Nyasulu, Tawachi and Crawford, David and Mikeka, Chomora (2018) Malawi's TV white space regulations : a review and comparison with FCC and Ofcom regulations. In: 2018 IEEE Wireless Communications and Networking Conference, 2018-04-15 - 2018-04-18, Barcelona International Convention Centre (CCIB). (In Press) ,

Malawi's TV White Space Regulations:

A Review and Comparison with FCC and Ofcom Regulations

T. Nyasulu and D. H. Crawford
Centre for White Space Communications
University of Strathclyde
Glasgow, UK

C. Mikeka
Physics Department
University of Malawi
Zomba, Malawi

Abstract—**Regulators are in the process of framing regulations to allow secondary use of vacant TV channels while protecting TV broadcast services from harmful interference. While the US and UK regulators have already passed such regulations in 2008 and 2015 respectively, other countries are still in drafting stages and the underlying circumstances in these countries could be different from those of the US and UK. Malawi released its final draft regulations in 2016. While the US and UK legislate for dynamic spectrum access and licence-exemption for secondary users, Malawi's draft regulations require such users to apply for a licence for assigned TV white space spectrum. This paper provides an analytical review of Malawi's regulations and a comparison with FCC and Ofcom regulations, which new regulations can build on. This analysis will also inform future work on network management tools that can enable practical deployment and co-existence of large-scale TV white space networks in a dynamic spectrum access environment in Africa.**

Keywords—TV white space; white space device; regulations; Dynamic Spectrum Access.

I. Introduction

'White space' refers to radio spectrum that is either allocated for licensed use but not assigned to a particular licensee due to limited demand, or not being used by licensees at all times and in all geographical locations. There are white spaces in the band that is allocated to TV broadcast services and these are commonly referred to as TV white spaces (TVWS). Wireless communication over TVWS has been proven feasible for a number of applications, including the provision of backhaul links and broadband internet [1][2][3]. The TV band is particularly attractive for rural broadband connectivity because it exhibits good propagation characteristics over undulating terrain and good penetration characteristics through trees and foliage – typically in non-line of sight conditions [4][5]. Furthermore, TV band networks have cheaper and lower infrastructure costs than higher frequency networks such as Wi-Fi because, owing to their longer range of coverage for a given transmission power, fewer base stations are required for the same coverage area. Broadband connectivity in the TV band also has potential for other applications such as wide-coverage hotspots with fewer dead spots, machine-to-machine communications and cellular off-loading to alleviate congestion [6][7].

TVWS spectrum can be accessed dynamically through the coordination of operating frequencies and the use of device location information, while observing the key regulatory requirement of not causing harmful interference to licensed or primary services. This can, in theory, be achieved in several ways, such as through the use of a geolocation spectrum database and/or spectrum sensing. Dynamic spectrum sharing has potential for improving spectrum utilization relative to static assignment of exclusive spectrum rights [8][9].

The US regulator, Federal Communication Commission (FCC), was the first to develop rules for TVWS operation based on dynamic spectrum access. Regulations were initially released in 2008 and have undergone revisions in 2010, 2012, and 2015 [10]. The European Telecommunications Standards Institute (ETSI) released a harmonized European standard for white space devices (WSD) in 2014 [11]. The UK regulator, Ofcom, released TVWS regulations in 2015 [12] [13]. The regulatory frameworks of FCC and Ofcom rely on regulator-approved geo-location spectrum databases as the main mechanism for controlling licence-exempt access to the spectrum. These two frameworks could potentially be used as templates alongside the guidelines for TVWS operation that were released by the Dynamic Spectrum Alliance (DSA) [14].

According to a 2014 survey, penetration of TV services remains low in Malawi. Usage of TV services among urban and rural households is at 46% and 6% respectively [15]. A 2012/2013 survey found that TV white spaces are available in the UHF band, both in urban and rural Malawi [16]. Migration from analog to Digital Terrestrial TV (DTT) was completed in 2015. A public multiplex operator and signal distribution company was also established to provide signal transmission services to licensed broadcasters. This resulted in more TV spectrum being freed. In 2013, the Malawi Communications Regulatory Authority (MACRA) authorized trials for rural internet provision using a TVWS network [17].

