A Global South Perspective on Alternative Spectrum Policy

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Executive Summary

Like voice services, mobile broadband has unlocked access for millions of people across Africa. This is mostly due to the success of mobile wireless technology in overcoming the many vast rural spaces throughout the continent, as well as the business models that allow for the investment in smart devices that are far cheaper and easier to use than computers, and availability of data services that can be purchased incrementally at low cost, such as top-up on demand.

The shift from voice networks to data in competitive markets has required upgrades and greenfield investments that have thinned out many operators and left others very marginal in increasingly concentrated markets. Mobile markets in sub-Saharan ICT sectors are increasingly characterised by one or two big mobile network operators (MNOs) who enjoyed first-mover advantages by investing in single-carrier cellular networks and purchasing expensive national spectrum licences. When early generation GSM technology was first deployed for voice and text services, regulators had to focus heavily on protecting other users from network interference by assigning spectrum to different services and operators at a national level to be used across their country's entire geographic area.

In this process, spectrum bands were reserved for TV broadcasting, which was the primary public use of spectrum prior to the introduction of mobile cellular services. Point-to-multipoint transmission broadcasting technologies use spectrum far more inefficiently than mobile network services, for which there was initially limited, but now high, demand. With regulatory obligations to expand their telecommunications network coverage to less-populated rural areas, new licensees initially were only able to achieve low returns on investments in the less economic areas.

Although this does not address the broader and more complex political and economic challenges associated with spectrum allocation in the public interest, this paper demonstrates that new spectrum policy approaches, which shift the focus away from the right to exclusive access to spectrum to the right to protection from interference, could overcome some of the current inefficiencies in allocating spectrum. This has the potential to result in positive outcomes in terms of realising policy objectives of affordable universal access, enhanced consumers' welfare through enabling fair competition, and technological and regulatory innovation.

This policy paper provides an overview of state-of-the-art technology and standards that would allow alternative spectrum licensing, as well as certain limitations – both from a technological and a policy perspective. Spectrum measurements undertaken for this study provide evidence that certain frequency bands are unused, particularly in rural areas, and could easily be assigned to alternative service providers. A range of stakeholders have provided input for this study. These include technology experts, researchers, community networks practitioners, representatives from regulatory agencies and policy makers. Arising from this, directions for future work on advocating for changes in the regulatory environment are provided.

The study reveals that there are a number of reasons why spectrum policies need a new paradigm to meet pent-up demand for communications services. Another argument for new policies on spectrum licensing comes from the success of community networks in providing broadband access in a number of cases. Community wireless networks are locally owned and operated networks that usually rely on alternative low-cost technologies and open-source solutions. They are being increasingly deployed to provide connectivity in remote rural areas that lack coverage or in areas covered by commercial operators where services are not affordable or use antiquated mobile technology, such as 2G GSM.

However, the success of such networks is often hindered by expensive and underutilised national exclusive spectrum licences, as well as the high, opaque and sometimes discriminatory wholesale network access pricing offered by vertically-integrated mobile network operators.

Contents

1. Introduction

Spectrum is governed by a set of rules and restrictions designed to limit interference. Radio spectrum is the part of the electromagnetic spectrum with frequencies from 30 hertz (Hz) to 300 gigahertz (GHz), and waves in these bands are widely used in telecommunications (e.g. telephony, wireless Internet), as well as for media and entertainment (television, radio), military use (e.g. radar), navigation (e.g. GPS), and more recently, Internet of Things.

To prevent interference between different users, the generation and transmission of radio waves is regulated by national communications regulatory agencies and coordinated by the International Telecommunication Union (ITU). Governments own and manage the use of radio spectrum within each country's borders. Licences define spectral dimension (frequency), geographic dimension (coverage area) and time dimension (expiry) of a spectrum usage right, as well as technical details such as allowed power levels to prevent interference, and the costs associated with the right to use spectrum bands.

Before mobile telephony and wireless broadband technologies became ubiquitous, the availability of spectrum exceeded demand. Spectrum licences were given for exclusive use and covered large geographic areas – in principle, nationwide. However, today the traditional ways of regulating spectrum have inefficiencies and are not keeping up with technological progress. In addition, access to high-demand International Mobile Telecommunications (IMT) spectrum is very expensive to secure and takes place via auctions and radio licensing. This is the case in South Africa, for instance, where spectrum allocation is technically inefficient, and the cost of securing radio licences is very high.[1]

The assignment of IMT spectrum bands in South Africa is shown in Figure 1.

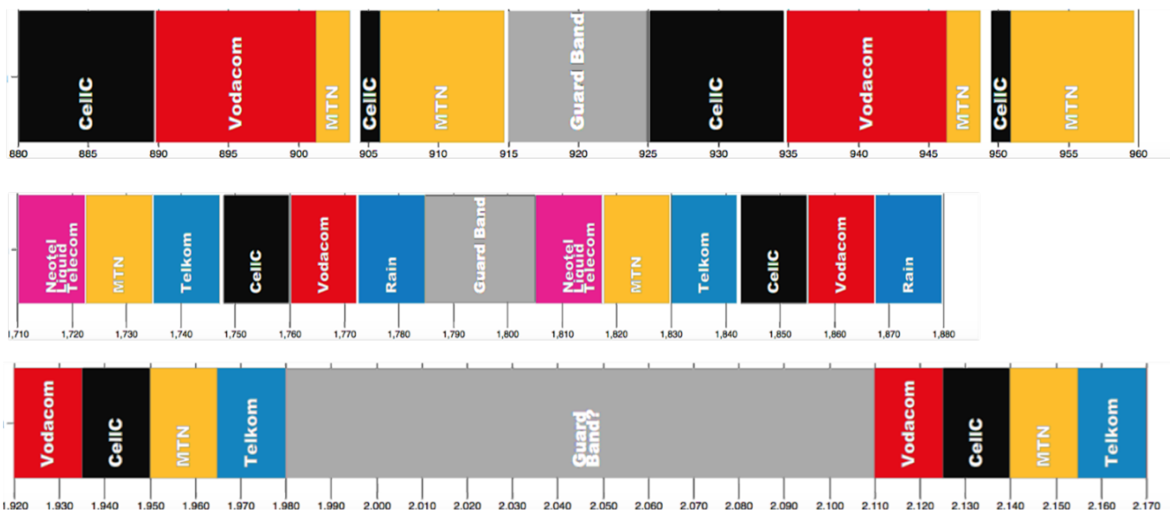

Figure 1: IMT spectrum assignment in South Africa

Source: https://opentelecomdata.org/spectrum-chart/

From a market transparency perspective, the IMT table is not sufficient to identify whether spectrum is actually in use. Rather, to improve transparency on spectrum allocation, and to improve its use, there is a need for comprehensive public information on spectrum assignments, that is, not just whether an

[1] Charley Lewis (2008) *Lessons from Spectrum Auctions: A Benchmark approach.* Available at https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3185752

organisation has received permission to utilise a given frequency band, but whether they are indeed using it across time and geographic dimensions.

Efficient spectrum utilisation directly affects retail pricing. High prices of mobile data are often due to inefficient policy and regulatory related issues. Vodacom, one of South Africa's largest mobile operators, stated that 'unquestionably the most significant obstacle to reducing input costs and, by extension, data prices is the fact that no new spectrum has been allocated to operators for the past 14 years', referring to the delays in digital migration and freeing up the high-demand spectrum, namely the 700 and 800 MHz digital dividend bands.[2]

A policy brief[3] published by the Internet Society in October 2017 elaborates on the critical importance of access to spectrum in order to provide unconnected communities in developing regions with access to ICTs. Until now, most community network projects have relied on unlicensed spectrum for access provision. Nevertheless, as many operators are not using their allocated bands efficiently across their licensed geographic allotments, it is essential to identify where community networks could use, lease or otherwise share that spectrum.

This research project explores new, blended approaches to spectrum use that have a mix of exclusive spectrum, unlicensed spectrum, dynamic spectrum access and lightly-licensed spectrum, as well as more community-based approaches to inform decisions on its best use.

The particular focus of this paper is the exploration of the potential of regional licences to reduce unused or inefficiently used spectrum in the South African mobile telecommunications market. It is a contention of this study that alternative spectrum allocation models can improve broadband access by decreasing input costs (licence costs), stimulating innovation in the delivery of wireless broadband services, and reducing retail pricing.

The research for this report draws on academic literature and regulatory documents to analyse existing technologies that enable alternative ways of spectrum licensing, as well as to analyse innovative policies and regulatory approaches. Additionally, spectrum measurements were performed to illustrate the low occupancy of IMT bands. Several stakeholders were interviewed to validate findings from the desk research. These include engineers, regulators, academics, activists, researchers, community network representatives and policy experts.

The rest of the paper is organised as follows. In Section 2, we provide a brief overview of radio frequency characteristics. Section 3 lists existing technologies for advances in spectrum management, and Section 4 lists pilot projects using white spaces. Section 5 provides an overview of the regulatory landscape. Spectrum measurements results are shown in Section 6, and findings from interviews with experts in Section 7. Finally, Section 8 concludes the paper with recommendations.

2. Radio Frequency Characteristics

In general, lower frequencies can reach further beyond the visible horizon – radio signals in these bands have a longer range and are able to propagate in non-line-of-sight conditions, meaning they are able to penetrate vegetation, rain or even buildings. On the other hand, the capacity of a wireless connection

[2] See: https://techcentral.co.za/if-you-want-data-prices-to-fall-give-us-spectrum-vodacom/89247/

[3] See: https://www.internetsociety.org/wp-content/uploads/2017/10/Spectrum-Approaches-for-Community-Networks_20171010.pdf

depends on the channel bandwidth – and wider channel bandwidths are more readily available at higher frequencies. Generally, the lower frequencies are cheaper than the higher frequencies.

For many wireless applications, the best trade-off of these factors occurs in the frequency range of roughly 400 megahertz (MHz) to 4 GHz, and there is great demand for this portion of the radio spectrum. These above-mentioned characteristics make sub-GHz frequencies the ideal candidate for rural connectivity, whereas higher frequencies serve well in dense urban areas where a lot of capacity is needed.

When using sub-GHz frequencies for rural connectivity, individual base stations have a larger propagation range, which means that the total number of required base stations is lower. As there is no line-of-sight requirement, the base stations do not need to be placed on very high towers, and this reduces the total cost of a network.

