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DEPARTMENT OF TELECOMMUNICATIONS AND POSTAL SERVICES

NO. 1003 **27 SEPTEMBER 2018**

ELECTRONIC COMMUNICATIONS ACT, 2005
(ACT NO. 36 OF 2005)

INVITATION TO PROVIDE WRITTEN COMMENTS ON PROPOSED POLICY AND POLICY DIRECTIONS TO THE AUTHORITY ON LICENSING OF UNASSIGNED HIGH DEMAND SPECTRUM

1.1 On 28 September 2016 Cabinet approved the National Integrated ICT Policy White Paper (White Paper) that was published on 03 October 2016 (Government *Gazette* 40325, Government Notice No. 1212).

1.2 Chapter 9 of the White Paper deals with the policy frameworks to address the supply side challenges to transform South Africa into an inclusive, people-centred and developmental digital society. It addresses open access policy, radio frequency spectrum policy, rapid deployment policy and licencing frameworks.

1.3 A framework is also established for the licencing of unassigned high demand spectrum to a wireless open access network in line with the new open access regime.

1.4 The Minister of Telecommunications and Postal Services (the Minister) intends to issue the policy directions in the Schedule to the Independent Communications Authority of South Africa (the Authority) in terms of section 3(2) read with section 5(6) of the Electronic Communications Act, 2005 (Act No. 36 of 2005) (the ECA). The purpose of the proposed policy directions is to direct the Authority to urgently consider the licensing of unassigned high demand spectrum.

1.5 As soon as possible after public consultation, the Minister will issue a final policy direction to the Authority.

1.6 Interested persons are invited to provide written comments on the proposed policy directions, within 30 working days of the date of publication, addressed to –

The Director-General, Department of Telecommunications and Postal Services For attention: Mr. T Ngobeni, The Deputy Director-General, Infrastructure Support
First Floor, Block A2, iParioli Office Park, 1166 Park Street, Hatfield, Pretoria
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2. Comments received after the closing date may be disregarded.

Dr Siyabonga Cyprian Cwele, MP
Minister of Telecommunications and Postal Services

SCHEDULE

PROPOSED POLICY AND POLICY DIRECTIONS TO THE AUTHORITY ON LICENSING OF UNASSIGNED HIGH DEMAND SPECTRUM

1. WHOLESALE ELECTRONIC COMMUNICATIONS NETWORK SERVICE

1.1 Chapter 9 of the National Integrated ICT Policy White Paper, 2016 (the White Paper) sets out the open access policy, spectrum policy and a policy framework to address the assignment of high demand spectrum to a wireless open access network. The goals of the open access policy in the White Paper include -

a) To allow for effective service-based competition and to ensure accessible, affordable, high quality and reliable services for consumers;
b) To increase network coverage, and enable the rapid deployment of broadband infrastructure and services across all areas of the country;
c) To promote shared and equal access to broadband infrastructure;
d) To remove barriers to competition and innovation in the provision of broadband services; and
e) To foster innovation and development of applications and services.

1.2 The White Paper states that Government fully supports wireless open access as a means to meet the public policy objectives such as lowering of the cost of communications, reducing last mile infrastructure duplication and encouraging service-based competition.

1.3 Mindful of the fact that the Electronic Communications Act, 2005 (Act No. 36 of 2005) (the ECA) does not have a license type for a wireless open access network, but that the Minister may direct the Authority to accept and consider applications for individual electronic communications network service licences, an electronic communications network service licensee that provide wholesale electronic communications network services (hereinafter referred to as the wholesale open access network or WOAN), is contemplated. The term WOAN is used for descriptive purposes in accordance with the White Paper and in line with the wholesale open access obligations proposed for it.

1.4 Moving forward, the new spectrum management regime set out in the White Paper encourages that licensees work together as far as it is practicable, including through the deployment of a WOAN. The White Paper states that in bands where demand exceeds the amount of spectrum available, assignment of spectrum must be on a non-exclusive basis. The value of sharing and collaboration between licensees is that it will result in the more effective use of scarce resources such as spectrum and a reduction of the duplication of infrastructure while facilitating service-based competition.

1.5 The White Paper provides that all currently unassigned high demand spectrum will be set aside for assignment to the WOAN. The Minister performed significant consultation with stakeholders on the best approach to implement this policy provision.

1.6 The Minister commissioned the Council for Scientific and Industrial Research (CSIR) to conduct a study, which is attached hereto, to determine the spectrum requirements for the WOAN to ensure its viability. The study focused on the Capacity and Quality of Services (QoS) determination with respect to the unassigned high demand spectrum bands namely; the network coverage spectrum (i.e. 700 MHz and 800 MHz) and the network capacity spectrum (i.e. 2600 MHz). The study provides recommendations on the unassigned high demand spectrum required by the WOAN to ensure its viability and sustainability on the basis of 20% market share; and excess unassigned high demand spectrum for other electronic communications network service licensees.

1.7 In view of the recommendations of the CSIR study, Cabinet approved that unassigned high demand spectrum may be licensed to a WOAN and to other electronic communications network service licensees simultaneously.

1.8 The Authority is directed to consider the recommendations of the CSIR study urgently.

1.9 The WOAN must provide wholesale open access to its electronic communications networks and facilities, upon request, to any other person licensed in terms of the ECA and persons providing services pursuant to a licence exemption, in accordance with the following wholesale open access principles:

a) Wholesale open access on terms that are effective, transparent and non-discriminatory;
b) Leasing of its electronic communications networks and electronic communications facilities; and
c) Charge wholesale rates as prescribed by the Authority.

1.10 Based on the provisions of the White Paper, the following conditions must apply to the WOAN. The WOAN -

a) must be a consortium of persons, at least 50% owned by South Africans, that participate voluntarily;
b) must comply with the empowerment requirements contemplated in section 9(2)(b) of the ECA;
c) must include diversity of ownership to ensure meaningful participation of all entities involved including SMMEs, and to prevent monopolistic behaviour;
d) must include effective participation by targeted groups, including women, youth and persons with disabilities;
e) may not be a public entity under the Public Finance Management Act, 1999 (Act No. 1 of 1999); and
f) may only provide wholesale services.

1.11 If any member of the consortium applying for the WOAN provides electronic communications services, the Authority must require functional separation between such electronic communications services and the member's participation in the WOAN, which must be provided by an independently operating business entity.

1.12 The Authority must determine the following for the WOAN—

(a) the terms and conditions, including universal service and access obligations; and

(b) incentives such as—

(i) a reduced spectrum application fee, only covering administrative costs;

(ii) reduced or waived radio frequency spectrum licence fees for a period of five years;

(iii) immediate facilities leasing of electronic communications networks and electronic communications facilities of the radio frequency spectrum licensees, if any, that are assigned currently unassigned high demand spectrum as contemplated in paragraph 2;

(iv) offtake i.e. a minimum of 30% national capacity is procured from the WOAN as soon as the WOAN is licenced, for a period of not more than three years, by each radio frequency spectrum licensee that is assigned currently unassigned high demand spectrum as contemplated in paragraph 2. The percentage to be procured by each licensee may be proportionate to the amount of high demand spectrum assigned to such licensee. The Authority may determine that, after expiry of the period contemplated herein, a minimum of 30% national capacity must be procured in the WOAN collectively by the radio frequency spectrum licensees contemplated in paragraph 2, for a further period determined by the Authority;

(v) delayed imposition of wholesale rates that must be charged by the WOAN, for a specific period.

1.13 The Authority must—

(a) consider imposing regulatory remedies on the WOAN, to ensure effective service-based competition, and to avoid any anti-competitive effects;

(b) perform strict regulatory oversight; and

(c) ensure that the applicants for a WOAN have a viable business plan, the technical capabilities and financial strength to build and operate a WOAN.

1.14 The Minister intends to direct the Authority, in terms of section 3(2) read with section 5(6) of the ECA, to issue an Invitation to Apply (ITA) and accept and consider applications for an individual electronic communications network service license and intends to direct the Authority in terms of section 3(2) to urgently consider the licensing of a radio frequency spectrum license, for a WOAN.

2. UNASSIGNED HIGH DEMAND SPECTRUM NOT ASSIGNED TO THE WOAN

2.1 The Minister intends to direct the Authority, in terms of section 3(2) of the ECA, to urgently consider the licensing of radio frequency spectrum licences for unassigned high demand spectrum not reserved for assignment to the WOAN.

2.2 The radio frequency spectrum licences contemplated in paragraph 2.1 must be issued on condition that—

(a) the licensees, must lease its electronic communications networks and electronic communications facilities, if any, to the WOAN upon request, as soon as the WOAN is licenced. The Authority must perform strict regulatory oversight to ensure compliance with this network and facilities leasing requirement;

(b) the licensees procure capacity in the WOAN as provided in paragraph 1.12(b)(iv);

(c) the spectrum is assigned subject to Chapters 8 and 10 of the ECA;

(d) universal access and universal service obligations are imposed on the licensees to ensure high quality network availability in rural and under-serviced areas; the obligations must be complied with in rural and under-serviced areas before the assigned spectrum may be used in other areas by the licensees;

(e) spectrum lots or capacity should be divided in a way that ensures that the relevant spectrum is not licenced to a single entity; and

(f) compliance with empowerment requirements in terms of section 9(2)(b) of the ECA and any regulations issued by the Authority.

2.3 Section 31(2)(b) of the ECA provides that an individual electronic communications network service licence is required in addition to any radio frequency spectrum licence where the provision of such service entails the use of radio frequency spectrum. Although some of the applicants for the radio frequency spectrum licences will have an existing individual electronic communications network service licence in compliance with section 31(2)(b), provision should also be made for applicants that do not have an existing individual electronic communications network service licence.

2.4 The Minister intends to direct the Authority, in terms of section 3(2) read with section 5(6) of the ECA, to issue an Invitation to Apply (ITA) and accept and consider applications for individual electronic communications network service licenses from applicants that intend to apply for the radio frequency spectrum licences, but do not have individual electronic communications network service licenses.

2.5 Any terms and conditions imposed by the Authority shall remain in force for the duration of the radio frequency spectrum licence issued.

2.6 The licences contemplated in this policy and policy direction shall be for such periods as determined by the Authority.

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Department:
Telecommunications and Postal Services
REPUBLIC OF SOUTH AFRICA

Abridged Final report

Spectrum requirements for Wholesale Open Access Network (WOAN)

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Executive Summary

A wireless open access network (WOAN) is a wireless telecommunications network built with the objective of providing network coverage and capacity to service providers on a wholesale basis. The expected benefits of a WOAN versus a vertically integrated network approach is cost savings from not duplicating the network infrastructure for each service provider, efficiencies from greater sharing of resources, and lowering barriers to entry for new service providers.

The South African Department of Telecommunications and Postal Services (DTPS) commissioned this study by the Council for Scientific and Industrial Research (CSIR) to determine the amount of spectrum needed for a WOAN to meet national objectives and targets for broadband delivery, as set out in 2013's National Broadband Policy. The DTPS also intends for the WOAN to address the rural coverage gap. The scope of the study is limited to the spectrum question and does not consider other WOAN success determinants, such as the backhaul network, market dynamics, and network economics.

The amount of spectrum needed was determined to be a function of network capacity (target/demand), the spectral efficiency of technology, a combination of the number of network sites and area covered, and the projected percentage of mobile users that would be served by a network. A detailed method and model for calculating the amount of downlink spectrum needed for a network is presented in this study. Total uplink requirements will follow the approved pairing in the Frequency Division Duplexing (FDD) mode and 4:1 of downlink-to-uplink ratio for Time Division Duplexing (TDD) mode.