Malawi's draft TVWS regulations (2016), are in two separate documents: operational regulations as an add-on to the Communications Act, and technical rules for operating licence-exempt TVWS devices. The operational regulations have deviated from the norm of licence exemption and dynamic spectrum assignment in that TVWS users are required to apply for a licence and pay licence fees according to TVWS spectrum usage. Nevertheless, the technical rules make provision for operation of licence-exempt WSDs under the management of a geo-location spectrum database or spectrum sensing. However, a geo-location spectrum database for Malawi has not yet been implemented. Currently, Malawi has issued a licence to one operator, C3, to deploy and operate TVWS on a commercial basis; however, they are using a static white space channel allocation.

The rest of the paper is structured as follows: An overview of Malawi's draft regulations is presented in Section II. Section III examines and compares the regulatory specifications among MACRA, FCC and Ofcom Results are discussed in Section IV. Finally, conclusions are drawn in Section V.

II. Overview Of Malawi's DRAFT Regulations and Technical Rules

The objectives of Malawi's regulations are two-fold: to enable low-cost broadband internet access and Internet of Things (IoT) applications and to promote efficient use of spectrum through dynamic spectrum access in order to achieve universal access of ICT services as required by the Malawi Communications Act.

A. Licensing and Spectrum Assignment

A TVWS user shall be required to apply for a licence. Nevertheless, part II, sub heading Requirements, sub regulation (1) states that both licensed and licence-exempt TVWS devices shall be allowed:

> *"A person shall not operate or use Television White Spaces equipment (that is any equipment other than license-exempted TVWS devices) without a valid licence issued by the Authority."*

The draft regulations also state that TVWS spectrum shall be assigned to users who shall pay an annual licence fee and shall operate on the assigned centre frequency and within the specified bandwidth. Specifically, Part III (d)(ii) states that:

> *"For any assigned White Space Channel, the licensee shall pay annual TV White Space license fees in the amounts and at the times prescribed by the Authority."*

Since there is no published data for a white space map for Malawi as a whole, the regulations do not specify the proportion of the available TV white space spectrum that shall be assigned through granting of exclusive licences or set aside for licence-exempt use.

B. Technical Rules for Operating Licence-Exempt WSDs

The technical rules provide the framework for operating licence-exempt WSDs in such a manner that no disruption is caused to TV broadcast services. The framework also provides strict specifications that WSDs must comply with in order to be authorised to operate in TVWS spectrum.

III. Analysis and Comparison

In the following subsections, Malawi's draft TVWS framework is evaluated. Key areas of variation among the regulations of MACRA, FCC and Ofcom are also discussed. A summary of the key differences is given in Table I.

A. Frequency Bands of Operation

Malawi's TV band used to span across VHF and UHF frequencies in the days of analogue TV services. However, following the digital migration that was completed in 2015, the TV band now comprises UHF frequencies only. Hence the designated TVWS band is in the UHF band only, from 470MHz to 694MHz. At the time of development of Ofcom's TVWS regulations, the UK's TV band also comprised UHF frequencies only, from 470MHz to 790MHz. TVWS is permitted in the entire TV band except for channel 38 (606 MHz to 614 MHz), which is reserved for programme making and special events (PMSE), and channel 60 (782MHz to 790MHz) in order to ensure coexistence with LTE mobile services that are allocated the 800MHz band (791MHz to 862MHz). In the US, the TV band still spans the VHF and UHF frequencies and consequently, TVWS operation is allowed in both frequency bands. However, the FCC regulations allow VHF operation solely for fixed WSDs that communicate only with other fixed WSDs. VHF frequencies propagate further for a given transmission power as compared to UHF frequencies. This means that the probability for interference is higher when using VHF frequencies than when using UHF frequencies. This could be the reason why FCC restricted VHF operation to fixed devices only which are easier to locate than portable devices in the event of an interference incidence.