In a nutshell, lower frequencies are better for providing coverage, and higher bands extend the capacity within that coverage. For this reason, in commercial deployments, LTE base stations using sub-GHz frequencies are used to provide wide coverage, while LTE base stations using above 1 GHz are used for providing capacity in denser areas. For urban areas, small WiFi cells are also used for offloading to provide additional capacity. In the case of low-cost deployments for rural areas, unused UHF bands (the so-called TV white spaces) can be used for coverage and WiFi for capacity. Theoretical calculations show that, with same transmission power, a TVWS signal has a range four times longer that WiFi range, and therefore covers an area sixteen times the size of that covered by WiFi, as illustrated in Figure 2.

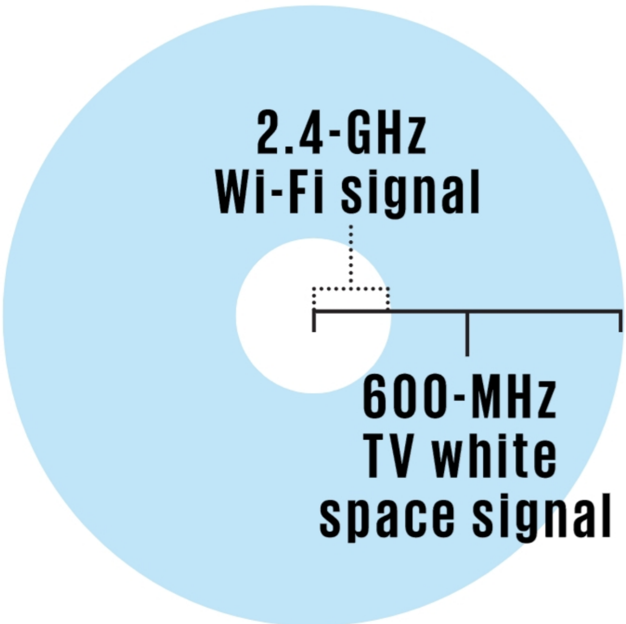

Figure 2: TVWS vs. WiFi – propagation range and coverage area with same transmission power

Source: IEEE Spectrum

Radio coverage is not a strictly defined line, as signal strength tends to fluctuate depending on environmental characteristics (e.g. rain), moving objects and obstacles, and user load. In this sense, it might be difficult to strictly define geographic areas where a regional spectrum licence would be valid. However, in practical scenarios, these areas tend to be remote and without any service, so their coverage area would certainly not overlap with other operators' service areas. In addition, one can rely upon spatial separation to avoid interference.

3. State-of-the-art Technology for Advanced Spectrum Management

Over the last decade, there has been an acceleration in technological progress to enable advanced use of spectrum. Motivated by the migration from analogue to digital TV and the fact that the most attractive portions of spectrum would soon become available, researchers and technologists started looking at new ways to access, manage and allocate this spectrum. The following section lists the technologies, standards and protocols that can enable alternative ways of spectrum access.

3.1. White Spaces

Portions of the radio spectrum that have been allocated and assigned to licensed (primary) users allow secondary access to spectrum not in use by the primary licence holder on a no-interference basis. This available spectrum is called 'white space'. Allowing secondary users access to available spectrum 'unlocks' existing spectrum to maximise its utilisation and to provide opportunities for innovation, resulting in greater overall spectrum utilisation. An obvious requirement is that these secondary transmissions do not interfere with the assigned use of the spectrum.

The potential of the TV white space (TVWS) spectrum has been particularly identified for last mile access and middle-mile connectivity to the Internet backbone.[4] A set of theoretical predictions and real-world measurements in different environments have been used to provide a comparison between TVWS and WiFi for connectivity in developing countries.[5]

TVWS spectrum regulation in South Africa allows secondary users to access channels in the 470–694 MHz band if a geolocation spectrum database (GLSD) authorises the use of a set of channels for a secondary user. The current terrestrial TV broadcast UHF frequency range is from 470–862 MHz.

The 800 MHz band from 791–862 MHz will be cleared in the coming years as part of digital dividend 1 for IMT use and the 700 MHz band from 703–788 MHz will be cleared as part of digital dividend 2 for IMT use. The timetable for clearing these bands has not yet been set in South Africa. In other African countries such as Mozambique, the 800 MHz band has already been cleared and auctioned.

3.2. Cognitive Radio and TVWS Standards

Cognitive radio is the technology that is enabling dynamic spectrum access. It is a form of wireless communication where a transceiver can detect which channels are and are not in use. A cognitive radio can change its transmission parameters to adapt to the dynamic wireless environment.

There are two dominant standards for TVWS: (1) IEEE 802.22 and (2) IEEE 802.11af.

IEEE 802.22[6] was the first standardised air interface based on cognitive radio (CR) techniques for the opportunistic use of TV bands on a non-interfering basis –- the standard was published in July 2011. An updated version of the standard, IEEE 802.22b, was published in 2015. The standard grew out of the WiMax

[4] Kassem MM et al (2018) On the Potential of TVWS Spectrum to Enable a low-cost Middle Mile Network Infrastructure. Paper presented at the 10th International Conference on Communication Systems & Networks (COMSNETS 2018) (3–7 January)
[5] Johnson D et al (2016) Head-to-head battle of TV White Space and WiFi for connecting developing regions. Paper presented at the 8th EAI International Conference on e-Infrastructure and e-Services for Developing Countries (AFRICOMM 2016) (6–7 December)
[6] See: https://standards.ieee.org/standard/802_22a-2014.html

standard with the additional requirement of checking availability of a channel for secondary use. The current maximum achievable speed for 802.22 is 29 Mbps for a single 8 MHz channel and 50 Mbps for the updated 802.22b standard. The typical range for the technology is 10 to 30 km, although the standard can support up to 100 km. The IEEE 802.22 has advanced incumbent protection and self-coexistence features. A coexistence beacon protocol is used to ensure that neighbouring cells using the same channel do not interfere with one another.

IEEE 802.11af[7] is a wireless computer networking standard in the IEEE 802.11 family of standards that allows wireless local area network (WLAN) operation in the TVWS spectrum in the VHF and UHF bands between 54–790 MHz. The standard was approved in February 2014. The achievable data rate per spatial stream is 35.6 Mbps for 8 MHz channels. With four spatial streams and four bonded channels, the maximum data rate is 568.9 Mbps. The typical range reported for IEEE 802.11af on Wikipedia and many sites is 1 km, although equipment manufacturers mention 25 km line-of-sight (LOS) and 5 to 10 km non-line-of-sight (NLOS).

3.2.1. TVWS devices

There is a wide range of TVWS devices from different manufacturers such as Adaptrum, Carlson wireless and 6Harmonics.

Adaptrum is a United States (US) company that is one of the TVWS pioneers from the late 2000s. Adaptrum was established as a Silicon Valley start-up in 2008 to develop cognitive radio technology with an initial focus on TVWS. Adaptrum's early TVWS devices were able to successfully demonstrate detection and avoidance of TV broadcast transmissions and formed part of the evidence that convinced the FCC to approve unlicensed use of TVWS in 2008. They are one of the few companies that produce TVWS products based on TVWS standards.

Carlson Wireless is a US company that began developing wideband fixed-wireless systems in 2001 using code-division multiple access (CDMA) technology. In 2012, they launched their first RuralConnect® radio that used TVWS. The company is now on Generation 3 of their RuralConnect® radios and use the 802.11af TVWS standard. Carlson Wireless RuralConnect® Generation 2 equipment was used in the first TVWS trial in South Africa in Cape Town in 2013.[8]

6Harmonics is a Canadian company that was founded in 2010 to develop TVWS technology. They have outdoor and indoor units, as well as a 'cab radio' unit designed to be mounted in a car or agricultural vehicle.

Radwin is an Israeli telecommunications company founded in 1997. They announced their first TVWS product in July 2018 after Microsoft agreed to a strategic partnership with Radwin for their rural broadband project.[9]

The newer generation of TVWS devices provide a maximum capacity of between 70 and 186 Mbps. This is still some way off the theoretical maximum of 568.9 Mbps in the current IEEE 802.11af standard, but future generations of devices are expected to achieve these speeds.

[7] See: https://standards.ieee.org/standard/802_11af-2013.html
[8] See: https://www.tenet.ac.za/tvws
[9] See: https://news.microsoft.com/2018/07/02/radwin-and-microsoft-announce-strategic-partnership-to-deliver-innovative-tv white-space-solutions/

3.2.2. TVWS Regulation in South Africa

South Africa published final TVWS regulations in March 2018,[10] which allows usage of some of the TV spectrum for communications by advanced devices called White Space Devices (WSDs). The regulation allows access to spectrum from 470–694 MHz excluding the radio astronomy sub-band from 606–614 MHz.

The regulation requires a geolocation spectrum database (GLSD) to control the availability of channels to WSDs requiring access to spectrum. A master WSD is required to have a GPS to determine its coordinates and is solely responsible for contacting the GLSD in order to obtain the allowed operating parameters (channels, maximum permitted EIRP for each channel, maximum permitted EIRP spectral density for each channel, and the time period during which the parameters are valid if less than the default maximum validity period). A master WSD must access the GLSD at least every 24 hours and the master WSD must communicate operational parameters to the associated client every 60 seconds.

White Space devices are required to be type-approved prior to operation.

3.3. Geolocation Databases

A geolocation database controls the TV spectrum utilisation by unlicensed WSDs within a determined geographical area. Its objective is to enable unlicensed access to white space spectrum while protecting incumbent broadcasting services. The WSD determines its location (e.g. using GPS), sends its geographical coordinates to the database and asks it (directly or via a master device) which channels are available under specific conditions (transmit power, antenna height, mode of operation, and so on). Data in the database can be changed easily, which offers the additional flexibility of spectrum usage and protection of incumbents. This approach basically shifts the complexity of spectrum-policy conformance out of the device and into the database. The adoption of policy changes becomes simplified, as only a handful of databases need to be updated, instead of numerous WSDs.

The Federal Communication Commission (FCC) and the Ofcom were the first two spectrum regulators to draft rules enabling unlicensed access to unused TV spectrum in the US and UK respectively.

