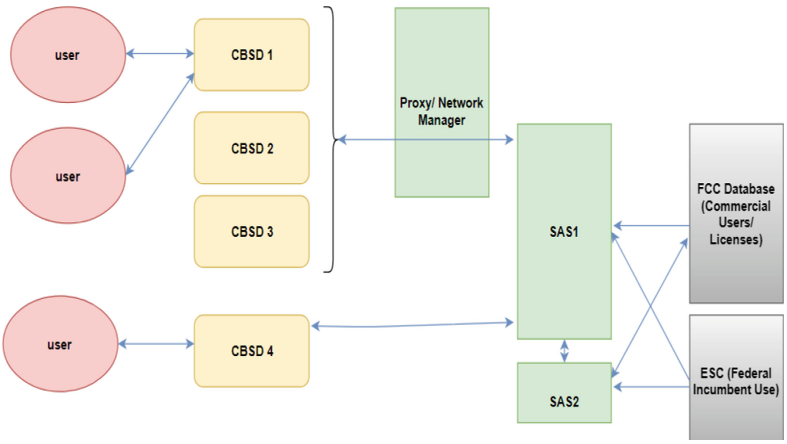


Fig. 4. SAS architecture.

commercial service provider i.e. a cellular service provider. The secondary licensee would have short-term priority operating rights, that is, Priority Access License (PAL), for a specified geographic area [7]. PAL is issued for a predefined term and bandwidth, such as, one minute or even one year for a 10 MHz unpaired channel with possibly varying spectral location. PAL could also guarantee the secondary licensee interference protection from the third level of the hierarchy often referred to as opportunistic use.

Third level of access is called the General Authorized Access (GAA) and is light licensed similarly to a Wi-Fi with the critical distinction that the GAA device or system must be capable of effectively interacting with the controlling SAS [5, 14]. GAA users are allowed to opportunistically access a specific spectrum band in a geographical area or time period when it is otherwise unoccupied by both the incumbent and the PAL licensee. The amount of spectrum reserved for PAL and GAA and the PAL license durations will strongly influence their demand.

The main functions of SAS include determining and assigning available frequencies at a given geographic location; registration, authentication and identification of user information and location as well as protection of the incumbent from harmful interference; through enforcing an Interference Limits Policy based approach to insure that harm claims threshold limits are not exceeded in exclusion or coordination zones. The SAS model is a general framework that could be applied to any bands and between any networks.

2.3 Television White Spaces (TVWS) Sharing Model

TVWS spectrum is found in VHF and UHF bands. TVWS are frequencies made available for unlicensed use at location where the spectrum is not being used by licensed services, such as Television broadcasting.

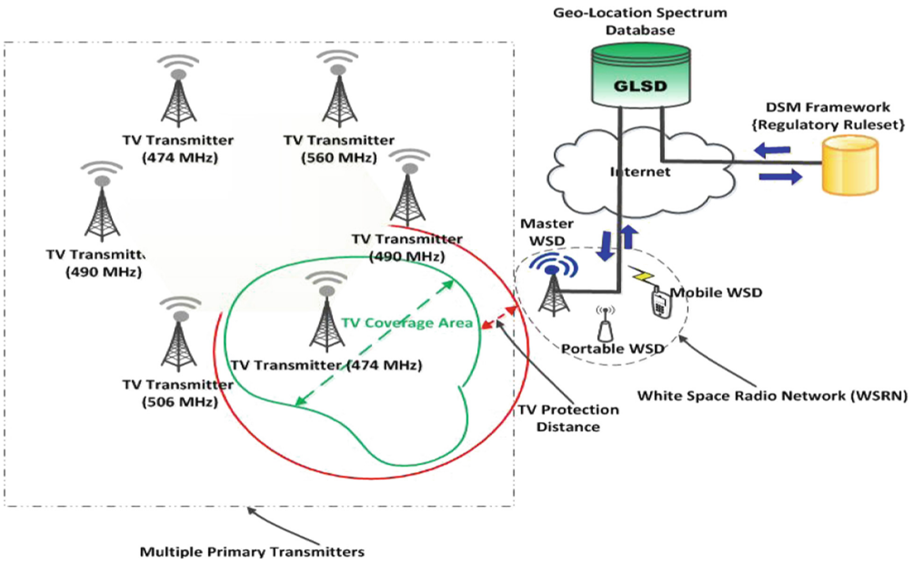


Fig. 5. TVWS architecture.