B. TVWS Spectrum Assignment and Licensing

Malawi's draft regulations require licence fees based on assigned TVWS spectrum and also specify the obligations of TVWS operators in the form of key performance indicators. If licensed commercial TVWS operators are to guarantee the service quality levels that are scheduled in the regulations, they need guaranteed interference protection from other WSDs. Hence the regulations provide for exclusive rights to TVWS spectrum to safeguard the operator's network from interference. This is achieved by static assignment of operating frequencies via a licence which the TVWS operator must obtain. Since Malawi has an abundance of unused TVWS spectrum – (the study in [16] has shown that up to 75% of the UHF band is available as a white space) – and because MACRA has made provision for static assignment of licensed TVWS spectrum, it is probable that a two-tier system in which licensed TVWS operators enjoy protection similar to that offered to licensed DTT operators will ensue. This would mean that licensed TVWS operators would have to be included in the geo-location spectrum database as protected entities. This opinion is supported by article 8.1.2.7 of the Technical Rules:

> *"Establish a process for the database administrator to include in the geolocation database any facilities that the Authority determines are entitled to protection but not contained in a database maintained by the Authority".*

Dynamic spectrum assignment, as specified in the technical rules, only applies to licence-exempt devices which comply with the specified rules. Ofcom and FCC have legislated dynamic spectrum access and licence-exemption for all WSD operation as long as the devices comply fully with the regulations and equipment standards. The main reason for licence-exemption is to stimulate innovation and business startups by excluding such entry barriers as expensive licence fees and licence application delays. A compelling case in favour of licence-exempt access in delivering broadband internet and machine-to-machine connections was made in [18]. The economic benefits as a result of enabling licence-exempt access to TVWS far outweigh the gains from TVWS spectrum licence fees.

C. Equipment Standards and Transmit Power Limits

In Malawi's technical rules, the maximum radiated power for WSDs is capped at 10W whereas in FCC's 2012 regulations, the maximum power for WSDs was 4W [19]. The FCC rules were revised in 2015 (FCC 15-99) to improve TVWS availability by allowing lower-power operation on vacant channels adjacent to occupied channels and to allow different separation distances for a range of power levels below 4W. Maximum transmit power was revised to 10W from 4W, but only for operation in less congested areas, i.e. areas where at least 50% of the TV channels are unused. Like the Ofcom rules, simultaneous operation on multiple channels (a.k.a. channel bonding) is now permissible to improve data rates. A 'push notification' feature has also been introduced to the geolocation database for the purpose of sharing ad-hoc updated channel information, which is similar to the 'unscheduled adjustments data' feature of Ofcom's rules.

MACRA's spectral emission mask specifications for WSDs are based on the FCC's 2012 standards, although Malawi's TV channels are 8 MHz wide, as is the case in Europe, rather than 6 MHz wide, as is the case in the US. The spectrum mask should be 20 dB in depth. However, incorporating both FCC and ETSI standards, as preceded by Singapore, would give users flexibility to obtain equipment from either American or European markets [20]. Similarly, DSA guidelines encourage that, for WSDs that are capable of providing their radio emission mask capabilities such as emission class, the database should compute adjustments to spectrum availability information to match the WSD's emission characteristics based on ETSI standards [11].

Ofcom's equipment standards are based on the ETSI harmonized equipment standards for WSDs. The most notable aspect of this standard is that WSDs are classified according to their emission performance and this is taken into account by the geolocation spectrum database when assigning specific operating parameters to the WSD. A WSD with better emission class is allowed to transmit at a higher power than one with a poor emission class. The maximum transmit power cannot exceed 4W.

D. Methods of Dynamic Spectrum Sharing

Whereas MACRA and FCC recognize both geolocation spectrum database and spectrum sensing as two standalone methods by which a WSD may determine availability of available channels, Ofcom/ETSI regulations recognize only the database method. Considering that spectrum sensing technology is not yet ripe, both MACRA and FCC regulations require type-approval tests prior to operation and also specify stringent transmit power limits (50mW EIRP) for sensing-only devices. Also, allowing spectrum sensing technology in the regulations provides incentives for further research aimed at improving the technology.

The database method of spectrum sharing relies heavily on location accuracy. MACRA's requirement for geolocation accuracy is ±50m. This is regardless of whether the antenna of the WSD is fixed in an outdoor setting or is an integrated antenna of a portable device that can be located indoors where the geolocation accuracy is worse than in an outdoor setting. FCC and Ofcom/ETSI rules instead provide an option for a WSD that is capable of communicating its location uncertainty to do so and this information is taken into account in the determination of its specific operational parameters.

