The Indonesian Journal of Computer Science
www.ijcs.net
Volume 14, Issue 3, June 2025
https://doi.org/10.33022/ijcs.v14i3.4861

A Model to Amplify Transmission Quality of Satellite Television

Lebogang Maja[1], Deon Du Plessis[2], Topside Mathonsi [3], Tshimangadzo Tshilongamulenzhe[4]
lebogangmaja174@gmail.com[1], duplessisdp@tut.ac.za[2], mathonsite@tut.ac.za[3], tshilongamulenzhetm@tut.ac.za[4]
[1,2,3,4] Tshwane University of Technology

Article Information

Received : 27 Apr 2025
Revised : 30 May 2025
Accepted : 9 Jun 2025

Keywords

Satellite Television, Satellite Technologies, broadcasting,

Abstract

One of the various applications of communication satellite technologies is broadcasting satellite television (TV). However, Satellite TV broadcasting has a deficiency of outage caused by rain fade that instigate due to bad raining weather which at once will cuts signal transmission from the transmitter satellite to the receiver dish. This study was undertaken to explore the challenges that satellite TV broadcasting faces, which is caused by the rain fade effect. Thereafter, a model to amplify the transmission quality of satellite television is designed. The proposed Gau-satcomm algorithm, ITU-R model, and SAM model had an average BER of 5%, 8%, and 10%, respectively. Additionally, the Gau-Satcomm algorithm, SAM model, and ITU-R model experienced 4%, 9%, and 11% attenuation, respectively. Furthermore, the study compared outage probability across three algorithms at frequencies over 10 GHz, the proposed Gau-satcomm algorithm, ITU-R algorithm, and the SAM algorithm minimized outages by 10%, 7%, and 5%, respectively.

A. Introduction

Satellite Television (TV) has enabled better viewing from the traditional analogue TV known as over the air (OTA) [1-5], which uses analog signals to transmit video Frequency Modulation (FM) by using antenna TV [6-10]. The introduction of satellite TV has improved the quality of the picture on television and provided much more entertaining viewing by providing more bandwidth, flawless and crisp video quality [11-15].

By far and large, satellites offer instant and almost total coverage within their footprint, giving it an advantage over both terrestrial and cable television [16-20]. A signal carrying the TV programs is beamed from the broadcast center station via a large satellite dish up to the satellite receivers that are in space, where it is amplified and retransmitted toward the earth to individual satellite receiver dish of consumers [20-25]. The arrival of digital satellite platforms has opened the way for increasing specialization in their content. Digital TV can increase segmentation and opens ways for the fragmented viewing and ethnicization of the media, in the sense that different ethnic groups consume their own media [16].

Satellites, which by far are the best available option for distributing television signals to the customers for better, clearer, and non-blurry television viewing, however, Satellite TV have some limitations that are caused by atmospheric conditions such as Air Density and Pressure, these atmospheric conditions are caused by rain fade. Rain fade outage has been for years the problem that disrupts satellite television viewing. Since satellite transmission is reliant on the weather, downtime can result from very rainy weather [18]. Satellite communication systems become increasingly sensitive to weather conditions as their operating frequency is increasing to avoid electromagnetic spectrum congestion and enhance their capacity [4].

Interference effects are of utmost importance to the reliable design of modern satellite communication systems operating at Kurtz under (Ku) and Kurtz above (Ka) bands. In these frequencies, rain attenuation is the dominant fading mechanism particularly for Earth-space systems, the Outage probability of the maximal ratio combining dual branch spatial diversity schemes operating above 10 GHz. At these frequency bands (Ka and Ku) considering the line-of-sight conditions, rain attenuation is the dominant fading mechanism, which should be considered in the radio communications system design as stated by [13].

B. Related Works

Over the past years, various studies were conducted to minimize the impact that is caused by rain-fade impacting Satellite TV viewing. This research study will show the previous studies that were conducted by other researchers and outline the gaps. Microwave telecommunications links operating above 10 GHz are severely faded by rain. Most Research studies discovered that the incidence of rain at outage levels for terrestrial links has been experiencing an increasing trend over the last twenty years.

Many links would have seen the underlying incidence of outages double or triple over this period. Globally, rain height has also been increasing as the world has warmed. This leads to an increasing trend in rain fade experienced by earth space links. In some areas of the world, these effects will be combining to cause steep increases in the levels of fading experienced by Earth-space links. Interference problems are arising from the spectral coexistence between satellite communication networks that operate at frequencies above 10 GHz and particularly when they employ power control as a fade mitigation technique. In this frequency range, rain attenuation is the dominant tropospheric fading mechanism. The conditional acceptable intersystem interference probability of the Carrier-to-Interference Ratio of a satellite terminal interfered by an adjacent satellite network is defined as a figure of merit and analytically calculated considering a physical-mathematical model for the rainfall medium [13].