The functionality of TVWS base stations accessing a GLDB is hard-coded into all FCC-approved TVWS devices. However, in many African countries, there may be hundreds of MHz of spectrum available in the UHF band because there are so few terrestrial broadcasters, and a GLDB may be redundant.

South Africa also has a database[11] developed at CSIR Meraka Institute to verify which channels are free in the standard 470–694 MHz TVWS spectrum block and the 790–864 MHz bands. UHF TV officially ends at 862 MHz in South Africa. The database operates over the whole of South Africa and uses the knowledge of the landscape/topology and locations of primary (protected) TV transmitters to perform propagation and coverage predictions. It then applies certain protection criteria to estimate which TV channels can be used by TVWS devices at specific coordinates and associated maximum power levels where the signal cannot be detected by a TV receiver tuned to any of the channels used by a primary broadcast transmitter. This permits TVWS devices to access the GLDB and obtain access to spectrum dynamically. The database is certified by the UK spectrum regulator Ofcom for commercial operation in the UK. CSIR is eventually going to expand the database to include the 700 MHz and 800 MHz bands and in the future other bands such as the 900 MHz band.

[10] See: https://www.icasa.org.za/uploads/files/Regulations-on-the-use-of-Television-White-Spaces-2018.pdf
[11] See: https://whitespaces.meraka.csir.co.za/

The idea of using licensed spectrum as secondary user, originally developed for TV bands, can also be extended to IMT bands, using a geolocation database to authenticate the availability of assigned but unused spectrum. This would ultimately require LTE radio equipment to be modified to query the geolocation database prior to powering up its LTE radio. It would also require detailed information from mobile network operators of their towers, radios, power output levels, and antenna designs in order to create an accurate geolocation database. Some LTE bands, including Band 20 (800 MHz digital dividend band), use frequency division duplex (FDD), which means that separate frequency bands are used for the uplink and the downlink. In this case, both bands need to be free and the database query should return free channel pairs instead of a single channel. For example, in Band 20, the portion of the spectrum used for the uplink is between 832 –862 MHz, and for the downlink between 791–821 MHz. Both portions of the spectrum would need to be identified as unused. In addition, IMT spectrum is different to TV spectrum in the sense that radiators are more dynamic, with new access points regularly being deployed in urban areas, be it for more capacity or once-off events. This dynamism requires a constantly updated database and more mobility from secondary transmitters. Therefore, a geolocation spectrum database in these bands would require an exploration of these difficulties.

3.4. PAWS Protocol

To achieve interoperability for geolocation databases among multiple devices and databases, a standardised protocol must be defined and implemented. The Internet Engineering Task Force (IETF) RFC7545 document[12] defines such a protocol – the 'Protocol to Access White-Space' (PAWS) Databases.

The IETF also defines use cases and requirements for this protocol.[13] For example, the messaging interface between the WSD and the database needs to be interface agnostic (wired or unwired, using any technology), spectrum agnostic (operating in any band) and globally applicable.

The PAWS protocol could be extended to work in cellular bands, but it would have to query for free channel pairs instead of single channels, as explained in previous section.

3.5. GSM White Spaces

Apart from TVWS, researchers at the University of Berkeley argue that GSM white spaces should also be regulated for dynamic spectrum use.[14] Exclusive spectrum licensing has created large areas of GSM white spaces – licensed GSM spectrum that is assigned to an operator but unused in a particular geographical area, as is the case in many rural areas worldwide. It could be reused by a secondary operator without interfering with the primary licence holder. Such regulation would support the growth of community networks operating in cellular bands. There are also cases where spectrum is un-assigned nationally for a number of years. In this case, a very simple database of unused blocks of spectrum could be used to check available GSM white space channels.

3.5.1. Open Source GSM

The open-source community has made cellular equipment widely available and affordable. OpenBTS[15] is an open-source GSM base transceiver station (BTS) implementation. Its architecture is open to innovation

[12] Protocol to Access White-Space (PAWS) Databases, available at: https://tools.ietf.org/html/rfc7545
[13] PAWS Use Cases and Requirements, available at: https://tools.ietf.org/html/rfc6953
[14] Hasan S, Heimerl K, Harrison K, Ali K, Roberts S, Sahai A & Brewer E (2014) GSM Whitespaces: An Opportunity for Rural Cellular Service. Paper presented at IEEE International Symposium On Dynamic Spectrum Access Networks (Dyspan 2014), Virginia USA (1–4 April)
[15] See: http://openbts.org/

by anybody, allowing the development of new applications and services, and significantly simplifying the setting up and operation of a mobile network. OpenBTS has enabled a wide range of projects aimed towards building community networks such as the community cellular deployed in Papua, Indonesia.[16] Rhizomatica[17] in Mexico uses OpenBSC[18] developed by Osmocom.

3.6. LTE White Space

Fourth generation IMT networks, also known as Long-term Evolution (LTE), introduced techniques that optimise the use of available spectrum. LTE makes use of advanced interference management techniques that allow cells to operate adjacent to each other using the same frequency. This effectively allows a carrier to reuse the spectrum at every adjacent cell. In the case of cells owned by different operators that may be adjacent to each other, the same frequencies can be used if they agree to share the control system.

CellFi[19] is an architecture for unlicensed networking in TVWS, built on top of the standard LTE architecture. It is equipped with GPS so that exact locations can be reported to the spectrum database. CellFi can achieve a range of 1 km while maintaining throughput above 1 Mbps, and in case a primary user appears it can quickly vacate a channel.

A feasibility study on the use of TVWS in the 5G architecture[20] provides a cost analysis, assuming that availability is prioritised over performance. With this assumption and a simple low-cost network architecture model, the solution yields cost savings compared to conventional deployments.

OpenCellular[21] technology supports small cell, low-cost, low-power deployment of cellular 2G or 4G base stations in poorly-serviced areas or areas where affordability is a barrier. It is a platform developed by Facebook as part of the Telecom Infra Project (TIP), an open-source hardware consortium headed by Facebook.

3.7. Summary on Existing Technology

While the communication technologies, protocols and devices continue to develop at a brisk pace, the general approach to regulating the spectrum has not changed much since the last century. There is already technology that would enable alternative access strategies, including low-cost hardware and open source software.

Communicating in white spaces is a well-researched phenomenon. The idea of using licensed spectrum as secondary user, originally developed for TV bands, can also be extended to IMT bands.

Low-cost alternative GSM and LTE technologies have existed for some time and there are a variety of new manufacturers in this space including Sysmocom, Vanu, Range Networks, NuRAN, Fairwaves, Baicells,

[16] Heimerl K, Hasan S, Ali K, Brewer E & Parikh T (2013) Local, sustainable, small-scale cellular networks. Paper presented at the Sixth International Conference on Information and Communication Technologies and Development (ICTD 2013), Cape Town South Africa (7–10 December)
[17] See: https://www.rhizomatica.org
[18] See: http://osmocom.org/projects/openbsc/wiki/OpenBSC
[19] Baig G, Alistarh D, Karagiannis T, Radunovic B, Balkwill M & Qiu L (2017) Towards unlicensed cellular networks in TV white spaces. Paper presented at the International Conference on emerging Networking EXperiments and Technologies (CoNEXT 2017), Seoul South Korea (12–15 December)
[20] Khalil M, Qadir J, Onireti O, Imran M & Younis S (2017) Feasibility, Architecture and Cost Considerations of Using TVWS for Rural Internet Access in 5G. 20th international conference on Innovations in Clouds, Internet and Networks (ICIN 2017), Paris France (7–9 March)
[21] See: https://oc.telecominfraproject.com/

Parallel Wireless, TIP's OpenCellular initiative and others. The result is that it is possible to put up a GSM or LTE base station for a few thousand dollars.

What constrains small operators and community networks from taking advantage of these innovations is the fact that the popular IMT spectrum bands have been assigned to existing mobile network operators (MNOs), typically on a national, exclusive-use basis.[22] However, regulatory innovations in some countries are beginning to change that reality. Table 1 summarises these technologies and their pros and cons.

Technology	Pros	Cons
TVWS	▪ Mature technology ▪ Existing standards and protocols ▪ A number of successful pilots ▪ Existing regulations	▪ Cost of equipment ▪ User devices do not support these bands ▪ Country-specific regulations
Open-source cellular	▪ Cost of equipment ▪ User devices ▪ Few successful deployments	▪ Expensive access to IMT spectrum ▪ Lack of regulations on spectrum sharing in IMT bands
GLDB	▪ Protects primary users from interference ▪ Relatively mature technology for TVWS	▪ Lack of data from MNOs to create a database for IMT bands

Table 1: Summary of technologies enabling spectrum sharing

In Africa, the bands 700, 800, 900, 1800, 2100, 2300 and 2600 MHZ (bands 28, 20, 8, 3, 1, 30 and 7 respectively) are in use for LTE/4G services. Once the 700 and 800 MHz bands are auctioned for IMT use in South Africa,[23] there could be an opportunity to explore spectrum sharing using a geolocation database in the IMT bands, with cellular tower data being used instead of TV transmitter tower data in the spectrum database. Cellular towers are considered primary users in this scenario, and low-cost open-source base stations such as OpenCellular are secondary users. Obviously, some parameters such as maximum transmission power and antenna height would also have to be adjusted for the LTE scenario. The 700 and 800 MHz bands allow for large cell sizes, which reduce the total cost of network deployment.

4. Pilot Projects using White Spaces

While deployments in cities and densely populated areas inevitably depend on geolocation spectrum databases, in rural areas most of the spectrum is underutilised. Therefore, a spectrum database is not technically essential. Furthermore, spectrum mask requirements for the low-cost equipment can be looser, since there are usually only few TV stations deployed in rural areas in developing countries, leading

[22] See: https://opentelecomdata.org/spectrum-chart/
[23] See: https://www.icasa.org.za/uploads/files/final-radio-frequency-migration-plan-2019.pdf

to very low channel occupancy.[24] In rural areas in sub-Saharan Africa, the entire UHF and VHF bands are available.

Preliminary results of a TVWS deployment in rural Malawi report coverage distances of up to 7.5 km, maximum throughput of 2 Mbps and average latency of 120 ms. A low-cost spectrum analyser indicated that out of 28 TV channels, only 7 channels were in use. The network included four sites, one of which was nearly 20 km away and set a record for the longest operational TV white space link.[25]

TVWS trials performed by TENET (the Tertiary Education and Research Network of South Africa) and the CSIR, with sponsorship from Google, in one of the suburbs of Cape Town showed that TVWS can provide interference-free Internet even in urban areas, with speeds of up to 12 Mbps for downlink and 5 Mbps for uplink, and average latency 120 ms.[26] In the trial, 10 schools were connected to base stations at Tygerberg Hospital.