It is to be expected that the network capacity (demand) will grow with time; some of the constraints for this growth, such as high data costs, are being addressed as part of the implementation of the National integrated ICT policy. The study team held workshops with various stakeholders with a view to understanding the current capacity demand for WOAN. The capacity workshops were held with the Operators Forum (representing the 6 large mobile network operators), the South African Communications Forum (SACF) and Black IT Forum (BITF). These workshops also sourced inputs, such as traffic models that operators currently use, as well as site information. Individual company meetings resulted from the workshops to obtain information deemed confidential to share in workshops.

The second parameter that is expected to evolve and improve over time is the spectral efficiency of technology. The study team held a workshop with telecommunications equipment Original Equipment Manufacturers (OEMs) that are active in South African market with a view of understanding the capabilities of the equipment that is now available in the market. The OEMs confirmed that network equipment and mobile device chipsets could currently operate at a network speed of up to 1 Gbps using 60 MHz of spectrum. This speed is delivered by combining three 20 MHz component carriers, using 4x4 MIMO antenna and 256 QAM modulation techniques. These capabilities exceed the minimum requirements for IMT-Advanced capabilities as determined by the ITU, therefore it is expected that these would result in spectral efficiencies that fall within ITU range [3]. A study to derive expected spectral efficiency of implementation of these technologies locally was not conducted; the values used were therefore derived from the ITU studies.

In addition to the capacity and spectral efficiency estimation from the above process, additional assumptions applied to the model include:

- The baseline for WOAN network sites are an optimised combination of current sites across all existing mobile networks. These networks cover close to 100% of the population and sites are configured in line with population distribution.

- The baseline for average amount of data used per user is 1 gigabyte per month.
- The baseline for number of users to be served by WOAN is 20% of projected mobile user population over the age of 6 (≈10.248 million). This baseline was derived from studies that show that a mobile operator needs to achieve a market share of 10%-15% to be viable.
- The baseline spectral efficiency is the mid-point of ITU range for IMT-Advanced technologies.

The spectrum bands considered in the study were limited to the following:

- Low band: "Band 28" (700 MHz band);
- Low band: "Band 20" (800 MHz band);
- High band: "Band 7" (FDD in the 2600 MHz band); and
- High band: "Band 38" (TDD in the 2600 MHz band).

Additional spectrum bands that are already available for IMT but not considered for this study and those that will be made available in future will be dealt with in line with the policy. Future studies need to look at spectrum and equipment available in bands such as 450 MHz (FDD), 2300 MHz (TDD) and 3500 MHz (TDD) and any additional bands that will be made available in future to inform timely implementation of the policy with respect to these.

Applying the model, the results are presented in Section 5.2, indicating the amount of spectrum required by WOAN to meet the SA connect targets when serving 10, 248 million users (20% of all users) to 40, 990 million users (80% of all users) respectively. These results are summarised in the table below.

WOAN users (%)	**Number of Users ('000)**	**Downlink spectrum required (MHz)**
20%	10 248	**40**
30%	15 371	**55**
40%	20 495	**70**
50%	25 619	**85**
60%	30 742	**105**
70%	35 867	**120**
80%	40 990	**135**

The results show that the amount of spectrum required is directly proportional to the number of users that the network is projected to serve. In order to serve 10,248 million users (20% of all users) each with 10 Mbps, WOAN will require 40 MHz of downlink spectrum. On the extreme end, in order to serve 40,990 million users (80% of all users) each with 10 Mbps, WOAN will require 135 MHz of downlink spectrum.

SA connect targets are presented in terms of average capacity per user. The recommendation made in this study therefore focuses on spectrum needs to meet the target for average speeds in 2030. When dimensioning the network, mobile operators typically use the busy hour capacity. We use this to ensure that the network can still deliver at least 5 Mbps (2020 target) during the busy hour.

The following are final recommendations made:

1. The department should consider setting aside only a portion of spectrum in these bands for WOAN and the remaining to other licensees.
2. The department should consider 20% of possible user population in 2020 as a baseline to ensure viability of WOAN.
3. The following spectrum combinations should be set-aside for WOAN as a minimum. These satisfy the baseline user population as well as provide enough capacity for high-end users of WOAN:
    a. 2 x 25 MHz of 800 band (Band 20);
    b. 2 x 20 MHz of 2600 FDD band (Band 7); and
    c. 25 MHz of 2600 TDD band (Band 38).

The above recommendations are meant to address the immediate requirements for WOAN, as per terms of reference for this study. In addition to this, the study team recommends that further studies, that are aimed at ensuring that WOAN remains relevant in the future be supported. The following additional studies are recommended:

4. A detailed market study to forecast the market size of WOAN beyond 2020 and up to 2030. This will enable the department to take early decision on the licensing of spectrum for 5G.
5. Experimentation with different spectrum assignment combinations for new mobile broadband spectrum bands to ensure that the emerging broadband needs are catered for and that new technologies, such as 5G are adopted as early as possible. This would include recalculation of WOAN spectrum needs beyond the year 2020 or at any point when the key assumptions change.
6. A technical study to determine spectral efficiency at five-year intervals as the technology improves.
7. Studies that investigate the deployment models and alternative technologies to for delivering broadband to the sparely populated areas of the country. Analysis of data from 2011 census, indicates 90% of the country's population live in 10% of the land, see Figure 4. LTE-Advanced technology, as is the case with the previous generation of mobile broadband technologies, is not well suited to serve sparsely populated areas and thus create a challenge to extend the network to cover the remaining 10% of the population.

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List of Abbreviations

3GPP	Third-generation partnership project
5G	Fifth-generation wireless technology
CA	Carrier Aggregation
CC	Component Carrier
CSIR	Council for Scientific and Industrial Research
DTPS	Department of Telecommunications and Postal Services
FDD	Frequency division duplexing
FRF	Frequency Reuse Factor
ICASA	Independent Communications Authority of South Africa
ICT	Information and Communications Technology
IMT	International Mobile Telecommunications
IoT	Internet of Things
ISP	Internet Service Provider
LAA	Licensed-Assisted Access
LTE-A	Long-Term Evolution – Advanced
LWA	LTE and WiFi Aggregation
MIMO	Multiple input multiple output
mMTC	Massive machine type communication
MNO	Mobile Network Operator
MTC	Machine type communication
MVNO	Mobile Virtual Network Operator
QAM	Quadrature Amplitude Modulation
PDCCH	Physical Downlink Control Channel
NB-IoT	NarrowBand Internet of Things
RATG	Radio Access Technology Group
RFP	Request for proposal
SACF	South African Communications Forum
SFR	Soft Frequency Reuse
SMME	Small, medium and micro-enterprise
TDD	Time division duplexing
UE	User Equipment
URLLC	Ultra-reliable and low latency communications
WOAN	Wireless Open Access Network

1. Introduction

This document is an abridged report of a study that was commissioned by the Department of Telecommunications and Postal Services ("the department") to determine the amount of spectrum that will be needed by the Wireless Open Access Network (WOAN), as stipulated in the National Integrated ICT Policy White Paper of 2016 [1]. This version was created to ensure that data that was obtained under the non-disclosure agreement is not exposed; it does not change the results of the model and the recommendations emanating from those results.

The report is structured as follows:

1. Introduction and context, including use cases for the WOAN – this section.
2. Legislative and Policy Context – Provided by the department
3. Consultation with the telecommunications industry
4. The model – overview of the model and additional assumptions not covered in previous sections.
5. Results from executing the model
6. Recommendations

1.1 Objectives of the study

The general objective of the study is to advise the department and Independent Communications Authority of South Africa (ICASA) on the amount of spectrum required to ensure that the WOAN meets the objectives of South Africa's 2013 Broadband Policy (known as SA Connect) [2].

The specific objectives of the study were to:

1. Estimate capacity of the WOAN if all high demand spectrum is assigned to the WOAN.
2. Determine sufficient amount of both coverage and capacity spectrum to meet Quality of Service targets of SA Connect. The SA connect targets are assumed to refer to downlink speeds; we therefore focus on amount of downlink spectrum in the study.
3. Determine the amount of spectrum after identifying spectrum for WOAN, if any, available for other licensees.

1.2 Project Scope

The scope of work required to achieve the objectives 1 and 2, required development of a model based on industry standard network planning parameters. For this high-level study a number of assumptions on these parameters were made. These assumptions are presented later in this document.

The high and low band WOAN spectrum used by this study is provided in Table 1. Low band spectrum refers to the 700 MHz and 800 MHz FDD spectrum. High band spectrum refers to 2600 MHz FDD and TDD spectrum.

Table 1: High and Low band spectrum used by the WOAN

Band	Spectrum	Band label
High	2600 FDD – 2 x70 MHz 2600 TDD - 25 MHz	Band 7 Band 38
Low	700 FDD - 2 x 30MHz 800 FDD – 2 x 25 MHz	Band 28 Band 20

In order to model capacity and spectrum, site data was required to be provided by operators providing a 3G data service, as current 3G sites achieve near 100% population coverage. The data was used to derive virtual base station sites[1] that were used in the execution of the model; therefore the results presented here do not use sites from one operator alone. The model is presented later in this document.

The following activities were out of the scope of this study:

- A market study to determine possible market share of WOAN.
- Detailed network planning and optimisation.
- Consideration of backhaul capacity and spectrum requirements for such; it is therefore assumed that there is sufficient backhaul to deliver required capacity to each site.
- Verification of some of the assumptions, such as projected market share for WOAN.

1.3 Project Approach

The high-level view of the methodology for the project is depicted in Figure 1. A more detailed description of the model is provided later in this report.

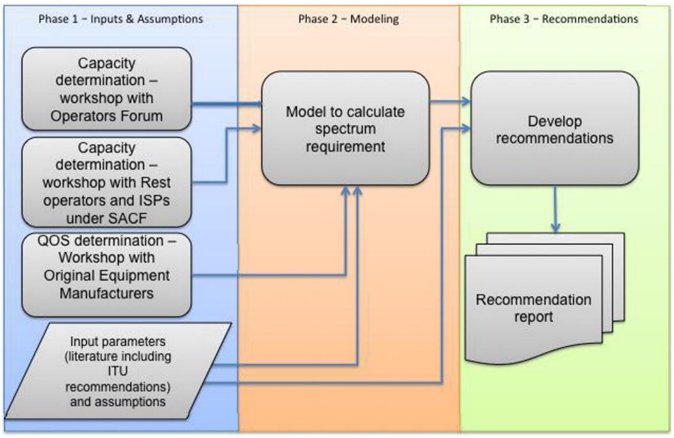

Figure 1: High-level Methodology

1.4 Acknowledgments

The study team acknowledges the very helpful interactions with the operators, OEMs and other industry players during the workshops and further one-on-one discussions that contributed to the definitions of capacity and capabilities of current and future LTE technology. The study team is also thankful for the high site data provided by the operators that were a critical input for the capacity and spectrum modelling work.

[1] A virtual operator site is derived from merging multiple operator sites that are in close proximity into one site. See Annex A for virtual site definition.