Figure 5 illustrates the TVWS sharing model. TVWS has become a focal point for research and development effort for the last couple of years [4, 6, 8, 9] due to its long range communication capabilities, good propagation and excellent in-building penetration. TVWS are enabled through GLSD; through GLSD harmful interference to the incumbents of the band is reduced.

3 Comparison of LSA, SAS and TVWS Models

All regulatory spectrum sharing models described in Sect. 2 present the state of the art sharing models. These models present the incumbent system on the highest level as shown in Fig. 6. LSA is a two tier model whereas SAS is a three tier model and TVWS is a two tier model [15]. The protection of the incumbent spectrum users' rights is the starting point for both models [4]. Additional users are introduced on times and geographical areas where the incumbent user is not using the spectrum.

LSA is foreseen to be based on the voluntariness and the incumbent can define on which bands, geographical areas and times to allow additional usage via licensing. While SAS is based on the assumption that the incumbent has an exclusive right to actual use but all spectrum resources unused by the incumbent user would be subject to additional usage. The second level on both spectrum sharing models introduce additional users on a controlled manner based on individual licensing [7, 10]. The major difference between the two models is that the SAS introduces a third level of usage rights. This additional level of the SAS introduces opportunistic access for light licensed users. Table 1 below represent the differences between the LSA, SAS and TVWS.

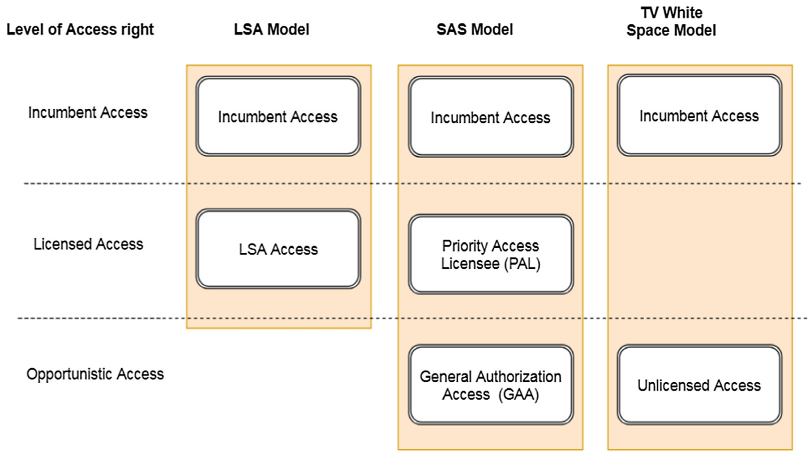


Fig. 6. LSA, SAS and TVWS at different levels of access rights.

Table 1. Comparison of LSA, SAS and TVWS spectrum sharing models [10]

Criteria	Licensed Shared Access (LSA)	Spectrum Access System (SAS)	TV White Space (TVWS)
Efficient spectrum utilisation	Enhanced utilisation through shared access spectrum	Enhanced utilisation through shared access spectrum, further efficiency obtained via GAA	Enhanced utilisation through unlicensed shared spectrum
Protection from the interference	Spatial separation obtained via LSA license and protection zones enforced by LSA database and management system	Spatial separation obtained via SAS license and protection zones enforced by SAS database. Number and character of GAA devices create interference concerns	Protection enforced by the geolocation database
Minimum impact to the technology of the system	The incumbent reports changes in licensing terms, LSA licensee needs means to respond to possible changes	Reporting all spectrum usage in SAS, direct interactions between systems pose changes to systems	Incumbents reports changes in the system, that's allow the secondary users to vacate or continue using the spectrum in the selected band
Reliable access and usage conditions	License, spectrum sharing framework, voluntariness	PAL license, access not guaranteed GAA	Access is not guaranteed for secondary users (unlicensed users)

