Spectrum Sharing for Unlicensed 5G Networks

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Abstract*—5th generation wireless ICT eco-system promises three important pillars of network innovation: (a) Ultra Reliable Low Latency Communication, (b) Enhanced gigabits wireless broadband and (c) massive machine type communication. 5G is expected to transform the way humans and devices communicate and exchange services and improved automation of industry. The aim of this paper is to discuss recent research in spectrum sharing and unlicensed wireless networks, including its extension to 5G research based on use cases and associated technologies to address the requirements of affordable wireless broadband. The paper presents research contributions on spectrum toolboxes, including smart spectrum sharing for 5G and affordable networks. The research outcome will be presented with a proof of concept network test-bed developed in South Africa. Finally the paper will conclude with a challenge to existing and future research in technology standards for 5G to contribute towards the achievement of universal affordable broadband for the next billion customers.

***Keywords*— Smart Spectrum sharing; Spectrum Database; Licensed/Unlicensed Spectrum, broadband, 5G networks**

I. INTRODUCTION

Static and ineffective allocation of radio frequency spectrum resources need to be replaces by smart spectrum management models. Smart spectrum sharing systems based on spectrum databases, augmented with interface to spectrum sensing, and artificial intelligence techniques aim to guarantee low interference between competing heterogeneous networks is proposed in this paper. As future wireless networks are demanding more spectrum availability to cater for the high bandwidth services, underutilization with the current static allocations should be replaced by dynamic and smart spectrum sharing models. The initial 5G standards have defined spectrum toolboxes such that new artificial intelligence AI inspired smart spectrum sharing (AI-S3) models are being promoted for future wireless network technologies. Such technologies will cater for the needs heterogeneous network operation and advanced interference mitigation in 5G and affordable rural broadband internet communications. Effective sharing and utilization of scarce radio frequency spectrum resources nationally is also a base for the development of new telecommunications policy for future internetworks and attainment of sustainable techno-economic development goals [1,2]. The paper will touch upon a number of research initiatives and synergies in 5G research standards that will help us to address these challenges in a constructive way [4,5]. This paper will touch on three research initiatives and proposed solutions, as contributions for the 5G Enhanced (5G-E) standard with an affordable broadband pillar: which is termed as the 4th pillar of 5G [4,11]. In this paper we will deal mainly on the first aspect of 5G research that is spectrum flexibility and spectrum sharing for unlicensed network operation in 5G. The organization of the paper is as follows, section II will present spectrum sharing research for wireless networks done to make possible unlicensed network deployment. Sections III will present the challenges and performance analysis results of a 5G network test-bed based on unlicensed spectrum principles, deployed in South Africa, based on unlicensed network operation in the television spectrum bands [6, 21]. Section IV will discuss the 5G spectrum toolbox research on unlicensed spectrum use and co-existence aspects in connection with unlicensed 5G networks.

II. SPECTRUM SHARING

Intensive research, development and testing of new innovative spectrum use and disruptive network technologies are being proposed globally to meet the gigabits wireless broadband requirements in 5G. This research is also expected to provide affordable broadband internet connectivity for underserved and rural communities in emerging economy countries [4,5,6]. This section will describe spectrum sharing paradigms and unlicensed spectrum networks for 5G as an important supplement to achieve the demands of future wireless networks [4,5].

