# COEXISTENCE STUDIES IN THE 6 GHZ BAND (5925 – 7125 MHZ) BETWEEN INCUMBENTS (FIXED SERVICES AND FIXED SATELLITE SERVICES) AND WIRELESS ACCESS SYSTEMS/RADIO LOCAL AREA NETWORKS (WAS/RLANS)

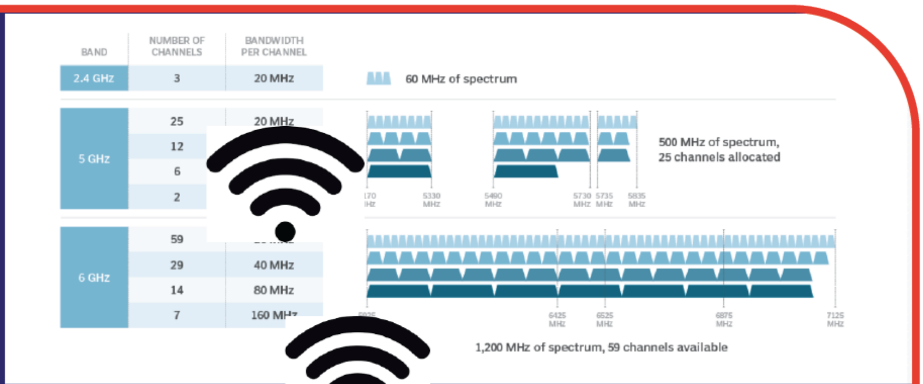
# 2022

Fixed Services(FS) - Microwave Links

Fixed Satellite Services (FSS)

Source: africanews.space

**Incumbents**




Source: techtarget.com

Wi-Fi 6E

**License-exempt Access**

**Kenya**

# EXECUTIVE SUMMARY

Interference analysis is the study of how one or more radio systems can degrade the operation of other users of the radio system. It includes techniques to predict the level of interference and whether that could be tolerated or would represent a serious degradation, otherwise known as **harmful interference.** One of the key questions about interference analysis is what counts as an acceptable level and what would be "harmful interference." A founding principle of the International Telecommunication Union's Radio Regulations is the need for spectrum efficiency, i.e. to use the limited natural resource of the radio spectrum as efficiently as possible. Often the limiting factor on its utilisation is interference and so the need to understand, predict and manage interference is central to spectrum management. Hence, the need for coexistence and compatibility studies.

In this report, we share the coexistence and compatibility studies for license-exempt devices in the 6 GHz Band for Kenya. The 6 GHz band is presently in use by terrestrial and earth-to-space satellite services. While we note the recommendation by the 6 GHz African Telecommunications Union's (ATU's) Task Group on allowing license-exempt access for Wi-Fi in the lower part of the band (5925 – 6425 MHz) first, this report shares findings in the full 6 GHz band (5925 – 7125 MHz). This is because the terrestrial incumbent services (Fixed Services) predominantly operate in the upper part (6425-7125 MHz). Hitherto, we hope that the work presented here provides a benchmark for rapid regulatory decision-making for Kenya as well as regulatory considerations by other countries on the African continent regarding the way forward in enabling spectrum sharing in the 6 GHz band.

The report examines the technical aspects of coexistence between the Fixed Services (FS) and the Fixed Satellite Services (FSS) who are the licensed occupiers of the 6 GHz band and the potential new entrant i.e. Wireless Access Systems/Radio Local Area Networks (WAS/RLANs), hereafter to be referred to as RLANs. RLANs, in this case, are intended to operate in the same band on a secondary opportunistic basis. The technical findings submitted here follow an earlier economic study of designating the 6 GHz band for unlicensed use in Kenya. Hence, while borrowing from other models of study conducted in other regimes such as the European Union (EU), United States of America (USA) as well as Mexico, economic variables have also been considered. Such variables range from market adoption, use cases to population distribution. Consequently, the technical assessment has taken the following into consideration:

- Wi-Fi usage based on the estimated population by 2025.
- Two different types of RLANs – Low Power Indoor (LPI) and Very Low Power (VLP) outdoor.
- Scenarios of urban, sub-urban and rural created by pairing up neighbouring counties based on population, economic activities and height of buildings.

Similar to Europe and Mexico, the studies are based on the Monte Carlo statistical method approach, especially between FS and WAS/RLANs. The method models a victim receiver amongst a population of interferers and provides a spectrally efficient result, subject to careful interpretation. The simulation tool used for this is known as Spectrum Engineering Advanced Monte Carlo Analysis Tool (SEAMCAT). For Kenya, SEAMCAT has been used for both long-term and short-term FS/RLAN scenarios. The FSS and RLANs approach has made use of a mathematical analysis based on Microsoft Excel and comparison analysis.

# TABLE OF CONTENTS

# LIST OF FIGURES

# LIST OF TABLES

# LIST OF ABBREVIATIONS

| | |
|---|---|
| AGL | Above Ground Level |
| AP | Access Point |
| APAC | Asia-Pacific |
| C/I | Carrier to interferer ratio |
| C/(I+N) | Carrier to interferer plus noise ration |
| CEPT | European Conference of Postal and Telecommunications Administration. |
| CSV | Comma Separated Values |
| ECC | Electronic Communications Committee |
| EMEA | Europe, the Middle East and Africa |
| e.i.r.p | Equivalent Isotropically Radiated Power |
| ETSI | European Telecommunications Standards Institute |
| FS | Fixed Services |
| FSS | Fixed-Satellite Service |
| IMT | International Mobile Telecommunications |
| IoT | Internet of Things |
| ITU | International Telecommunication Union |
| LAT | Latitude |
| LON | Longitude |
| LOS | Line of sight |
| NLOS | Non line of sight |
| OoB | Out of band |
| QAM | Quadrature Amplitude Modulation |
| RLAN | Radio Local Area Networks |
| Rx | Receiver |
| SNR | Signal to noise ratio |
| SNIR | Signal to noise plus interferer ratio |
| STA | Wi-Fi Station |
| Tx | Transmitter |
| WAS | Wireless Access Systems |

ACKNOWLEDGEMENT

Strathmore University (SU) in collaboration with the Dynamic Spectrum Alliance (DSA) sincerely thanks the Foreign, Commonwealth and Development Office (FCDO) for the funding provided to conduct this study and the Communications Authority of Kenya (CA) for the immense support provided in terms of data, consultation in regards to spectrum assignment in the 6 GHz band and the incumbent usage of the band. Special thanks go to Dr. Jean-Philippe Kermoal whose experience on SEAMCAT and coexistence studies helped to rapidly get this work completed. We also appreciate various groups of people we reached out to during the study including some of the stakeholders in the Satellite network ecosystem such as Intelsat. The following are the specific names of individuals from the different institutions who actively participated in this study:

**Strathmore University**

Julius Butime

Joseph Sevilla

Vitalis Ozianyi

Kennedy Ronoh

Leonard Mabele

Oscar Onyango

Alois Mbutura

Anthony Onyango

**Dynamic Spectrum Alliance**

Martha Suarez

Trevor Genis

Mark Rotter

Heikki Kokkinen

Jean-Philippe Kermoal

**Communications Authority of Kenya**

Haji Mohamed

Gababo Wako

Dennis Sonoiya

# 1. INTRODUCTION

Wi-Fi has become a necessity in today's world. It has evolved into a fundamental utility, that everyone expects it to be available everywhere irrespective of whether it is a school, hotel, restaurant, office building or a friend's home. Wi-Fi – a wireless local area network technology (WLAN) technology allows devices to connect to the Internet without being tethered by any wires or cables via wireless access points (APs). Hundreds of millions of Wi-Fi APs connect billions of computers, smartphones, smart TVs, game consoles, cameras, printers, Internet of Things (IoT) devices and other consumer devices to the internet to enable millions of applications to reach everyone, everywhere [1]. According to a study by the Wi-Fi Alliance (WFA), Wi-Fi's economic value is expected to grow to $4.9 trillion by 2025 [2].

As one of the greatest success stories of the modern technology, however, Wi-Fi has been able to carry more internet traffic than any other wireless technology with less than 300 MHz of unlicensed spectrum available in the 2.4 GHz and 5 GHz bands [3]. The 2.4 GHz band is crowded and is used by more than just Wi-Fi. Old cordless phones, baby monitors, microwave ovens and Bluetooth devices also use the 2.4 GHz band. To overcome the connectivity issues such as slow and dropped connections in the 2.4 GHz band, countries globally made a decision at the WRC-2003 to open new spectrum in the 5 GHz band which has been revolutionary in addressing the demand caused by the rise of mobile devices as well as new multiple user needs such as through IoT. To sustain the widely projected growth in busy hour Internet traffic, WFA proposes that by 2025, various regions need to find at minimum between 500 MHz and 1 GHz more spectrum than currently available. In addition to simply needing more spectrum in total, WFA suggests sufficient contiguity such that wide channels of 160 MHz (or future 320 MHz) are constructed with ease to eliminate the risk of restricting Wi-Fi growth and the economic benefits that come with it [4].

The advent and developments in the 6 GHz band supported by device manufacturers, chipset vendors, a number of regulators and application providers that rely on license-exempt spectrum is a notable step towards addressing the aforementioned WFA findings. The need for access to the full 1200 MHz spectrum, however, is one that has attracted sensitive consideration, particularly as ITU studies it to determine whether the band is suitable for IMT-2020 (5G) in its upper part [5]. Besides, a priority balance has to be stricken to ensure the incumbent needs of terrestrial and satellite services are protected. The findings we present in this report, demonstrate that coexistence between Wi-Fi 6E and the incumbents in Kenya, while looking at the full 1200 MHz is possible and that the incumbents do not have to be moved out of the band. However, the possibility of designating IMT in the 6 GHz band was not part of the scope of this study. Therefore, ahead of the WRC-2023 decision in regards to IMT, the technical feasibility of introducing low power Wi-Fi devices in the entire 6 GHz band (5925 – 7125 MHz) under a non-protected basis for Kenya is made available here with the aim of exploring availability of more spectrum to increase data capacity and speed.

## 2. 6 GHZ FREQUENCY BAND ALLOCATION AND USE IN KENYA

Table 1 shows an extract of the current Radio Frequency Allocation (RFA) table in Kenya between 5850-7250 MHz as published by the Communications Authority of Kenya (CA). The range of the 6 GHz (5925-7125 MHz) is found within this allocation. The first column shows the allocations in line with nominal designations by ITU [6]. The second column shows the allocation of the services within the band in Kenya. Presently, there are only two main incumbents – Fixed Services and Fixed Satellite services (Earth-to-space, also known as uplink in other studies). According to CA, a Fixed Service (FS) refers to a radiocommunication service between specific fixed points while a Fixed Satellite Service (FSS) refers to a radiocommunication service between *earth stations* at given positions. When one or more satellites are used; the given position may be a specified fixed point within specified areas; in some cases, this service includes satellite-to-satellite links, which may also be operated in the *inter-satellite service* (links between artificial satellites); the fixed satellite service may also include *feeder* links for other space radiocommunication services. The Earth Exploration Satellite Service, on the other hand is between earth stations and one or more space stations, which may include links between space stations, in which:

- Information relating to the characteristics of the earth and its natural phenomena, including data relating to the state of the environment – obtained from active or passive sensors.
- Similar information is collected from airborne or earth-based platforms.

A mobile service is between mobile and land stations or between mobile stations. Within the study, the consideration of the incumbents as advised by CA is based on Point-to-Point (P2P) links of the FS and Earth-to-Space FSS services as shown in the remarks column of Table 1.

**Table 1: Extract of 6 GHz Allocation from the CA's National Table of Frequency Allocation 2020**

| FREQUENCY BAND (MHz) | ALLOCATION TO SERVICES | REMARKS ON ALLOCATED SERVICE(S) |
|---|---|---|
| 5 850 – 7075 | FIXED K171 | Point-point links<br>Channel plan ITU-R F.383 and ITU-R F.384. |
| | FIXED-SATELLITE (Earth-space)<br>K154 K172, K173, K174 K175, | Satellite uplinks - National allotment for FSS uplink. |
| | MOBILE | Mobile |
| | | |
| 7 075 – 7250 | FIXED K171 K176 | Point-to –point fixed links (Channel plan ITU-R F. 385) |
| | MOBILE K176 | Mobile |
| | EARTH EXPLORATION-SATELLITE (Earth-to-space) K176A | Earth exploration satellite services |

# 3. APPROACH TO THE STUDY

This technical study is divided into two parts. The first part examines the coexistence of Fixed Services (FS) and the RLANs. The second part examines the coexistence of Fixed Satellite Services (FSS) and the RLANs. Both parts of the study considered the following:

1. The country's population by 2025: Assessment of coexistence between FS and RLANs, in particular, considered the following counties: Kiambu, Nairobi, Kilifi, Mombasa, Bungoma, Kakamega, Turkana and Marsabit. These counties (based on 2025 population estimates) make up 30% of the population as shown in Figure 1 and were adopted to provide the three scenarios for the study – *urban*, *sub-urban* and *rural* scenarios. For the coexistence between FSS and RLANs, the study considered the 2025 populations of Africa, Europe and the Middle East. The reference documents in this regard include the *2019 Kenya Population and Housing Census (Volume I: Population by County and Sub-County)* [7] and the *United Nations, Department of Economic and Social Affairs: Population Division* [8].
2. The incumbent utilisation of the radio frequency (RF) spectrum and the accompanying parameters such as bandwidth, antenna pattern, noise figure, antenna height and gains. The incumbent RF usage patterns is provided by the CA from where we extract the centre frequencies used in the study.
3. The power considerations for performance of the RLAN devices for both outdoor and indoor deployment in coexistence with the incumbents - based on the existing implementations across various regimes which include APAC, EMEA and Americas [9] and in line with the provisions given by the CA as shown in Table 2. Table 2 is an extract from the CA Guidelines on the Use of Radiofrequency Spectrum by Short Range Devices [10], which is also based on the ATU Recommendations on 6 GHz [11].
4. Sensitivity analyses taking the following into account: RLAN antenna height distribution and building types.
5. A statistical approach based on Monte Carlo analysis for the FS studies using Spectrum Engineering Advanced Analysis Tool (SEAMCAT). The Monte Carlo approach models a victim receiver amongst a population of interferers and can include variations in any number of parameters as statistical distributions so that the results are statistically representative of all the input variable distributions, taking into account the underlying geometry, propagation environment and link budgets. The results of the simulation include the probability that an interference threshold is met (or exceeded) and an output variable's time average [12]. SEAMCAT is an open-source tool developed by the CEPT and also used outside CEPT for statistical simulation of radio spectrum sharing. It allows one to build their own libraries (such as antennas, spectrum masks, propagation models and radio systems) or use those provided by other users to ease the effort to build complete scenarios for investigation [13]. Figure 2 shows an interface of SEAMCAT (version 5.4.2) used for this study.

**Table 2: Extract of the LPI and VLP Wi-Fi 6E Power Consideration**

| FREQUENCY BAND (MHz) | POWER / MAGNETIC FIELD | NOTES |
|---|---|---|
| 5925 – 6425 | 23 dBm (200 mW) mean e.i.r.p. Mean e.i.r.p density for in-band emissions – 10 dBm/MHz | Restricted to Low Power Indoor (LPI) use only Outdoor use (including in road vehicles) not permitted. An LPI access point or bridge is a device that is supplied power from a wired connection, has an integrated antenna and is not battery powered. An LPI client device, on the other hand, is a device that is connected to an LPI access point and may or may not be battery operated. |
| | | |
| 5925 – 6495 | 14 dBm (25 mW) e.i.r.p | Very Low Power (VLP) Indoor and Outdoor use. Use of drones is prohibited. VLP device is portable. |