2. Legislative and Policy Context

(Provided by the Department of Telecommunications and Postal Services)

2.1 Background

Government followed a policy of managed liberalization of the telecommunication sector in accordance with the White Paper on Telecommunications in 1996. Such policy was incorporated in the Telecommunications Act, 1996 and later the enacted Electronic Communications Act (the "Act"). In terms of the ECA the Minister may make policies on matters of national policy applicable to the ICT sector, consistent with the objects of the Act. One of the reasons for managed liberation was the management of scarce resources since there is insufficient spectrum to assign to all players in the market.

The Altech judgement changed the planned trajectory since it allowed former Value Added Network Services (VANS) licensees to self-provide ICT Infrastructure. This resulted in approximately 400 licensees having the same rights that large operators had at the time. During license conversion to align the licensing framework with the ECA, the former VANS licensees also received Electronic Communications Service (ECS) and Electronic Communications Network Service (ECNS) licences.

2.2 Problem Statement

The prospects of service providers rolling out modern broadband services in rural and less affluent areas without government intervention are minimal. Key challenges that have resulted in a skewed network roll-out in South Africa pertains to ineffective regulatory regime, a concentrated broadband infrastructure market, high communications prices and significant barriers to entry. If these challenges persists, they will perpetuate the digital divide, compromise the country's ability to meet its aggressive broadband targets set out in SA Connect, and will cause South Africa to miss the opportunity provided by broadband to improve the economy.

2.2.1 Ineffective regulatory regime

The facilities leasing framework outlined in the ECA requires every ECNS licensee to provide access to electronic communications facilities, on negotiated terms, unless the request for access is technically or financially unreasonable. In practise this has not worked well, with incumbents refusing access to local loops, landing stations, ducts etc.

2.2.2 Concentrated broadband infrastructure market

The broadband market is characterised by a few very strong and vertically integrated players. The result of the use of infrastructure as a competitive advantage is (1) the lack of infrastructure in less affluent areas (2) infrastructure sharing bottlenecks, (3) high costs to communicate, (4) the duplication of infrastructure (5) the inefficient use of scarce resources such as the radio frequency spectrum; and (6) barriers to entry for new entrants and SMMEs. The largest infrastructure bottleneck is in the provision of last mile infrastructure, also known as the access network. The WOAN can play a critical role in providing access networks that are open to many service providers to render services.

2.2.3 High cost to communicate

The duplication of infrastructure and commercially driven rollout plans lead to expensive

infrastructure deployment, which costs are passed on to consumers. In addition, the limited number of service providers are not able to adequately exert pressure on retail prices.

2.2.4 Barriers to entry

It is necessary to reduce market entry barriers and enable sharing of infrastructure and scarce resources, thereby reducing duplication of infrastructure; and to enable innovation in the development of digital applications and services. One of the most significant barriers to market entry for these former VANS licensees, is the exclusive assignment of spectrum resulting in vertical integration of the market where only a few incumbent operators benefitted from scarce resources like spectrum. Thus, the introduction of the Wireless Open Access Network is envisaged to address this particular challenge. A WOAN will be created as a vehicle that can be used to provide competitive services to even licensees historically excluded. Access to frequency spectrum is necessary to enable last mile access. Spectrum, in this market, constitutes a bottleneck. It is therefore important that, in line with the principle of openness, a shared approach to spectrum use is taken

2.3 New Paradigm shift

The Integrated ICT White Paper of 2016 identifies that the ICT infrastructure market, particularly in relation to broadband, is characterised by fundamental market problems of ineffective competition and infrastructure sharing, unnecessary duplication of infrastructure, and limited availability of scarce resources. Although multiple networks have been rolled out across the country, the deployment is skewed towards urban areas characterised by infrastructure duplication. Competition, in particular in the mobile broadband market, is limited to a number of players that have access to scarce frequency spectrum resources.

Spectrum generally needs to be managed and used effectively and efficiently; and in particular “high demand” spectrum where demand exceeds supply of spectrum, needs to be governed in line with a paradigm shift towards the non-exclusive assignment. To support the new paradigm shift, the open access regime has to be extended to include how networks should be shared between licensees for the benefit of society, including through a Wireless Open Access Network. The reconceptualised spectrum policy as outlined in the ICT White Paper and the enforcement of an open access regime will facilitate lower costs and more efficient networks that use the latest technologies and are able to deliver multitude of services. This will also promote the extension and deployment of networks in rural and underserviced areas to support inclusive economic growth. The Government recognises that time is of the essence if the country is to meet the targets set out in SA Connect and the economic growth targets put forward in the NDP.

With open and shared networks as a feature of the new policy environment, competition will be focused at the service level – enabling internet service providers (ISPs), mobile virtual network operators (MVNO) and other service providers to provide high quality and innovative products and services to South Africans – at affordable rates. This will in turn facilitate universal service and access – and broadband access for all. This approach reduces duplication and the inefficiency that arises from the building and operation of multiple networks. It also encourages service based competition in a way that the current oligopoly does not.

3. Consultation with Industry

3.1 Capacity determination with Industry

Estimating the capacity of the WOAN is one of the objectives of this study. In order to achieve this, the study team found it crucial to first have a common or general understanding with the industry when it comes to the definition of "capacity". Two separate workshops were then held between the study team and key industry players.

3.1.1 Capacity determination Workshop 1 with Operators Forum

The first workshop was held with the Cell-C, Liquid Telecom, MTN, Rain, Telkom and Vodacom collectively referred to as Operators Forum on the 6th July 2017 at the Council for Scientific and Industrial Research (CSIR), Pretoria. As preparation for the workshop, a questionnaire was sent to all six operators. The objective of the questionnaire was to assist the study team in the definition of capacity from each operator's perspective.

Each operator presented their process of determining capacity and their planning parameters. While there are some differences in approach due mainly to their different target markets, common elements were noted. All operators indicated that, due to the competitive nature of the information required, they would prefer to have one-on-one meetings where they can share some of their sensitive data. The study team received additional information in one-on-one meetings with all the operators.

At the end of the workshop, there was an agreement on the understanding of capacity as it is used in consultation with the department to be referring to aggregate capacity in a cell and that this can be calculated from the spectral efficiency of the specific LTE technology being used, the cell area and the amount of WOAN spectrum allocated to the cell. The study team did not fully explore whether the 30% capacity that the operators had committed to, meant 30% in every cell or 30% of the total available capacity countrywide. This was to be finalized in consultations between the operators and the department.

3.1.2 Capacity determination: Workshop 2 with Industry associations

The industry associations that were invited to the second workshop were South African Communications Forum (SACF), Black IT Forum and Internet Service Provider's Association (ISPA). The workshop was held on the 11th July 2017 at the CSIR, Pretoria. SACF and Black IT forum attended together with the members of the SACF; Altron, Boston Consulting Group, GH Communications, Huawei, MTN, Sentech, SMILE Communications, Vodacom, PYGMA, ABT and BT. ICASA was also represented at this workshop. There was no new or different definition of capacity provided during the workshop. Instead, the SACF members indicated that they would like the CSIR to provide its own definition of capacity under this study.

Below is the summary of key points raised during the workshop with the SACF and Black IT Forum:

- The Black IT Forum requested that SMMEs should be allowed maximum participation in the ownership of the WOAN.
- The SACF wanted to understand if this study has considered any constitutional issues that might arise as a result.
- The SACF also clarified that operators purchasing 30% of the WOAN capacity will help ensure the sustainability of the WOAN.

These were noted for consideration for implementation by the DTPS, however they were not directly considered when making the recommendations in this report.

3.1.3 One-on-one meetings with Industry

Following these workshops, the study team held a number of one-on-one meetings with the industry. The discussions were held under non-disclosure agreements; the contents are therefore not disclosed in this report.

3.2 LTE-Advanced technology

3.2.1 Quality of Service and ecosystem discussion with Industry

A third workshop was held with the telecommunication equipment OEMs and the system integrators on the 13th July 2017 at the CSIR in Pretoria. In this workshop OEMs that are active in the telecommunications space in South Africa were invited. The OEMs that attended the workshop were Ericson, Huawei, Intel, Nokia and Qualcomm. The main aim of this workshop was to determine:

- The current real-world technical capabilities of vendor equipment that is available now, and in the near future. Key parameters were LTE-A release version, support for spectral efficiency and achievable speeds.
- The current technical capabilities of the mobile device ecosystem available in South Africa. Key parameters were LTE-A device category – including frequency bands supported and price points.

OEMs confirmed the availability of commercial equipment that is capable of speeds of up to 1 Gbps using 60 MHz of spectrum aggregated over 3 component carriers, up to 4x4 MIMO and 256-QAM and highlighted some scenarios where they tested these speeds. The chipset manufacturers also confirmed the availability of chipsets for mobile devices that can support the above-mentioned features in the planned WOAN frequencies and we could therefore consider these features.

Additional recommendations were that the study should consider:

- The possible future use of Internet of Things (IoT), which will require the network to be tailored for massive machine type communications (mMTC) or ultra-reliable and low latency communications (URLLC), but for now it is assumed the network will be tailored for enhanced mobile broadband (eMBB).
- Use of other LTE frequency bands by the WOAN. Future network studies could look at bands such as 450 MHz (FDD), 2300 MHz (TDD) and 3500 MHz.

3.3 Key outputs of the workshops used in the study

3.3.1 Cell Capacity definition as used in the project

From the point of view of an operator owning spectrum (used for this study):

For an operator planning a network or for broadband planning or spectrum studies such as this, aggregate capacity in a cell is the most important measure of capacity. The aggregate capacity is a statistical representation of the sum of the capacities experienced by users randomly distributed across the cell area. This aggregate capacity factors in the spectral efficiency of the base station and end-user device and is also dependent on the cell area. Larger cell areas result in lower aggregate capacity and smaller cell areas result in higher aggregate capacity. The aggregate capacity divided by the amount of available spectrum in a cell produces the cell spectrum efficiency discussed in Annex B that is used for calculating the required spectrum in this study. Aggregate capacity is also used for dimensioning a network and ensuring that you are meeting potential capacity demands.

There are other definitions of capacity that are used in the industry, from the point of view of lower tier operators buying capacity from higher tier operators, or from the point of view of experience of a mobile user. These are not used in the study but are provided here for context.

From the point of view of a lower tier operator purchasing capacity from a higher tier operator

For a lower tier operator, such as an MVNO or ISP purchasing capacity from the WOAN (a higher tier operator), the WOAN would sell capacity as the maximum achievable supply side capacity for an LTE-A radio serving the cell by only using the spectral efficiency of the base station radio and assuming the best possible signal conditions, without considering the area of the cell.

From the point of view of a mobile user

Capacity experienced by mobile users is highly dependent on where they are in the cell (affecting the signal strength and interference), the category of device used (e.g. whether it supports 2x2 or 4x4 MIMO), and how congested the cell is. Typically an operator will advertise the maximum experience the user could have during quiet hour in the best possible signal conditions with the highest category device.

3.3.2 LTE-Advanced assumptions made for this study

For the purposes of this study we made use of the concept of cell spectral efficiency, described in Annex B, to calculate spectrum requirements for the WOAN. In order to meet the requirements of the parameters set for cell spectral efficiency, a certain set of minimum assumed capabilities should be available. We will assume the use of LTE Release 12 or any later release with the following minimum capabilities.

- 4x4 MIMO supported on LTE-A base station; and
- Maximum modulation rate of 256-QAM.