TABLE I. SUMMARY OF COMPARISON OF MACRA, FCC AND OFCOM REGULATIONS

	MACRA	*FCC*	*Ofcom*
TVWS Band	UHF band only (470 to 694 MHz)	Fixed devices only: VHF band (54-72 MHz, 76-78 MHz, 174-216 MHz) Both fixed and portable devices: UHF band (490-698 MHz)[a]	UHF band only (470 to 606 MHz, and 614 - 782 MHz)
Licensing	Mixed (Licensed and Licence-exempt)	Licence-exempt	Licence-exempt
Equipment Standards	Based on FCC standards of 2012.	FCC 2015 standards	European Standard ETSI EN 301 598 V1.1.1 (2014-04)
Maximum transmit power for fixed devices	10W	10W[b]	4W
Dynamic Spectrum Sharing methods	Geolocation Spectrum Database and Spectrum Sensing.	Geolocation Spectrum Database and Spectrum Sensing.	Geolocation Spectrum Database only.
Database implementation approach	Not specified. However there is mention of preference for point to point, terrain based propagation models like the Longley Rice algorithm (DSA model).	Protected contour approach, calculated using F (50,50) and F (50,90) curves propagation models.	Reduction in location probability threshold approach, calculated using a statistical model (UKPM)
Standard Validity period of available channel information	Provided by the database as part of operational parameters.	Static at 48-hour period, starting from the time when the WSD last accessed the database for a list of available channels.	Provided by the database as part of operational parameters. Value shall be indicated by the regulator and can be dynamic. (Value set to 15 minutes initially as recorded in footnote of Section 5.23 of [12].)

a. WSDs many only operate in the 600MHz service band in areas where licensees are not operating.

b. 10W applies only to less congested areas, 4W otherwise.

E. *Database Implementation Approach*

The main difference between Malawi's technical rules and FCC's regulations lies in the methodology of the geolocation spectrum database. A database implementation methodology specifies the method of analysing channel availability and calculating maximum permitted transmit power levels. It includes a database algorithm that uses information about the coverage of primary users, regulatory rules and WSD's location and device parameters to supply a list of available channels and the maximum transmit power for each channel. According to the FCC framework, the minimum output data that a database must provide is a list of available channels, whereas MACRA and Ofcom regulations require transmit power limits for each available channel and validity period of the given operating parameters to be provided, among other parameters.

There are three common approaches to database implementation: signal-to-interference-plus-noise ratio (SINR) threshold, contour boundaries, and reduction of location probability threshold [21].

The SINR threshold method is based on the premise that a channel is occupied if the received signal power, calculated by a terrain based propagation model, is greater than the SNIR limit plus link margin for the transmitter. This is a computationally intensive method outlined in the DSA guidelines [14].

MACRA's draft regulations do not specify the details of the database algorithm, assumed to be provided by FCC-authorized database operators such as Spectrum Bridge, Google, and Microsoft. MACRA recommends any point-to-point model that takes into account terrain conditions, e.g. the Longley Rice algorithm and/or other fading channel algorithms. This is consistent with DSA guidelines which are based on the SINR threshold approach. MACRA regulations also provide freedom to database administrators to implement alternative algorithms that can be proven to provide the recommended protection to licensed users. Locally, researchers have developed a 'TV White Spaces Geo-Location Database as a Rule based Expert System' [22].

In the contour based approach, a channel is available if a WSD is located outside the minimum separation distance from the edge of the specified polygonal contour surrounding the coverage area of the DTT transmitter that is operating on co-channel or adjacent channel. This is a robust but less computationally intensive approach that is used by the FCC. However, the impact of terrain on signal propagation is not taken into account, which results in either over-protection of primary users where undulating terrain blocks signals or under-protection in flat terrain where signals travel further than what the model predicts.

The UK uses the location probability approach, which is computationally intensive. A proprietary statistical model called the UK planning model (UKPM) is used to calculate the permitted reduction in location DTT coverage probability per 100m by 100m locality (known as a pixel) as a result of interferers, the concerned WSD included [12].

Most countries may be more likely to follow the first two approaches because the third approach requires a high resolution propagation model, up to 100m by 100m pixels. It is therefore likely to be an expensive and time consuming exercise for a country to develop its own model unless such a model already exists, as was the case in the UK. Developing countries are likely to implement the approach that has already been developed by the DSA because it takes into account the impact of terrain.