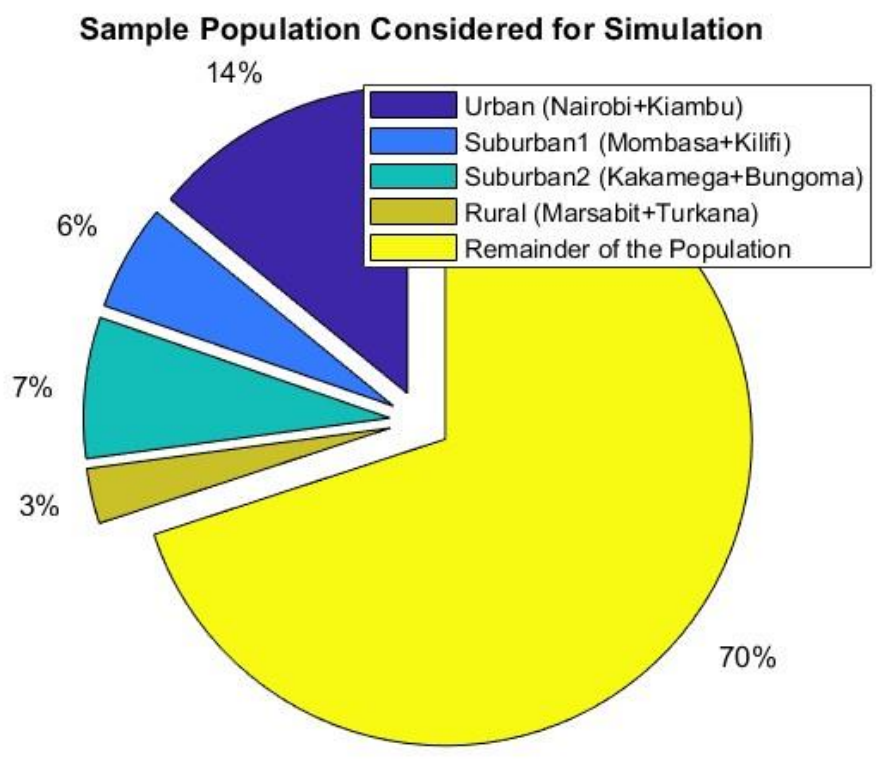



**Figure 1: Percentage of Population by 2025 as considered within the study**

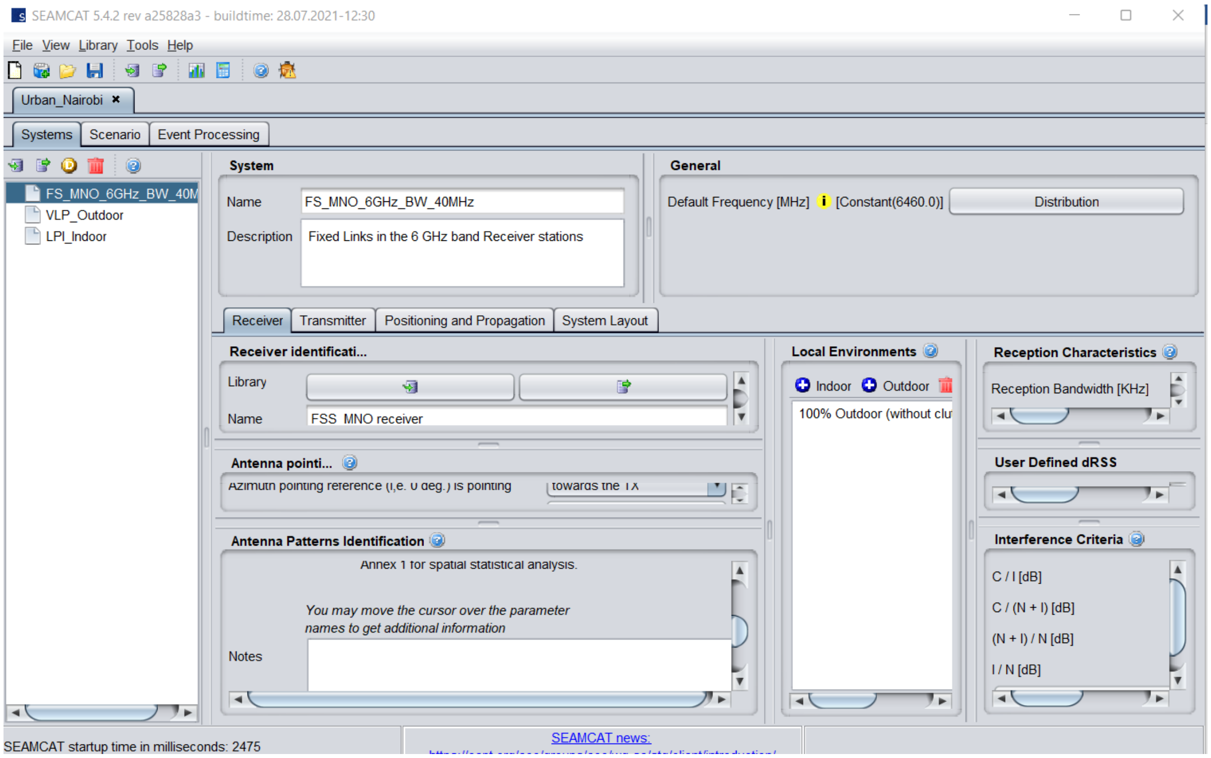



**Figure 2: SEAMCAT Tool Interface - version 5.4.2**

# 4. OVERVIEW OF MONTE CARLO AND SEAMCAT

## 4.1. MONTE-CARLO ANALYSIS

Monte-Carlo method performs calculations on a computer using random numbers and their statistical distributions. The basic idea is to run a number of trials using a mathematical model of the system of interest. For each trial, specific values are selected for various input parameters from appropriate statistical distributions. The values of the output parameters from all the trials are then collected and manipulated to obtain the measures of interest, like the overall average and its variability. For any simulation to be feasible using the Monte-Carlo method, not only must a calculation model exist, but the distribution of its input parameters must also be known [14]. In the context of this study, Monte-Carlo method extends static analysis by changing one of the required inputs (e.g. $u_1$) in each of the categories below to be one of number $m$ of different values in order to provide a set of Xs as output [12]:

$$X[1 \ldots m] = X(u_1[1 \ldots m], u_2 \ldots u_n)$$

- Station locations plus antenna gain and pointing angles.
- Link budget parameters, including transmit powers, bandwidths, polarisations, frequencies, transmit spectrum mask and gain patterns.
- Receiver characteristics including, where necessary, receive spectrum mask, noise temperature and feed loss.
- Propagation environment including models and associated parameters, most importantly the associated percentage of time (if required).

Monte-Carlo analysis can include variations in any number of parameters so that the resulting statistics S[X] are a convolution of all the input variable distributions, taking into account the underlying geometry, propagation environment and link budgets. These statistics could include the probability that a threshold is met (or exceeded) and an output variable's time average.

The Monte-Carlo methodology to analyse radio systems is available on SEAMCAT and other tools such as Visualyse Professional[1]. The use of Monte-Carlo in SEAMCAT within this study has allowed us to reduce the computational problem experienced in static analysis. It has also enabled us to exploit the approach of taking $m$ samples of each input variable to create a histogram and hence Cumulative Distribution Function (CDF) that gives the likelihood of link metric X occurring given the distribution of the input variables. The inverse of the CDF is computed from the outcome of events of the Unwanted Interfering Received Signal Strength (iRSS) shown in Figure 8 and plotted against I/N. iRSS corresponds to the interference level (I) which is calculated as a link budget between the Victim Link Receiver (VLR) and the interfering link transmitter (ILT)

## 4.2. SEAMCAT

[1] Visualyse

SEAMCAT is a software implementation that allows quick yet reliable considerations of spatial distributions of the received signals and the resulting statistical probability of interference in a wide variety of scenarios. By adapting the operational conditions of radio systems with respect to the probability of exceeding the protection criterion, the most efficient use of the radio spectrum can be demonstrated. In this case, the operational conditions of RLANs have been simulated with respect to the probability of exceeding the protection criterion spelt out in ITU-R F.758-7 [15]. The simulation through SEAMCAT allows implementing own libraries or importing the ones developed by other users to ease the effort of building the scenarios to be simulated [13]. The libraries may contain predefined antenna patterns, spectrum emission masks, propagation models etc. While implementing the distributions for Kenya, this study also made use of the library for propagation model previously used in ECC 316. A simulation instance on SEAMCAT is stored as a workspace composed of *Systems*, *Scenarios* and *Event Processing* as described on the SEAMCAT interface shown in Figure 3.

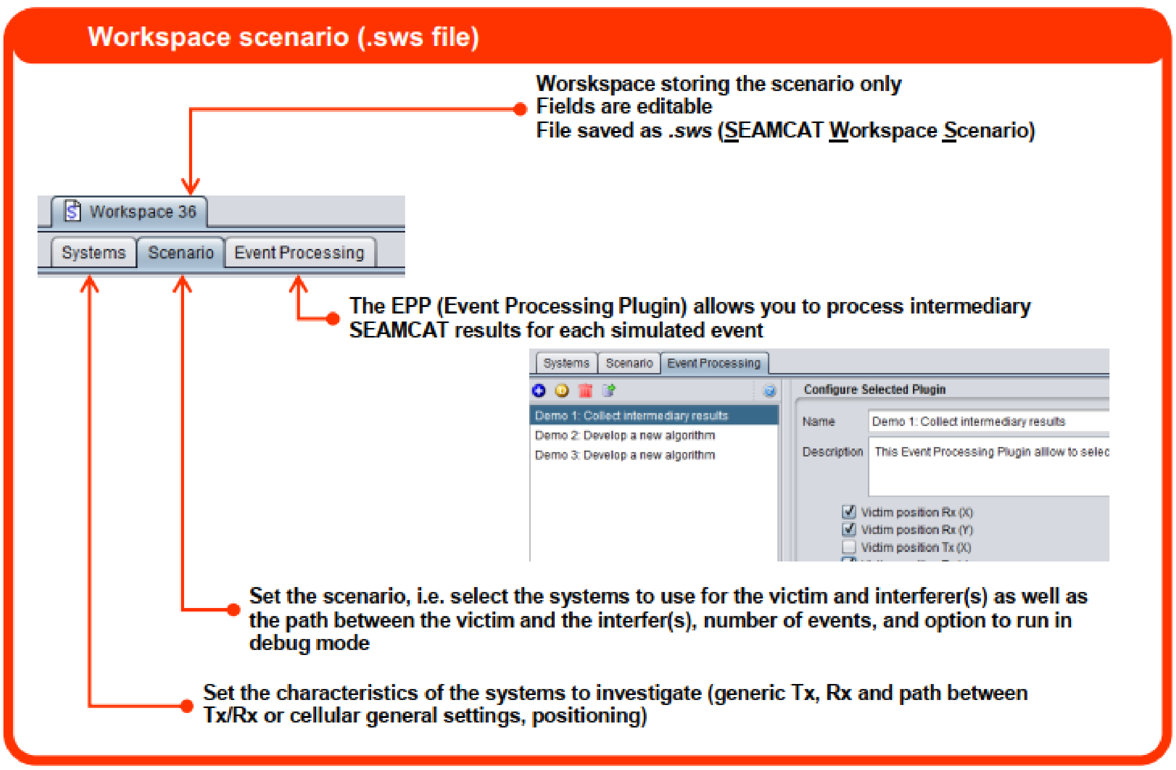



**Figure 3: SEAMCAT interface showing a simulation instance of a Workspace**

Source: SEAMCAT Handbook.

The typical SEAMCAT simulation focuses on a single Victim Link Receiver (VLR) -Victim Link Transmitter (VLT) pair, and one or more interfering transmitters with the interference evaluated at the VLR. In this case, the VLR is the FS while the VLTs are the RLANs as shown in Figure 4. Figure 5 shows a screenshot of the parametric interfaces on SEAMCAT for Nairobi with System and Scenario tabs toggled. The scenario tab (the one on the right in Figure 5 highlights the Victim and the Interfering system). Four interference criteria are considered within SEAMCAT:

- C/I:  Carrier to interference ratio;
- C/(I+N): Carrier to interference plus noise ratio;
- (N+I)/N:  Desensitisation;
- I/N: Interference to noise ratio.

Levels for all of these criteria are specified as input to the simulation as shown in Figure 2 but a single criterion needs to be chosen for the interference calculation. In the long-term criterion, -10 dB is entered for I/N while +19 dB is entered for short-term criteria.

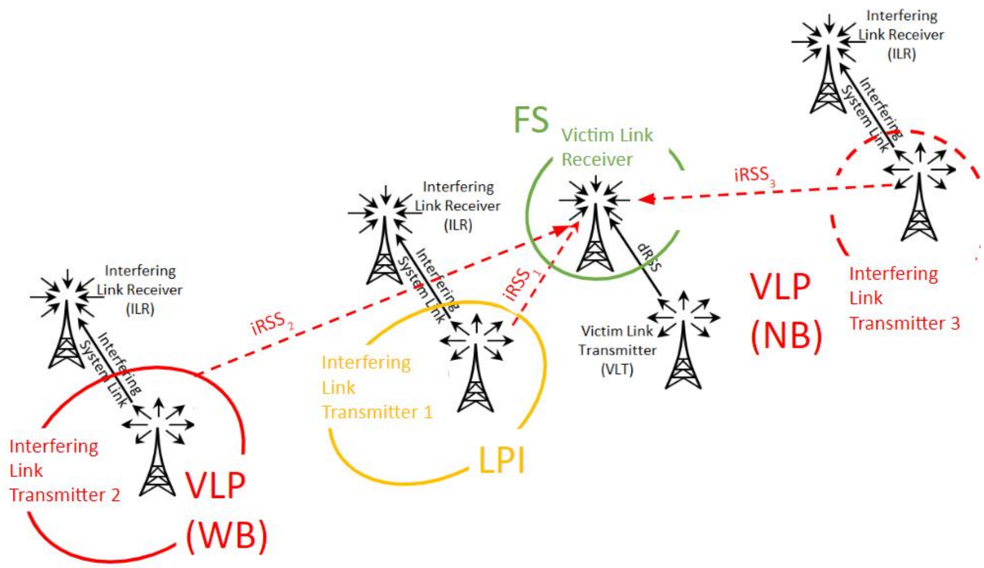



**Figure 4: SEAMCAT Simulation architecture between FS and RLANs**

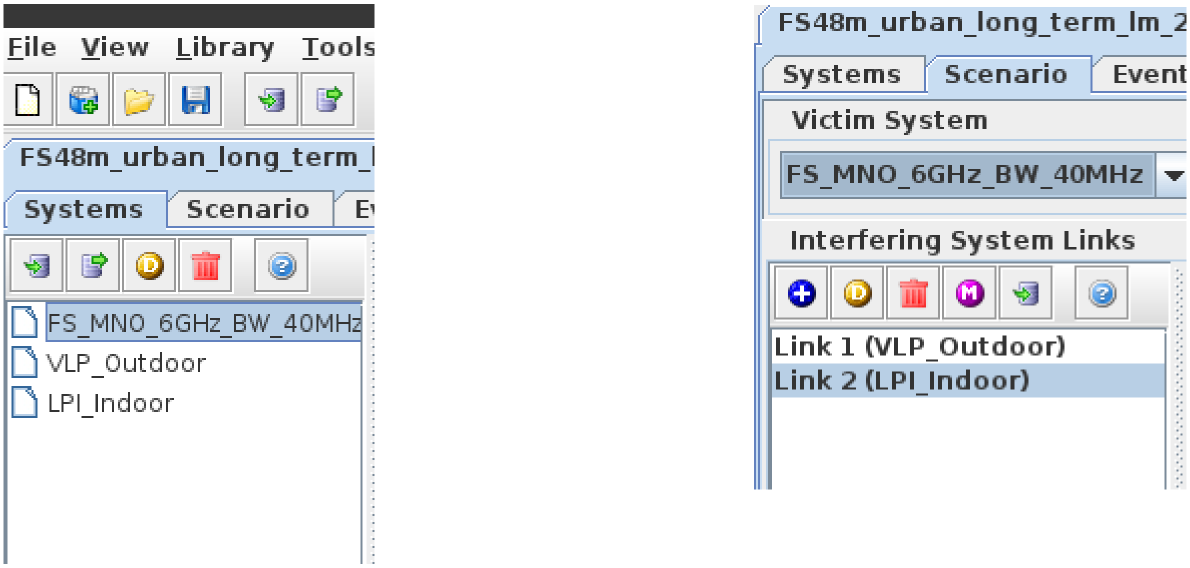



**Figure 5: SEAMCAT Interface with System and Scenario tabs Toggled**

Figure 6 shows various screenshots of the Frequency (one of the Centre frequencies selected), number of events (based on Monte-Carlo analysis under the long-term criterion), the receiver characteristics of the Victim links and the propagation model (under the scenario tab).

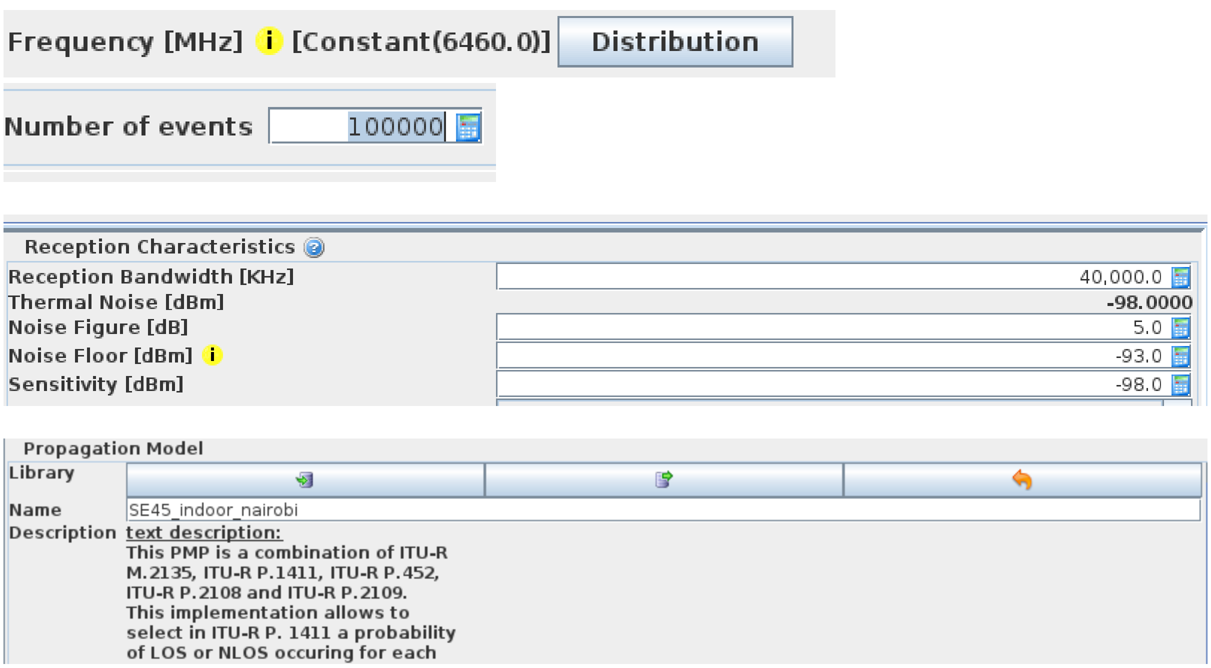



**Figure 6: SEAMCAT screenshots on Frequency, No. of Events, Reception Characteristics and Propagation Model**

Table 3 provides descriptions to the terminologies shown in the Reception Characteristics of Figure 6 as well as other important terms pertaining to the FS parameters [13]. Figure 7 is a screenshot of completed Monte-Carlo events simulation status for 100,000 events shown in Figure 6 based on the long-term scenario. It is important to note that for each event, SEAMCAT stores the signal strength of the interfering and the desired signals calculated in dedicated data arrays coming from the distributions of the inputs. The level of unwanted emissions (i.e. consisting of the out-of-band emissions and the spurious emissions of the ILT) falling within the VLR receiver bandwidth as shown in Figure 8 is determined using the interferer's transmit mask, the receiver bandwidth of the VLR, the interferer-to-victim frequency separation, the gains of the antennas and the propagation loss. The receiver experiences the unwanted power directly as additional noise in terms of I+N. The Receiver bandwidth is taken into account in the unwanted calculation.