In order to achieve a maximum possible instantaneous throughput of 1 Gbps[2], Carrier Aggregation of 3 or more component carriers (CC) will need to be supported where each CC can be up to 20 MHz in bandwidth. Carrier aggregation can be across different bands - the current ecosystem supports aggregation across Band 7 (2600 MHz FDD band), Band 20 (800 MHz band) and Band 38 (2600MHz TDD band). The WOAN will also need to support IoT in the future and the NB-IoT protocol should be supported in the future, although its spectrum requirement is insignificant.

[2] 1Gbps is the SA Connect targets for government facilities in 2030, a provision is therefore made for WOAN to provide fixed LTE-A service to those facilities.

4. The model

4.1 Network dimensioning to meet capacity demand

When dimensioning a cellular network to meet the expected capacity demand, there are several factors that influence the total available capacity of a network in specific areas or across the total footprint of the network:

- Total number of cells per unit area: The total available capacity per unit area increases proportionally to the total number of cells per unit area. Cost also increases proportionally as new sites need to be acquired or leased and additional radio equipment and supporting infrastructure needs to be installed. In this study, we assume the use of existing mobile operators' sites and calculate capacity assuming the use of all existing sites; hence we do not carry out studies on the effect of proportional increase in site density on the total available capacity.
- Number of sectors per site: Another tool to increase capacity per unit area is to increase the number of sectors used per site. The capacity per unit area also increases proportionally to the number of sectors used. In this study, we assume a standard 3 sector LTE-A installation as this is the most commonly available configuration and do not carry out any calculations on the influence of the number of sectors on capacity.
- Amount of spectrum and spectrum efficiency of the technology: Increasing the amount of spectrum allocated to the LTE radios and the spectral efficiency of the radios is a key part of this study and is addressed in later sections of the report.

4.2 Previous work

ITU-R M.1768 published in 2013 describes a methodology for spectrum requirement calculations [3]. A technology neutral approach allows the methodology to handle both existing and emerging communication systems.

The technical process of estimating spectrum requirements is based on service definition, market expectations collected via questionnaires, technical and operational framework and the spectrum calculation algorithm.

A service category is defined as a combination of service type (super high/ high/ medium multimedia, low data rate and very low data rate - including voice and SMS) and traffic class (conversational, streaming, interactive or background). Mobility classes are mapped to radio environments as follows: high mobility - macro only, low mobility - micro and macro, stationary/ pedestrian - all radio environments.

The conversational and streaming traffic classes are serviced with circuit switching, while the background and interactive class are serviced with packet switching. The required system capacity is determined separately for circuit switched and packet-switched traffic, combining uplink and downlink and using traffic volumes from market studies.

The ITU-R M.1768 methodology transforms capacity requirements into spectrum requirements using spectral efficiency values, which are different for macro, micro, pico and hot-spot cells. Finally, adjustments are made taking into account the minimum spectrum requirement for a network deployment, necessary guard bands, and the impact of the number of operators.

ITU-R M.1768 defines values for all the input parameters needed for spectrum calculations to convert the capacity requirements in terms of bits/s/cell to the spectrum requirements in Hz.

A study of the spectrum requirements for China done in 2013 considered voice, data and total traffic estimation, a total number of sites estimation, and traffic distribution by site allocation and technologies to estimate the amount of IMT spectrum required by 2020 [4]. The Chinese model was also tested using sensitivity analysis. The authors introduce the concept of a virtual base station where multiple operators using sites in close proximity are merged into one virtual base station site. They make use of generic area spectral efficiencies from ITU-R M.2078 [5] and note that these are higher than practical IMT systems. The Chinese spectrum requirement study divided area spectral density into 4 classes for RATG2:

- Macro: 2,2 bps/Hz/cell;
- Micro: 3,7 bps/Hz/cell;
- Pico: 5,2 bps/Hz/cell; and
- Hot spot: 6,6 bps/Hz/cell.

The study suggests that by 2020, IMT services would require at least 200 MHz of spectrum below 1 GHz in China.

4.3 Model Overview

4.3.1 Estimating capacity of WOAN if all spectrum is assigned

For achieving objective 1 (as described in sub-Section 1.1), the methodology follows a set of logical steps that apply well-established principles highlighted in ITU-R M.1768 to convert available spectrum to capacity [3]. The methodology does not use the market study steps highlighted in ITU-R M.1768 [6].

The model makes use of the following inputs:

- Estimated LTE-A cell areas,
- Specific cell spectral efficiencies for LTE-A downlink and uplink,
- Spectrum reuse factor used for LTE-A, which defines the rate at which the same frequency can be used in the network
- Spectrum allocated to each cell,
- Estimated WOAN user population per cell using even distribution of total WOAN users over available cells,
- Downlink activity factor: A measure of the fraction of time a user is actively receiving packets from the base station averaged over a month, and
- Typical traffic distribution for existing 3G networking in the form of hourly usage across the entire network.

The model then produces the following outputs:

- Aggregate capacity available per cell for the uplink and downlink;
- Total available wholesale capacity for the WOAN across the whole country (sum of all aggregate cell capacities); and
- Estimated average and busy hour capacity per user across the whole country for the uplink and downlink.

A detailed mathematical description of the model is provided in Annex D.

High-level steps are provided below :

Step 1: From supplied high site data from each operator, derive the set of sites to use for WOAN using the following method:

- Select operator with largest population coverage as base set.

- For each other operator, add sites that are further than 1 km away[3], that add additional macro cell coverage, from any site in base set to a supplementary set. All sites closer than 1 km to a member of the base set are considered virtual sites[4].
- The final set of WOAN sites is the combination of the base set and supplementary set.

Step 2: Using WOAN high sites, derive estimate site radii using inter-site distances.

Step 3: Classify each site as Macro, Micro or Hotspot using cell areas and ITU M.1768 teledensity classifications [3].

Step 4: Assign spectral efficiencies to each high site using ITU M.2074 spectral efficiency tables [7].

Step 5: From available WOAN spectrum pool shown in Table 3, assign high and low band spectrum to each high site using the following spectral assignment rules:

- Assign high band spectrum to all sites.
- Assign low band spectrum to sites greater than 15 m in height that are not classified as hot-spots or indoor sites.
- Divide WOAN assigned spectrum per site by the spectrum reuse factor.

Step 6: Calculate the amount of downlink capacity available per site by multiplying spectrum available in each band by the spectral efficiencies associated to each site and the number of sectors per site. Sum these downlink capacities.

Step 7: Calculate total capacity available across all sites in the country by summing all individual cell capacities.

Step 8: Using average downlink activity factor and total estimated WOAN users across the country, calculate average capacity per person for the whole country. Using hourly activity factor profiles, calculate busy hour and quiet hour capacity for the whole country.

4.3.2 Determining sufficient amount of spectrum for WOAN

For objective 2, the reverse of this process is followed. The peak and average capacity required per cell are given and, using traffic distributions and population served in a cell, the aggregate capacity required per cell is calculated. Following this, the area spectral efficiency and cell areas are used to calculate the low and high band WOAN spectrum required per cell. The total low and high band spectrum required across the country is calculated and the average required per cell is calculated by dividing this quantity by the number of cells. A detailed mathematical model is presented in Annex D. High-level steps are provided here:

Step 1: From supplied high site data provided by each operator, derive the set of sites to use for WOAN using the following method:

- Select operator with largest population coverage as base set.

[3] Sites greater than 1km are considered Macro cells in original ITU definitions (ITU-R M.1035) which add additional coverage.

[4] Virtual sites [4] are a combination of operator sites within a specified radius that are effectively treated as a single site for the purposes of calculating spectrum or capacity requirements. See Annex A.

- For each other operator add sites that are further than 1 km from any site in the base set to a supplementary set. All sites closer than 1 km to the base set are considered virtual sites.
- The final set of WOAN sites is the combination of the base set and supplementary set.

Step 2: Using WOAN high sites, derive estimate site radii using inter-site distances.

Step 3: Classify each site as Macro, Micro or Hotspot using cell areas and ITU M.1768 teledensity classifications.

Step 4: Assign spectral efficiencies to each high site using ITU M.2074 [7]spectral efficiency tables.

Step 5: Assign high and low band classification to each high site using the following spectral assignment rules:

- Assign high band classification to all sites.
- Assign low band classification to sites greater than 15 m in height that are not classified as hotspots or indoor sites.

Step 6: Calculate total downlink capacity required per site using required average downlink capacity, downlink activity factor, and estimated WOAN users serviced per site.

Step 7: Calculate total required spectrum per site by dividing aggregate downlink capacity by associated site spectral efficiency multiplied by the number of sectors per site and multiply result by frequency reuse factor. If low and high band is allowed on site then partition the spectrum equally between the low and high band. If only high band is allowed on site then assign all spectrum to the high band.

Step 8: Calculate total low band and high band spectrum across all sites for the country and then calculate average low band and high band spectrum required by dividing the total low and high band spectrum by the number of sites across the country.

5. Executing the model and discussion of results

The parameters shown in Table 2 were used for executing the model.

Table 2: Table of parameters used in the study

Parameter	Value
Average Downlink (DL) activity factor	0,025
Busy hour DL activity factor	0,039
Number of Outdoor sites	Calculated using virtual site definition in Annex A (cannot be revealed due to sensitivity of information)
Number of Indoor sites	Provided by operators (cannot be revealed due to sensitivity of information)
Frequency Reuse Factor	1,5
Spectral efficiency macro	3 (bps/Hz/Cell)
Spectral efficiency micro	4 (bps/Hz/Cell)
Spectral efficiency indoor hotspot	7,5 (bps/Hz/Cell)
Number of sectors	3
Number of potential mobile users in 2020	51 238 073
Percentage of potential mobile users served by WOAN	Varies between 20% and 80%

The average downlink activity factor of 0,025 (2,5%) was chosen based on a potential average usage of 1 GB per month for a user in 2020 using Cisco predictions [8].

The busy and quiet hour traffic were calculated from a combination of the download activity factor and hourly traffic profiles provided by the operators.

The frequency reuse factor can approach 1 using fractional frequency reuse techniques such as Soft Frequency Reuse (SFR) highlighted in Annex C. We use a frequency reuse factor of 1,5, calculated using Strict Fractional Frequency Reuse (FFR), and a ratio of centre to edge spectrum of 3:1 shown in Annex C. Using strict FFR rather than SFR ensures less probability of cell edge interference and hence improved performance at the cell edge. The selection of a frequency reuse factor of 1,5 is also based on an upper conservative estimate from vendors. More modern Inter-cell Interference Coordination (ICIC) schemes, such as Extended ICIC (eICIC) and Further Extended (feICIC), make use of a time domain solution and also achieve a frequency reuse factor of 1 similar to SFR. However, these schemes do not guarantee a collision free environment for control packets at the cell edge and also rely on phones that support this feature.

The cell spectral efficiencies for macro, micro and indoor hotspots were chosen based on ITU recommendations provided in ITU-R M.2074 [7]. The ITU recommendations provide cell spectral efficiency ranges for each class of site and we chose the mid-point of these ranges - a slightly less conservative estimate than those used for the China IMT 2020 study [4]. A detailed description of spectral efficiency is provided in Annex B.

South Africa's 2016 mid-year population is approximately 55 908 865 and is projected to reach 59 620 750 by mid-year 2020 at 1,62% year-on-year growth if we assume population growth remains at current growth rates[5]. The potential for South Africa's population above the age of six that could be using mobile broadband in 2020 is estimated to be 85,94% or 51 238 073 users[5]. As indicated in section 1.2 above, the high and low band WOAN spectrum used by this study is provided in Table 1. In this study we determine the downlink capacity if all spectrum considered is assigned to WOAN. We further determine the amount of downlink spectrum for WOAN to meet the SA connect targets. The amount of spectrum used in the study is 145 MHz. Table 3 shows the detailed available spectrum.