(*continued*)

Table 1. (*continued*)

Criteria	Licensed Shared Access (LSA)	Spectrum Access System (SAS)	TV White Space (TVWS)
Implementation and enforcement by regulatory authorities	Based on licensing procedure	PAL, device standardization for opportunistic access, enforcement for GAA more challenging	Enforcement for unlicensed users is challenging
Fairness and pro-competition	Based on licensing procedure, negotiations between the incumbent and LSA licensee challenging	Based on licensing procedure, but GAA option provides a "pro-competition edge" to SAS	There is no negotiations between incumbents and unlicensed users
Legal certainty	License provides legal certainty, database security	Legal certainty is provided for PAL level licensees, GAA licenses are only provided with opportunistic access to the spectrum. Both are provided with, database security	Secondary users are only provided with opportunistic access to the spectrum
Foster innovation	Makes spectrum available, flexible regulatory framework allows access to new systems and new innovative	Makes spectrum available, flexible regulatory framework allows access to new systems and new innovative services, GAA allows for broad set of innovators	TVWS allows for broad set of functions for innovative use of spectrum
Quality of Service (QoS)	QoS is guaranteed through licensing	QoS for PAL users is guaranteed while as for GAA is not guaranteed	Secondary users QoS for TVWS operation is not guaranteed
Market Acceptance	There is market acceptance and support from manufactures	There is market acceptance and support from manufactures	Market acceptance is low and remains below the original expectations

4 Discussion

Table 1 compares the LSA, SAS and TVWS spectrum sharing models. LSA, SAS and TVWS models enhance spectrum utilisation through shared access, they allow spectrum to be shared while giving the priority to the incumbents of the chosen bands. This is essential since there is a demand for new spectrum for the growing radiocommunication services [10]. The incumbents of the bands are protected from interference through database the unlicensed users of SAS (GAA) and TVWS pose a slightly concern to assure an interference free environment. The unlicensed users of SAS and TVWS are not guaranteed to get the QoS, they are required to vacate the band whenever the licensed users' needs to use the spectrum in the selected bands.

5 Recommendations

The proposed 5G standard and its services ecosystem require the availability of sufficient spectrum allocation to provide high bandwidth (gigabit wireless) services and massive machine-2-machine (M2M) communications [16]. 5G standards identified a number of frequency bands as shown in Table 2.

Table 2. Identified frequency bands for the 5G ecosystem.

Band range	Spectrum and application types		
	Typical spectrum types	5G App1	5G App2
54 kHz – 1 GHz	Widespread coverage range, 700, 800, 900 MHz	Rural/unlicensed	Urban, WLAN (IoT)
1 GHz– 6 GHz	Mixed range and capacity, 1800 MHz, 3.3–3.8 GHz	Urban/rural/unlicensed	IoT/ITS
>6 GHz	Gigabits wireless broadband (6–28 GHz)	UWB, wireless fiber	Wireless VOD

LSA, SAS and TVWS models enables dynamic spectrum sharing to increase the spectrum utilisation and also to meet the ever-increasing demand of the new spectrum in the rapidly growing radiocommunication services. However, LSA, SAS and TVWS are currently defined for usage only in specific frequency bands of interest.

Since LSA, SAS and TVWS are all database-assisted models; we propose that a unified spectrum sharing database containing the local regulatory rules for wireless networks co-existence, geo-location information and dynamic licensing mechanism as a solution for future wireless network deployments.

Artificial Intelligence (AI) techniques coupled with cloud-based distributed ledger (blockchain) architectures are being considered to solve the computational resources challenges associated with big-data. The proposed unified approach will enable seamless dynamic spectrum access in the bands of interest by heterogeneous networks in the 5G ecosystem. This will provide the required quality of service for each application. Figure 7 depicts a high-level proposed architecture of the unified database-assisted spectrum sharing framework.