The CDF of the distribution of the iRSS Unwanted (from the unwanted calculation) as shown in Figure 9 is exported as a text file and in this case, computed in MATLAB to generate the interference graph from the iterations (e.g. 100,000 events). It is important to note that SEAMCAT version 5.4.2 used assumes a flat Earth model for calculating path geometries and propagation losses. This limits the range of considered standard interference scenarios, by design, to terrestrial configurations and non-path specific propagation models.

**Table 3: Description of the terminologies of the Reception Characteristics**

| ***Terminology*** | **Description** |
|---:|---|
| *Receiver Bandwidth* | This is the bandwidth obtained from the data shared by CA for FS. In this case, it is 40 MHz with the consideration of 64-QAM modulation only. It falls within the range of ITU-R F.383-9 and ITU-R F.384-11 in the band 5925-7125 MHz. |
| *Thermal Noise* | This is the amount of thermal agitation appearing in the output of a receiver. It is expressed as $N_o(Watts) = KT_0B$. K is the Boltzmann's Constant In a FS bandwidth of 40 MHz that translates to 1.6008e-13 W (approx. -98 dBm) for the temperature $T_o$. |
| *Noise Figure* | This is the noise performance of a receiver. It is the noise factor expressed in decibels (dB). Noise factor is a ratio of the output noise power of a device to the portion thereof attributable to thermal noise. |
| *Noise Floor* | This limits the smallest measurement that can be taken with certainty since any measured amplitude cannot on average be less than the noise floor. |
| *Receiver Sensitivity* | This is normally taken as the minimum input signal required to produce a specified output signal having a specified signal-to-noise (S/N) ration. It is the difference in decibels between |

carrier-to-noise ratio (C/N) and carrier-to-noise-plus-interference ratio (C/ (N+I).

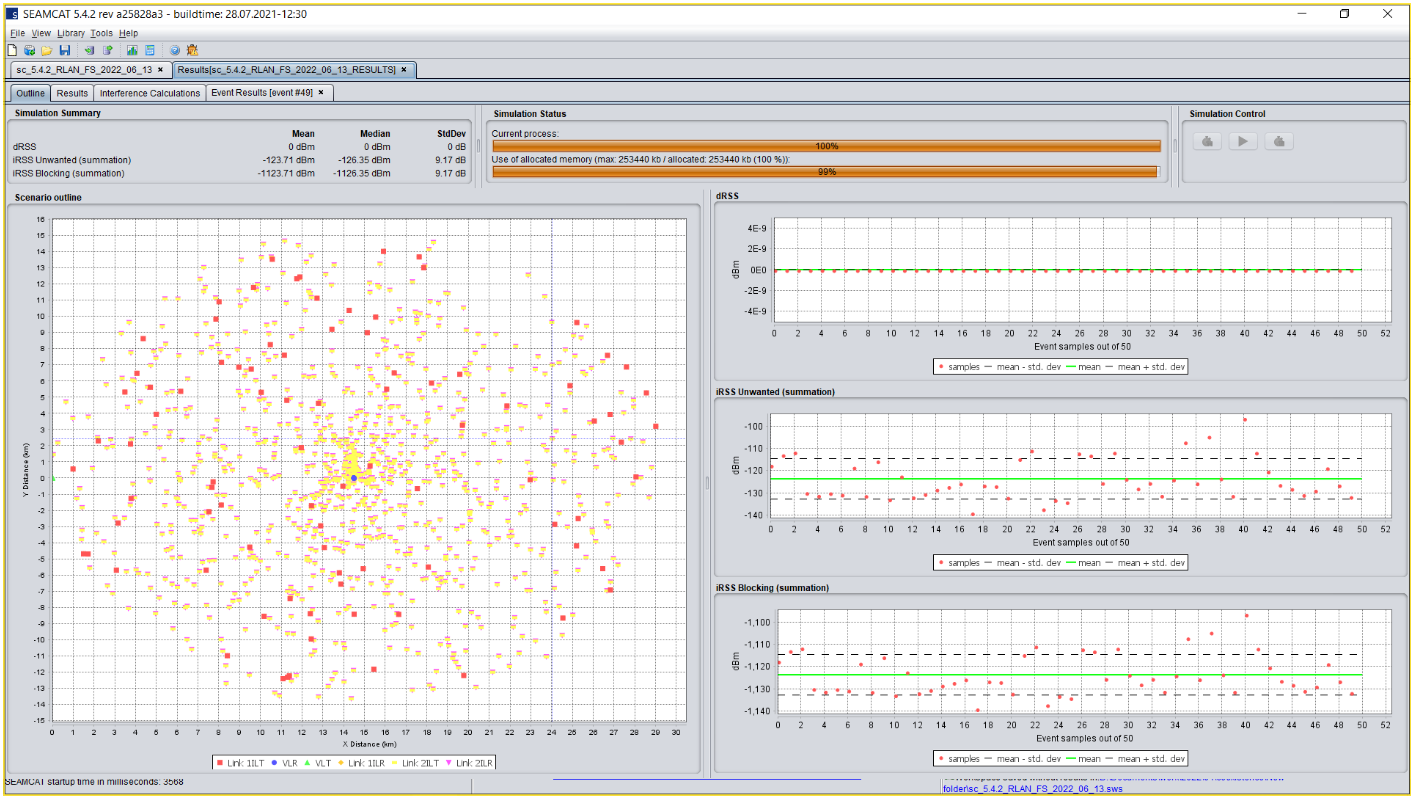


**Figure 7: Screenshot of completed 100k Monte-Carlo Simulation events status in SEAMCAT**

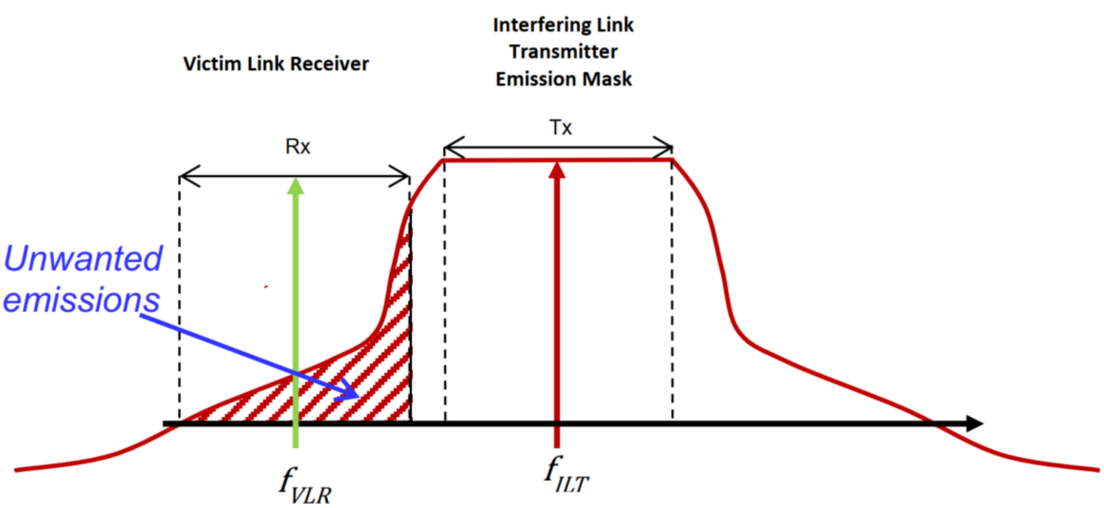


**Figure 8: Illustration of the interference due to the unwanted emissions (i.e. the unwanted emissions of ILT falling in the receiver bandwidth of VLR)**

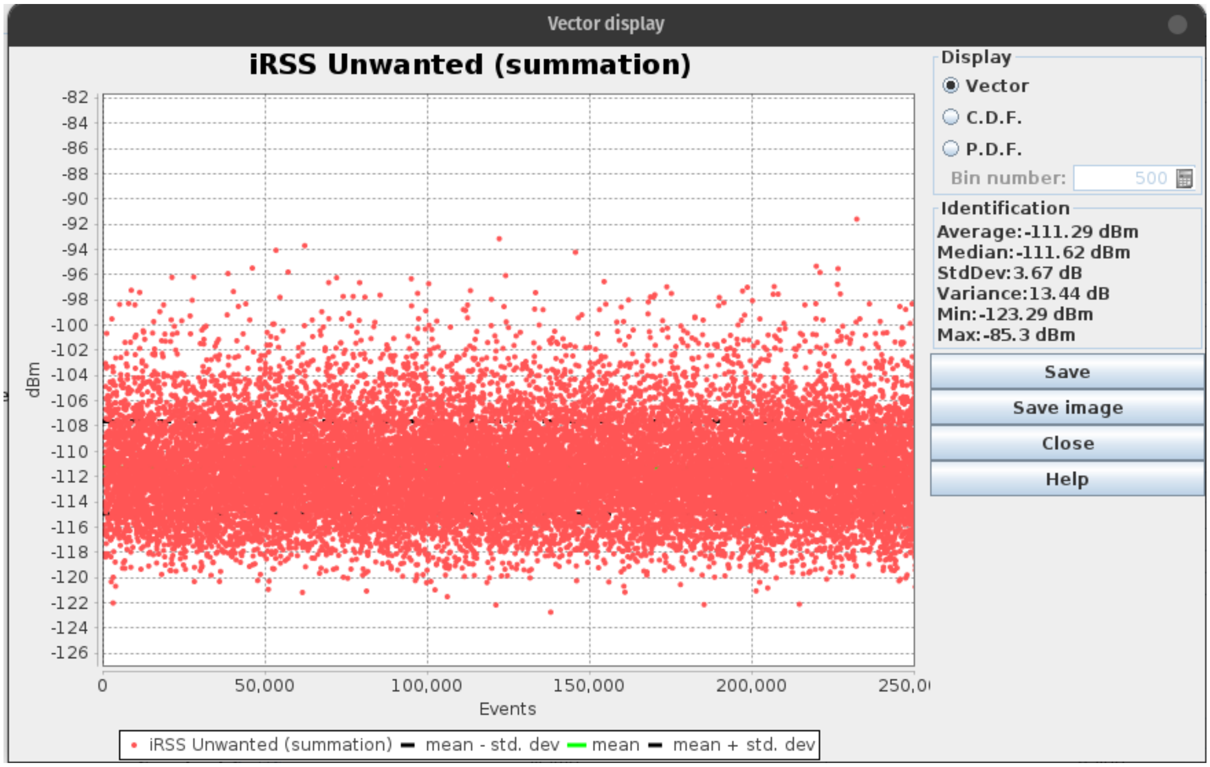



**Figure 9: SEAMCAT Screenshot of the iRSS Unwanted generated from the simulation events for a long-term scenario**

# 5. SHARING BETWEEN FS AND RLAN

The analysis of interference between FS and RLANs has considered both short-term and long-term interference. Short-term interference is the term used to describe the highest levels of interference power that occur for less than 1% of the time. Long-term interference, on the other hand, addresses the remaining portion of the interference power distribution [16]. Most frequency management procedures require a short term (0.01% probability) and long-term (greater than 80% probability) received signal estimate. In the analysis of compatibility between unlicensed stations in the 6 GHz and the FS services, the long-term estimate may be especially consequential. However, short-term variations must also be considered in relation to assessment of bit-error rates to a victim receiver and the frequency of exercise of Link Adaptation (LA) mechanisms designed to handle events like weather as opposed to interference. Similar to ECC 302, the sensitivity analyses have taken into account different RLANs e.i.r.p density levels, indoor and outdoor deployments, population density types for the selected scenarios, FS and RLAN antenna heights, FS antenna gains and building types, while computing both short-term and long-term interference.

The long-term interference is seen to degrade the error performance and availability of a system by reducing the fade margin that is available to protect the fixed service system against fading. In sharing and compatibility studies, long-term interference is characterised as the interference power that is exceeded by 20% of the time, at the victim receiver input. Hence, in considering the degradation in fade margin due to the interference, which is directly calculated from ($I/N$) value[2], as 10 log (($N + I$)/$N$) = 10 log ((1 + ($I/N$))) (dB), the protection threshold used is I/N = -10dB. The threshold I/N = -10dB relates to co-primary status while I/N = -20 dB relates to system that does not have co-primary status.

Short-term interference requires separate consideration because the interference power may be high enough to produce degradation even when the desired signal is unfaded. Such interference must occur rarely enough and in events of short duration for the interference to be acceptable. A short-term interference criterion is set based on the interference power necessary to cause a particular error performance defect (such as an errored second) when the desired signal is unfaded. This is the approach in Recommendations ITU-R SM.1448, ITU-R F.1494, ITU-R F.1495, ITU-R F.1606, ITU-R F.1669 and ITU-R SF.1650. The short-term protection threshold used is I/N = 19 dB.

In both cases of short-term and long-term interference, a combination of low power indoor (LPI) RLANs operating at power levels of up to 200mW and outdoor Very Low Power (VLP) portable RLAN up to 25mW was considered as presented in Table 2.

[2] I/N: The ratio of the interfering signal to noise

## 5.1. FS SYSTEM PARAMETERS AND ASSUMPTIONS

The technical characteristics of point-to-point (P2P) Fixed Service (FS) links are shown in Table 3. These characteristics, in the context of this study, consider frequencies in the 5925-6425 MHz and 6440-7060 MHz which are the most heavily used by the common carrier fixed P2P microwave service and private operational fixed P2P microwave services as provided by CA. Table 3 is based on the Long-term criterion while Table 4 shows the technical characteristics for the short-term scenario. These parameters are derived from the Recommendation ITU-R F.758-7 [15]. The antenna pattern used (based on aggregate interference) is derived from the ITU-R F.1245.3 [17]. Similar to the link lengths, the antenna height of both 48m and 100m was used based on the data shared by CA and estimated in accordance with both ECC 302 and ECC 316. Both ECC considerations had a modal height of 55m. While the average height provided within Kenyan data was 48m, our consideration for the urban scenario in regards to the deployment of RLANs will be in practical violation of this incumbent height considering some of the building heights. Hence, we adopted 100m (10m less of what is used in ECC 302 but more than twice our least height). Based on the data provided, this study considered an estimated total of 350 links. A large fraction of these links serves critical functions that must maintain a high level of availability. Table 5 lists some of the centre frequencies selected during the simulations. Figure 10 shows a distribution of some of the FS links in Kenya based on the data provided.

**Table 4: Technical Characteristics of Point-to-Point (P2P) FS Links (Long-term criterion)**

| **System Parameters for PP FS Systems in allocated bands between 3 and 7.2 GHz (5925-7125 MHz)** | |
|---|---|
| Modulation | 64-QAM |
| Centre Frequency | 6734.29 |
| Average Receive Bandwidth | 40 |
| Feeder/Multiplier loss between antenna and receive input (dB) | Usually between 0 and 6.3 - 1.8 used |
| Antenna Gain range (dBi) | Usually between 32.6 and 47.4 (ITU-R F.758-7) – 40 used |
| Antenna Peak Gain | 38.2 |
| Antenna pattern | ITU-R F.1245-3 |
| Antenna pointing (Azimuth, elevation) | Assumptions made based on Kenyan Data – P2P configuration between transmitter and receiver. |
| Antenna height (m) | Assumed between 48 m and 100 (Mode: 48) |
| Receiver Noise Figure (N.F.) in dB | 4.5 to 5 (ITU-R F.758-7) – 5 used |
| Receiver Noise floor (dBm) | -93 (= -173.97 + 10log10(BW in Hz) +NF) |

| | |
|---|---|
| Receiver noise power density typical (=NRX) (dBW/MHz) | −139.5… −139 |
| Nominal long-term interference power density (dBW/MHz) | −139.5… −139 + I/N |
| e.i.r.p. range (dBW) | 15.8…48.8 |
| Protection requirement (dB) | I/N = −10 and −20 (Recommendation ITU-R F.758) |
| Link Length | Between 6.78 and 80.64 Mode 74.55 |

**Table 5: Technical Characteristics of Point-to-Point (P2P) FS Links (Short-term criterion)**

| **System Parameters for PP FS Systems in allocated bands between 3 and 7.2 GHz (5925 – 7125 MHz)** | |
|---|---|
| Modulation | 64-QAM |
| Centre Frequency | 6460 |
| Average Receive Bandwidth | 40 |
| Feeder/Multiplier loss between antenna and receive input (dB) | Usually between 0 and 6.3 -1.3 used |
| Antenna Gain range (dBi) | Usually between 32.6 and 47.4 (ITU-R F.758-7) - 40 used |
| Antenna Peak Gain | 38.7 |
| Antenna pattern | ITU-R F.1245-3 |
| Antenna pointing (Azimuth, elevation) | Assumptions made based on Kenyan Data – transmitter pointing in the direction of receiver |
| Antenna height (m) | Assumed between 48 M and 100 (Mode: 48) |
| Receiver Noise Figure (N.F.) in dB | 4.5 to 5 (ITU-R F.758-7) |
| Receiver Noise floor (dBm) | -93 (= -173.97 + 10log10(BW in Hz) +NF) |
| Receiver noise power density typical (=NRX) (dBW/MHz) | −139.5… −139 |
| Nominal long-term interference power density (dBW/MHz) | −139.5… −139 + I/N |

| | |
|---|---|
| e.i.r.p. range (dBW) | 15.8…48.8 |
| Protection requirement (dB) | I/N = +19 (Recommendation ITU-R SF.1650-1[3]) |
| Link Length | Between 6.78 and 80.64 Mode 74.55 |