Table 3: Amount of downlink spectrum used in the study

Band	Amount of downlink spectrum	Comment
High band – 90MHz	2600 FDD – 70MHz 2600 TDD – 20MHz	FDD specifies equal amount of spectrum for downlink and uplink. We assume 4:1 downlink-to-uplink configuration for TDD spectrum.
Low band – 55MHz	800 – 25MHz 700 – 30MHz	FDD specifies equal amount of spectrum for downlink and uplink.

This spectrum arrangement follows the IMT roadmap published by ICASA in 2014 [11].

5.1 Objective 1: Estimate capacity of the WOAN

5.1.1 Total supply side capacity

Total supply side capacity is calculated for each spectrum band and for all the spectrum bands combined. The results are shown in Figure 2 for all sites, and only outdoor sites. This result reflects the aggregate capacity that is shared amongst all users of the WOAN.

[5] Statistics South Africa, Mid-year population estimates 2016, Statistical Release P0302, 25 August 2016 (https://www.statssa.gov.za/publications/P0302/P03022016.pdf)

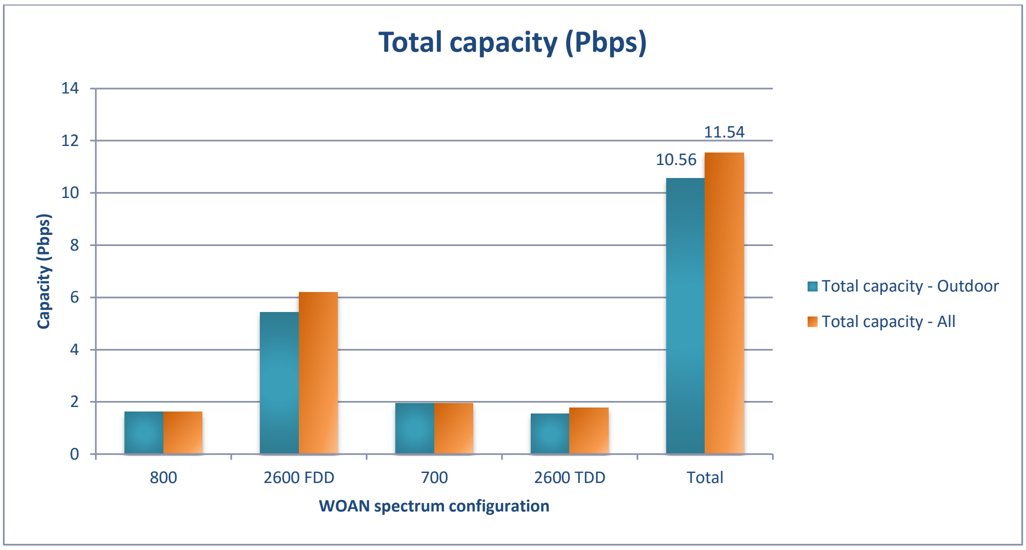

Figure 2: Total WOAN capacity available when using all sites and when only using outdoor sites

The amount of capacity in the individual bands is directly proportional to a combination of the amount of spectrum in those bands and the number of sites with radios using those bands. Due to there being more high than low band spectrum and due to a larger number of sites using the high band than those using the low band (see Section 4.3 Step 5), the quantity of high band (2600 MHz) capacity is significantly greater than the quantity of low band capacity (700 MHz and 800 MHz).

5.1.2 Average capacity per user

We present the average capacity per user in terms of percentage of projected mobile users in 2020 in Figure 3. The actual number of users corresponding to the percentages used in the above graph is as in Table 4.

Table 4: Projected number of mobile data users in 2020

Percentage	10	20	30	40	50	60	70	80	90	100
Number of users ('000)	5 124	10 248	15 371	20 495	25 619	30 743	35 867	40 990	46 114	51 238

Note *– The projected total number of users is based on 2016 projections of the population, the population growth and only considered person aged 7 and above as mobile users. It did not consider the case of any user having multiple SIM cards.*

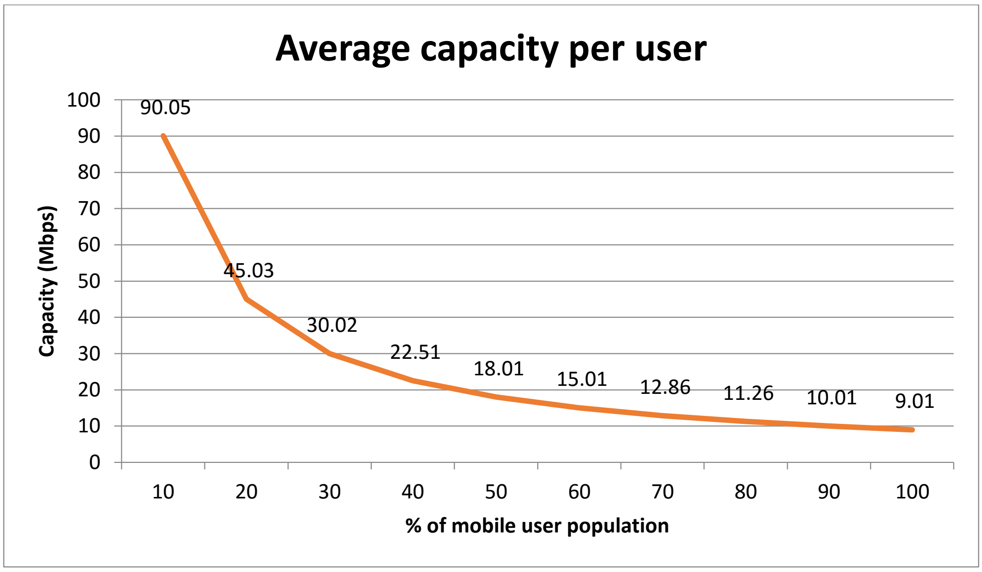

Figure 3: Average capacity per user

***Note** - As indicated in the algorithm presented in the previous section, the average capacity per user is dependent on download activity factor, traffic distribution and number of users served. These results assume equal distribution of traffic across all sites and an average download activity factor; we then varied the number of users served and derived average capacity per user.*

The results show that if the entire spectrum under consideration is set aside for WOAN and it served 10% of mobile user population (5 962 075), each user will get an average of 90,05 Mbps. The average speed decreases as the number of people served increases. If WOAN were to serve 100% of mobile user population (59 620 750), each user will get an average of 9,01 Mbps.

The key implication of an assumption of WOAN serving 100% of the mobile users is that all current mobile data customers would have migrated to WOAN by 2020. While the forecasting of the percentage of users to be served by WOAN in 2020 was out of scope of this study, it is clear that it is not possible for WOAN to serve 100% of population with LTE-Advanced.

In the next three sub-sections, we discuss three of the factors that will hinder migration of 100% LTE-Advanced user to WOAN by 2020. Key factors that are discussed here are timeline for rolling out a nationwide network, customer acquisition strategies, and availability of user devices in the bands that are used by WOAN.

5.1.3 Rolling out nationwide network

If we assume the best case where agreements are reached for sharing of existing sites as well as the backhaul network, the rollout of the nationwide network can quickly reach 90% of the population. Figure 4 shows that 90% of population can be reached with 75% of the existing sites. This figure also shows that these sites cover only 10% of the land. The challenge therefore will be to roll out the network to cover the remaining 90% of the land, to cover the remaining 10% of the population. While WOAN would eventually cover 100% of the land, as this is one of its main use cases, it may require either alternative technologies and/or alternative deployment models to drastically reduce the cost. It is unlikely that these alternatives would require as much spectrum as that required to reach the first 90% of the population.

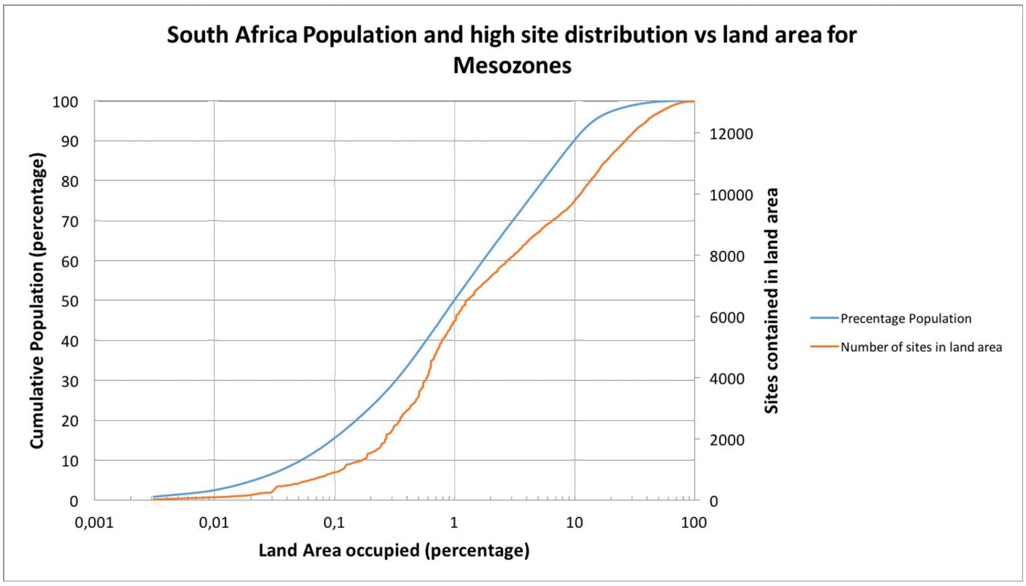

Figure 4: Population and high site distribution vs land area

5.1.3.1 Customer acquisition

The incumbent operators are already utilizing a portion of the currently licensed spectrum to provide data services using the latest available LTE Advanced technology. While they have committed to buying 30% of capacity provided by WOAN, it is understood that WOAN capacity will supplement their own capacity where they own the network infrastructure and only completely rely on WOAN where they do not have their own network. As an example Vodacom reported that as of the end of March 2017, it had 78.5% LTE population coverage and 5.1 million 4G customers using re-farmed spectrum [report]. For WOAN to serve 100% of the population implies that these Vodacom customers and customers of all incumbents would migrate to WOAN by 2020.

5.1.3.2 Availability of user devices

Another factor that drives migration of users is the availability of user devices. A July 2017 report by GSA states that up to 62,9% of LTE devices operate in band 3 (1800) spectrum. It further shows that the top three most supported FDD bands are band 3 (1800), band 7 (2600FDD) and band 1 (2100) in that order, and the top three TDD bands are band 40 (2300), band 38 (2600) and band 41 (a variant of 2600 TDD). Table 5 and Table 6 (copied from the GSA 2017 report [12]) show the number of user devices that support each band.