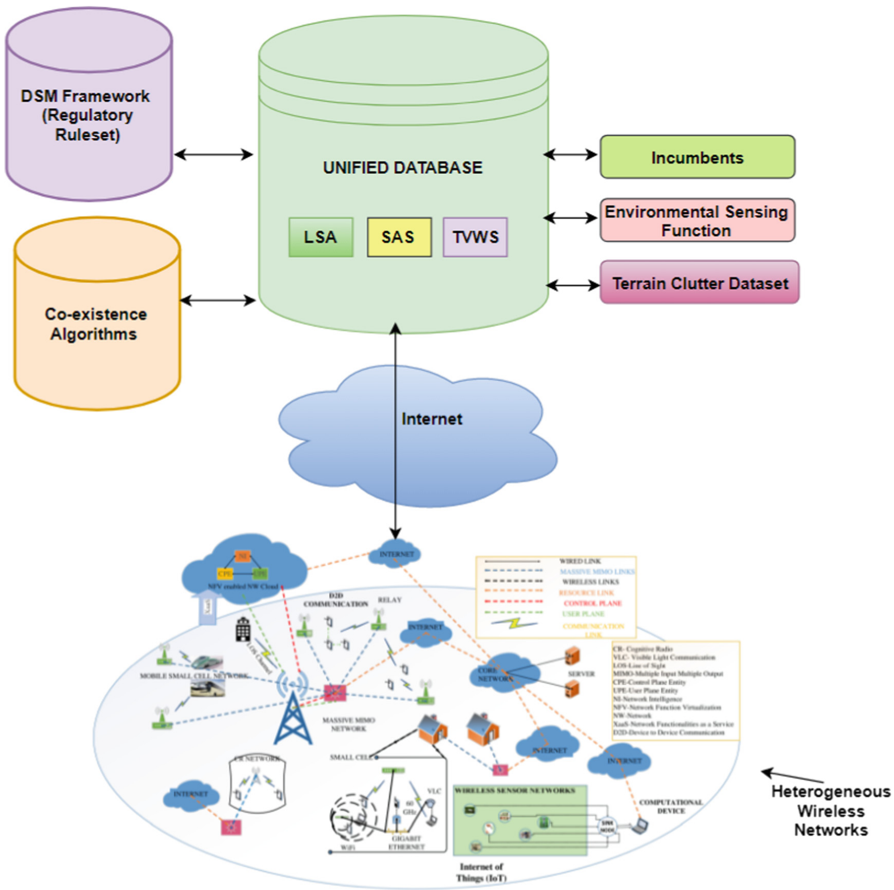


Fig. 7. Proposed high-level architecture of a unified database-assisted spectrum sharing framework for the 5G ecosystem.

6 Conclusion

The commercial access and use of spectrum is generally authorised in two ways (i) either through individual licenses or; (ii) in accordance with license exempt (unlicensed or ‘commons’) rules. Database-assisted dynamic spectrum management models investigated in this paper namely; LSA, SAS and TVWS brings the benefit of enabling dynamic allocation and sharing of spectrum in the bands of interest. LSA and SAS guarantee the QoS for the users of the band through licensing part of the spectrum for other services whereas the TVWS doesn’t guaranteed the QoS. SAS and TVWS allows more dynamic spectrum sharing model which is likely to promote competition and foster innovation. In LSA there is no requirement for sensing mechanism for supporting the system for the identification of the incumbents as compared to the SAS where it is a mandatory requirement, while in TVWS it is optional.

However, the major drawback of the aforementioned database-assisted spectrum sharing approaches is that they are all band specific (i.e., each model is applicable in a given band of interest). This drawback could be a costly hindrance in the 5G network ecosystem in which heterogeneous wireless access networks are expected, possibly each network operating in different spectrum bands.

This paper has proposed a unified spectrum sharing database-assisted model that will enable dynamic spectrum sharing in many bands of interest relevant for the 5G networks ecosystem. Spectrum sharing approaches such as white space communications technologies are expected to transform the upcoming 5G standard to achieve its promise of gigabit wireless connectivity services. Additionally, the paper has highlighted the importance of research which will lead towards promoting the unlicensed sharing of spectrum as a new use case in the future 5G networks. The benefit of such research is to allow provision of low-cost broadband connectivity in the developing countries particularly in the rural areas. This new drive has been termed as the "4^{th} Pillar of 5G" [17].

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