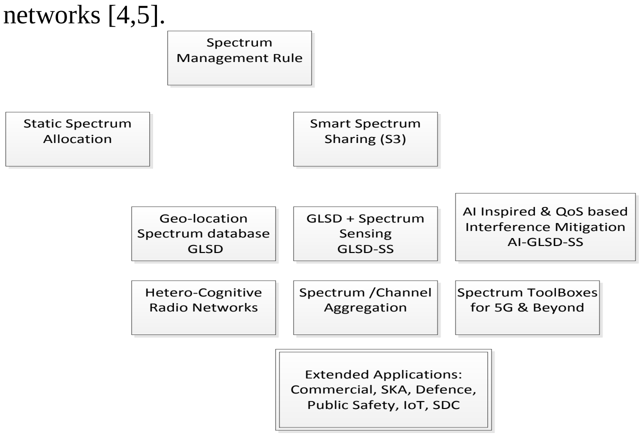

Figure 1, Spectrum sharing paradigms & techniques

Smart spectrum sharing (S3) research and unlicensed network in 5G, will be discussed with reference to standards such as the IEEE 802.22 & 802.11af and the S3 paradigms depicted in figure 1. These standards are a pre-cursor for more technologies to come, which will allow S3 and unlicensed network operation in all bands of interest based on reconfigurable and software defined radio technologies and devices [6-8].

Unlicensed white space networks (UWSN) based on smart spectrum sharing are expected to extend the reach of broadband in 5G standards for rural broadband connectivity [6, 12]. An example of an unlicensed spectrum network deployed in Tygerberg, Western Cape is shown in figure 4. The network is based on Television white spaces (TVWS) broadband network technology, where 10 underserved schools are connected to broadband internet using unlicensed spectrum TVWS networks. The unlicensed network is assisted by a smart spectrum sharing database (S3DB) interfacing to reconfigurable network devices through the IETF PAWS protocol (Protocol to Access White Spaces) [12]. The S3DB identifies and allocates unused spectrum channels for non-interfering co-existence operation and sharing of spectrum with TV broadcasting networks [4, 12, and 15].

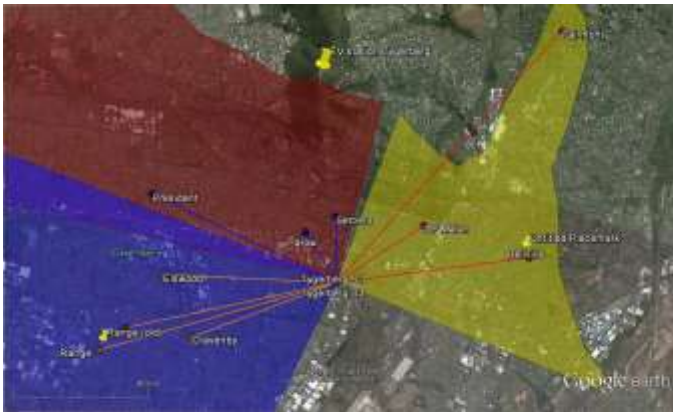
Figure 2, Coverage Prediction for an unlicensed network [6]

Coverage prediction for connecting the 10 schools with three TVWS reconfigurable radio base stations and a 3 sectored antenna is shown in figure 2. Each base station outputs a +28 dBm of RF power. Each antenna offers gain of about 10 dBi. Vertical polarization is used throughout all links.

III. UNLICENSED SPECTRUM IN 5G

The requirement of Gigabit services in the 5G standards, and proliferation of ubiquitous wireless smart phones is prompting intensive research on dynamic spectrum sharing. Spectrum sharing technologies such as licensed shared access (LSA), spectrum access systems (SAS), opportunistic spectrum access (OSA) and LTE_Unlicensed, aim for spectrum sharing and co-existent operation of heterogeneous mobile networks in the context of 5G [4,11]. A first step in enabling co-existence technology for unlicensed 5G networks is the smart spectrum sharing database (S3DB) designed to guarantee co-existence and unlicensed network operation. For heterogeneous unlicensed network operation in 5G guaranteeing a minimum of interference is task undertaken by the S3DB allocation [12]. The co-existence technology, termed smart sharing spectrum database (S3DB) for TV band (UHF/VHF) of frequencies and its functional operation is shown in figure 3. The S3DB also built with an interface to spectrum sensing devices to provide enhanced spectrum monitoring tasks and enable parameter adaptations.

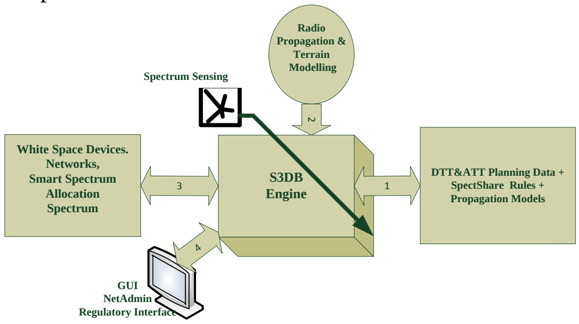

Figure 3, The S3DB co-existence tool [12].