**Table 6: List of Centre Frequencies used during the Simulations**

| **Centre Frequencies (MHz)** |
|---|
| 5974.8 |
| 6460 |
| 6460 |
| 6480 |
| 6520 |
| 6540 |
| 6620 |
| 6680 |
| 6720 |
| 6780 |
| 7020 |
| 7060 |

[3] Recommendation ITU-R SF.1650-1

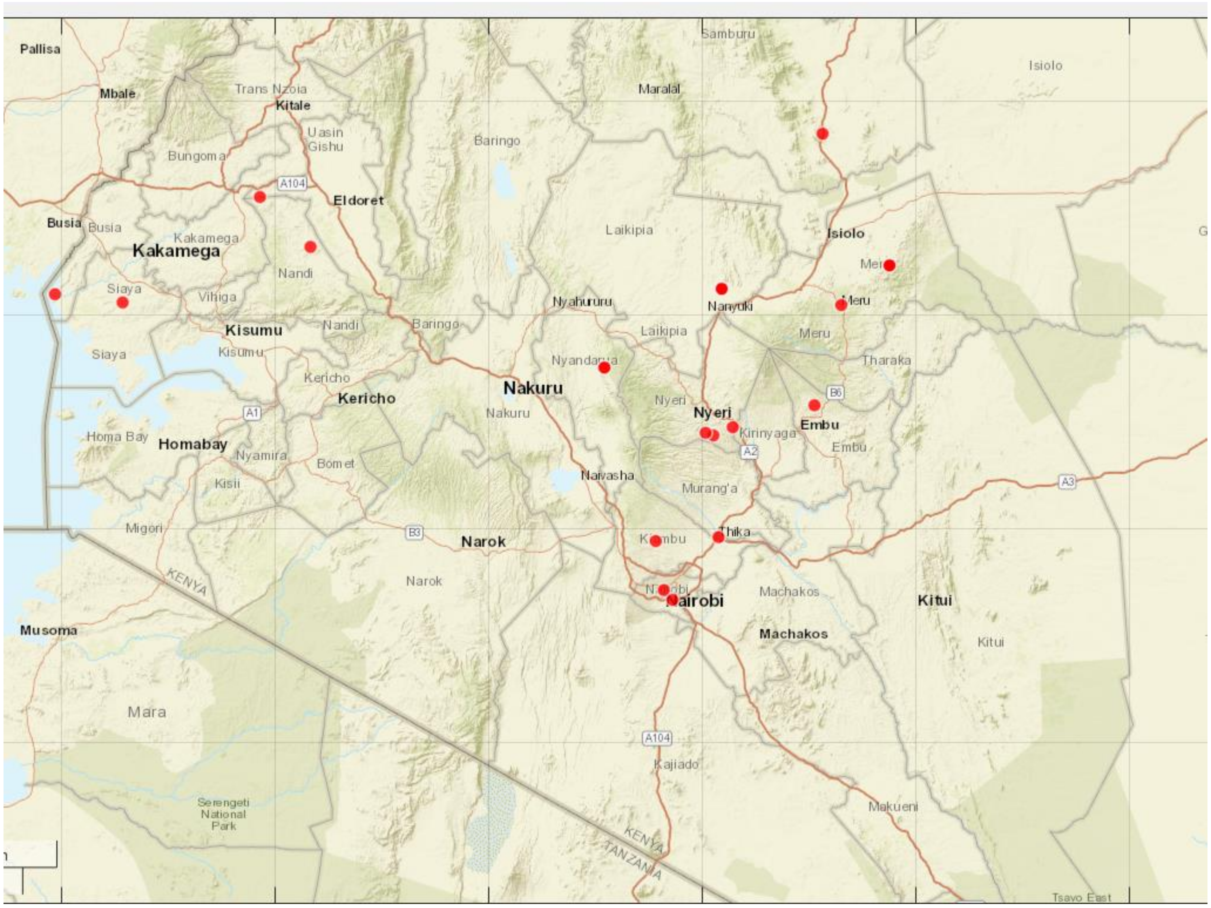



**Figure 10: Distribution of some of the FS Links in Kenya (shown by the red dots)**

### 5.1.1. PROPAGATION OVERVIEW

In our analysis of interference into the FS stations from a deployment of a large number of RLANs across a large geographical area, the RF propagation modelled the variations in interference path morphologies that exist [18]. A key aspect considered is FS stations are designed to be line of sight (LoS), and therefore the path from transmitter to receiver should be above obstructions, including terrain and nearby buildings. This aspect should hold in all the three scenarios – urban, sub-urban and rural. In particular, the modelling allowed the following requirements:

1. Applicability from low distances e.g. at least 10m from a protection distance of 50 metres to the FS receive site to an upper limit of 70-200 kilometres.
2. Applicability in the band of interest i.e. 5925 -7125 MHz.
3. Modelling based on a flat terrain model (SEAMCAT approach).
4. Modelling of terrain over long-distance propagation paths, with additional consideration of clutter beyond the break-point between LoS and NLoS propagation.
5. Modelling of clutter and environmental effects over short distances.

6. Consideration of the effect of propagation paths where one of the end-points (e.g. RLAN station) is within clutter and FS receiver is above the clutter.
7. Modelling of building entry loss where applicable to RLAN stations that are placed indoors.

Interference paths and their corresponding morphologies were modelled using the following choices for propagation and clutter models:

- For indoor WAS/RLAN usage, Recommendation ITU-R P.2109 [19] is used for computing indoor-to-outdoor interference path propagation losses.
- For near-in, out to 1km, propagation loss including clutter, WINNER II model is used for suburban and urban areas. WINNER II covers propagation scenarios of indoor office, large indoor hall, indoor-to-outdoor, urban micro-cell, bad urban micro-cell, outdoor-to-indoor, stationary feeder, sub-urban macro-cell, urban macro-cell, rural macro-cell and rural moving networks. While the WINNER II model follows a geometry-based stochastic channel modelling approach that is antenna independent, it is applicable to wireless systems operating in the 2-6 GHz frequency range with up to 100 MHz RF bandwidth [20]. Similar to ECC 302, for sub-urban and urban macro-cells, the FS stations are assumed to be located above rooftops and RLANs below the rooftops with both FS and RLANs being in the same clutter field with a conservative approach of using the model out to 1km.
- For propagation loss beyond 1km in suburban and urban areas, Recommendation ITU-R P.452 [21] with terrain data is used in combination with Recommendation ITU-R P.2108-1 [22]. ITU-R P.2108-1 describes a set of models that can be used for estimating the loss due to clutter for a number of different environments. Such environments include vegetation and buildings for long distance paths with RLANs in the clutter field. In SEAMCAT, ITU-R P.2108-1 is implemented in a library that also includes ITU-R P.1411 for urban/suburban propagation environments for short-range radio systems.
- For rural propagation, Recommendation ITU-R P.452 with terrain data including rural endpoint clutter model is used. Since the rural scenario considers Marsabit and Turkana counties, a rural tree clutter morphology is used for irregularly spaced trees and space houses. ITU-R P.452 is applicable from 50m in coniferous and deciduous trees and from 100m over open fields or sparse vegetation. It is also valid beyond 1km making the clutter loss model applicable without restrictions. The simulation radius in the rural scenario of this case (Marsabit and Turkana) was 148.5 km.

## 5.2. RLAN DEPLOYMENT AND OPERATING ASSUMPTIONS

### 5.2.1. USE CASES

Various use cases for RLANs and their benefits as identified and studied during the technical assessment include:

- Indoor Enterprise/Consumer Access Points (APs) and Indoor Internet of Things (IoT) systems and gaming. The consumer access include connection through a variety of devices such as tablets, computers in the home, laptops, televisions and mobile phones. This translates to services of highresolution video streaming, Wi-Fi calling, smart home monitoring, hotspot access etc [11]. Enterprise access includes Agriculture, Manufacturing Industry, Shopping malls, Healthcare, Education, Enterprise offices and Public Services [5].

- Indoor/Outdoor Client stations (STA) as well as short-range IoT implementations, outdoor backhaul of Low Power Wide Area Networks (LPWANs) such as Long Range Wide Area Network (LoRaWAN), Augmented/Virtual Reality (A.R. /V.R.).
- Studies such as the *Socio-economic benefits of IMT versus RLAN in the 6425-7125 MHz* [5] show that enabling RLAN deployment in the entire 6 GHz band can provide additional capacity and Quality of Service (QoS) benefits beyond those of access to the lower 6 GHz band. Specifically, wider bandwidth channels (160/320 MHz) can be made available enabling the full benefits of 1 Gbit/s connectivity. Access to the full band can ease congestion on 2.4 GHz and 5 GHz networks in densely populated areas resulting in an overall uplift in QoS for Wi-Fi users. Wi-Fi 6E can also cover from 3 to 4 times more users compared to currently deployed Wi-Fi.

### 5.2.2. BUSY HOUR CONSIDERATION

In determining the worst-case time of interference into incumbent systems, we considered busy hours for corporate to be during the day between 9am-5pm while home usage to be between 7.30pm to 11pm. This is supported by traffic statistics published from the Kenya Internet Exchange Point (KIPX) as shown in Figure 11. However, these data includes throughput regardless of access technology, the statistics show general usage patterns of usage from 9am-5pm and nighttime use from 7pm to midnight.

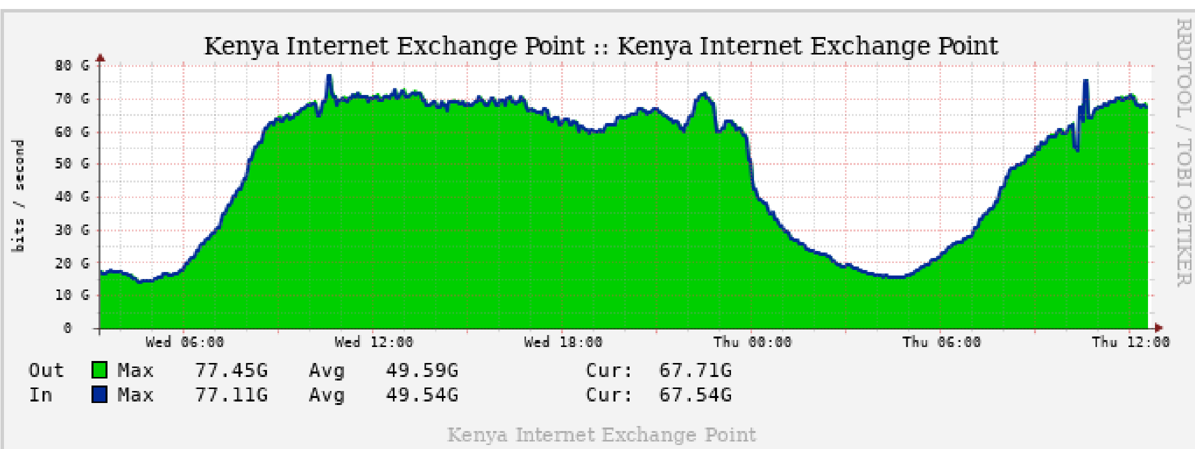



**Figure 11: Image of Data throughput profile in Kenya as at 8th-9th September 2022**

Source: Kenya Internet Exchange Point – Tespok

### 5.2.3. WEIGHTED AVERAGE E.I.R.P OF WAS/RLAN DEVICES

Similar to ECC 302, we considered a 98% transmission by the WAS/RLAN devices to be indoor and 2% outdoor. The power distributions for both VLP and LPI use cases within the said percentages are shown in Table 7 and 8.

**Table 7: WAS/RLAN Power distribution for the VLP case**

| Tx e.i.r.p. | 25 mW | 12.5 mW | 3.25 mW |
|---|---|---|---|
| Percentage of VLP devices | 6.93% | 45.71% | 47.36% |

**Table 8: WAS/RLAN Power distribution for the LPI case**

| Tx e.i.r.p. | 200 mW | 100 mW | 50 mW | 13 mW | 1mW |
|---|---|---|---|---|---|
| Percentage of LPI Devices | 9.81% | 6.24% | 26.01% | 52.31% | 5.63% |

### 5.2.4. WAS/RLAN BANDWIDTH DISTRIBUTION AND ASSOCIATED E.I.R.P

The WAS/RLANs modelled in this study operate in the 20 MHz, 40 MHz, 80 MHz and 160 MHz bandwidth channels. The bandwidth distributions and associated e.i.r.p. for VLP outdoor is summarised in Table 9 while for indoor is shown in Table 10.

**Table 9: Bandwidth distribution and associated e.i.r.p. for LPI WAS/RLAN outdoor simulation**

| **VLP e.i.r.p. levels(mW)** | **25** | | | | **12.5** | | | | **3.25** | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Channel bandwidth (MHz)** | 20 | 40 | 80 | 160 | 20 | 40 | 80 | 160 | 20 | 40 | 80 | 160 |
| **WAS/RLAN device percentage** | 10 | 10 | 50 | 30 | 10 | 10 | 50 | 30 | 10 | 10 | 50 | 30 |
| **Bandwidth conversion factor(dB) [*Note 1]** | 0 | 0 | -3.01 | -6.02 | 0 | 0 | -3.01 | -6.02 | 0 | 0 | -3.01 | -6.02 |
| **Power (PTx)** | 13.97 | 13.97 | 13.97 | 13.97 | 10.96 | 10.96 | 10.96 | 10.96 | 5.11 | 5.11 | 5.11 | 5.11 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **(dBm)** | | | | | | | | | | | | |
| **Percentage associated to the power (%)** | 6.94 | 6.94 | 6.94 | 6.94 | 45.7 | 45.7 | 45.7 | 45.7 | 47.36 | 47.36 | 47.36 | 47.36 |
| **PTx+CF_BW (dBm)** | 13.97 | 13.97 | 10.96 | 7.95 | 10.96 | 10.96 | 7.95 | 4.94 | 5.11 | 5.11 | 2.10 | -0.90 |
| **PTx+Body loss +CF_BW (dBm)** | 9.97 | 9.97 | 6.96 | 3.95 | 6.96 | 6.96 | 3.95 | 0.94 | 1.11 | 1.11 | -1.89 | -4.90 |
| **Combined percentage (%)** | 0.69 | 0.69 | 3.47 | 2.08 | 4.57 | 4.57 | 22.85 | 13.71 | 4.73 | 4.73 | 23.68 | 14.20 |
| Note 1: A bandwidth conversion factor is introduced to take into account only the overlapping portion of transmitted power. It is applied if the bandwidth of the WAS/RLAN device is greater than the bandwidth of the FS channel. It is calculated as follows: 10log(BW_FS/BW_RLAN) | | | | | | | | | | | | |

**Table 10: Bandwidth distribution and associated e.i.r.p. for LPI WAS/RLAN indoor simulation**

| **Power Level (mW, BL incl)** | **Power Level (PTx) BL incl. (dBm)** | **Channel Bandwidth (MHz)** | **Device Perc. (%)** | **BW Conversion Factor (dB) (CF_BW)** | **Percentage associated to the power (%)** | **PTx+CF_BW (dBm)** | **Combined perc. (%)** |
|---|---|---|---|---|---|---|---|
| 200 | 23.01 | 20 | 10 | 0 | 9.81 | 23.01 | 0.98 |
| | | 40 | 10 | 0 | 9.81 | 23.01 | 0.98 |
| | | 80 | 50 | -3.01 | 9.81 | 20 | 4.91 |
| | | 160 | 30 | -6.02 | 9.81 | 16.99 | 2.94 |
| 100 | 20 | 20 | 10 | 0 | 4.39 | 20 | 0.44 |
| | | 40 | 10 | 0 | 4.39 | 20 | 0.44 |
| | | 80 | 50 | -3.01 | 4.39 | 16.99 | 2.20 |
| | | 160 | 30 | -6.02 | 4.39 | 13.98 | 1.32 |
| 50 | 16.99 | 20 | 10 | 0 | 13.76 | 16.99 | 1.38 |
| | | 40 | 10 | 0 | 13.76 | 16.99 | 1.38 |
| | | 80 | 50 | -3.01 | 13.76 | 13.98 | 6.88 |
| | | 160 | 30 | -6.02 | 13.76 | 10.97 | 4.13 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 13 | 11.14 | 20 | 10 | 0 | 39.63 | 11.14 | 3.96 |
| | | 40 | 10 | 0 | 39.63 | 11.14 | 3.96 |
| | | 80 | 50 | -3.01 | 39.63 | 8.13 | 19.82 |
| | | 160 | 30 | -6.02 | 39.63 | 5.12 | 11.89 |
| 1 | 0 | 20 | 10 | 0 | 5.62 | 0 | 0.56 |
| | | 40 | 10 | 0 | 5.62 | 0 | 0.56 |
| | | 80 | 50 | -3.01 | 5.62 | -3.01 | 2.81 |
| | | 160 | 30 | -6.02 | 5.62 | -6.02 | 1.69 |
| 40 | 16.02 | 20 | 10 | 0 | 1.85 | 16.02 | 0.19 |
| | | 40 | 10 | 0 | 1.85 | 16.02 | 0.19 |
| | | 80 | 50 | -3.01 | 1.85 | 13.01 | 0.93 |
| | | 160 | 30 | -6.02 | 1.85 | 10 | 0.56 |
| 20 | 13.01 | 20 | 10 | 0 | 12.25 | 13.01 | 1.23 |
| | | 40 | 10 | 0 | 12.25 | 13.01 | 1.23 |
| | | 80 | 50 | -3.01 | 12.25 | 10 | 6.13 |
| | | 160 | 30 | -6.02 | 12.25 | 6.99 | 3.68 |
| 5 | 6.99 | 20 | 10 | 0 | 12.69 | 6.99 | 1.27 |
| | | 40 | 10 | 0 | 12.69 | 6.99 | 1.27 |
| | | 80 | 50 | -3.01 | 12.69 | 3.98 | 6.35 |
| | | 160 | 30 | -6.02 | 12.69 | 0.97 | 3.81 |

### 5.2.5. ANTENNA HEIGHTS

The antenna heights are based on the locations (counties) considered. These studies developed the location scenarios using the following approaches for both short-term and long-term.