The Cape Town trial was the first in the world to use white space frequencies adjacent to TV channels that were actually in use, and even frequencies directly between two channels in use. Interference would occur only if the devices were placed at a distance of less than 200 metres from a TV set.

Microsoft has launched pilot deployments in Kenya, Tanzania, Namibia and South Africa.[27]

A very successful trial was deployed in India, covering a rural area of 25 km^2 and using TVWS in the 470–590 MHz bands for the backhaul links, and WiFi for access.[28] Unfortunately, the Telecom Regulatory Authority of India (TRAI) is not renewing any experimental or trial licences. They stated that they would stop providing any more licence-exempt spectrum, which means they will most likely start allocating it though an auction process.

Both the technology and policy sides of dynamic spectrum access, as well as some tested pilot projects, are explored in a collection of articles,[29] presenting ways in which TVWS can be used to solve the lack of rural connectivity. It is even suggested that spectrum regulation be included as a development policy issue.

5. Spectrum Regulation and Licensing

A recent report by the GSMA pointed out emerging evidence of a link between high spectrum prices and high consumer prices in developing countries.[30] The release of high-demand spectrum in South Africa is expected to bring socio-economic benefits[31], and questions around the planned wholesale open-access network have received much media coverage in the past several months.[32]

[24] Zennaro M, Pietrosemoli E & Sathiaseelan A (2014) Architecting a Low Cost Television White Space Network for Developing Regions. Paper presented at the Fifth ACM Symposium on Computing for Development (DEV-5 2014), California USA (5–6 December)
[25] See: https://spectrum.ieee.org/telecom/internet/malawi-and-south-africa-pioneer-unused-tv-frequencies-for-rural-broadband
[26] Lysko AA et al (2014) First large TV white spaces trial in South Africa: A brief overview. Paper presented at the 6th International Congress on Ultra Modern Telecommunications and Control Systems (ICUMT 2014), St Petersburg Russia (6–8 October)
[27] Roberts S, Garnett P & Chandra R (2015) Connecting Africa Using the TV White Spaces: From Research to Real World Deployments. Invited paper presented at IEEE International Workshop on Local and Metropolitan Area Networks (LANMAN 2015), Beijing China (22–24 April)
[28] See: grammarg.in
[29] See: http://wireless.ictp.it/tvws/book/
[30] See: https://www.gsma.com/spectrum/wp-content/uploads/2019/09/Impact-of-spectrum-prices-on-consumers.pdf
[31] See: https://www.engineeringnews.co.za/article/spectrum-release-expected-to-bring-big-economic-and-social-benefits-2018-07-06
[32] See: https://techcentral.co.za/woan-must-get-only-a-small-spectrum-set-aside-treasury/92107/

However, the issue of more equitable spectrum access[33] is also bound up with general licensing issues, and these burdens are going to remain even if access to spectrum becomes open.

In this section, we provide an overview of spectrum regulation in South Africa, as well as some examples of innovative approaches from Latin America and recent announcements made by the UK regulator Ofcom.

5.1. South Africa

South Africa published the Electronic Communications Amendment bill in 2018, which mandated that high-demand spectrum (700MHz, 800MHz and 2600 MHz bands) would be licensed using an open access philosophy and a portion of this spectrum would be used to create a wholesale open access network (WOAN). Initially, the WOAN defined an entire spectrum band as a wholesale network that would be made available to all licensed operators so they could offer services using these bands – a common concept in fibre optic networks. Far more restricted WOANs, usually on limited portions of the digital dividend spectrum in highly-concentrated markets have been introduced in Mexico, Kenya and Rwanda, but only Mexico has reached implementation stage, with the Kenyan and Rwandan initiatives petering out.[34]

In South Africa, a consultative process in 2018 was started to calculate what portion of this band would be licensed to the WOAN and what remaining portion should be auctioned in lots to the current incumbents. The CSIR carried out a modelling study and calculated that providing access to 20% of the population in 2020 would require 2 x 25 MHz of the 800 band (Band 20), 2 x 20 MHz of the 2600 FDD band (Band 7) and 25 MHz of the 2600 TDD band (Band 38).[35]

In February 2019, the amendment bill was dropped by the government and the future of the WOAN is still unknown at this stage. Policy around which portions of these bands would go to the WOAN will be part of ongoing engagement between government and industry. In July 2019, Minister Ndabeni-Abrahams asked the regulator to ensure that the WOAN is given enough spectrum and other support to ensure its success.[36]

According to a report[37] published by the Policy Impact Partners (PIP) in association with the Dynamic Spectrum Alliance (DSA), new ways of spectrum sharing could enable many more people to benefit from broadband connectivity and digital services. If designed well, these models could expand access to broadband while ensuring that incumbents are protected. The report analyses the regulatory landscape in Colombia, Malaysia and South Africa, and through engagement with government and industry stakeholders concludes that there are no major regulatory obstacles to spectrum sharing in any of the three countries. However, new frameworks may be needed to clarify the rules that would govern these new models. Technology trials would help raise awareness of the potential of spectrum sharing.

33 See: https://www.apc.org/en/news/whats-new-spectrum-%E2%80%9Cwe-need-more-tools-spectrum-briefcase%E2%80%9D-discussing-approaches-access-mike

34 See spectrum review in Gillwald A, Mothobi O and Rademan B (2018) State of ICT in South Africa, Policy Paper 5, Policy Series 5: After Access, Research ICT Africa, pp42-44, available at: https://researchictafrica.net/wp/wp-content/uploads/2018/10/after-access-south-africa-state-of-ict-2017-south-africa-report_04.pdf

35 Policy on High Demand Spectrum and Policy Direction on Licensing of a Wireless Open Access Network, available at: https://www.greengazette.co.za/notices/electronic-communications-act-36-2005-policy-on-high-demand-spectrum-and-policy-direction-on-the-licensing-of-a-wireless-open-access-network_20190726-GGN-42597-01013

36 See: https://www.itweb.co.za/static/misc/pdf/Gazette-2019.pdf

37 See: https://policyimpactpartners.com/wp-content/uploads/2019/10/Enhancing-Connectivity-Through-Spectrum-Sharing.pdf

Looking at the Southern African region, Mozambique's regulator INCM is one of the most progressive authorities. INCM is preparing ground to test a new way of spectrum licensing, including exploring white space cellular.[38]

5.2. Latin America

A regulatory trend towards new licensing models can be identified in Latin America.[39] Mexico, Bolivia, Brazil and Argentina are providing specific licences for community operators, Peru for rural operators, and Ecuador for solidarity-based enterprises such as cooperatives. These are all examples of a general movement towards recognising community operators in the region.

Brazil's regulator, ANATEL, recently approved a new regulation on radio equipment that eliminates licensing requirements for providers serving less than 5% of the federal state's telecommunications market. Providers simply need to communicate that they would like to start providing connectivity, but are not obliged to obtain a multi-media communications service licence.

In Argentina, the telecom regulator allocated the 450 MHz band to rural broadband services to increase reach and coverage, which had an impact in a reduction of costs for deployment and management of infrastructure, benefiting small providers and community networks.[40]

In Colombia, Colnodo established an agreement with country's Information and Communications Technology (ICT) Ministry that allows them to use 5 MHz in the 900 MHz band for a pilot community network in the Cauca province.[41] In return, Colnodo will establish a framework that will enable the implementation of community networks nationwide. In this context, Colnodo is working on four aspects of sustainability of community networks: technological, legal, economic and social.

At the First Latin American Summit on Community Networks held in Argentina in September 2018, the following set of recommendations for spectrum regulations was proposed:

- Spectrum planning should consider reserves for social, community or indigenous uses.
- Agile, adequate and free spectrum licensing processes, for example by direct assignment, should be considered.
- Mechanisms for the efficient use of spectrum and spectrum sharing, such as secondary use, dynamic access and allocation of local or regional coverage, should be considered.
- Experimental licences must easily transition to definitive licences once the viability of the project has been demonstrated.

5.2.1. Mexico

Mexico is the only country in the world where a segment of the spectrum dedicated to mobile network services has been set aside for social purpose use.[42] Social use gives rights to use and exploit frequency bands in the radio spectrum to provide telecommunication services for cultural, scientific and educational community services on a not-for-profit basis. After a successful pilot by Rhizomatica in the state of Oaxaca,

[38] Interview with David Salomao, INCM
[39] See: https://www.internetsociety.org/wp-content/uploads/2018/12/2018-Community-Networks-in-LAC-EN.pdf
[40] See: https://digitalpolicylaw.com/argentina-enacom-asigna-banda-de-450-mhz-para-servicios-de-banda-ancha-en-localidades-rurales/
[41] See: https://www.apc.org/en/news/colnodo-access-spectrum-and-community-networks-quality-connectivity-rural-areas-possible
[42] See: http://www.ift.org.mx/industria/espectro-radioelectrico/programa-anual-de-uso-y-aprovechamiento/programa-2015

the assignments in the 850 MHz band were analysed and it was concluded that a small amount of spectrum remained unassigned. The amount of spectrum available was small enough to be of little value to commercial operators. Mexico's regulator, Instituto Federal de Telecomunicaciones (IFT), has set aside 2 x 5 MHz of paired FDD uplink and downlink spectrum (824–849 and 869–894 MHz) specifically for the use of small operators and community networks in underserved regions. To use these bands, the community served must be less than 2 500 people, or be an indigenous region or otherwise designated for such use.