The S3DB shown in figure 3, is designed for management and co-existence of TV band unlicensed spectrum allocation [12]. However, efforts are being taken to generalise the S3DB technology for management and co-existence monitoring of unlicensed network operation using white space spectrum in all bands of interest. Therefore, the research group developing this paper was involved in an international qualification and standards process for white space database (WSDBs) which was led by the Office of communications OFCOM UK [1]. The outcome and evidence of this process is now leading to WSDBs being considered as a technology of choice, for providing the necessary management and co-existence monitoring for unlicensed spectrum networks in all radio frequency bands of interest, including the spectrum areas being considered for 5G. This will have a profound impact on future wireless networks such as the emerging 5G mobile standard [4].

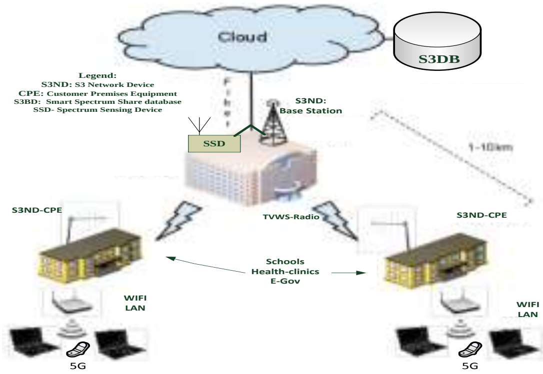

Figure 4, A Typical unlicensed TVWS network

The concept of unlicensed white space communications networks which are ushered alongside these S3DB and TV white space network (TVWS) technologies will also play an important role in enabling unlicensed 5G networks. A synergetic outcome of this research in spectrum flexibility is to support the 5G standard's gigabits bandwidth requirements in future wireless 5G networks. The research frontiers in this paper therefore continuing to develop further the S3DB system to create unlicensed spectrum hit maps for all bands of interest, based on geo-location. An example of an unlicensed spectrum availability hit-map for the TV band (UHF/VHF) of frequencies in South Africa is shown in figure 5. This spectrum availability result is now being used, to develop unlicensed networks for internet connectivity all over South Africa, and for use cases such as smart cities, e-education, e-government & smart-grids [12, 15].

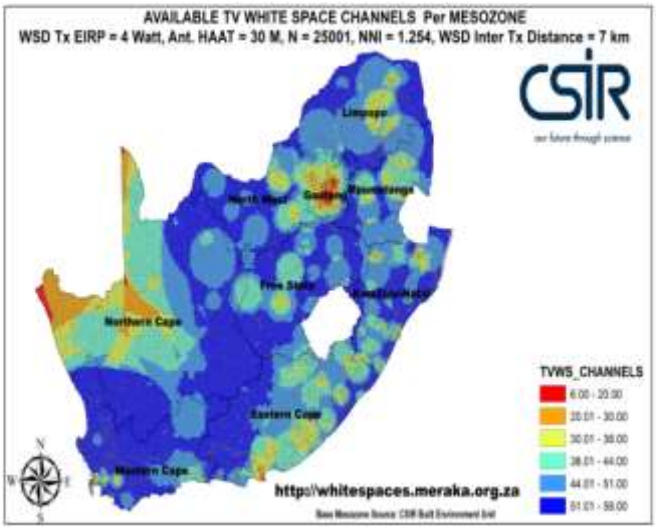

Figure 5, White space spectrum hit-map for South Africa

A. 5G & Spectrum Demand

5G standards require the availability and allocation of large amount of spectrum to provide the promise of gigabits wireless ICT services. The requirements of harmonized spectrum allocation and flexible access to spectrum for 5G systems range, from i) sub 1 GHz spectrum ii) 1-6 GHz and iii) beyond 6GHz. Shannon's pivotal equation on channel and network capacity clearly indicates that, the amount of spectrum allocated either as primary or secondary user in a wireless network is directly proportional to the spectrum available to build the network. How do we as researchers model this for maximum network capacity is the question that will enable or fail the success of 5G? As pointed out in the previous section, the way to achieve this in a non-interfering and co-existent way is through an adaptive spectrum database as shown in figure 3.