Table 5: LTE FDD user devices - frequency bands supported by the ecosystem

LTE FDD	
1800 MHz band 3	5,426 devices
2600 MHz band 7	5,042 devices
2100 MHz band 1	4,364 devices
800 MHz band 20	3,135 devices
800/1800/2600 tri-band	2,983 devices
850 MHz band 5	2,522 devices
AWS band 4	2,310 devices
900 MHz band 8	2,247 devices
1900 MHz band 2	2,067 devices
700 MHz band 17	1,741 devices
700 MHz band 13	877 devices
APT700 band 28	741 devices
700 MHz band 12	654 devices
1900 MHz band 25	393 devices

Table 6: LTE TDD user devices – frequency bands supported by the ecosystem

LTE TDD	
2300 MHz band 40	2,608 devices
2600 MHz band 38	2,065 devices
2600 MHz band 41	1,886 devices
1900 MHz band 39	1,558 devices
3500 MHz band 42	130 devices
3600 MHz band 43	98 devices

The incumbents have already deployed LTE Advanced in two of the top three FDD bands and in the top TDD band, all of which would not be available to WOAN. The most supported bands also imply that most affordable devices would be in those bands. For WOAN to serve 100% of users, it implies that all users would have devices in the bands that WOAN would be operating in.

5.2 Objective 2: Spectrum required to meet SA Connect targets

In order to calculate the required spectrum to meet SA Connect targets for 2020 (5 Mbps downlink) and 2030 (10 Mbps downlink) we follow the process highlighted in Section 4.3. The amount of spectrum required is sensitive to a number of factors:

- Total number of sites available to use;
- Number of sectors used;
- Spectrum efficiency of technology used (both for the base station and the user device);
- Spectrum reuse factor; and
- Percentage of WOAN users.

For the purposes of this study we keep a number of parameters fixed at the values specified in Table 2. The results are shown for different targets of percentage of mobile broadband population using mid-ITU spectral efficiency values. The model produces the total average spectrum required per site.

In this model, high band spectrum is allocated to all sites and low band is only allocated to sites greater than 15 m in height or not classified as hot-spots or indoor sites. The sites that only have high band spectrum require double the high band spectrum than the high band spectrum allocated to a dual high and low band site for the same capacity requirement. This is due to the high band needing to carry all the capacity of the site in high-band-only sites.

For this model there were more sites allocated for high band spectrum than for low band spectrum. This results in the total average high band spectrum required per site being slightly higher than the average low band spectrum required. In scenarios where more spectrum is required than the sum of the low and high band spectrum combined, additional spectrum is only sourced from the high band and the low band is locked at the maximum available (55 MHz downlink spectrum).

We believe that any LTE spectrum assignment below 5 MHz will not result in efficient utilization, we therefore rounded up all the results to the nearest 5 MHz. Operators typically use the busy hour capacity to dimension their network. We use this to ensure that there the network can still deliver at least 5 Mbps (2020 target) during the busy hour. In order to ensure the network is future proof we also ensure that at least 10 Mbps average capacity (2030 target) is possible.

5.2.1 Summary of results

There is a direct relationship between the number of users to be served and the amount of spectrum required. The amount of spectrum required for different percentages of users between 20% and 80% is summarised in Table 7. The required spectrum for each population target is rounded up to the nearest 5MHz. This results in slight variation in the spectrum vs population increase ratio for different population percentages.

Table 7: Downlink spectrum for varying percentage of users

WOAN users (%)	Number of Users ('000)	Downlink spectrum required (MHz)
20%	10 248	**40**
30%	15 371	**55**
40%	20 495	**70**
50%	25 619	**85**
60%	30 742	**105**
70%	35 867	**120**
80%	40 990	**135**

The downlink spectrum in Table 7 is the total required, thus it includes both low band and high band spectrum. The study did not derive a strict formula to split this total downlink spectrum required into low and high band spectrum, an assumption was therefore made that only sites that are higher than 15m will use low band for coverage. As a result, the total average high band spectrum required per site is slightly higher than the average low band spectrum. An example of the output from the model for a baseline case of 20% of the mobile population (or 10 247 615 users) is presented in Table 8 and Table 9. Table 9 shows the total required spectrum rounded up to 5 MHz.

Table 8: WOAN Spectrum required for average and busy hour for SA Connect targets (20% population)

Target rate	Ideal Low band spectrum required (MHz)	Ideal High band spectrum required (MHz)	Total spectrum required (MHz)

5 Mbps (average)	7,87	8,87	16,74
5 Mbps (busy hour)	12,43	13,81	26,24
10 Mbps (average)	15,74	17,74	33,48

Table 9: Spectrum required for WOAN rounded up to 5MHz (20% population)

Target rate	**Ideal Low band spectrum required (MHz)**	**Ideal High band spectrum required (MHz)**	**Total spectrum required (MHz)**
5 Mbps (average)	10	10	20
5 Mbps (busy hour)	15	15	30
10 Mbps (average)	20	20	40

Similar tables for any percentage of user population can be produced on request.

6. Recommendations

In line with discussion presented in section 5.1, it is recommended that the department consider setting aside only a portion of spectrum in these bands for WOAN and the remaining to other licensees.

The next recommendation focuses on the amount of spectrum required by WOAN to meet the SA connects targets, based on the baseline assumptions as stated in section 5.2. The recommendations based on the results of the model are therefore sensitive to those parameters that were beyond the scope of the study to verify. In section 5.2, we presented the results that show sensitivity to percentage of users served by WOAN. The projection of the actual number of users that would be served by WOAN in 2020 was beyond the scope of this study; we can therefore recommend a minimum percentage of users to consider based on prior studies. A study by Roland Burger [13] reveals that operators that fail to achieve 10-15% market share often struggle to secure EBITDA margins of around 20%, which are typically needed to cover CAPEX investments, interest payments, and tax. Our recommendation is therefore to consider a minimum of 20% of user population to ensure viability of WOAN.

A third recommendation is that sufficient downlink spectrum in band 20 be set aside for WOAN to lower the cost of deploying the network in rural areas while still delivering sufficient speeds. Band 20 is preferred to band 28 due to it being supported by higher number of devices. In order to afford high-end users of WOAN the benefit of higher broadband speeds through the carrier aggregation feature of LTE advanced, it is further recommended that sufficient spectrum from both band 7 and band 38 be set aside for WOAN. The most dominant chip manufacturer for high-end devices supports the carrier aggregation of these three bands. The following spectrum combinations should be considered as the minimum:

- 2 x 25 MHz of 800 band (Band 20);
- 2 x 20 MHz of 2600 FDD band (Band 7); and
- 25 MHz of 2600 TDD band (Band 38).

With the downlink-to-uplink ratio of 8:2 split for unpaired Band 38, this would lead to 65 MHz of downlink spectrum for WOAN.

A fourth recommendation is that a detailed market study be undertaken to forecast the market size of WOAN beyond 2020 and up to 2030. This will enable the department to take early decision on the licensing of spectrum for 5G.

A fifth recommendation is experimentation with different spectrum assignment combinations for new mobile broadband spectrum bands to ensure that the emerging broadband needs are catered for and that new technologies, such as 5G are adopted as early as possible. This would include recalculation of WOAN spectrum needs beyond the year 2020 or at any point when the key assumptions change.

A sixth recommendation is a technical study to determine spectral efficiency at five-year intervals as the technology improves.

In addition to these recommendations that are directly related to this study, the department needs to consider supporting studies that investigate the deployment models and alternative technologies to cover the 10% of population living in 90% of the land as depicted in Figure 4. LTE-Advanced technology, as is the case with the previous generation of 3G and LTE, is well suited to serve densely populated areas.

Reference Documents and URLs

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-- End of Report –

Annex A Virtual site definition

Figure 5: Virtual site illustration

The concept of a virtual site, as illustrated in Figure 5, was used in the IMT-2020 China report [4] to make the estimation of the number of sites more manageable when the goal is to determine total capacity, despite different operators having different sites, often very close to one another. A virtual site is a logical abstraction for a site that has the traffic of the combined traffic of different base sites within a chosen radius. In this study the chosen radius to a base site within which other operator's sites are combined into a combined virtual site is 1 km. Figure 5 illustrates base sites as blue dots and other operator's sites as red dots. When the distance between a base site and another site no in the base set is less than a km these are combined into one virtual site, as illustrated with blue rings in the figure.

Annex B Spectral efficiency

Spectral efficiency, measured in bits per second per Hertz (bps/Hz) is a measure of the useful data available in a given amount of spectrum. However, this definition does not capture the nuances of the various ways this can be implemented and calculated. Spectral efficiency can be defined as a maximum possible or average value. It is dependent on the modulation scheme in use, which is in turn dependent on the perceived SINR. The physical and higher layer protocols that employ channel coding (such as Forward Error Correction) and all other non-payload overhead all degrade the spectral efficiency. Complex simulations are often required to determine average spectral efficiency that users can expect to experience [9].

Area spectral efficiency is defined as the average user rate/unit bandwidth/unit area (bps/Hz/km^2). while cell spectral efficiency is a related term for the average efficiency over a cell. The ITU-R M.2074 (2006) recommendations calculated areas spectral efficiencies for four classes of cells, macro-, micro-, pico-cells and hot spot [7], while in the study of Spectrum Requirements for China in 2020 [4], slightly different values were used. Bearing this in mind, the values used for this WOAN study are given in Table 10, compared to the aforementioned sources. Cell spectral efficiency values as per tests described in ITU-R Report M.2134 are given in Table 11.

Table 10: Spectral efficiency of different cell-types in bps/Hz/cell

Cell type	*Value used for WOAN study*	*ITU M.2074 range set for RAT2*	*IMT-2020 China report*
macro	3	2-4	2,2
micro	4	2-6	3,7
pico	4,5	3-6	5,2
hotspot	7,5	5-10	6,6

Table 11: Cell spectral efficiency values according to ITU-R M.2134

Environment	*Downlink*	*Uplink*
Indoor 4X2 MIMO	3	2,25
Microcellular 4X2 MIMO	2,6	1,8
Macro urban 4X2 MIMO	2,2	1,4
High speed 4X2 MIMO	1,1	0,7

In reality, the spectral efficiency relies on a large number of factors, so that users at different places or at different times within a cell experience very different spectral efficiencies. One of these is the modulation and coding scheme employed, which in turn is chosen according to the perceived SINR, and influenced by the number of antennas and MIMO technique employed. The most obvious influence is the distance of a user from the base station. Within a certain “dead zone” radius the power received by users will be very low. Beyond this region the received power and thus the spectral efficiency (in the absence of noise) starts at a peak and drops off according to path loss equations. Additionally, users at increasing distances from the base station may experience more interference from neighbouring base stations, which further reduce the received SINR and thus the channel quality and spectral efficiency. For cell spectral efficiency, however, we average out these effects over the users in a cell.

Annex C Frequency reuse factor

There are two common Fractional Frequency Reuse (FFR) deployment modes: Strict FFR and Soft Frequency Reuse (SFR) [10]. While FFR can be considered in the uplink or downlink, we focuses on the downlink since it typically supports links with greater rate requirements with a low margin for interference and additionally we can, unlike the uplink, neglect power control by assuming equal power downlinks.

Strict FFR

Strict FFR is a modification of the traditional frequency reuse used extensively in multi-cell networks. Figure 6 illustrates Strict FFR for a hexagonal grid modelled deployment with a cell-edge reuse factor of RF=3. Users in each cell-interior are allocated a common sub-band of frequencies while cell-edge users' bandwidth is partitioned across cells based on a reuse factor of RF. In total, Strict FFR thus requires a total of RF + 1 sub-band. Interior users do not share any spectrum with exterior users, which reduces interference for both interior users and cell-edge users.