Telecomunicaciones Indígenas Comunitarias (TIC), a non-profit organisation based in Oaxaca, Mexico, holds a concession as a social telecommunications operator, and currently serves 3 350 active daily users spread across 63 villages and communities in the state of Oaxaca with 2G voice and data services. These users are served by 14 community-owned and operated cellular sites. The Mexican regulator has raised the importance of community networks with this intervention.[43]

5.3. Ofcom UK

Ofcom, the UK's communications regulator, recently announced it would reserve 390 MHz of spectrum between 3.8 GHz and 4.2 GHz for local coverage. In this scheme, anyone could apply for a 5G licence covering a small area (ca. 50 square metres) and develop their own local 5G network.[44] Apart from that, 1800 MHz and 2300 MHz spectrum bands will also be available through local licences where one can apply to Ofcom for coordinated access to ensure they will not cause any interference, on a first come, first served basis. The licence fee will reflect Ofcom's cost of issuing the licence. The 24.25–26.5 GHz band is added to the spectrum sharing framework for indoor-only deployment.[45]

Ofcom's approach to local licences and shared access to spectrum has been explained in detail in a statement[46], aiming to address the need for alternative spectrum for local connectivity. Where spectrum is licensed on a national basis and not being used in every location, Ofcom thinks it is appropriate to allow new users to use this spectrum. It is anticipated that spectrum is only likely to be available to share in remote areas, but it could also be used in other locations, for example, for private networks or wireless broadband services.

6. Spectrum Measurements

In this section, spectrum measurement data from different locations in South Africa are provided, in order to illustrate the low occupancy of IMT bands.

6.1. Ocean View, South Africa

LTE Band 20 operates at 832–862 MHz uplink, and 791–821 MHz downlink. Once this band is assigned for IMT use in South Africa, there will be an opportunity to explore spectrum sharing using a geolocation database. The idea is to install an OpenCellular base station to act as a secondary user and show that a community network using low-cost alternative equipment can coexist with existing operators without causing interference.

[43] See: https://www.telesemana.com/blog/2019/07/01/el-regulador-mexicano-pone-sobre-la-mesa-la-necesidad-de-redes-comunitarias-en-el-pais/
[44] See: https://www.lightreading.com/mobile/spectrum/uk-may-get-thousands-of-5g-new-entrants-under-proposed-shake-up-by-ofcom/d/d-id/752153
[45] See: https://www.ofcom.org.uk/__data/assets/pdf_file/0033/157884/enabling-wireless-innovation-through-local-licensing.pdf
[46] See: https://www.ofcom.org.uk/consultations-and-statements/category-1/enabling-opportunities-for-innovation

Initial spectrum scans were performed at the end of 2018 in Ocean View, a township in the southern Cape Peninsula. Figure 3 shows the spectrum occupancy in Band 20. Both the downlink (the 30 MHz-wide section between 791–821 MHz) and the uplink (the 30 MHz-wide section between 832–862 MHz) have been divided in six separate 5 MHz channels.

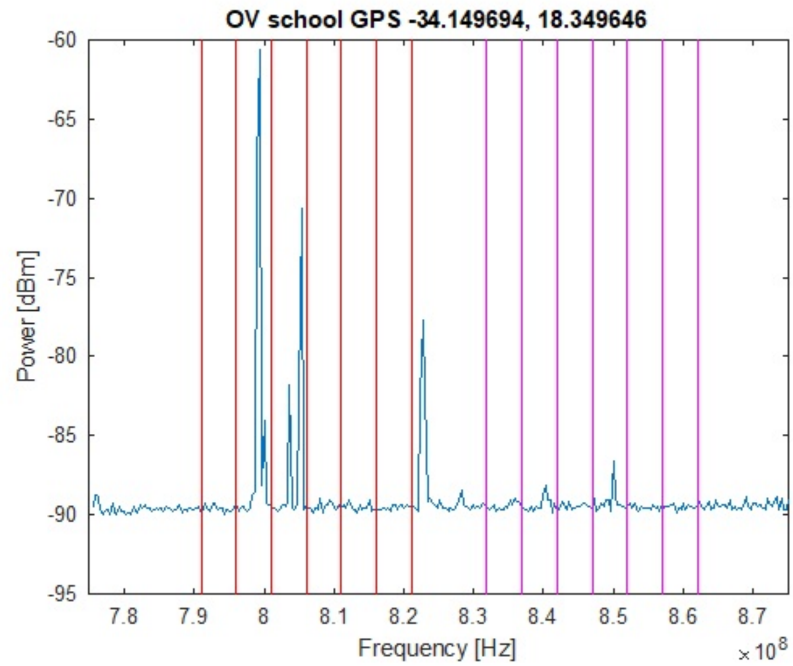

Figure 3: Spectrum occupancy in the 800 MHz band, Ocean View (Cape Town)

At least three channels in the downlink and practically all six channels in the uplink are not being used. Similar results were obtained in nearby locations within Ocean View, as illustrated in Figure 4 and Figure 5. All the measurements were static.

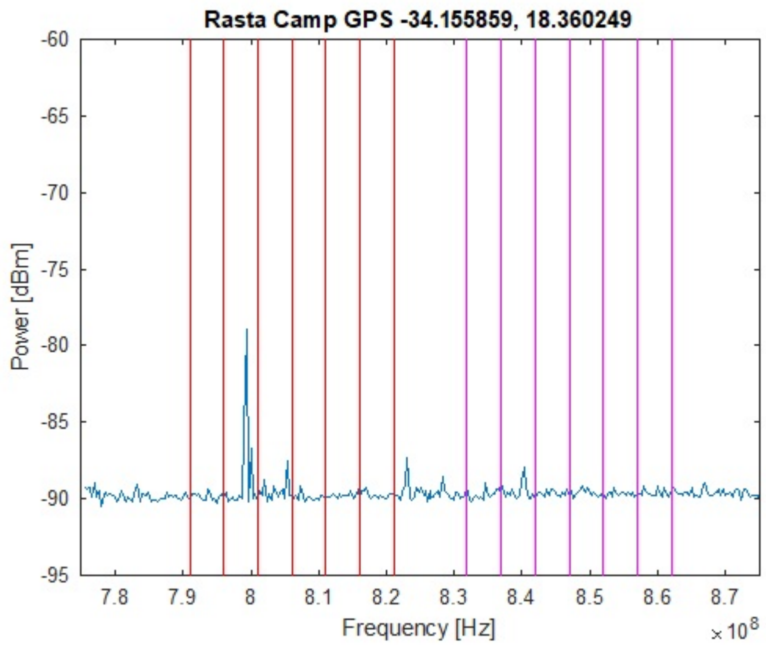

Figure 4: Spectrum occupancy in the 800 MHz band, Ocean View (Cape Town)

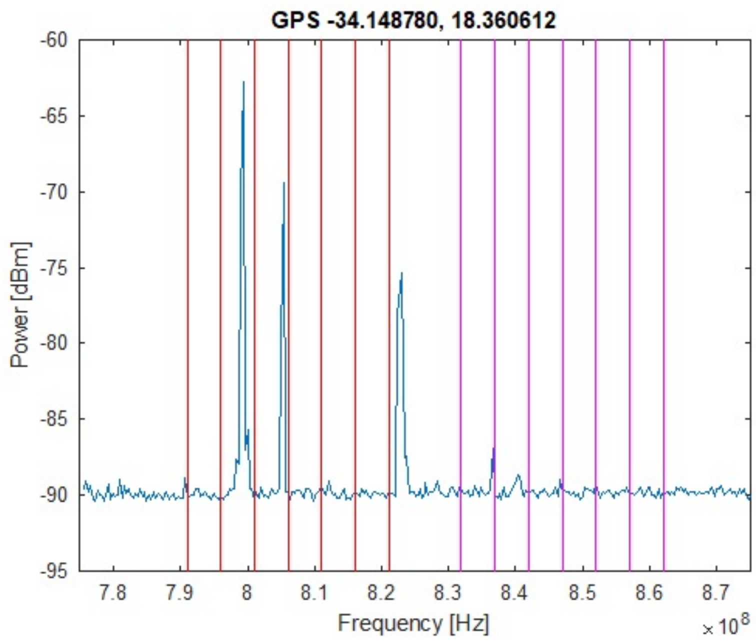

Figure 5: Spectrum occupancy in the 800 MHz band, Ocean View (Cape Town)

Another set of static measurements in Figure 6 shows spectrum occupancy in the 300–900 MHz band at the same locality using RFTrack[47] – a low-cost monitoring system for white space frequencies running on Android phones (with OS 4.0 onwards). It uses an RF Explorer spectrum analyser to gather the spectrum measurements.

[47] See: http://wireless.ictp.it/tvws/rftrack/

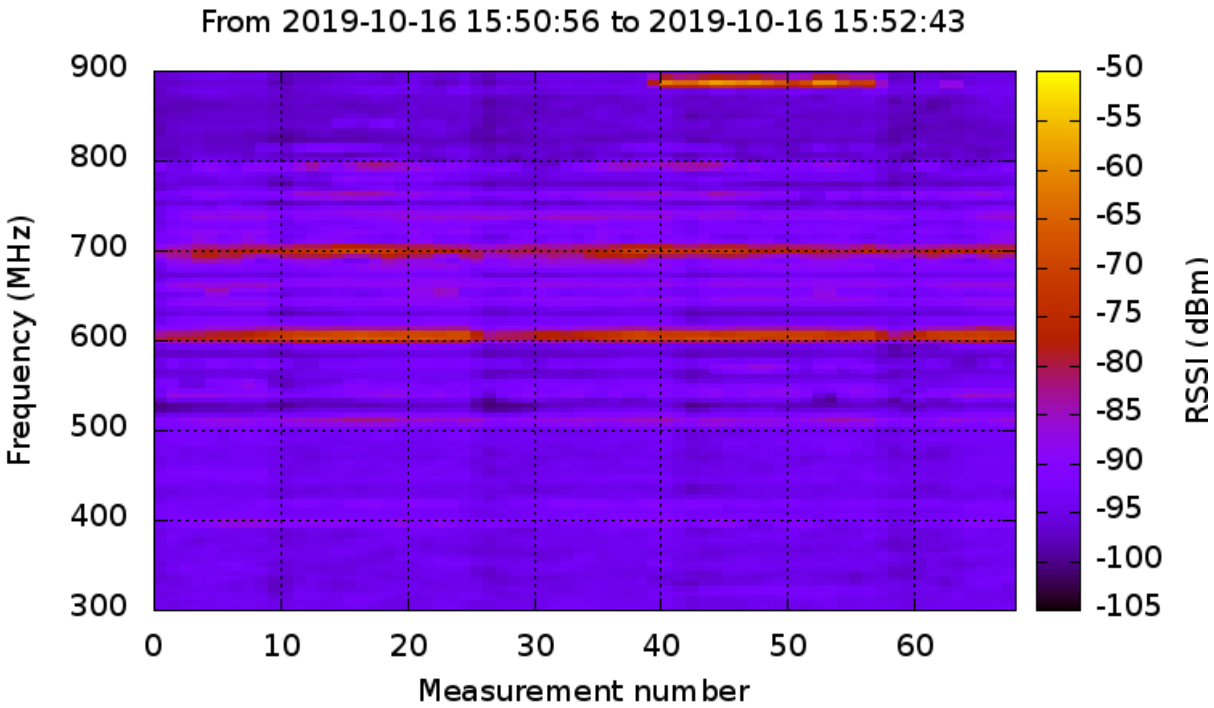

Figure 6: Static measurements using RFTrack

6.2. Southern Cape Peninsula, South Africa

A dynamic measurement campaign was performed in the 300–900 MHz band in the Southern Cape Peninsula (Scarborough to Cape Point),[48] although the primary interest is in the 700 MHz and 800 MHz bands. It was a 25.5 km route lasting 0:44:39 (hour:min:sec) and captured spectrum data at 1 712 points along the route.