- Nairobi: Due to the high population density and the numerous buildings within Kenya's capital. Going by the definition of the Organisation of Economic Co-operation and Development (OECD), Nairobi is seen as an urban core with a population that live to more than 50% in urban high-density clusters.
- Urban (Nairobi and Kiambu counties combined).
- Sub-urban I (Mombasa and Kilifi counties combined).
- Sub-urban II (Kakamega and Bungoma counties combined).
- Rural (Marsabit and Turkana combined).

The average areas of these scenarios are shown in Table 11

Table 11: The Areas of the Scenarios, Radius of simulation and the 2025 population densities

| Location Scenario | Average Area (in sq. km) | Radius (in km) | Population Density as at 2025 (per sq. km) |
|---|---|---|---|
| **1. Nairobi** | 703.9 | 14.9686 (14.5 used) | 6809 |
| **2. Urban** | 3,242.5 | 32.1263 (31.7 used) | 7309 |
| **3. Sub-urban I** | 12,759.6 | 63.7299 | 5720 |
| **4. Sub-urban II** | 6,043.9 | 43.8611 | 930 |
| **5. Rural** | 139,177 | 210.4780 | 13 |

The rural scenario considered a constant building height of 1.5m for both indoor and outdoor RLAN. The antenna height distributions for the various scenarios for both VLP and LPI are shown in Table 12 and 13.

Table 12: VLP Height Distribution for Nairobi, Urban and Sub-urban Scenarios

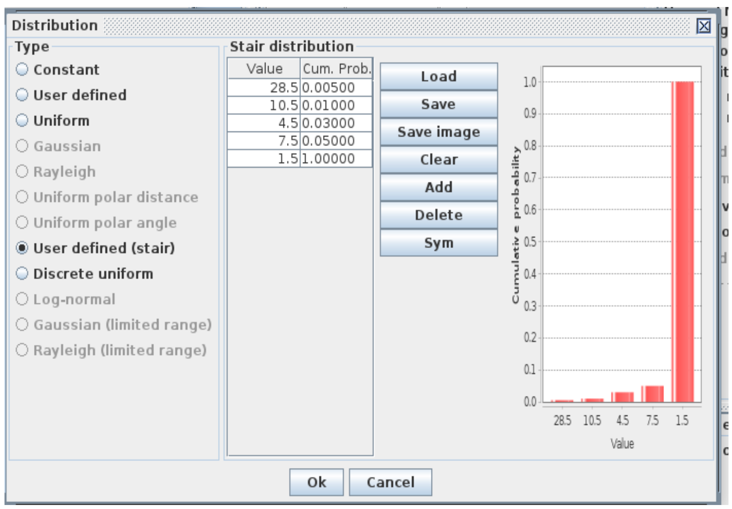
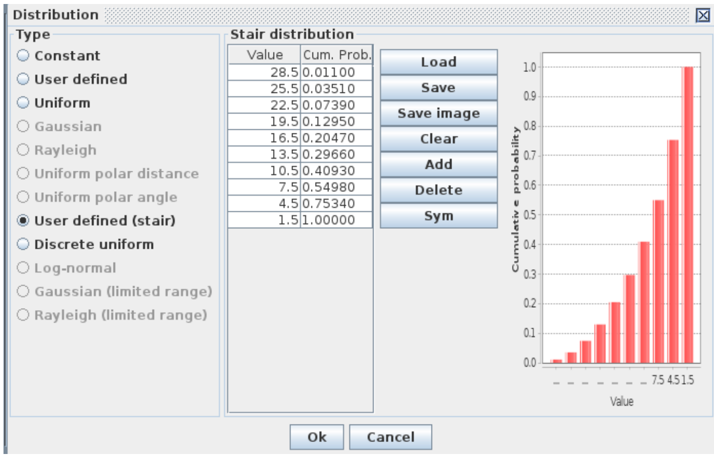


**Table 13: LPI Height Distribution for Nairobi and Urban Scenarios**




The building heights distributions are computed based on the physical heights of the buildings (No. of floors) in all the scenarios, except for rural. The building height type probability is recast into the probability of WAS/RLAN presence on each floor of a multi-story building. The equation used to obtain the probability used (borrowed from Europe's scenario) is shown below:

*WAS/RLAN on 1st Floor Probability = 1 Story Building Probability + 2 Story Building Probability/2 Floors … +10 Story Building Probability/10 Floors*

### 5.2.6. WAS/RLAN DEPLOYMENT MODEL

The deployment model is based on Kenya's projected population of 2025. The population compares the data from Kenya's 2019 census and the UN's projected population of 2030 across the world that is accessible through this link: https://population.un.org/wpp/Download/Standard/Population/. An excel workbook that considers the MEDIUM VARIANT of the population by 2025 for Kenya is also available on this link as used within this study. The populations are incremented accordingly as per the scenarios identified in section 5.2.5 from the 2019 Kenya's population [7]. Kenya's total population based on 2019 census stands at **47,564,296** and the 2025's total projected population is **59.981,000.** Further, other variables such as instantaneously transmitted devices, busy hour factor, 6 GHz factor, market adoption factor and RF activity factor per person are taken into consideration as well. A detailed excel workbook with the parameters used as well as the different distributions is available here. For example, taking into consideration – Nairobi's population in 2019 and 2025 as shown in Table 14 and 15 respectively.

**Table 14: Nairobi Population 2019**

| **Based on National Census: 2019** | | | |
|---|---|---|---|
| **County: Nairobi - 2019** | | | |
| **Total Population: 4,397,073** | | | |
| | | | |

| Sub-Counties | Population | Household Size | Population Density per Sq. Km |
|---|---|---|---|
| | | | |
| **Dagoretti** | 434,208 | 2.8 | 14,908 |
| **Embakasi** | 988,808 | 2.8 | 11,460 |
| **Kamukunji** | 268,276 | 3.1 | 25,455 |
| **Kasarani** | 780,656 | 2.8 | 9,058 |
| **Kibra** | 185,777 | 2.9 | 15,311 |
| **Lang'ata** | 197,489 | 3.1 | 911 |
| **Makadara** | 189,536 | 2.7 | 16,150 |
| **Mathare** | 206,564 | 2.7 | 68,941 |
| **Njiru** | 626,482 | 3 | 4,821 |
| **Starehe** | 210,423 | 2.8 | 10,205 |
| **Westlands** | 308,854 | 2.9 | 3,167 |

**Table 15: Nairobi Population 2025**

| Based on UN Estimates of 2020-2030 | | | |
|---|---|---|---|
| **County: Nairobi - 2025** | | | |
| **Total Population:** | | **5,398,290** | |
| | | | |
| **Sub-Counties** | **Population** | **Household Size** | **Population Density per Sq. Km** |
| **Dagoretti** | 473,287 | 3.052 | 16,250 |
| **Embakasi** | 1,077,801 | 3.052 | 12,491 |
| **Kamukunji** | 292,421 | 3.379 | 27,746 |
| **Kasarani** | 850,915 | 3.052 | 9,873 |
| **Kibra** | 202,497 | 3.161 | 16,689 |
| **Lang'ata** | 215,263 | 3.379 | 993 |
| **Makadara** | 206,594 | 2.943 | 17,604 |
| **Mathare** | 225,155 | 2.943 | 75,146 |
| **Njiru** | 682,865 | 3.27 | 5,255 |
| **Starehe** | 229,361 | 3.052 | 11,123 |
| **Westlands** | 336,651 | 3.161 | 3,452 |

This population is fed as input into the computation to obtain the number of instantaneously transmitting RLAN devices in Nairobi in 2025. The summary of the deployment model is shown in Table 15. These studies assume a conservative 32% figure of the market adoption factor and a busy hour population of 62.7%. The bandwidth overlapping factor reflects the number of WAS/RLAN that would fall into the bandwidth of the FS receiver. The overall envisaged bandwidth to WAS/RLAN is 1200 MHz, while the studies receiver bandwidth is 40 MHz. Thus, the receiver is not going to "see" all WAS/RLAN in its observing bandwidth but only a "portion" of them. This portion need to be calculated according to WAS/RLAN channelization as shown in Figure 12.

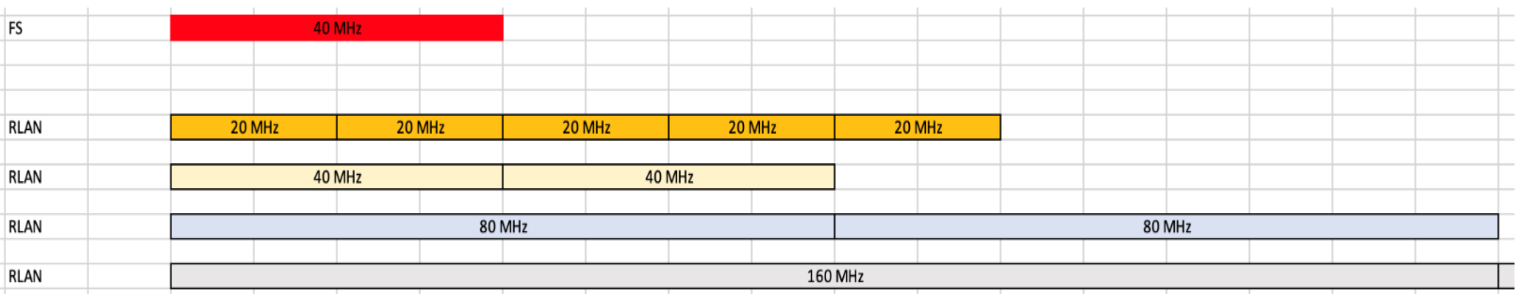



**Figure 12: WAS/RLAN Channelization**

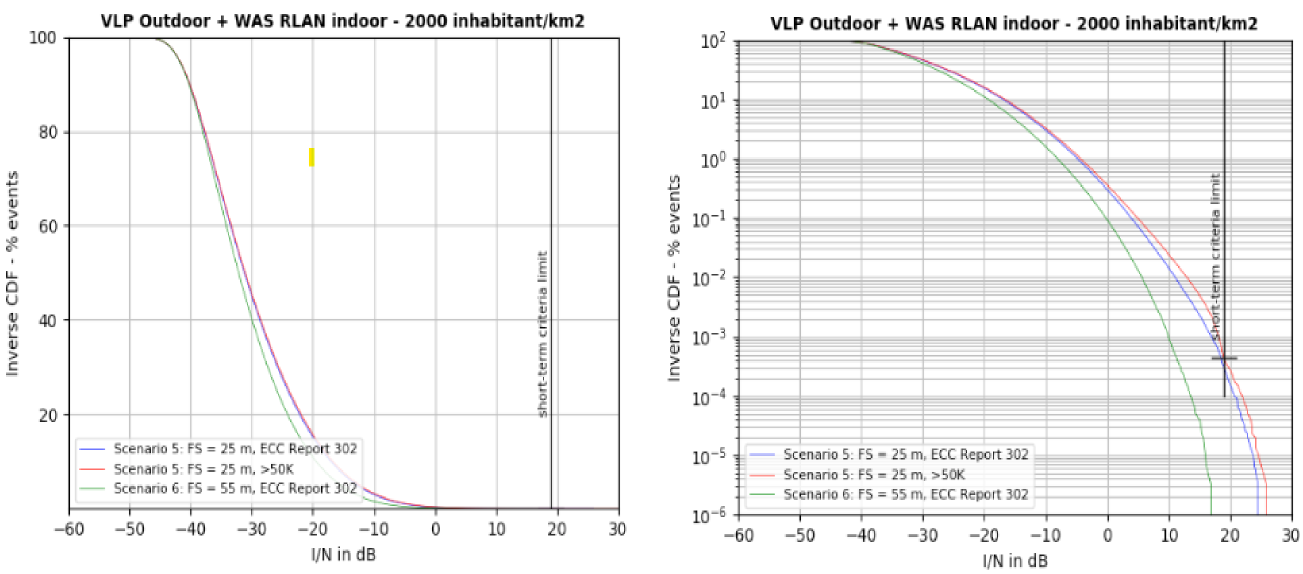
**Table 16: Summary of WAS/RLAN Deployment Model for Nairobi Scenario**

| Parameter | Mid |
|---|---|
| Total Population of Nairobi 2025 | **5,398,290** |
| Wireless devices operating in licence exempt spectrum | 80% |
| Busy Hour Population | 62.70% |
| 6 GHz Factor | 64.39% |
| Market Factor | 32% |
| RF Activity Factor | 1.97% |
| Overlap Factor | 12.28% |
| Instantaneously Transmitting Devices within a 40 MHz FS Channel | 1349 |
| **Outdoor RLANs** | 26 |
| **Indoor RLANs** | 1323 |

This shows the number of RLAN devices in 2025 for outdoor in Nairobi will be 26 and Indoor 1323. Based on this computation approach, the urban scenario produces 42 devices outdoor and 2070 devices indoor as per the urban scenario population in 2025 (8,447,177 people), the sub-urban I scenario: 16 and 823 (population: 3,357,069), sub-urban II scenario: 22 and 1093 (population: 4,461,786) and the rural scenario: 1 and 67 (population: 1,748,776). The rural scenario in this case, considered 5%, 3% and 1% of market adoption as shown in Figure 19.

### 5.2.7. SEAMCAT SIMULATION

A simulation is defined by a target number of simulation events in a specified simulation radius and for a given scenario according to Table 11. In each event, the parameters influencing the simulation are pseudo-randomly adjusted according to their defined probability distributions. Aggregate Interference to Noise ratio (I/N) is used as an interference measure with aforementioned I/N requirements for both short-term and long-term interference criteria of ITU-R. F-758 [16]. At the end of the simulation, the aggregate I/N results per event are then exported to a file and graphed for assessment of interference criteria performance. In our Kenyan approach, the short-term and long-term study had an approximate target of events per simulation at 10 million and 250,000 events respectively for each of the various scenarios, i.e. urban, sub-urban and rural. The particularly large number of events for the short-term criterion is necessary as the criterion as a percentage of events is small, and therefore a large number of events are needed for certainty of results. These large number of simulation events necessitates that the abscissa of the plot to be logarithmic for ease of visualising the large span of values as shown in Figure 13. Note that Figure 13 shows explorative simulation with the short-term interference criterion exceeded (or violated).




Using linear scale          Using logarithmic scale

**Figure 13: Two output graphs of a simulation with linear and logarithmic abscissa scales**

## 5.3. RESULTS FROM SEAMCAT SIMULATION

In SEAMCAT, each sample of dRSS and iRSS generated during the simulation is compared against the relevant signal-to-noise criterion (specified in the scenario, such as C/N, C/N+I etc). The probability of interference is calculated for all events where the dRSS is greater than the sensitivity of the victim link receiver. In this case, the CDF of the iRSS (unwanted) is the file exported from the simulation described in section 5.2.7 in text format from the simulation events of both short-term and long-term criteria. A calculation is done through a MATLAB script to determine the level of I/N based on the curve of the inverse CDF events. The calculation of I/N from these events is computed as artificial noise iRSS on top of the noise floor. If I/N ≤ -10 dB, the impact of the interferer is negligible compared to the noise floor for the long-term scenario and if I/N ≤ 19 dB, the impact of the interferer is negligible compared to the noise floor for the short-term scenario.

Figures 14 to 18 shows the findings of the long-term and short-term criteria spanning the three scenarios – urban, sub-urban and rural. With all the iterations of the simulation modelling a set of instantaneously transmitting devices in the RLAN network, NONE of them had the aggregate I/N exceeding the -10 dB for the long-term criterion and 19 dB for the short-term criterion. This demonstrates no interference instance from the RLAN deployment to the FS incumbents, hence showing strong possibility of non-interfering coexistence.