However, some modifications that meet the specific needs in their areas of jurisdiction may be adopted. For instance, the drawback of the DSA method is that, because it relies heavily on SINR, it cannot protect primary users at the edge of coverage areas who may use abnormally high TV antenna masts to compensate for the low power of the received signal [16]. This was one of the factors that prompted developers of South Africa's geolocation spectrum database to use three propagation models in their database implementation. These were: a) FCC's F-curves modified to accept ITU region I grade B and C contours, b) the irregular terrain with obstruction model (ITWOM) for longer separation distances at higher WSD antenna height, and c) the FCC/OET TM91-1 for shorter separation distances at lower WSD antenna height [21].

F. *Validity Period of Operating Parameters*

During operation, WSDs are required to re-verify validity of operating parameters at fixed intervals. Both MACRA and Ofcom rules specify that the validity period shall be provided by the database. For Ofcom, the initial value is currently set to 15 minutes [12]. For FCC, a fixed or portable master device (Mode II device) that fails to verify its available channel list during any given day, has up to midnight of the following day to contact the database, otherwise it must cease operation [10].

G. *Border Areas*

MACRA's technical rules do not include mechanisms for protection of primary users of neighboring countries in border areas. This is an area that needs to be covered in subsequent revisions since Malawi is a landlocked country. FCC and Ofcom rules specify that the database shall include protected services in border areas of neighboring countries.

The US and Canada share borders and both have TVWS regulations in place based on the same contour-based approach in their database implementation algorithm [23]. However, there is no precedence yet for a case where neighboring regulators differ on key areas of the frameworks such as maximum transmit power and database implementation methodologies. It is therefore envisioned that as the TVWS industry develops, regional regulatory bodies such as the Communications Regulators Association of Southern Africa (CRASA) would also have to standardize regulatory frameworks to ensure harmony in border areas of their member states.

H. *Device Initialisation*

On initial contact with a master device, MACRA and FCC rules require that a client device or a fixed device that has no direct internet connection should transmit on available channels that are used by the master device or are indicated by the master device as free. But the proper functioning of a geo-location spectrum database hinges on accurate geo-location information. Since the location of a non-geo-located slave WSD that requires initialization may not be the same as that of the master WSD, there could be possibility for brief unintentional interference to protected services [24]. Ofcom regulations instead provide for a master WSD to acquire from the database more constrained "generic operational parameters" that slave devices in the same geographic area or in the master WSD's coverage area may use for initial transmission. However, as documented in section 4.71 of [12], it was observed in Ofcom trials that the generic parameters were sometimes too restrictive for reliable communication.

I. Master/Slave Coordination

MACRA and FCC rules require that a fixed/master device should cease operation immediately when the database indicates that the channels are no longer available. This means that its slave devices would continue to transmit on the invalidated operational parameters until after the next 60 second update interval when the slave devices would cease transmission because they are unable to make contact with their master device. There could be a possibility of interference from the slave devices during that period. Ofcom rules instead require that the master device should send instructions to its slave devices to immediately cease transmitting before itself ceasing transmission. This appears to be a more orderly approach. However, the master device is also likely to cause brief interference while broadcasting the cease transmission instructions, although this is likely to occupy a relatively shorter time than in the previous case.

J. Interference Management

Although dynamic spectrum sharing aims at interference avoidance, tools that facilitate determination of WSD-WSD coexistence as well as quick resolution in the event of a complaint, such as a spectrum occupancy repository, are necessary. For example, Ofcom requires feedback from WSDs in the form of channel usage parameters. A WSD reports back the channel(s) that it intends to use out of the given list of available channels. Furthermore, the Ofcom framework also requires database operators to provide an information system of white space devices that provides data for investigating interference cases [12]. MACRA and FCC rules, on the other hand, require only that fixed devices be registered with the database, including the device's unique identifier and contact details of the owner to facilitate interference management. However, there is no requirement for feedback on actual parameters being used by WSDs.

IV. DISCUSSION

TV white space communication is regarded as one of the potential solutions towards bridging the digital divide in the developing world [2][4][5]. However, TVWS networks, using dynamic spectrum access, have so far been implemented mainly in pilot projects only. Scale-up of TVWS networks depends on enactment of regulations, ease of networking management in a dynamic spectral environment, availability of sufficient TVWS bandwidth, and potential applications, among other factors.