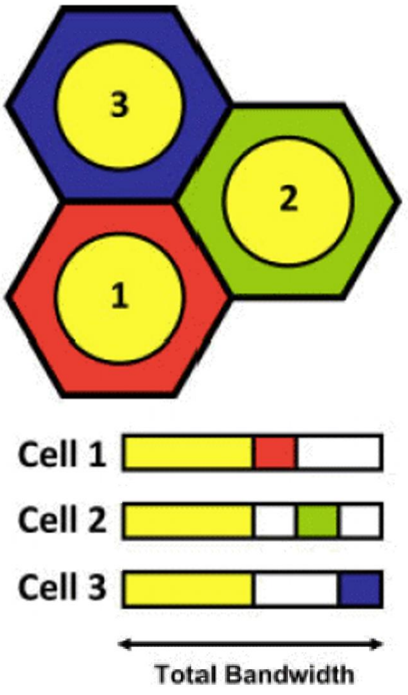

Figure 6: Strict Fractional Frequency Reuse (FFR)

Soft Frequency Reuse (SFR)

Figure 7 illustrates a SFR deployment with a reuse factor of RF = 3 on the cell-edge. SFR employs the same cell-edge bandwidth partitioning strategy as Strict FFR, but the interior users are allowed to share sub-bands with edge users in other cells. Because cell-interior users share the bandwidth with neighbouring cells, they typically transmit at lower power levels than the cell-edge users. While SFR is more bandwidth efficient than Strict FFR, it results in more interference to both cell-interior and edge users.

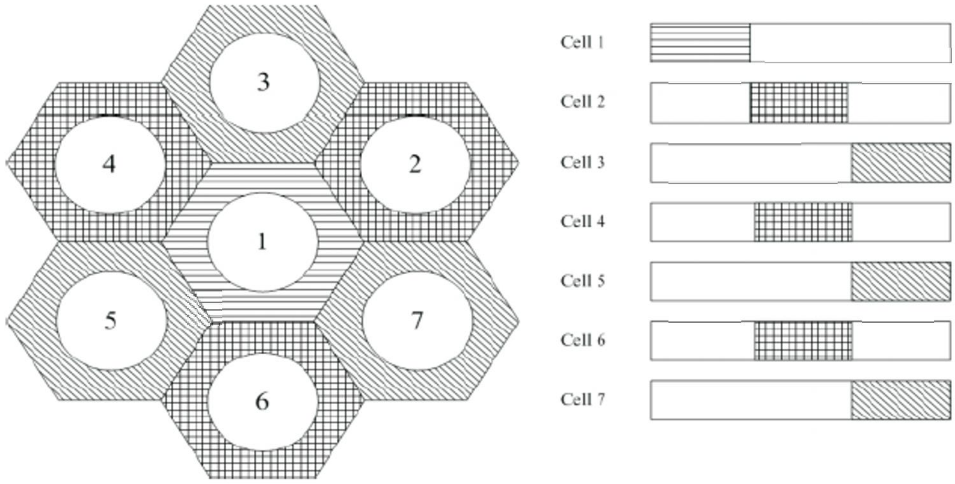

Figure 7: Soft Frequency Reuse (SFR)

Calculations of Frequency reuse factor for strict FFR

Calculations are carried out for strict FFR for different proportions of spectrum allocated to the central portion of the cell interior and the cell edge shown in Figure 8 . When the ratio of central to edge spectrum is 3:1, the frequency reuse factor is 1/(1/2+1/6) = 1,5. When the ratio of central to edge spectrum is 6:1, the frequency reuse factor is 1/(2/3+1/9) = 1,3. A 3:1 ratio of central to edge spectrum corresponding to a frequency reuse factor of 1.5 is commonly used as it provides good interference protection at the cell edge and is used in this study.

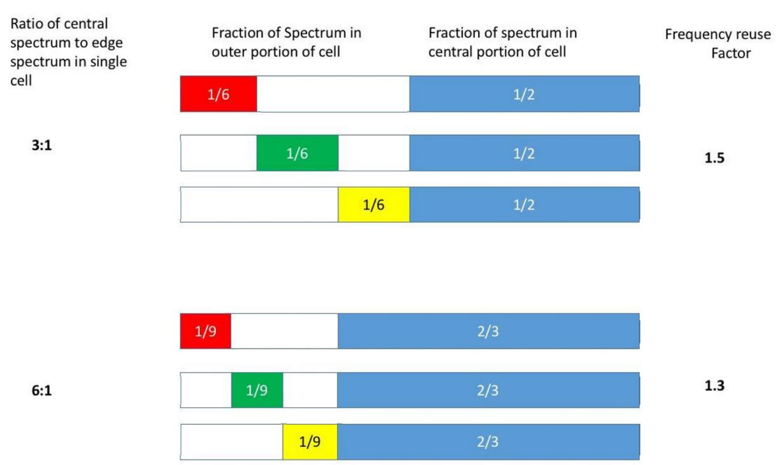

Figure 8: Different ratios of central to edge spectrum for strict FFR

Annex D Mathematical description of model

List of Symbols

γ	Frequency Reuse Factor
B	Total bandwidth allocated to a cell in Hz
$F_i = \{F_{i,1}, F_{i,2}, \dots, F_{i,n}\}$	Centre frequencies in MHz used in cell i
$W_i = \{W_{i,1}, W_{i,2}, \dots, W_{i,n}\}$	Channel widths in MHz used in cell i
$DIR \in \{D, U\}$	Direction of link
D	Downlink
δ_D	Fraction of TDD spectrum to use for downlink
U	Uplink
$G_i \in \{urban, suburban, rural\}$	Class of site i in terms of environment
$R_i \in \{macro, micro, pico, hot - spot\}$	Type of cell in terms of size
S_i	Number of sectors in the site i
H_i	Height above ground of site i in m
$DUP \in \{FDD, TDD\}$	Type of duplexing
FDD	Frequency Division multiplexing
TDD	Time Division multiplexing
N	Number of sites or cells
A_i	Cell area of site i in km^2
L	LTE site
η	Cell spectral efficiency in bps/Hz/cell
C_i	Capacity of cell i in bps
ν	Activity factor
V	Hourly activity factor usage
p_i	Population per WOAN site i
I_W	Proportion of population using WOAN network

Objective 1: Determining capacity

Step 1. The process of determining the number of WOAN sites to use for the calculation is illustrated in Figure 9. It starts with a list of existing LTE-A base station sites.

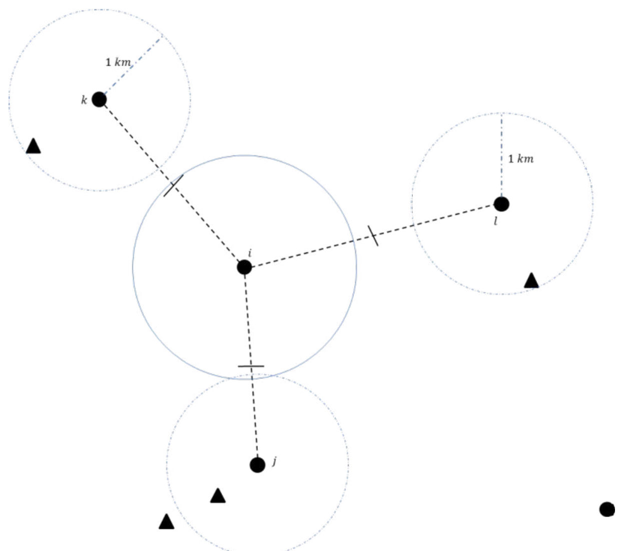

Figure 9: Illustration of site area estimation method

a. The sites of the operator with the largest population coverage form the base set of WOAN sites L_{base}, represented by black circles in Figure 9. Then, consider the sites of all other operators $j \in L_{\backslash base}$ (illustrated with triangles in Figure 9) and add these sites to a supplementary set L_{sup} if the distance from j to the closest site belonging to the base set ($i \in L_{base}$) is great than 1 km. If the distance is within 1 km, combine the capacities of the closest neighbour base site i with that of the considered non-base site j to create a new virtual site v located at $|i|$ with the combined capacity of sites i and j, i.e.

$$\forall \text{ sites } j \notin L_{base}:$$

$$\begin{cases} \text{if } \||j| - |i|\| > 1\ km \implies L'_{sup} = \{j\} \cup L_{sup} \\ \text{if } \||j| - |i|\| \leq 1\ km \implies L'_{base} = \left(L_{base\backslash\{i\}}\right) \cup \{v\} :\ C(v) \triangleq C(j) + C(i) \end{cases}$$

where we denote the physical coordinates of a site as $|\cdot|$ and use $\|\cdot\|$ to indicate distance.

b. $L_{WOAN} = L'_{base} \cup L'_{sup}$

Step 2. To determine WOAN site radii, we identify the closest 3 neighbours to each site, and find the distance between the site i considered and each of the 3 closest neighbour sites $\||j| - |i|\|$. The radius of the cell covered by the site i is $r_i = \frac{\||j|-|i|\| + \||k|-|i|\| + \||l|-|i|\|}{6}$.

Step 3. To classify sites, use radii to determine the area: $A_i = \pi {r_i}^2$. Then, use these with teledensity values to assign cell type $i \longleftrightarrow R_i\ \forall\ i \in L_{WOAN}$.

Step 4. Area spectral efficiencies will make use of ITU recommended area spectral efficiency η_R [bps/Hz/cell] for 4 classes of cells: Macro, Micro, Pico and hot-spot, represented by R. Uplink and downlink spectral efficiency is treated as the same.

- Macro: $\eta_{macro} = [2,4]$.
- Micro: $\eta_{micro} = [2,5]$.
- Pico: $\eta_{pico} = [3,6]$.
- Hot-spot: $\eta_{hot-spot} = [5,10]$.

Assign spectral efficiencies to each site according to tabulated η_R such that

$$\eta_i = \begin{cases} \eta_{macro} \text{ iff } R_i = macro \\ \eta_{micro} \text{ iff } R_i = micro \\ \eta_{pico} \text{ iff } R_i = pico \\ \eta_{hot-spot} \text{ iff } R_i = hot-spot \end{cases}$$

Step 5. Spectrum will be allocated to each cell using a frequency reuse factor γ. The WOAN will exclusively use FDD duplexing for LTE-A in the 700 MHz and 800 MHz bands and FDD and TDD in the 2600 MHz band. FDD spectrum will be divided into **equal** downstream and upstream spectrum pairs. TDD spectrum can dynamically apportion spectrum to downlink or uplink. The amount of spectrum available per RATG serving cell i will be:

$$B_{DIR,F,DUP}(i) = \frac{B(raw)_{DIR,F,DUP}}{\gamma} \qquad (1)$$

where

$$DIR \in \{D, U\}$$

$$F \in \{700, 800, 2600\}\ MHz$$

$$DUP \in \{FDD, TDD\} \text{ iff } F = 2600\ MHz$$

given a pool of available downstream WOAN spectrum:

$$\{B_{D,700,FDD}(raw), B_{D,800,FDD}(raw), B_{D,2600,FDD}(raw), B_{D,2600,TDD}(raw)\}$$

and available upstream WOAN spectrum:

$$\{B_{U,700,FDD}(raw), B_{U,800,FDD}(raw), B_{U,2600,FDD}(raw), B_{U,2600,TDD}(raw)\}$$

where

$$B_{D,2600,TDD}(raw) = \delta_D \cdot B_{2600,TDD}(raw)$$

and

$$B_{U,2600,TDD}(raw) = (1 - \delta_D) \cdot B_{2600,TDD}(raw).$$

δ_D represents the fraction of TDD bandwidth assigned to the downlink.