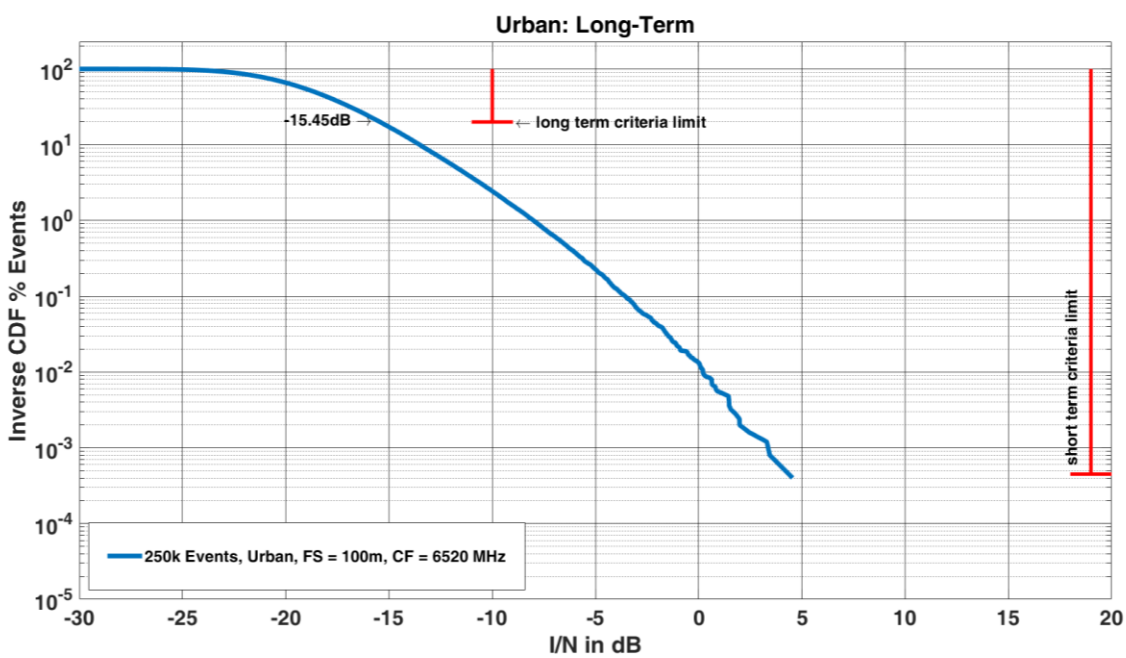



**Figure 14: Long-term Scenario Urban at an FS Height of 100m**

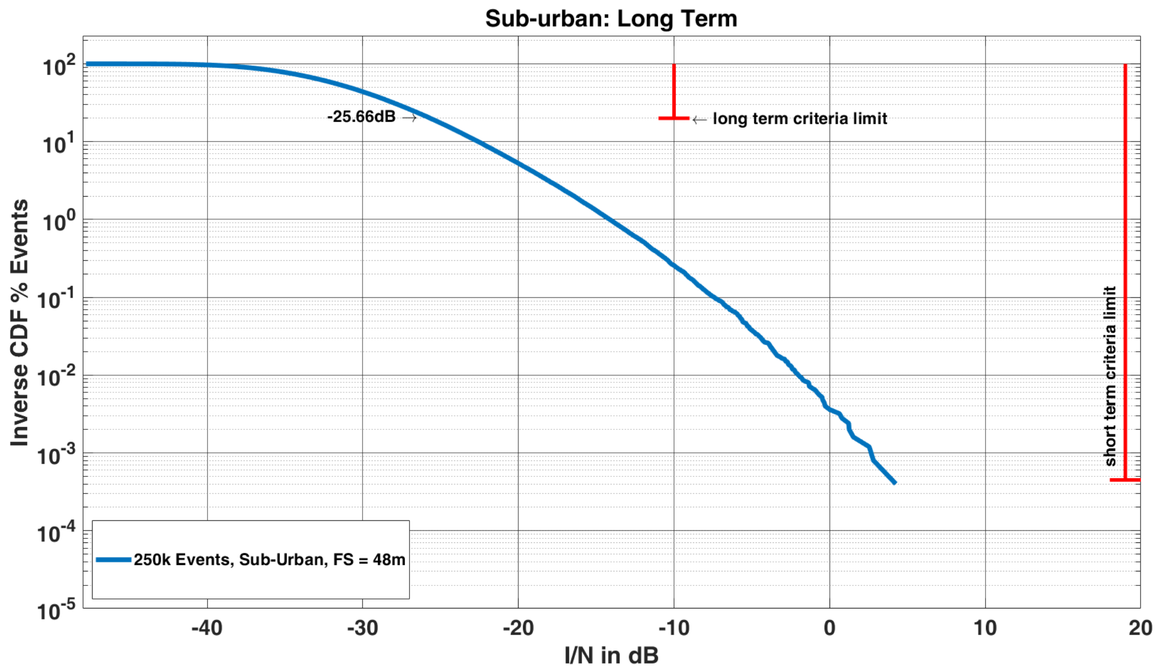



**Figure 15: Long-term Scenario Suburban at FS Height of 48m**

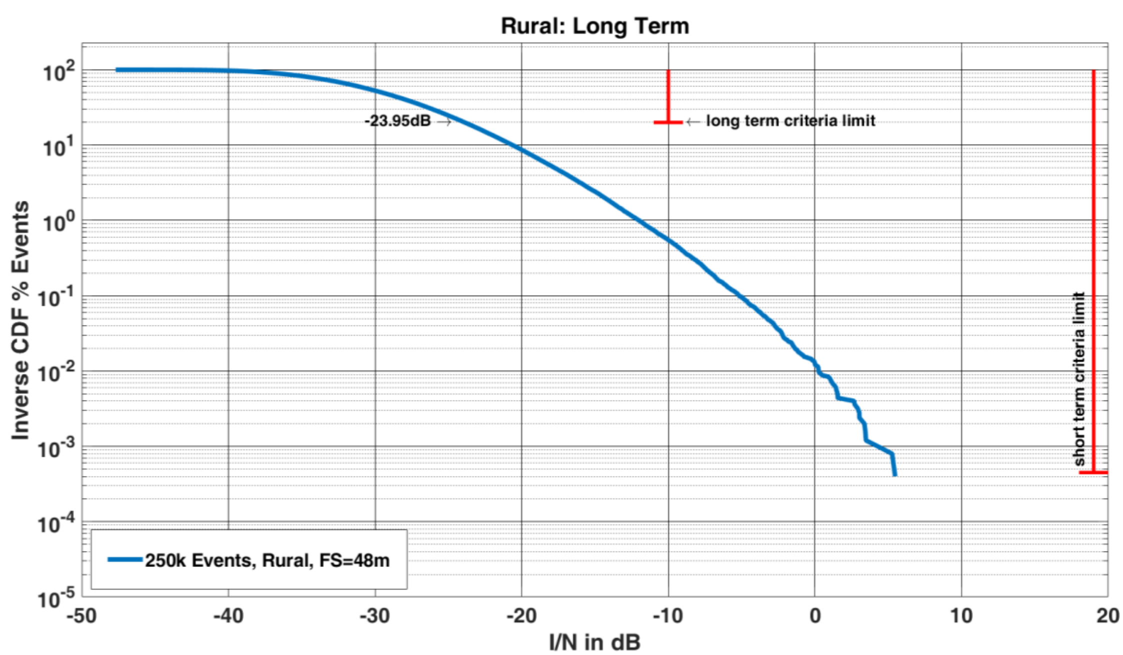



**Figure 16: Long-term Scenario Rural at FS Height of 48m**

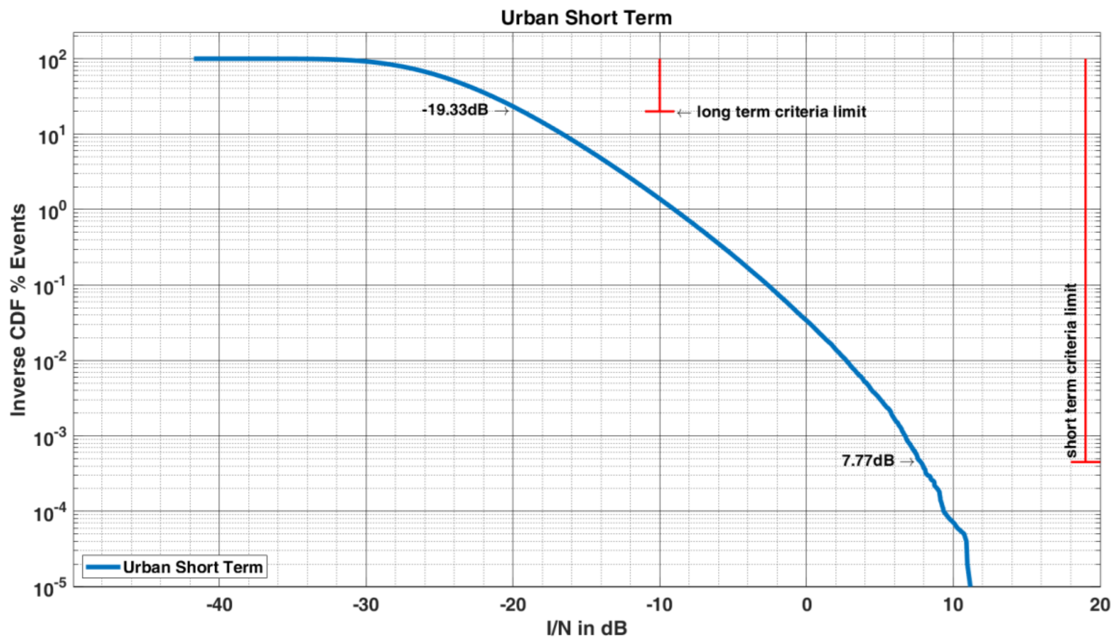



**Figure 17: Short-term Scenario Nairobi at FS Height of 48m**

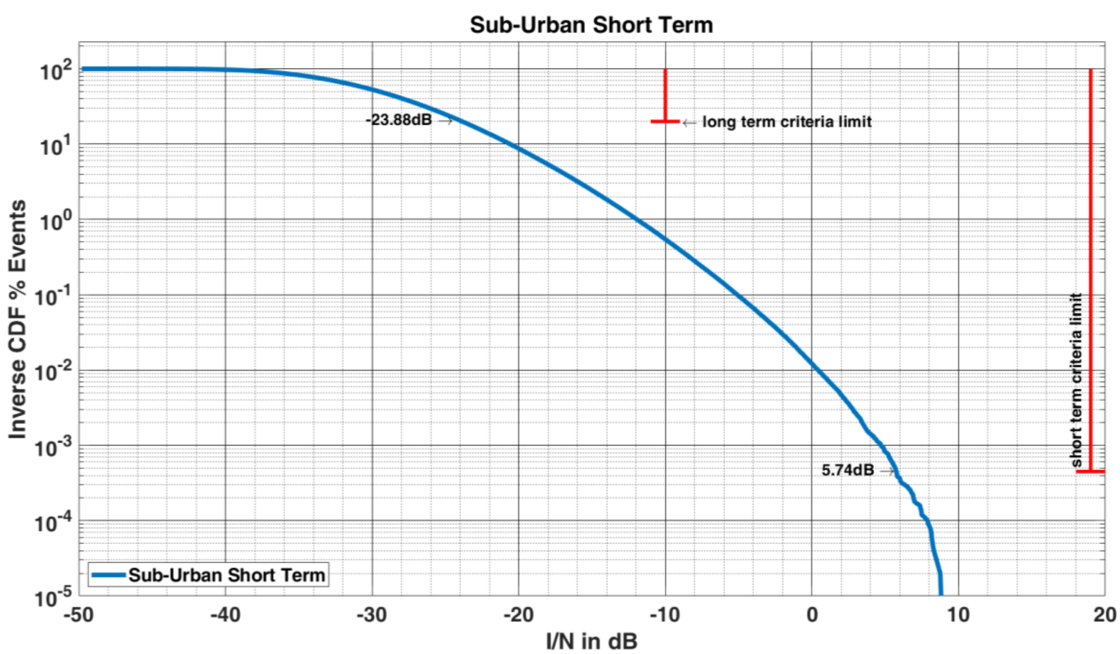



**Figure 18: Short-term Scenario Sub-Urban at FS Height of 48m**

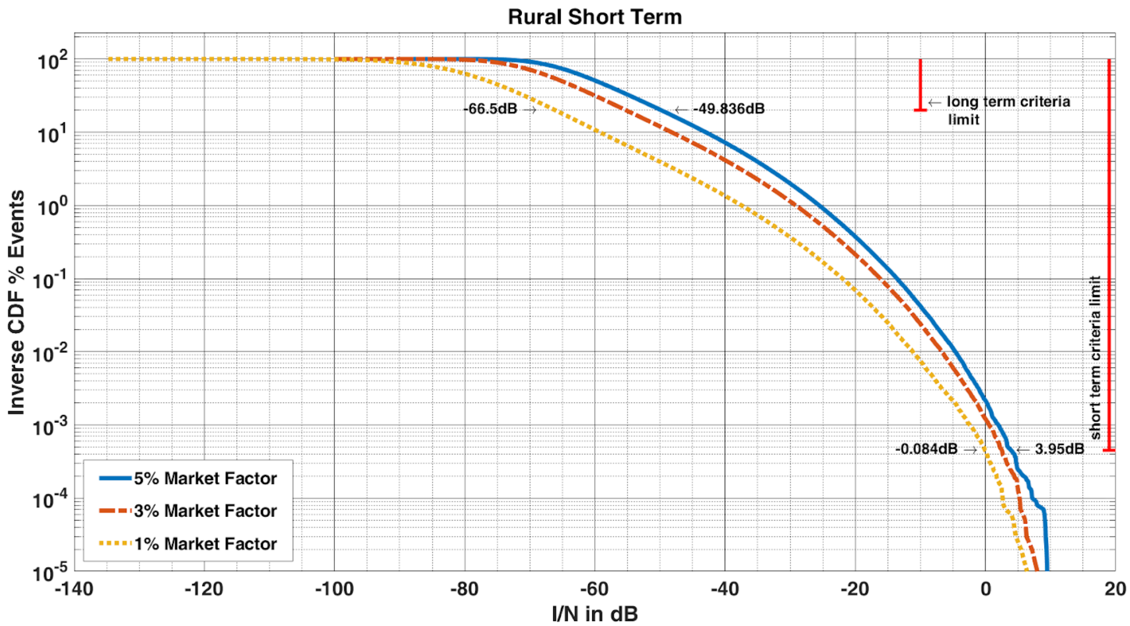



**Figure 19: Short-term Scenario Rural at FS Height of 48m and at different Market adoption factors**

# 6. SHARING BETWEEN WAS/RLAN AND FIXED SATELLITE SERVICES (FSS)

The other service considered in this coexistence study is Fixed Satellite Service (FSS). Although we note that, there exists Satellite services in the upper part of the 6 GHz band in other regimes[4], in this study, the range of frequencies provided by CA fall in the lower part of the 6 GHz band. Hence, considered as is, the study has assessed the uplink (earth-to-space) links coexisting with the RLANs.

## 6.1. GENERAL RESEARCH APPROACH

With SEAMCAT not designed for earth to space coexistence study, a statistical and deterministic comparison approach was taken based on the footprint of the satellites considered. It was assumed that whenever a satellite wide beam is considered, all the RLANs under the satellite footprint contribute to interference in the FSS uplink towards the satellite space station (the transponder). In satellite spot beam assumption, only the population for Kenya was considered. The regions under consideration for interference computation from RLANs are therefore either Kenya only or all the continents under the satellite footprint. Once the region has been defined the population of the region is then transformed into an active RLAN device population (more details in Section 4.3). The RLAN device population is then used to calculate the aggregate interference incident to the satellite. In calculating the aggregate interference a propagation system model consisting of propagation path loss, building loss, body loss, clutter loss, polarisation mismatch loss and antenna gain are considered. This is elaborated in detail in Section 4.3.

## 6.2. SATELLITES CONSIDERED AND THEIR PARAMETERS

Satellites considered in this study are listed in Table 21. The table lists satellites that have been taken as representative as those requiring protection interference from RLANs in the African region. Their associated parameters are also shown in the table. Details of the satellites were obtained from https://satbeams.com/ and the respective satellite operator websites. Maximum receive antenna gain is calculated from the receiving thermal noise temperature and the figure of merit. Satellite receiving system noise temperature is assumed to be 250 K. Satellite footprints for the satellites listed in the table are shown in Sections 4.2.1 to 4.2.4.

[4] Immersat Response to Ofcom on "Strategic Review of Satellite and Space Science use of Spectrum"

**Table 17: Satellites considered for co-existence calculations and their parameters**

| Satellite | Beam Reference | Sub-satellite longitude | Maximum Receive Gain (dBi) | Figure of merit (dB/K) (using thermal noise) | Receiving System Noise Temperature (K) | Populations included in calculation |
|---|---|---|---|---|---|---|
| **Intelsat 39** | C Band Hemi-beams | 62° E | 29.18 | 5.2 | 250 | Africa, Europe, Asia, Australia |
| **Intelsat 37** | C Band Beams | 342° E | 26.98 | 3 | 250 | Africa, Latin America, Europe |
| **Intelsat 901** | C Band Hemi-beams | 332.5° E | 29.88 | 5.9 | 250 | Africa, South America, Europe |
| **Intelsat 36** | C Band Land Mass Beam | 68.5° E | 24.98 | 1 | 250 | Africa, Europe, Asia, Australia |

### 6.2.1. INTELSAT 39 FOOTPRINT

C-band and Ku-band capacity to provide broadband and video distribution services across Africa, Europe, the Middle East and Asia. The satellite will also enhance mobile connectivity for aero, maritime and government users operating in the Indian Ocean region. replacing Intelsat 902.