Spectrum usage audits done by FCC, OFCOM and recently regulatory body ICASA in South Africa, has also shown that there is a significant portion of spectrum that is lying idle, in the high-impact licensed spectrum ranges [1, 2]. Therefore smart spectrum sharing databases (S3DB) have become extensively used to turn the spectrum scarcity to spectrum abundance. The technology also promises to provide the necessary unlicensed spectrum to 5G networks to boost network capacity [3, 4]. Figure 6, shows a block diagram view of Shannon's network capacity equation, where spectral efficiency measures in the form of source coding, channel coding and network densification is used extensively. However, the new wave of network capacity increments is expected to come from identification of white spaces or unlicensed spectrum by using S3DB technologies. In figure 6, the outcome of the CSIR spectrum database, is shown to add non-consecutive 14 channels of 8MHz in the TV band of frequencies, which gives a total of 112 MHz of spectrum for increased network capacity. Although this research result is an outcome of our activities to accelerate affordable broadband to rural underserved communities, extensive research is being undertaken by academic and industrial counterparts to bring such techniques to the 5G network standards [1, 3, and 10].

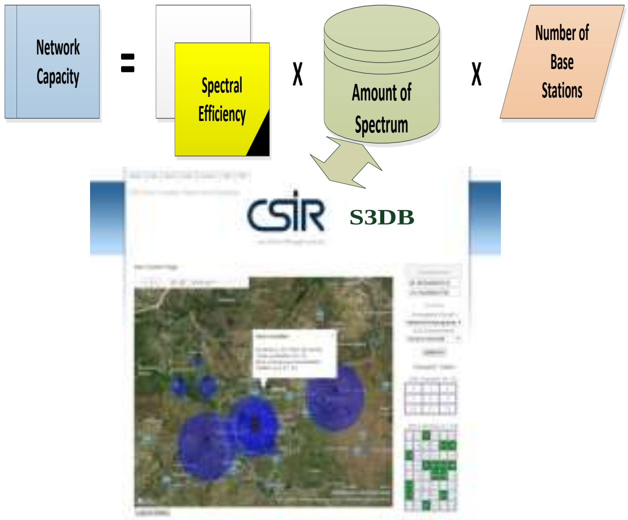

Figure 6, Enhancing Network Capacity based on S3DB

Development of smart spectrum sharing databases for 5G spectrum sharing and spectrum aggregation is an active research area to enable unlicensed spectrum networks in the era of 5G networks based on 5G spectrum table I, shown below.

IV. 5G SPECTRUM TOOLBOXES

A. Spectrum & Channel Aggregation

Two important techniques being studied in the 5G spectrum toolbox developments are channel and spectrum aggregation. The technique of spectrum aggregation can be realized with a simple extension of the S3DB technology. There is a realization that the full potential of 5G can only be achieved with such innovative technologies as spectrum and channel aggregation. A simple realization of a spectrum channel aggregation for a TV band spectrum can be seen in the S3DB output shown in figure 6, where the contiguous channels 41-45 can be aggregated, giving a 40MHz bandwidth channel and increased network capacity. Network operators are also studying and researching techniques to aggregate channels and wireless signals, coming from different base stations to boost capacity [13, 20].

B. Spectrum Sharing & Regulation

Spectrum regulators should state their objectives and define frameworks for unlicensed smart spectrum sharing (S3) based on the following guiding principles:

a) Improved and effective utilisation of national spectrum resources in all bands of interest.
b) Development of reliable spectrum monitoring and co-existence tools with legacy licensed networks to enable non-interfering and DSS network technologies.
c) Enabling broadband network innovation in support of and provision of affordable broadband for the unconnected, and the fulfilment of the national development plan for future 5G ICT eco-systems and wireless broadband services.
d) Harmonisation of unlicensed S3 rules along country boundaries following international telecommunication union (ITU) standards and guidelines should be drafted and publicly available.