For each given LTE-A high site L_i, assign WOAN LTE-A spectrum tuple $\langle F_i, W_i, DUP_i, S_i, G_i, R_i \rangle$ $\forall\ i \in \{1,2, \ldots, N\} \subset \mathbb{N}$ from available spectrum: $F_{D,700,FDD}$, $F_{D,800,FDD}$, $F_{D,2600,FDD}$ or $F_{D,2600,TDD}$ so that $L_i \rightarrow \langle F_i, W_i, DUP_i, S_i, G_i, R_i \rangle$ for N LTE high sites, where

F_i represents a set of n downlink frequencies (in MHz), i.e. $F_i = \{F_{i,1} F_{i,2} \ldots F_{i,n}\}$, in use in cell i, in the case of using *FDD* or the centre frequency of the band in the case of *TDD*,

W_i represents a set of n assigned downlink channel widths $\{W_{i,1} W_{i,2} \ldots W_{i,n}\}$ (in MHz),

S_i represents the number of sectors used per frequency band,

G_i represents the type of cell in terms of environment: $G_i \in \{urban, suburban, rural\}$,

R_i represents the class of cell: $R_i \in \{macro, micro, pico, hot-spot\}$.

The 700 MHz and 800 MHz FDD bands will be referred to as the low bands and the 2600 MHz FDD and TDD bands will be referred to as the high bands.

Bands and sectors will be allocated based on the following method:

a. All sites are allocated high band spectrum.

b. If site height is greater than 15 m ($H_i > 15$) and site class is not hotspot ($R_i \neq$ *hot-spot*) $\Longrightarrow$ assign low band spectrum to site.

c. Configure the number of WOAN LTE-A sectors (S_i) according to: assign 3 sectors per LTE-A site for each frequency band n, $S_{i,n} = 3$.

Step 6. Calculate potential WOAN capacity using all assigned WOAN capacity.

a. Calculate aggregate FDD downlink capacity for cell i ($C_{i,D}$) using equation (2) below and uplink capacity ($C_{i,U}$) using equation (3), for all high sites with coverage area $\mathrm{A_i}$:

$$C_{i,D} = \eta_{R_i} \cdot \sum_{j=1}^{n} S_{i,j} W_{i,j} \text{ [Mbps]} \tag{2}$$

where R_i is the cell size class as defined in Step 2 above, $S_{i,j}$ is the number of sectors and $W_{i,j}$ is downlink channel width.

$$C_{i,U} = \eta_{R_i} \sum_{j=1}^{n} S_{i,j} W_{i,j,FDD} + \eta_{R_i} \frac{1-\delta_D}{\delta_D} S_{i,j} W_{i,j,TDD} \text{[Mbps]} \tag{3}$$

Step 7. Calculate total downlink and uplink capacity for the country's N LTE-A high sites using equations (4) and (5).

$$C_{T,D} = \sum_{i=1}^{N} C_{i,D} \text{ [Mbps]} \tag{4}$$

$$C_{T,U} = \sum_{i=1}^{N} C_{i,U} \text{ [Mbps]} \tag{5}$$

Step 8. Calculate average capacity per person for the whole country and calculate busy hour and quiet hour capacity for the whole country

a. Using GIS tool overlay cell areas on population data and, assuming even population distribution, estimate population per high site (p).

b. Calculate predicted average, minimum and peak capacity per user at each high site and aggregate average, minimum and peak capacity over entire WOAN for downlink using:

- Downlink activity factor $\nu_{D,G}$ where $G \in \{urban, suburban, rural\}$
- Average downlink activity factor ν_D

- Traffic model for urban, suburban and rural areas showing hourly activity factor usage (derived from 3G data usage profile from operators), denoted $V_{t,G} \in \mathbb{R}$, with

$$t \in \{1, 2, \ldots, 24\}: t \in \mathbb{N}$$

and

$$\frac{\sum_{t=1}^{24} V_{t,G}}{24} \triangleq \nu_{D,G}$$

The average traffic usage across all classes, showing activity factor usage per hour is V_t, as defined in equation (6) where N_G is the total number of sites of type G, totalling to N sites altogether

$$V_t = \frac{N_{G(1)} \times V_{t,G(1)} + N_{G(2)} \times V_{t,G(2)} + N_{G(3)} \times V_{t,G(3)}}{N} \qquad (6)$$

The maximum and minimum traffic per site type are given by equations (7) and (8)

$$V_{t(max),G_i} = max\left(V_{1,G_i}, V_{2,G_i}, \ldots, V_{24,G_i}\right) \qquad (7)$$

$$V_{t(min),G_i} = min\left(V_{1,G_i}, V_{2,G_i}, \ldots, V_{24,G_i}\right) \qquad (8)$$

and the maximum and minimum traffic across all cell classes are given by equations (9) and (10)

$$V_{t(max)} = max(V_1, V_2, \ldots, V_{24}) \qquad (9)$$

$$V_{t(min)} = min(V_1, V_2, \ldots, V_{24}) \qquad (10)$$

- WOAN population per high site (p_i)
- Proportion of population using WOAN network (I_W)
- Total South African population (p_{total})

The average user capacity per high site i, $C_{i,D}(avg)$, is given by equation (11)

$$C_{i,D}(avg) = \frac{C_{i,D} \cdot \nu_{D,G_i}}{I_W \cdot p_i} \qquad (11)$$

$C_{i,D}(min)$ is the busy hour user capacity per high site i (equation 12) while $C_{i,D}(max)$ is the quiet hour capacity per high site i (equation (13))

$$C_{i,D}(min) = \frac{C_{i,D} V_{t(max),G_i}}{I_W \cdot p_i}; \qquad (12)$$

$$C_{i,D}(max) = \frac{C_{i,D} \cdot V_{t(min),G_i}}{I_W \cdot p_i}; \qquad (13)$$

$C_{T,D}(avg)$ (equation (14)), $C_{T,D}(min)$ (equation (15)) and $C_{T,D}(max)$ (equation (16)) give the average, busy hour and quiet hour capacity available to users across the whole country respectively

$$C_{T,D}(avg) = \frac{C_{T,D} \cdot \nu_D}{I_W \cdot p_{total}} \qquad (14)$$

$$C_{T,D}(min) = \frac{C_{i,D} \cdot V_{t(max)}}{I_W \cdot p_i}; \quad (15)$$

$$C_{T,D}(max) = \frac{C_{i,D} \cdot V_{t(min)}}{I_W \cdot p_i}; \quad (16)$$

Objective 2: Determining spectrum requirements.

How much WOAN spectrum is required, given SA Connect average downlink targets $C_{SAC,D}(avg)$ and SA Connect average uplink targets $C_{SAC,U}(avg)$ and minimum capacity rates for busy hour for the downlink $C_{SAC,D}(min)$, and for the uplink $C_{SAC,U}(min)$.

Follow steps 1 to 5 from Objective 1 apart from channel width assignments. In final part of step 5, assign WOAN spectrum assignment tuples $\langle F_i, D_i, S_i, G_i, R_i \rangle$ per LTE-A high site L_i from 700 MHz FDD, 800 MHz FDD and 2600 MHz FDD and 2600 MHz TDD sets.

Step 6. Calculate required aggregate downlink and uplink capacity per high site using hourly traffic model and estimated population per cell i (p_i) , where I_W is the average proportion of high site population using the cell and using the average traffic model showing activity factor usage per hour, denoted V_t, as described in 5(d).

Equations (17) and (18) are the average downlink and upload WOAN capacity required per cell given SA Connect targets

$$C_{i,D}(avg) = C_{SAC,D}(avg) \cdot I_W \cdot \frac{p_i}{v_{D,G_i}} \quad (17)$$

$$C_{i,U}(avg) = C_{SAC,U}(avg) \cdot I_W \cdot \frac{p_i}{v_{U,G_i}} \quad (18)$$

Step 7. Calculate the average WOAN spectrum required per high site for downlink and uplink, as shown in equations (19) and (20). Assume equal assignment of spectrum across available bands on site.

$$W_{i,j,D} = \gamma \cdot \frac{C_{i,D}(avg)}{\sum_{j=1}^{n} \eta_{R_i} \cdot S_{i,j} \cdot 10^6} \text{ [MHz]} \quad (19)$$

$$W_{i,j,U} = \gamma \cdot \frac{C_{i,U}(avg)}{\sum_{j=1}^{n} \eta_{R_i} \cdot S_{i,j} \cdot 10^6} \text{ [MHz]} \quad (20)$$

a. If the calculated WOAN spectrum per cell exceeds maximum available in band, then cap WOAN spectrum at the maximum available. If the WOAN spectrum per cell is less than minimum assignable spectrum per radio $W_{j,D}(min)$ and $W_{j,U}(min)$, then set the WOAN spectrum in the cell to minimum. Assume frequencies are ordered from lowest to highest. *This step assumes that operators do not have to buy national WOAN spectrum but can purchase WOAN spectrum on a set of sites.*

$$W_{i,j,D} = \begin{cases} W_{j,D}(min) \text{ if } W_{i,j,D} < W_{j,D}(min) \\ B_{DIR,FREQ,DUP} \text{ if } W_{i,j,D} > B_{DIR,FREQ,DUP} \end{cases} \quad (21)$$

$$W_{i,j+1,D} = W_{i,j+1,D} + B_{DIR,FREQ,DUP} - W_{i,j,D} \text{ if } j+1 \leq n$$

$$W_{i,j,U} = \begin{cases} W_{j,U}(min) \text{ if } W_{i,j,U} < W_{j,U}(min) \\ B_{DIR,FREQ,DUP} \text{ if } W_{i,j,U} > B_{DIR,FREQ,DUP} \end{cases} \quad (22)$$

$$W_{i,j+1,U} = W_{i,j+1,U} + B_{DIR,F,U} - W_{i,j,U} \text{ if } j+1 \leq n$$

where $DIR = U; FREQ = F_{i,j}; DUP = D_{i,j}$.

Step 8. Calculate fraction of WOAN spectrum required in each band for all cells nationally.

For 700 MHz FDD band (equation (23)), 800 MHz FDD (equation (24)), 2600 MHz FDD downlink band (equation (25)) and 2600 MHz TDD downlink band (equation (26)), the fractions of WOAN spectrum required are calculated.

$$B_{W,D,700,FDD} = \frac{\sum_{i=1}^{N} W_{i,j,D}}{N_{700,FDD} \cdot B_{D,700,FDD}} \quad (23)$$

$$B_{W,D,800,FDD} = \frac{\sum_{i=1}^{N} W_{i,j,D}}{N_{800,FDD} \cdot B_{D,800,FDD}} \quad (24)$$

$$B_{W,D,2600,FDD} = \frac{\sum_{i=1}^{N} W_{i,j,D}}{N_{2600,FDD} \cdot B_{D,2600,FDD}} \quad (25)$$

$$B_{W,D,2600,TDD} = \frac{\sum_{i=1}^{N} W_{i,j,D}}{N_{2600,TDD} \cdot B_{D,2600,TDD}} \quad (26)$$

where $N_{700,FDD}$ is all 700 MHz FDD cells, $\mathrm{N}_{800,\mathrm{FDD}}$ is all 800 MHz FDD cells, $N_{2600,FDD}$ and $N_{2600,TDD}$ are all 2600 MHz FDD and TDD cells respectively.

Carry out similar process for uplink bands.