Regulatory frameworks for dynamic spectrum access represent the first step towards implementation of flexible spectrum management. An analysis of Malawi's TVWS regulations was found to be useful towards prospecting the needs for the growth of TVWS networks in Africa. Comparison with regulations of countries such as the US and the UK, that have already tested the database method provides valuable insights.

None of the regulations released to date have specifically covered WSD-WSD coexistence as this typically is not the focus of regulators but rather that of equipment technology standardization bodies. Coexistence among similar devices is implemented using multiple access protocols of the WSDs such as frequency hopping and carrier sense multiple access with collision avoidance (CSMA/CA). In 2017, the IEEE published the amended version of the 802.19.1-2014 standard for network-based coexistence management for heterogeneous and/or independently-operated networks to collect and share coexistence information [25]. Radio frequency planning tools that can leverage input from geo-location spectrum database and co-existence systems would be useful in management of large scale networks whose applications require a certain guaranteed quality of service.

In Malawi, not all TV spectrum that was released as a result of the digital TV migration and the establishment of a multiplex operator has been returned back to the regulator. Incumbent licence holders are likely to be reluctant to give up their long term right to spectrum. One approach to motivate broadcasters to release unused spectrum is that which was taken by the FCC in its 2017 broadcast television spectrum incentive auction. The auction had two components: the reverse auction, in which TV operators were given an opportunity to bid to voluntarily relinquish spectrum usage rights and would in turn receive a share of the auction proceeds as an incentive payment, and the forward auction in which operators could bid for the spectrum in the 600MHz service band. This will enable the FCC to repack the broadcast television spectrum and free up more spectrum for licence-exempt dynamic spectrum sharing.

Another approach for licensed spectrum sharing that has been proposed is authorised shared access (ASA) between incumbent services and other applications with guaranteed interference protection for both services, and without the incumbent necessarily losing its long term right to the spectrum. In Europe, this has been termed Licensed Shared Access (LSA) and in April 2017 ETSI released its specifications for LSA, initially in the 2300-2400 MHz band [26]. A real-time secondary spectrum market (RTSSM) policy, where incumbents can voluntarily share their excess licensed spectrum through private spectrum brokerage, was also proposed in [27]. As the scope of dynamic spectrum sharing broadens, a market for database tools for real-time white space spectrum auctioning and allocation in reconfigurable radio networks is envisioned.

V. CONCLUSION

The TVWS industry is still developing, and regulations will continue to evolve as the market develops. The FCC pioneered development of TVWS regulations in 2008 with subsequent incremental improvements in 2010, 2012 and 2015. In 2008, Ofcom announced plans to repurpose TV spectrum that would be freed up by the switch to digital television. Since then, Ofcom has collaborated with ETSI on developing Europe's harmonized WSD standards, as well as developing its own TVWS co-existence framework. ETSI's hardware standards were released in 2014 and Ofcom released its TVWS regulations a year later. MACRA started TVWS trials in 2012. Three years later, MACRA released its draft TVWS regulations for consultation and the final draft was available by 2016.

Analysis of the three regulations has shown both similarity and variation in many areas such as licensing, equipment standards, frequency allocations, operational parameters, spectrum sharing techniques, geolocation spectrum database algorithms and interference incidence management mechanisms. It is clear that TVWS co-existence framework approaches depend on the needs and circumstances in the regulator's area of jurisdiction as well as engineering resources that are at its disposal. This analysis of approaches has yielded valuable knowledge for new regulations to build upon. Furthermore, it also presents prospects for regional regulatory bodies to envision approaches for harmonization of regulatory frameworks.

Enactment of regulations and implementation of geo-location spectrum database presents the first step towards development of dynamic TVWS networks. The Centre for White Space Communication, in collaboration with Microsoft and Nominet among other partners, has embarked on a 3-year project, funded by the Engineering and Physical Sciences Research Council (EPSRC), to investigate and test how the use of dynamic spectrum access (DSA) systems and geolocation spectrum databases may be used to enable effective and efficient wireless white space networks to be built at scale in four African countries, including Malawi. Results and outcomes of the research activities will be published in due course.

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