[48] See: http://wireless.ictp.it/tvws/201909201348320101_Scarborough_Cape_point/filedown/video2.mp4

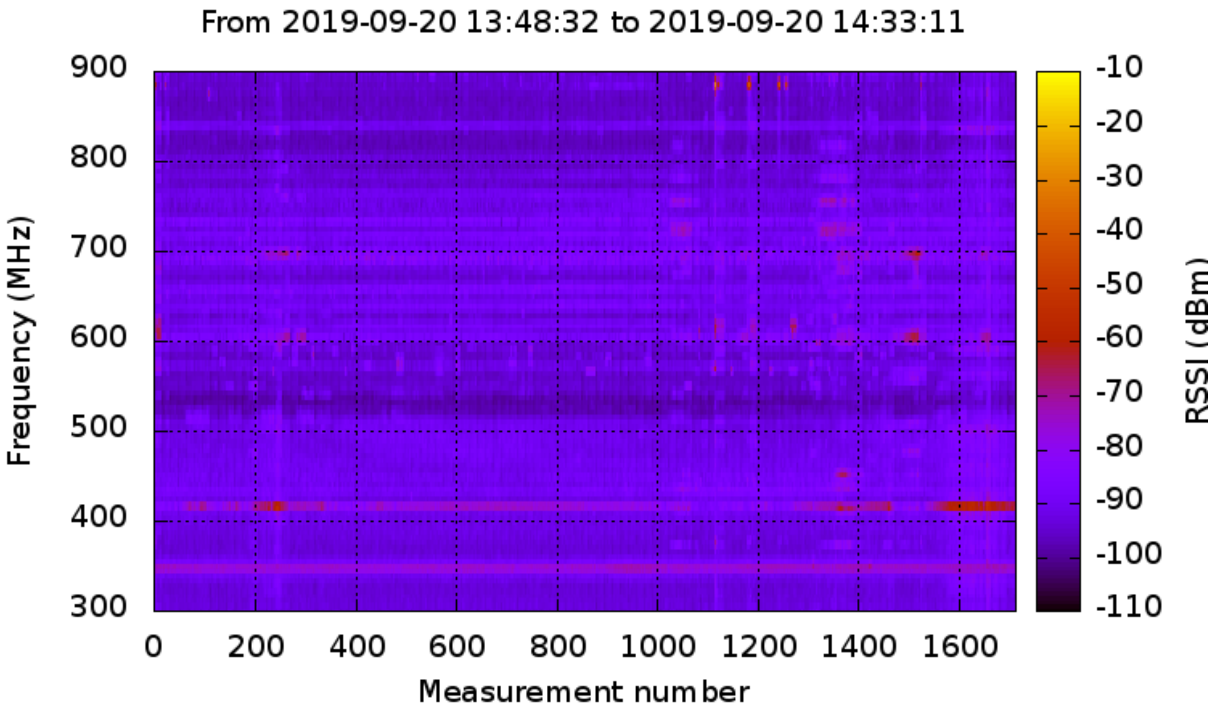

Figure 7: Power levels over time in the 300–900 MHz band

6.3. Eastern Cape, South Africa

GSMtrack[49] is another project developed at International Centre for Theoretical Physics (ICTP) in Italy. It analyses GSM frequencies with an Android phone using an RF Explorer spectrum analyser and saving measurement data on the phone together with the GPS positions. Those data are then sent to the server for analysis and visualisation. Reports from several countries are available: Democratic Republic of Congo, Rwanda, Kenya, Italy and South Africa. In this report, the graphs for the 900 MHz and 1.8 GHz bands in rural Eastern Cape, South Africa are shown.[50]

The measurement campaign shown in Figure 8 took a 139.9 km route lasting 1:33:48 (hour:min:sec) and captured spectrum data at 1 408 points along the route.

[49] See: http://wireless.ictp.it/gsm/gsmtrack/
[50] Measurements carried out by Carlos Rey Moreno, APC

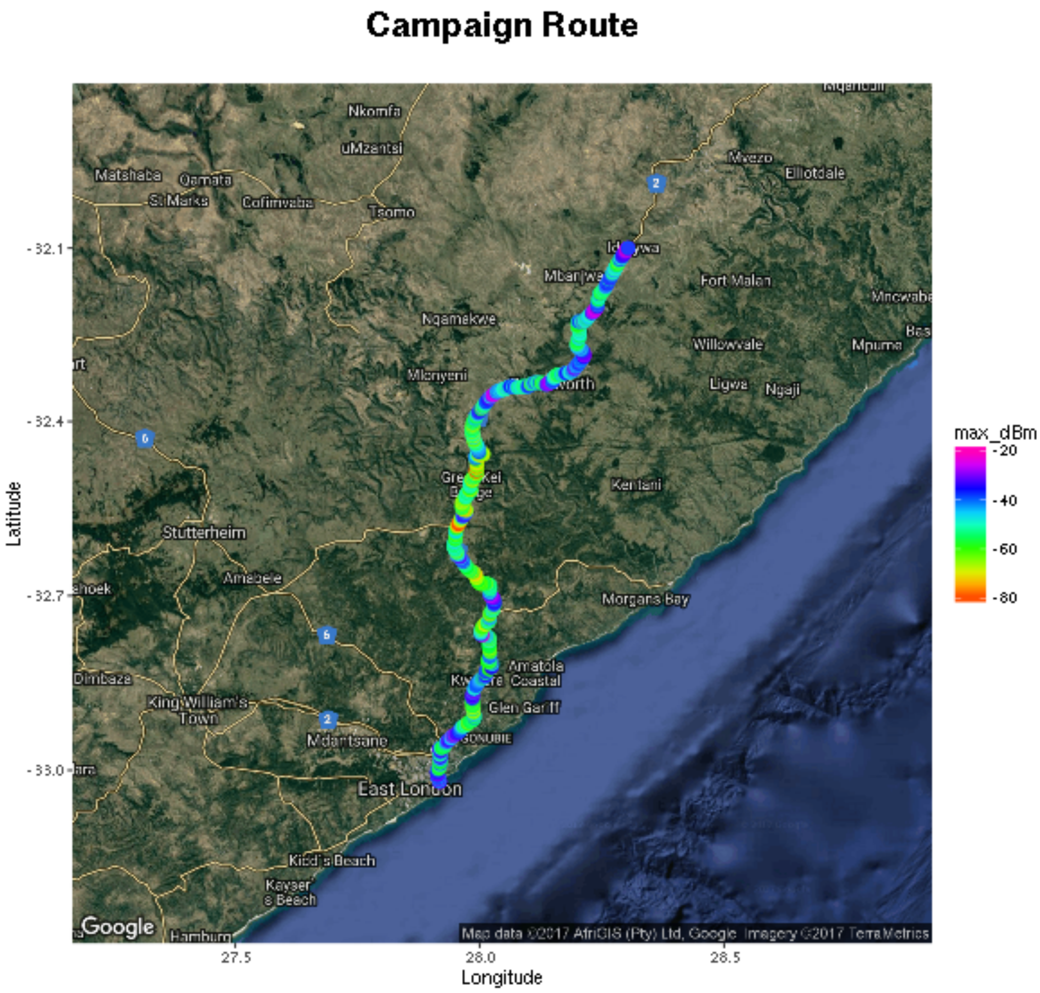

Figure 8: Campaign route

Figure 9 shows power levels over time for a total number of 1 408 measurements along the route in the 915–960 MHz frequency range, while Figure 10 shows power levels on the same route in the 1805–1880 range.