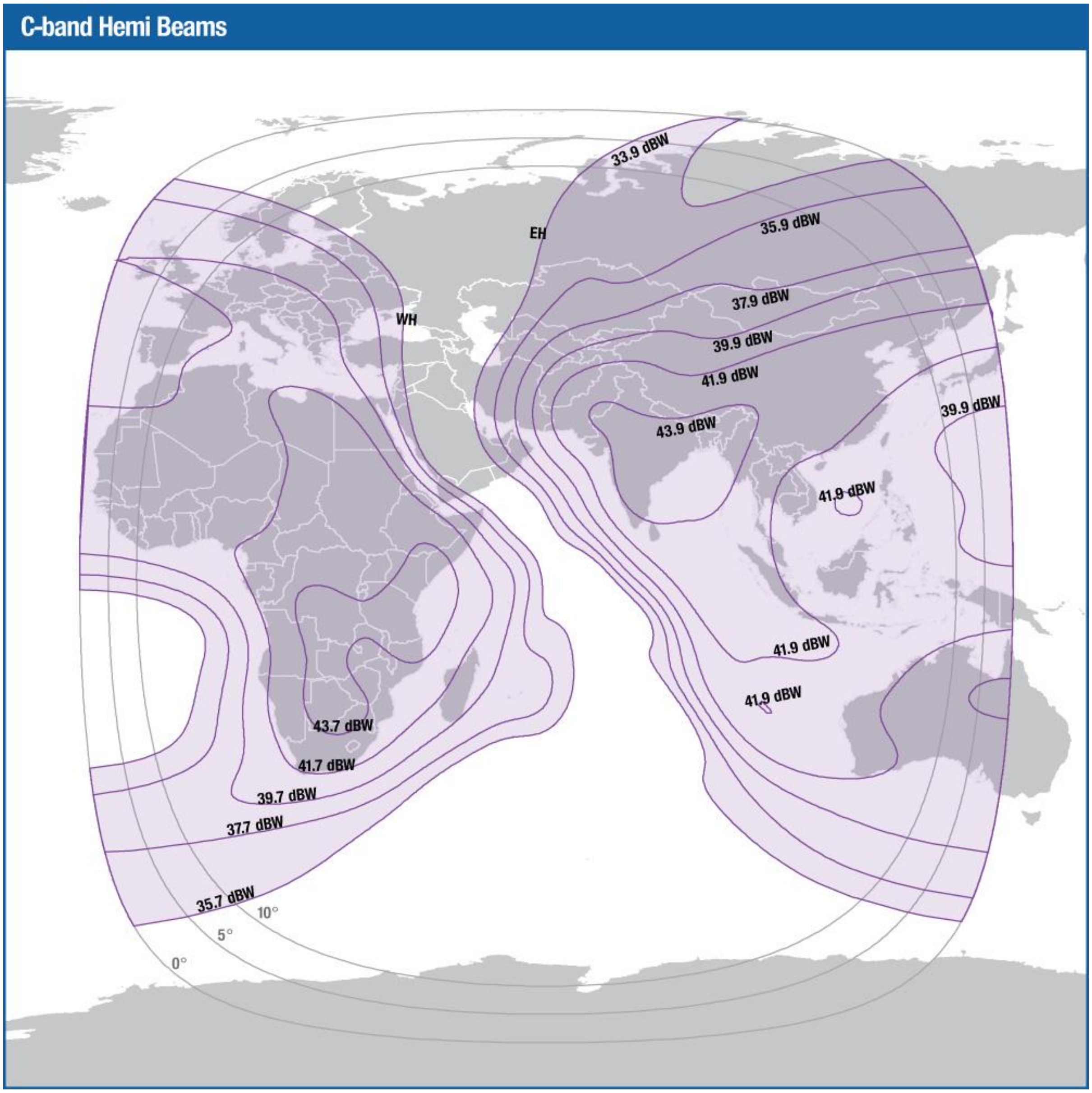



**Figure 20: Intelsat 39 Footprint**

Source: SatTvInfo.net

## 6.2.2. INTELSAT 37E FOOTPRINT

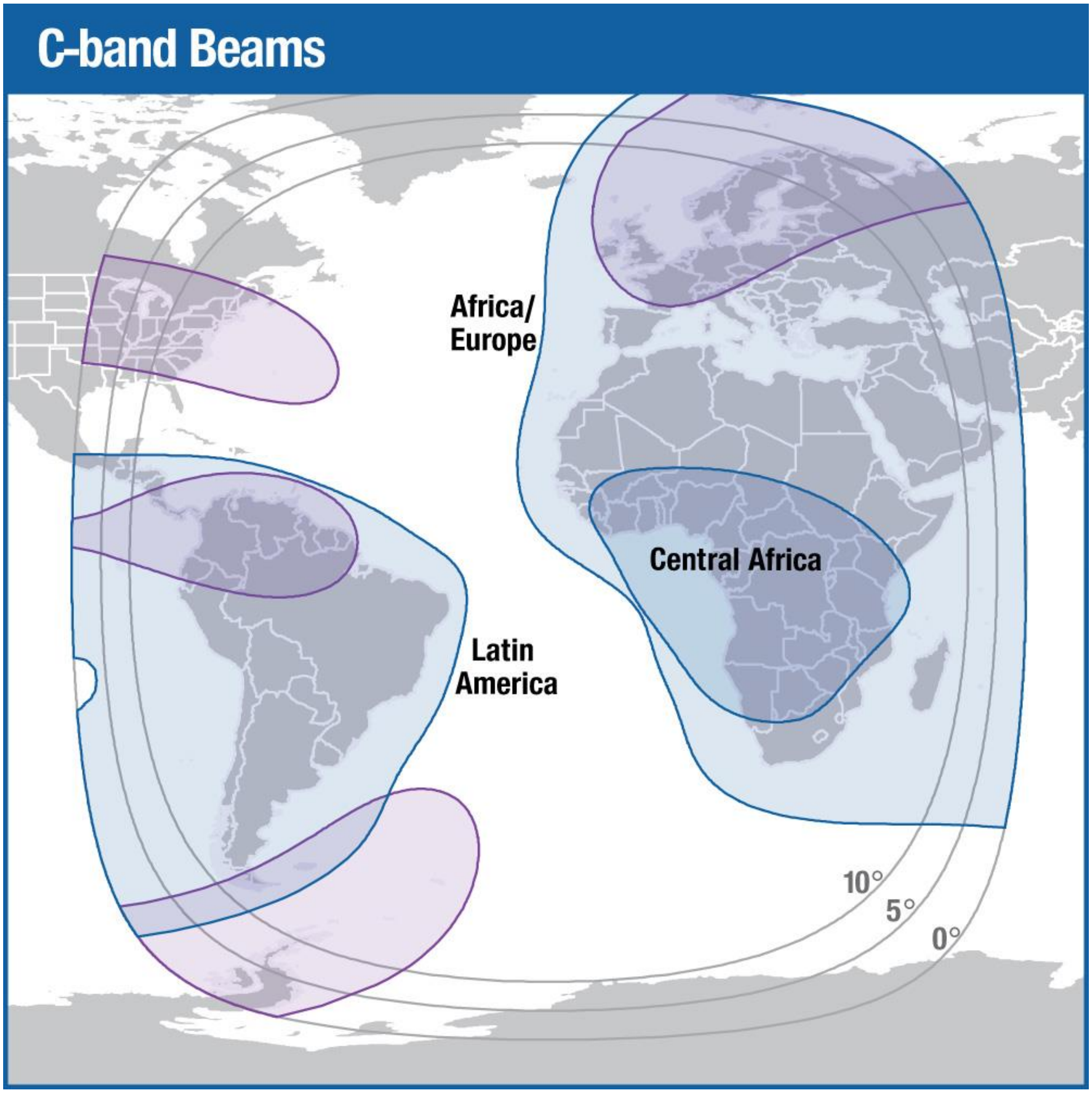



**Figure 21: Intelsat 37E Footprint**

Source: Intelsat 37e at 342˚E

### 6.2.3. INTELSAT 901 FOOTPRINT

44 C-band and 12 Ku-band transponders, broadcasting, business services, direct-to-home TV broadcasting, telecommunications, VSAT networks. Planned for deployment to the 27.5° W.L. orbital location. The was raised to 300 km above the geostationary arc and docked with the MEV-1 (S2990) spacecraft. Intelsat 901 was then reinserted to 27.5° W.L as a combined vehicle stack ("CVS") with MEV-1.

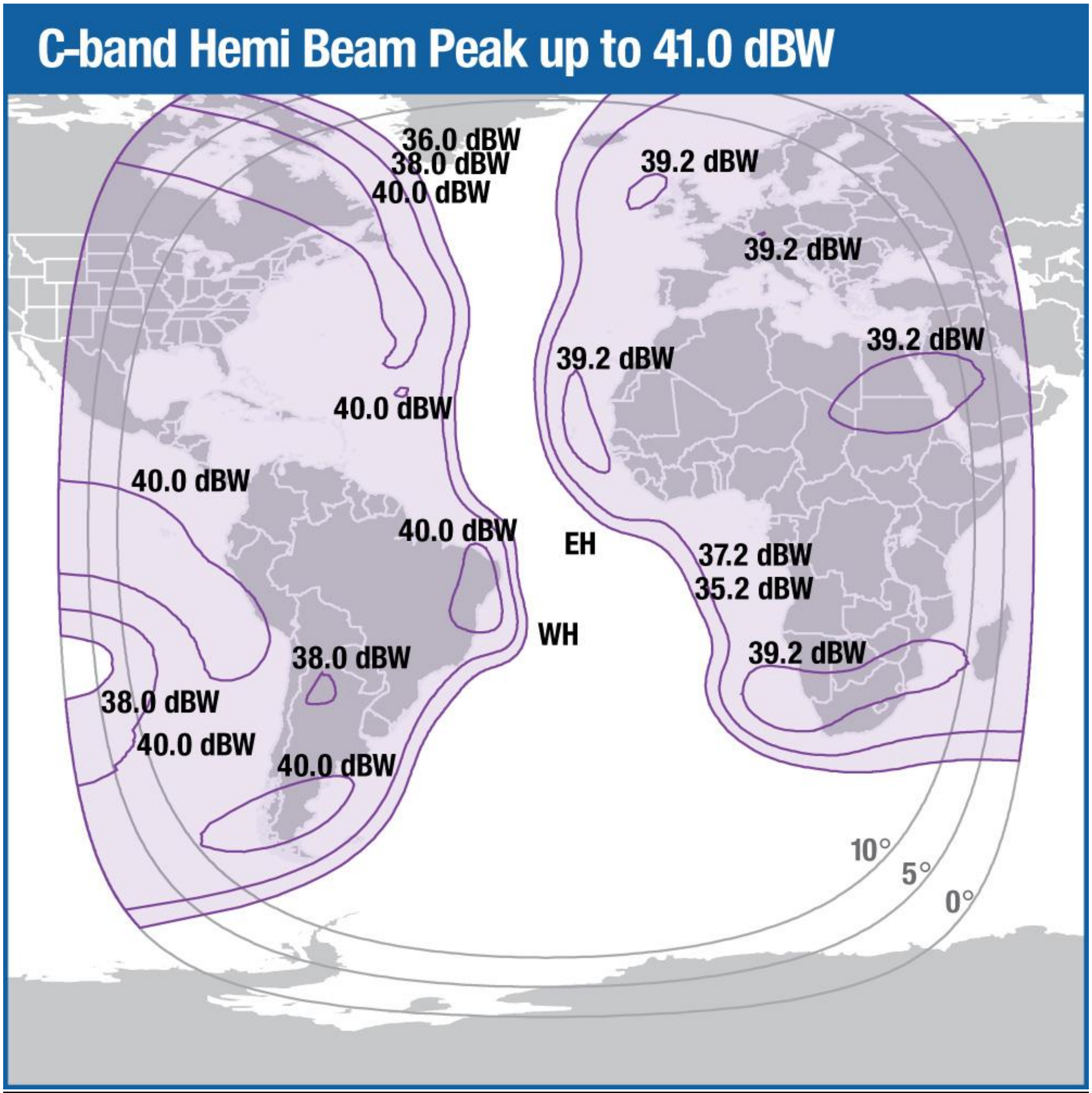



**Figure 22: Intelsat 901 Footprint**

Source: SkyBrokers

### 6.2.4. INTELSAT 36 FOOTPRINT

12 C-band and 42 Ku-band transponders to provide direct-broadcast television services to a broad swath of Africa, with African satellite-television provider MultiChoice using the Ku-band payload under a contract agreement with Intelsat.

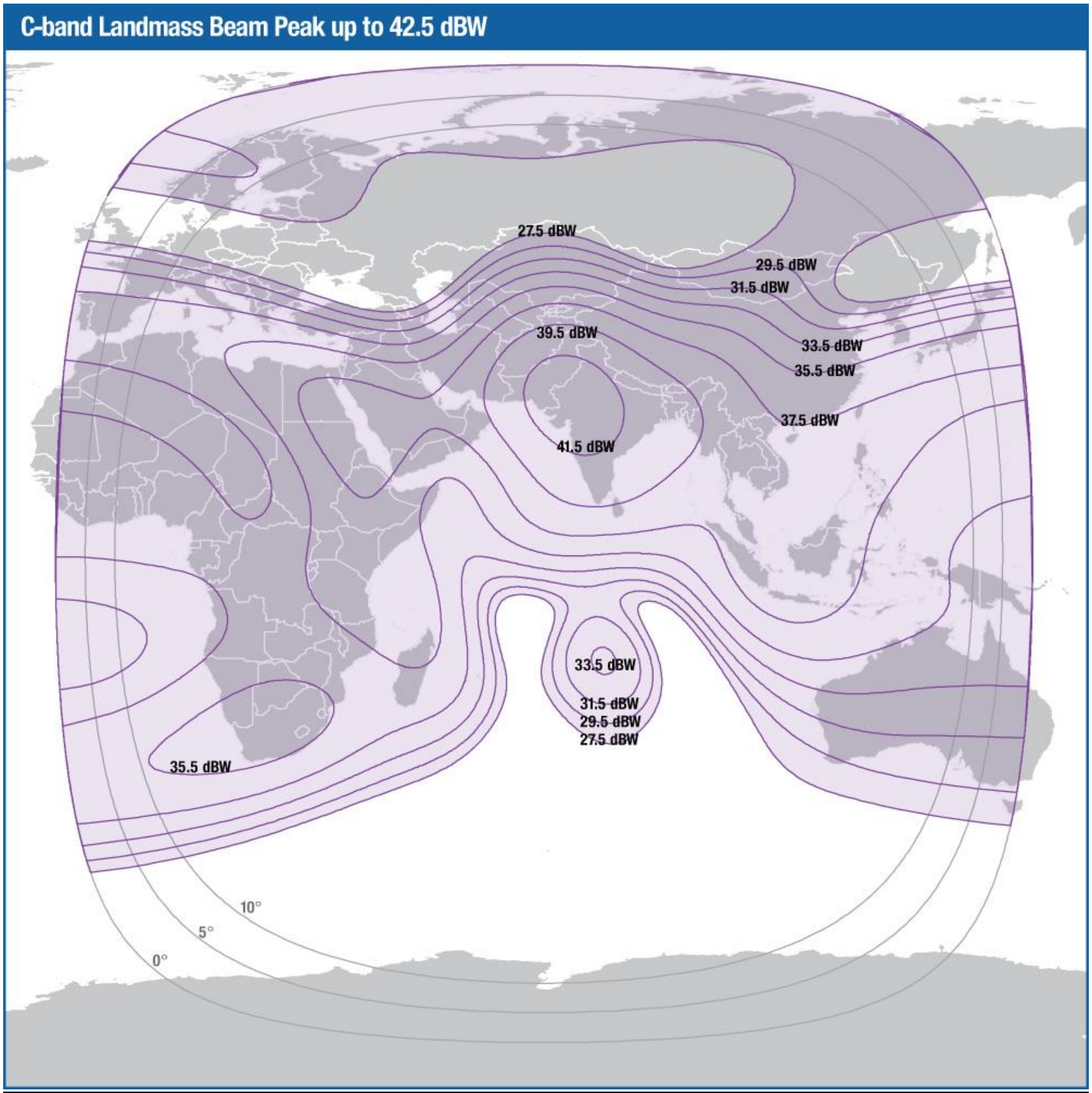



**Figure 23: Intelsat 36 Footprint**

Source: FlySat

## 6.3. RLAN DEPLOYMENT MODEL

The deployment model applied for the FSS coexistence study took a similar approach to that of FS. The same parameter values used in the FS study are also applied in the FSS study. Table 21 shows the deployment model. The parameters used in the calculation of instantaneously transmitting devices that have been applied for Kenya were assumed to apply for all the regions. Different continents are listed because GEO satellite footprints transcend multiple continents. 98% and 2% are assumed the percentage of indoor and outdoor devices, respectively. The estimated population values for the various continents listed in the table have been adopted from ECC Report 302 and  Mexico 6 GHz coexistence study.

**Table 18: RLAN Deployment Model**

| Parameter | Kenya | Africa | Europe | Middle East | Latin America |
|---|---|---|---|---|---|
| Total Population in 2025 | 59,981,000 | 1,517,706,140 | 768,589,000 | 496,337,400 | 934,760,659 |
| Wireless devices operating in licence exempt spectrum | 80.00% | 80.00% | 80.00% | 80.00% | 80.00% |
| Busy Hour Population | 62.70% | 62.70% | 62.70% | 62.70% | 62.70% |
| 6 GHz Factor | 64.39% | 64.39% | 64.39% | 64.39% | 64.39% |
| Market Factor | 32.00% | 32.00% | 32.00% | 32.00% | 32.00% |
| RF Activity Factor | 1.97% | 1.97% | 1.97% | 1.97% | 1.97% |
| Overlap Factor | 12.28% | 12.28% | 12.28% | 12.28% | 12.28% |
| Instantaneously Transmitting Devices within a 40 MHz FSS Channel | 14,996 | 379,470 | 192,169 | 124,098 | 233,717 |
| | | | | | |
| Number of Outdoor Devices (2%) | 299 | 7589 | 3843 | 2481 | 4674 |
| Number of Indoor Devices (98%) | 14,696 | 371,880 | 188,325 | 121,616 | 229,042 |

## 6.4. RLAN TO FSS PROPAGATION SYSTEM MODEL AND CALCULATION OF I/N

In order to compute the I/N value, the aggregate interference from RLANs is first computed before adding the antenna gain and subtracting clutter loss, building penetration loss, body loss and building penetration loss. The following considerations are made for the entire RLAN for FSS propagation system model:

- Free space propagation model as per Recommendation ITU-R P.525 with a distance of 37,000 km and frequency of 6 GHz. These values give a path loss value of 199.8 dB.
- Clutter loss as per recommendation ITU-R P.2108. An average value of 3 dB is considered similar to ECC 302 Report.
- Indoor RLANs experience a building penetration loss according to Recommendation ITU-R P.2109. An average value of 14 dB is considered, similar to ECC 302 Report.
- Polarisation mismatch of 3dB as per ECC 302 Report because this is a similar study.