TABLE I. 5G SPECTRUM

Band Range	Spectrum and application Types		
	Typical Spectrum Types	*5G App1*	*5G App2*
54KHz -1GHz	Widespread Coverage Range, 700,800,900 MHZ	Rural/Unlicensed	Urban, WLAN (IoT)
1GHz - 6GHz	Mixed Range and Capacity, 1800MHz, 3.3 -3.8 GHz	Urban/Rural/Unlicensed	IoT/ITS
> 6GHz	Gigabits Wireless Broadband (6-28GHz)	UWB, Wireless Fiber	Wireless VOD

V. CONCLUSION

Future developments of smart spectrum sharing systems will provide the necessary technical co-existence framework, AI inspired interference mitigation and regulatory mechanisms to make smart spectrum sharing work in all bands of interest. The development of technologies for software defined radios and spectrum sensing are also the other drivers in the quest for dynamic access to spectrum and cognitive radio based networks.In this paper aspects of smart spectrum sharing databases (S3DB) as enabler for affordable and unlicensed network deployment in 5G have been presented. The study also showed that the S3DB technology and framework is easily adaptable for use as one of the 5G spectrum toolboxes to boost network capacity. Spectrum regulators and network operators globally are working towards spectrum flexibility paradigms, where smart spectrum sharing database is used to provide flexible spectrum allocation and interference control, and at the same time accelerate affordable broadband networks and increased network capacity in future wireless 5G networks. Spectrum sharing unlicensed networks are expected to address the connectivity divide existing between the urban and rural communities in emerging markets. Therefore the paper also argues for an extension of the existing 5G standards to address emerging market contextually relevant use cases for affordable wireless broadband connectivity. It is also argued that the availability of large swaths of under-utilized radio frequency spectrum in rural areas can be used to provide low-cost unlicensed wireless broadband internet services to rural, sparsely populated, low-income population regions in emerging economy countries [1-4, 11, 12].

The technology of smart spectrum sharing and unlicensed 5G networks is also expected to extend the upcoming 5G standards to achieve its promise of gigabit wireless connectivity services. This is possible with a unified smart spectrum sharing databases and advanced interference mitigation techniques developed to operate in the spectrum areas allocated for 5G. Such a concept of a unified spectrum database is shown in figure 7, below. The concept is a future research project by the CSIR to enable Licensed & Unlicensed 5G and beyond future networks. At the same time the paper has shown the synergetic research on unlicensed 5G which will support the ITU broadband commission's recommendation for affordable broadband connectivity. Spectrum sharing and unlicensed 5G network technologies are supported by new 5G use cases to enable provision of low cost broadband connectivity in Emerging Market countries, and allow an extension of the 5G standard & applications to the benefit of rural underserved communities.

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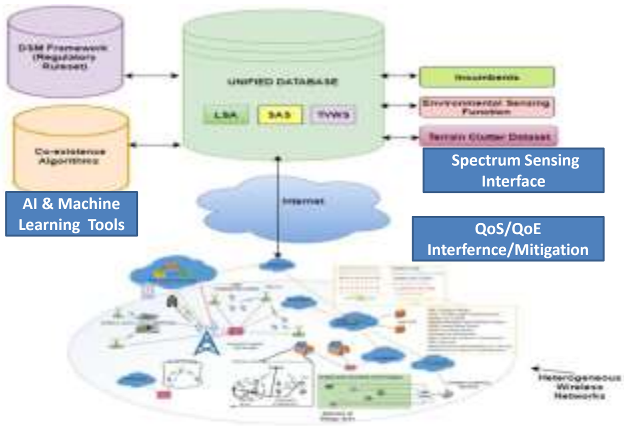

Figure 7, the concept of a Unified Spectrum Database

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