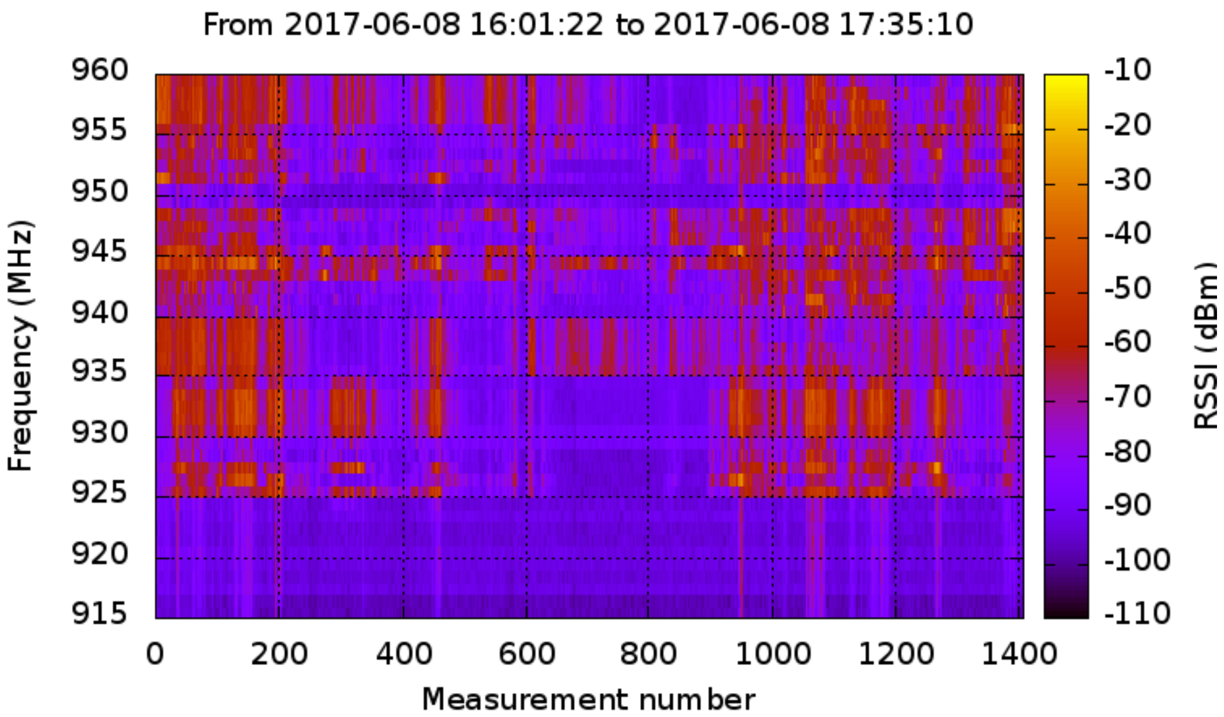

Figure 9: Power levels over time in the 915–960 MHz band

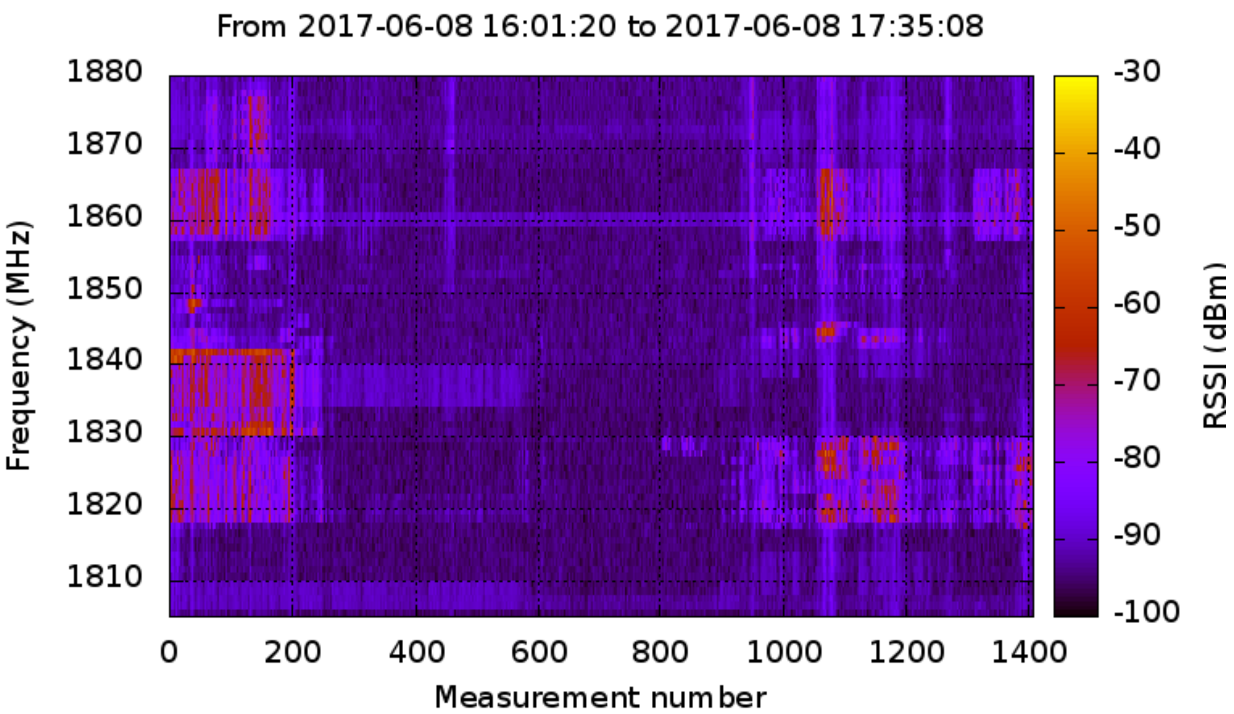

Figure 10: Power levels over time in the 1805-1880 MHz band

In the 1805–1880 MHz frequency range, one can observe that the spectrum is basically available between measurements number 200–900 (Figure 10).

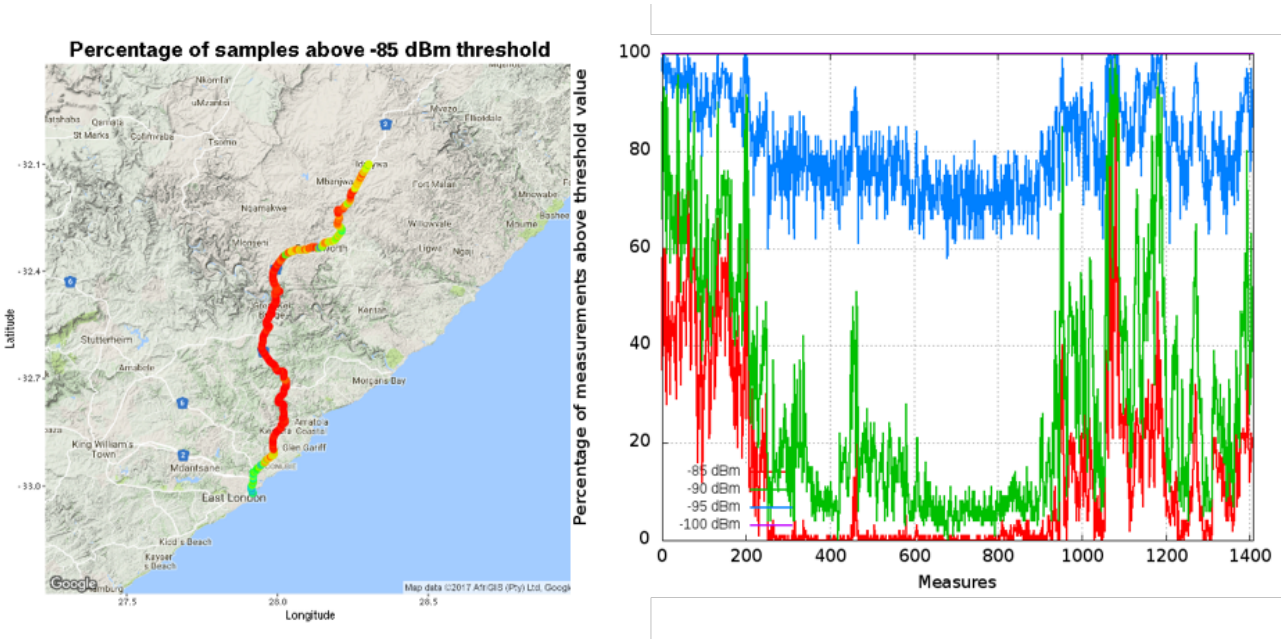

Figure 11: Percentage of measurements above –85 dBm

Measurement data for other campaign routes in the rural Eastern Cape are available at http://wireless.ictp.it/gsm/, along with measurements from central Cape Town showing much higher spectrum occupancy than in rural areas.

7. Findings

A number of stakeholders were identified to be interviewed, in order to probe the technical data further and better understand the regulator and market bottlenecks. A questionnaire was sent to a number of experts (two engineers, one regulator, three academics, two civil society activists, three researchers and three community network representatives). The questionnaire is attached in the Appendix 1, and was used to validate findings from the desk research. The list of interviewees is also included.

7.1. Spectrum Assignment

All interviewees agreed that the current way of assigning spectrum is inefficient. As also demonstrated by this paper, national allocations do not make much sense and present a barrier to market entry of small operators, as well as an obstacle to efficient and optimised spectrum use. Suggestions for ways to identify unused spectrum are the following:

- Publicly available data on spectrum allocations (including tower locations and equipment specifications)
- Required reporting by transmitters
- Allocation data combined with local sensing and spectrum scans
- Radio coverage modelling (assuming availability of accurate datasets).

Ultimately, combining all this information into a geolocation database would allow for the most effective use of the information.

Most interviewees suggest hybrid models as the best strategy for spectrum assignment, with each of the options suggested in the questionnaire (dynamic spectrum, shared spectrum, set-aside, regional licensing, hybrid) being variously applied depending on a variety of factors. One participant suggests a set-side for particular types of organisations (such as co-ops) and that portion of spectrum is then shared, using a dynamic spectrum approach with geolocation database.

IMT bands are very context-specific to what bands are currently in use in a country and therefore suggestions ranged from 800 MHz (especially for set-aside), 900 MHz, 1800 MHz and 2600 MHz. Some interviewees advocate for UHF/VHF bands and accordingly, dynamic spectrum allocation. Other suggestions are to look at CBRS[51] spectrum or ISM bands in 5 GHz and 6 GHz. There is also a need for high capacity mid-band spectrum for point-to-point wireless links (between 3 GHz and 11 GHz).

7.2. Alternative Technologies

With regard to the availability of alternative technologies, TVWS and DSA were pointed out as the most mature. A lot of potential was identified with the reduced costs of cellular equipment. In Mexico, this even allowed Rhizomatica to start economically-feasible operations of a community cellular network and to request a license from the Mexican regulator, which led to a permanent (15-year) license.

Some participants suggested that Citizens Broadband Radio Service (CBRS) and 6 GHz WiFi could be the technologies to keep an eye on in the future.

The idea of using licensed spectrum as secondary user, originally developed for TV bands, in IMT bands, was generally supported, and it was agreed that the PAWS protocol could be extended to operate for cellular technologies. While some participants pointed out the importance of a geolocation database, which would include detailed information from mobile network operators about their tower locations, radios, power output levels and antenna designs, others believe that, in rural areas, it is usually pretty clear when the primary user is present, and it is very straightforward to give small operators secondary licenses that cover specific uncovered areas.

7.3. Incentivising Operators to Share Spectrum

Operators may resist sharing their assigned spectrum, even if they are not using it in certain areas and not planning to extend their services in these regions due to lack of economic opportunity. Some ways to incentivise them to share unused spectrum (either on a fixed basis where it is entirely given to another operator, or dynamically where another operator is acting as secondary user) would be the following:

- Operators should be given tax rebates for sharing spectrum.
- Operators could be forgiven a percentage of spectrum fees and/or universal service fund contributions based on the number of hectares of land covered on a shared basis.
- Operators should not be given all the spectrum in the first place, but start with small assignment areas, with the understanding that if they do not cover certain areas, someone else will be allowed to come in as a secondary user and do so.
- Introduce penalties for operators who do not use the spectrum in their whole concession or license area. These penalties could be financial, or the operators could actually lose chunks of the geographic coverage of the license.