The following are detailed of the steps in calculation I/N:

### 6.4.1. CALCULATION OF AGGREGATE RLAN EIRP

The total number of instantaneously transmitting RLAN devices is first computed as per Table 21. The computation is similar to that of the FS study. This computation takes into account the entire footprint of the satellite if a wide beam scenario is considered. If a spot beam scenario is considered, only the Kenya population is considered as per Table 21. In order to get the aggregate interfering power, the average EIRP per RLAN device is first computed according to Table 22. Table 22 shows details about computation of average EIRP per device. Details about computation of the bandwidth factor in Table 22 can be found in Annex 2 of ECC Report 302. Average power in the same table is calculated using a value of 2125 total number of devices as computed also in Annex 2 of ECC Report 302. Average EIRP indicated in Table 22 (2.095 mW) is computed considering the power distribution probability in Table 23. The RLAN power distribution is similar to the FS study. In computing the average EIRP applied in Table 22 , a building entry loss of 14 dB is subtracted from the sum power in Table 23 for the indoor RLANs. Unlike the average EIRP computed in Table 22, the one computed in Table 23 considers bandwidth overlap factor. Aggregate RLAN EIRP is then calculated by multiplying the average EIRP per device with the total number instantaneously transmitting devices.

**Table 19: Computation of Average EIRP per Device**

| WAS/RLAN Channel (MHz) | Average EIRP (mW) | Number of WAS/RLAN | Bandwidth Factor | Total Power (mW) |
|---|---|---|---|---|
| 20 | 2.095 | 126 | 0.6666 | 175.970 |
| 40 | 2.095 | 166 | 0.5 | 173.892 |
| 80 | 2.095 | 833 | 0.5 | 872.604 |
| 160 | 2.095 | 1000 | 0.25 | 523.772 |
| | | | Aggregate power (mW) | 1746.238 |
| | | | Average EIRP per Device (mW) | 0.822 |

**Table 20: RLAN Power Distribution**

| Power (mW) | 200 | 100 | 50 | 13 | 1.000 | Sum Power (mW) |
|---|---|---|---|---|---|---|
| Indoor | 9.81% | 6.24% | 26.01% | 52.31% | **0.056** | |
| Outdoor | 0.00% | 0.00% | 6.93% | 93.07% | **0.000** | |
| | | | | | | |
| Indoor (98%) | 19.62 | 6.24 | 13.005 | 6.8003 | **0.056** | **45.72** |
| Outdoor (2%) | 0 | 0 | 3.465 | 12.0991 | **0.000** | **15.56** |

### 6.4.2. CALCULATION OF AGGREGATE INTERFERENCE INCIDENT TO SATELLITE

Aggregate interference incident to satellite is calculated using the following formula:

$I_{sat}$= EIRP - $L_{blg}$- $L_{body}$- PL - $L_p$- $L_c$- $L_s$ + G,

where

$I_{sat}$ = Aggregate interference incident to satellite (dBW)

$E$IRP = WAS/RLAN aggregate EIRP (dBW),

$L_{blg}$ = Building Entry Loss (dB),

$L_{body}$ = Body loss,

PL = Free space path loss (dB),

$L_p$ = Polarisation mismatch loss (3 dB),

$L_c$ = Clutter loss (dB),

G = Antenna gain (dBi).

### 6.4.3. CALCULATION OF EQUIVALENT NOISE TEMPERATURE

Equivalent noise temperature is calculated using the following formula:

$T_{equiv}$ = $10^{I_{sat}}$ / $10^{k}$,

where:

$T_{equiv}$ = Satellite equivalent noise temperature (K),

$I_{sat}$ = Aggregate interference incident to satellite (dBW/Hz) and

$k$ = Boltzmann's constant (-228.6 dBW/K/Hz).

### 6.4.4. CALCULATION OF CHANGE IN SATELLITE NOISE TEMPERATURE DUE TO RLAN INTERFERENCE

This is calculated as follows:

$\frac{\Delta T}{T}$(%) = ( $T_{equiv}/S_{Ntemp}$) × 100, where:

$\frac{\Delta T}{T}(\%)$ = Change is satellite noise temperature due to interference,

$T_{equiv}$ = Satellite equivalent noise temperature (K) and

$S_{Ntemp}$ = Satellite noise temperature (K).

### 6.4.5. CALCULATION OF I/N

I/N is calculated using the following formula:

$\frac{I}{N}$ (dB) = 10 $Log_{10}(\frac{\Delta T}{T}/100)$,

where

$\frac{I}{N}$ = Interference to noise ratio (dB) and

$\frac{\Delta T}{T}$ = Change is satellite noise temperature due to interference (%).

### 6.5.6. RESULTS

This section presents the I/N results for the different satellites. Computation of aggregate interference incident to satellite has already been elaborated in section 4.3. According to ITU-R S. 1432-1, the minimum I/N threshold for satellites in the earth to space scenario where interference is caused by many RLANs is -10.5 dB. The I/N results for all the satellites under consideration provided in Tables 24 to 27 show that there is a good protection margin for all the satellite beams under consideration. All the I/N values for the different satellite beams are way below the minimum (threshold) I/N value of -10.5 dB. As expected, the I/N is much lower for the spot beam case (Kenya only population considered) compared to the wide beam scenario when the entire population under a satellite footprint is considered.

**Table 21: Results for Intelsat 39**

| | Kenya only | Entire Satellite Footprint |
|---|---|---|
| Instantaneous Number of Transmitting 6 GHz Devices (Total) | 14,996 | 695,737 |
| Number of WAS/RLAN in 40 MHz receiver (bandwidth factor 12.28%) | 1842 | 147496 |
| Transponder bandwidth (MHz) | 40.00 | 40.00 |
| Aggregate e.i.r.p. (bandwidth correction) (mW) | 1513.28 | 403490 |
| Aggregate e.i.r.p. (bandwidth correction) dBW | 1.80 | 26.06 |

| | | |
|---|---|---|
| WAS/RLAN antenna discrimination (dB) | 0 | 0 |
| Free Space Path Loss (dB) | 199.8 | 199.8 |
| Polarisation discrimination (dB) | 3 | 3 |
| Clutter loss (dB) | 1.7 | 1.7 |
| Weighted satellite antenna gain (dBi) | 29.17 | 29.17 |
| Aggregate interference incident to satellite (dBW) | -173.53 | -149.27 |
| Aggregate interference incident to satellite (dBW/Hz) | -249.55 | -225.29 |
| Satellite receiver Noise Temp. (K) | 250 | 250 |
| Boltzmann's Constant (dBW/K/Hz) | -228.6 | -228.6 |
| Equiv. interfering Temp. (K) | 0.01 | 2.14 |
| ΔT/T (%) | 0.00 | 0.86 |
| I/N (dB) | -45 | -21 |

**Table 22: Results for Intelsat 37**

| | Kenya only | Entire Satellite Footprint |
|---|---|---|
| Instantaneous Number of Transmitting 6 GHz Devices (Total) | 14996.00 | 805356.00 |
| Number of WAS/RLAN in 40 MHz receiver (bandwidth factor 12.28%) | 3179.15 | 170735.47 |
| Transponder bandwidth (MHz) | 40 | 40 |
| Aggregate e.i.r.p. (bandwidth correction) (mW) | 2612.50 | 403490 |
| Aggregate e.i.r.p. (bandwidth correction) dBW | 4.17 | 26.06 |
| WAS/RLAN antenna discrimination (dB) | 0 | 0 |
| Free Space Path Loss (dB) | 199.8 | 199.8 |
| Polarisation discrimination (dB) | 3 | 3 |
| Clutter loss (dB) | 1.7 | 1.7 |
| Weighted satellite antenna gain (dBi) | 29.99 | 29.9 |
| Aggregate interference incident to satellite (dBW) | -170.34 | -148.54 |
| Aggregate interference incident to satellite (dBW/Hz) | -246.36 | -224.56 |
| Satellite receiver Noise Temp. (K) | 250 | 250 |
| Boltzmann's Constant (dBW/K/Hz) | -228.6 | -228.6 |
| Equiv. interfering Temp. (K) | 0.02 | 2.53 |

| | | |
|---|---|---|
| ΔT/T (%) | 0.01 | 1.01 |
| I/N (dB) | -42 | -20 |

**Table 23: Results for Intelsat 901**

| | Kenya | Entire Satellite Footprint |
|---|---|---|
| Instantaneous Number of Transmitting 6 GHz Devices (Total) | 14,996 | 805,356 |
| Number of WAS/RLAN in 40 MHz receiver (bandwidth factor 12.28%) | 1842 | 170735 |
| Transponder bandwidth (MHz) | 40 | 40 |
| Aggregate e.i.r.p. (bandwidth correction) (mW) | 32588.94 | 403490 |
| Aggregate e.i.r.p. (bandwidth correction) dBW | 15.13 | 26.06 |
| WAS/RLAN antenna discrimination (dB) | 0 | 0 |
| Free Space Path Loss (dB) | 199.8 | 199.8 |
| Polarisation discrimination (dB) | 3 | 3 |
| Clutter loss (dB) | 1.7 | 1.7 |
| Weighted satellite antenna gain (dBi) | 29.87 | 29.9 |
| Aggregate interference incident to satellite (dBW) | -159.50 | -148.54 |
| Aggregate interference incident to satellite (dBW/Hz) | -235.52 | -224.56 |
| Satellite receiver Noise Temp. (K) | 250 | 250 |
| Boltzmann's Constant (dBW/K/Hz) | -228.6 | -228.6 |
| Equiv. interfering Temp. (K) | 0.20 | 2.53 |
| ΔT/T (%) | 0.08 | 1.01 |
| I/N (dB) | -31 | -20 |

**Table 24: Results for Intelsat 36**

| | Kenya Only | Entire Satellite Footprint |
|---|---|---|
| Instantaneous Number of Transmitting 6 GHz Devices (Total) | 14,996 | 695,737 |

| | | |
|---|---|---|
| Number of WAS/RLAN in 40 MHz receiver (bandwidth factor 12.28%) | 1842 | 147496 |
| Transponder bandwidth (MHz) | 40 | 40 |
| Aggregate e.i.r.p. (bandwidth correction) (mW) | 1513.28 | 403490 |
| Aggregate e.i.r.p. (bandwidth correction) dBW | 1.80 | 26.06 |
| WAS/RLAN antenna discrimination (dB) | 0 | 0 |
| Free Space Path Loss (dB) | 199.8 | 199.8 |
| Polarisation discrimination (dB) | 3 | 3 |
| Clutter loss (dB) | 1.7 | 1.7 |
| Weighted satellite antenna gain (dBi) | 24.98 | 24.98 |
| Aggregate interference incident to satellite (dBW) | -177.72 | -153.46 |
| Aggregate interference incident to satellite (dBW/Hz) | -253.74 | -229.48 |
| Satellite receiver Noise Temp. (K) | 250 | 250 |
| Boltzmann's Constant (dBW/K/Hz) | -228.6 | -228.6 |
| Equiv. interfering Temp. (K) | 0.00 | 0.82 |
| ΔT/T (%) | 0.00 | 0.33 |
| I/N (dB) | -49 | -25 |

## 6.5. FSS CO-EXISTENCE CONCLUSION

The results have shown that for all the satellite beams under consideration, the I/N threshold is not exceeded. This implies that RLANs can co-exist with FSS uplink without any harmful interference in the 6 GHz band.

# REFERENCES


[1] S. R. Gulasekaran and S. G. Sankaran, Wi-Fi 6 Protocol and Network, Norwood: Artech House, 2021.

[2] Dynamic Spectrum Alliance, "6 GHz License Exempt: Why the full 1200 MHz and Why Now?," August 2021. [Online]. Available: https://dynamicspectrumalliance.org/wp-content/uploads/2021/08/6GHz-License-Exempt-Band-Why-1200-MHz-and-Why-Now.pdf. [Accessed 27 September 2022].

[3] Litepoint, "A Guide to Wi-Fi 6E: Wi-Fi in the 6 GHz Band," Litepoint, San Jose, 2020.

[4] Wi-Fi Alliance, "Wi-Fi Spectrum Needs Study," February 2017. [Online]. Available: https://www.wi-fi.org/download.php?file=/sites/default/files/private/Wi-Fi%20Spectrum%20Needs%20Study_0.pdf. [Accessed 27 September 2022].

[5] Dynamic Spectrum Alliance, "Socio-economic benefits of IMT versus RLAN in the 6425-7125 MHz Band in Europe," DSA, Oregon, 2022.

[6] International Telecommunication Union, "Nomenclature of the frequency and wavelength bands used in telecommunications," August 2015. [Online]. Available: https://www.itu.int/dms_pubrec/itu-r/rec/v/R-REC-V.431-8-201508-I!!PDF-E.pdf. [Accessed 27 September 2022].

[7] Kenya Nationa Bureau of Statistics, "2019 Kenya Population and Housing Census Volume 1: Population by County and Sub-County," August 2019. [Online]. Available: https://www.knbs.or.ke/?wpdmpro=2019-kenya-population-and-housing-census-volume-i-population-by-county-and-sub-county. [Accessed 27 September 2022].

[8] UN Department of Economic and Soical Affairs - Population Division, "World Population Prospects 2022," July 2022. [Online]. Available: https://population.un.org/wpp/Download/Standard/MostUsed/. [Accessed 27 September 2022].

[9] Wi-Fi Alliance, *Global Spectrum Series - 'The WRC-23 Webinar',* Virtual: Wi-Fi Alliance, 2021.

[10] Communications Authority of Kenya, "Guidelines on the Use of Radiofrequency Spectrum by Short Range Devices," June 2022. [Online]. Available: https://www.ca.go.ke/wp-content/uploads/2022/07/Guidelines-on-the-Use-of-Radiofrequency-Spectrum-by-Short-Range-Devices-2022.pdf. [Accessed 26 September 2022].

[11] African Telecommunications Union, "ATU-R Recommendation 005-0," July 2021. [Online]. Available: https://atuuat.africa/wp-content/uploads/2021/08/En_ATU-R-Recommendation-005-0.pdf. [Accessed 2022 September ].

[12] J. Pahl, Interference Analysis - Modelling Radio Systems for Spectrum Management, Chichester: John Wiley and Sons, Ltd., 2016.

[13] European Communications Committee, "ECC Report 252 - Spectrum Engineering Advanced Monte Carlo Analysis Tool," CEPT, Copenhagen, 2016.

[14] A. Stevens, Monte-Carlo Simulation - An Introduction for Engineers and Scientists, Florida: Taylor and Francis Group, LLC, 2022.

[15] International Telecommunication Union, "Recommendation ITU-R F.758-7," November 2019. [Online]. Available: https://www.itu.int/dms_pubrec/itu-r/rec/f/R-REC-F.758-7-201911-I!!PDF-E.pdf. [Accessed 26 September 2022].

[16] International Telecommunication Union, "Recommendation ITU-R F.758-7," November 2019. [Online]. Available: https://www.itu.int/dms_pubrec/itu-r/rec/f/R-REC-F.758-7-201911-I!!PDF-E.pdf. [Accessed 26 September 2022].

[17] International Telecommunication Union , "Recommendation ITU-R F.1245-3," January 2019. [Online]. Available: https://www.itu.int/dms_pubrec/itu-r/rec/f/R-REC-F.1245-3-201901-I!!PDF-E.pdf. [Accessed 23 September 2022].

[18] Wireless Innovation Forum, "Propagation Models and Interference Protection Criteria for Sharing Between the Fixed Service and Unlicensed Deviced in the 6 GHz Band," The Software Defined Radio Forum Inc., Reston, 2019.

[19] International Telecommunication Union Radiocommunication Sector (ITU-R), "Recommendations ITU-R P.2109-1 - Prediction of Building Entry Loss," August 2019. [Online]. Available: https://www.itu.int/dms_pubrec/itu-r/rec/p/R-REC-P.2109-1-201908-I!!PDF-E.pdf. [Accessed 3 November 2022].

[20] Information Society Technologies, "WINNER II Channel Models," NOKIA SIEMENS NETWORKS, Muenchen, 2007.

[21] International Telecommunication Union - Radiocommunication Sector, "Prediction Procedure for the Evaluation of Interference Between Stations on the surface of Earth at Frequencies above about

0.1 GHz," July 2015. [Online]. Available: https://www.itu.int/dms_pubrec/itu-r/rec/p/R-REC-P.452-16-201507-S!!PDF-E.pdf. [Accessed 3 November 2022].

[22] International Telecommunication Union, "Prediction of Clutter Loss," September 2021. [Online]. Available: https://www.itu.int/dms_pubrec/itu-r/rec/p/R-REC-P.2108-1-202109-I!!PDF-E.pdf. [Accessed 3 November 2022].

[23] Electronic Communications Committee, "SEAMCAT Handbook," European Communications Office, Copenhagen, 2016.

[24] Kenya National Bureau of Statistics, "2019 Kenya Population and Housing Census," KNBS, Nairobi, 2019.

Strathmore University

*@iLabAfrica Centre*

4th Floor, Student Centre,
Strathmore University,
Madaraka Estate, Ole Sangale Road
P.O Box 59857 - 0200 City Square
Nairobi Kenya

Facebook: @iLabAfrica
Twitter: @iLabAfrica
Instagram: @iLabAfrica
LinkedIn: @iLabAfrica
www.ilabafrica.ac.ke