[51] CBRS is a 150 MHz-wide broadcast band of the 3.5 GHz band (3550–3700 MHz). The FCC completed a process begun in 2012 to establish rules for commercial use of this band in the US.

- The regulator could offer MNOs discounts on a 5G spectrum licence if they are willing to share their currently assigned spectrum.
- Small operators could help incumbents achieve universal service obligations – where community networks are perceived not as competitors, but rather as partners in helping achieve coverage in rural or unserved areas. Incumbents could take over a small operator's client base, once the rural area becomes an economically viable location. In this way, community networks could pave the way for investors.
- If the spectrum has not been used for a number of years in a given region, then the operator might lose the right to operate it.

Another recommendation is that this is an area where small operators, community networks, regulators and mobile network operators should come together to think creatively about solutions that serve the interests of all concerned.

7.4. Advocating for Changes in Spectrum Policy

Progressive regulators and strong civil society are seen as the main drivers behind innovative licensing models emerging in Latin America. Specifically, in Mexico, the set-aside was the product of many decades of struggle by indigenous communities and their allies to access spectrum for FM radio. Due to the emerging presence of the community cellular networks and the connection among the actors, the set-aside was made to apply to both radio and telecommunications – it is basically a social purpose license with a spectrum guarantee.

When asked about the right entity to propose changes, most experts pointed out the role of the regulator and government, but also industry bodies working with researchers and community networks who then present evidence to government to drive policy – the regulator then ensures that this policy is enacted with the right regulation. Government policy is often essential to enable or empower the regulator to take steps and the regulator is ultimately responsible for ensuring that operators, large and small, commercial and non-commercial, are treated fairly and do not interfere with each other in the use of spectrum.

There is also a clear need for capacity and movement building using evidence. Technology trials would help to raise awareness of the potential of spectrum sharing for increased broadband connectivity and digital services. Many regulators and policy makers do not know that community networks exist, and that, together with small operators, they can actually provide real models that can contribute to reducing the digital exclusion. A bottom-up approach, with local groups or multi-sectorial local coalitions that understand the needs on ground and have a way to put ideas into action (technologically, economically, socially), could be a good way to pressure governments and regulators to change policies.

Several interviewees suggested convening an independent body or multi-stakeholder forum that builds consensus among all the stakeholders. It is also important to provide examples of good practice from elsewhere that can be learned from. Right now, a regulator-by-regulator mechanism is the only way to advocate for changes. This means that, in each new country, we have to find the community network operators, technical capacity and civil society, and organise them all to present the case to the government and the regulator. While organisers and implementers from other countries can come in and assist by telling their stories, in the end, the local forces will need to drive the change and, in South Africa, move from endless consultation, non-implementation of policy and failure to review evidence to informed action.

8. Conclusion and Recommendations

While in urban areas, spectrum is often scarce, a large amount of licensed spectrum lies unused in remote, sparsely populated and often poor regions. A variety of low-cost 2G and 4G equipment has become available, and many manufacturers have emerged recently. Availability of such hardware and open-source software could significantly impact the cost model for sustainable rural mobile network deployment. However, for these technologies to be successfully deployed in ways that enable innovative approaches, there is a need for open telecom data – detailed information from mobile network operators of their towers, radios, power output levels and antenna designs – in order to create an accurate geolocation database, as well as information about the fiber backbone and backhaul pricing.

Spectrum measurements show that there are huge portions of unused spectrum that were originally assigned to incumbent operators, but how much is actually used is unclear. Knowing what equipment operators have deployed would help demonstrate this reality.

Strong civil society is seen as the main driver behind non-commercial innovative licensing models, although the key is in communicating the ideas to a receptive audience, namely, a progressive regulator. Market entry by small commercial niche operators, however, also drives market innovation. The creation of an enabling environment for these different types and sizes of operators to compete and collaborate is something that is already happening among commercial operators voluntarily through shared infrastructure and complementary investments. National access strategies need to enable the networks to extend throughout the country to create a single seamless national network.

Regulators should consider frameworks for offering spectrum to community networks in rural areas where spectrum may not have value for incumbent operators, but which will have a significant impact for small operators and community networks. There are ways to incentivise operators who have the rights to use portions of the spectrum nationwide, but only deploy their services in economically viable areas.

An independent body or multi-stakeholder forum that builds consensus among all the stakeholders (civil society, technical community, government, regulator, researchers, industry bodies and community networks representatives) would be an adequate body to advocate for changes in spectrum policy. The regulator could be the entity convening such a multi-stakeholder consultative process, but with a limited consultation period. Although changes can only be applied locally, it is important to have examples and best practices from other countries.

The recommendations are summarised in Table 2:

Table 2: Recommendations

Recommendation	
Identifying unused spectrum	▪ Obtain detailed coverage maps and information from mobile network operators of their towers, radios, power output levels and antenna designs. ▪ Identify which entity needs to disclose this type of information. ▪ Perform local sensing and spectrum scans.
Incentivising operators to share spectrum	▪ Give operators tax rebates or discounts on 5G spectrum licences for sharing their currently assigned spectrum. ▪ Introduce penalties for operators who do not use the spectrum in their whole concession or licence area. ▪ Create a business model where small operators help incumbents achieve universal service obligations.
Advocating for changes	▪ Raise awareness of potential of spectrum sharing for increased broadband connectivity and digital services through technology trials. ▪ Form an independent body or multi-stakeholder forum to advocate for changes in spectrum policy.

Appendix 1

Introduction to the project: Alternative spectrum licensing

National mobile markets in Africa's ICT sectors are characterised by one or two big mobile network operators (MNOs) who enjoyed first-mover advantages by investing in single-carrier cellular networks and purchasing expensive (auctioned) national spectrum licences. However, this model failed to provide universal connectivity. Considering that there is evidence that large portions of assigned spectrum bands remain unused, especially in rural areas, the success of community networks in providing broadband access is making a strong case for new alternative policies on spectrum licensing. Community wireless networks are locally owned and operated networks, usually relying on alternative low-cost technologies and open-source solutions. They are being increasingly deployed to provide connectivity in remote rural areas that lack coverage or in areas covered by commercial operators where services are not affordable or use antiquated mobile technology, such as 2G GSM.

However, the success of such networks is often hindered by expensive national exclusive spectrum licences, as well as the high, opaque and sometimes discriminatory wholesale network access pricing offered by incumbent mobile network operators.

Questionnaire

1. In your opinion, is wireless connectivity the ultimate solution for affordable rural broadband? Please justify your answer (Y/N). If No, please also state what would the alternative connectivity/ technology be?

2. *As it is general knowledge, mobile operators are not efficiently using their allocated bands across the licensed geographic allotments. The information on the bands and areas not covered is not disclosed or shared, and having access to this level of information would be essential to identify areas where community networks could use, lease, or share that spectrum.*

   Do you agree with this statement?
   What are your thoughts on the way spectrum is currently assigned?
   What do you think is the best way to identify unused spectrum?

3. There are state-of-the-art technologies and standards (including low-cost hardware and open-source software) that would allow for alternative spectrum licensing. Some of these technologies are dynamic spectrum access, geolocation spectrum databases, Protocol to Access White-Space (PAWS) and low-cost equipment such as OpenBTS or OpenCellular.

   Do you agree that these are enabling some of the alternative ways for spectrum licensing? Please justify your answer.
   Can you rank these technologies from the most mature to the least mature? Please justify your answer.
   Are there any other types of technologies missing from the list? If so, please name them and justify why could they be an alternative?

4. Providing broadband in white spaces is a well-researched phenomenon. The idea of using licensed spectrum as secondary user, originally developed for TV bands, can also be extended to IMT bands.

   Do you agree with this? If so, can you please explain how could this be done?
   Otherwise, please explain why this cannot not be an alternative for broadband access.

5. From the options below, what do you think is the best strategy for spectrum allocation and licensing? Please justify your answer.

   a) Dynamic spectrum
   b) Shared spectrum
   c) Set-aside spectrum
   d) Regional licensing
   e) Other

   Do you think a hybrid model should be implemented?

6. Which frequency bands would you like to see have portions of spectrum allocated for community networks and small operators?

7. What incentives should mobile operators be given to share spectrum?

   Should spectrum be shared on a fixed basis when spectrum is given to another operator, or dynamically when another operator is acting as secondary user?

8. Latin America has shown a regulatory trend towards new licensing models, such as set-aside spectrum for social purpose use in Mexico or elimination of multi-media communications service licensing requirements in Brazil for providers serving less than 5% of the state telecommunications market.

   What is your opinion on these new models?
   What do you think was the driver behind these new licensing models? Please tick one or more options from the list below and explain your reasoning.

   a) Progressive regulators
   b) Amount of community networks
   c) Strong civil society
   d) DIY networking skills
   e) Other

   Do you have other examples from other regions or countries? Please explain.

9. Who do you think would be the right entity to propose changes to spectrum assignment?

   a) Government
   b) Regulator
   c) Researchers
   d) Civil society
   e) Industry representative body, such as Wireless Access Providers' Association (WAPA in SA) or equivalent elsewhere
   f) Community network representatives
   g) Technologists
   h) Others

   Do you think that it is necessary to form an independent body to manage spectrum? Please explain your reasoning.

10. What do you think is the right approach to propose a change in the current way of assigning and managing spectrum?

Interviewees

Steve Song, Mozilla Foundation

Carlos Rey Moreno, APC

Peter Bloom, Rhizomatica

David Johnson, University of Cape Town

Kashif Ali, Facebook

Tim Genders, Project Isizwe

Arzak Khan, Internet Policy Observation Pakistan

Sarbani Belur, Gram Marg/IIT Mumbai

Ritu Srivastava, IIT Mumbai

Kurtis Heimerl, University of Washington/Facebook

Bruna Zanolli, Article 19

Verengai Mabika, Internet Society

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Ariel Barbosa, Colnodo

Valeria Betancourt, APC