Interference effects are of utmost importance to the reliable design of modern satellite communication systems operating at Ku-bands and Ka-bands. In these frequencies, rain attenuation is the dominant fading mechanism particularly for Earth-space systems located in subtropical and tropical regions. On the other hand, the main propagation effect on interference between two adjacent satellite systems is considered the differential rain attenuation.

[7] stated that other than rainfall, sunshine, and cloudy weather are investigated on the Ku-band for the digital satellite television system. It was shown that; of all the adverse weather conditions, rainfall remains the greatest source of attenuation on signal propagated, miss alignment loss, ionosphere losses, fixed atmospheric loss, etc.

[5] proposed an artificial neural network-based algorithm used to classify dry and rainy periods and to model the signal variability obtained from non-rain-related effects. The rain attenuation can be reversed to obtain the path-averaged rain rate when the altitude of the rain layer is considered. Compared with co-located rain gauges and radar measurements taken over the full period of the campaign, the rainfall rates collected from this phase are compared and the most important rainfall events are analyzed. However, this method may cause signal attenuations and fixed atmospheric loss.

[6] stated that a new model, which uses prediction of carrier-to-noise plus interference ratio (CNIR) statistics, under the presence of rain fading conditions, applied to heavy rain climatic regions. The method is based on a model of convective rain cells and the gamma distribution assumption for point rainfall rate statistics, which fits better than lognormal distribution in subtropical and tropical regions. The study also predicted power-law parameters of specific rain attenuation. The numerical results are concentrated on the analytical examination of various operational parameters upon the CNIR statistics and the subsequent outage performance of the system. Comparison of the proposed model with an already existing one was attempted however, they still experiencing an outage that is caused to due rain fade.

Some high gain antennas with narrow beams were attempted by [14] which increased the signal-to-noise ratio (SNR) of received signals, and then to improve the rate and quality of communication. A Tower Mounted Amplifier (TMA) provides the ability to sense the directions of received signals, which can be exploited on both the satellite and the ground station. This method has low efficiency.

[8] conducted a study of the transfer of array unit-cell to operate at a single frequency of 12 GHz or 17.5 GHz. The peak gains of transmitting arrays are 25.31 dBi and 27.1 dBi, respectively. Hybrid arrangement consisting of an alternating

replacement of the unit-cell elements from the single frequency transmit arrays designed at 12 GHz and 17.5 GHz which was used to enhance the gain bandwidth of the transmit array. A broadband gain response was achieved with 2.4 GHz over the band from 12 to 19 GHz. This method has low gain and low efficiency, which need to be overcome in this research study.

Three separate adaptive frequency hopping (FH) schemes using channel prediction were proposed by [18]. The first, by using a channel ineptness probability approximation as the input of a look-up table, determines how many channels to evaluate. The second does the same but in addition to the probability of channel ineptness, it also uses the receive buffer's number of packets as an input parameter. Look-up tables are not used in the third algorithm. To preserve a list of ready-to-use platforms, this prediction scheme only transmits test packets. Therefore, it does not use projections, nor does it consider the buffer load.

A frequency-hopping spread spectrum security enhancement with encrypted spreading codes in a partial band noise jamming environment was suggested by [24] The main objective of the research was to test the insecurity of codes for linear feedback shift registers (LFSRS). Here the new approach to improve the protection of frequency hopping spread spectrum was proposed based on the encryption algorithm applied over spreading codes, called secret frequency hopping. The proposed encryption protection algorithm is highly reliable and, based on spread spectrum techniques, can be extended to all existing data communication systems. Since multi-user detection is an intrinsic function of the frequency hopping spread spectrum (FHSS), careful analysis of multi-user interference is carried out. A new set of methods must therefore be proposed that will reduce interference below the desired constant threshold.

[23] performed a report on electromagnetic interference, causes, impacts, and mitigation. The work was focused solely on the origins of electromagnetic signal transmission interference and their effects on critical devices, such as television. Reasonable electromagnetic compatibility experiments were carried out in such a way that the effects could be reduced or removed with, among others, the use of shielding, grounding, and filtering techniques. In its overview, the work is very modern and serves as a framework for advancement. However, the research work was mainly focused on communication frequencies at 10 GHz, which is considered a Ku-band.

Previously proposed methods mainly focused on communication frequencies at 10 GHz. In the proposed algorithm the transmission improvement of frequencies will be set over 10GHz to better avoid attenuation that is caused by rain at this frequency and improve efficiency. Therefore, the thrust of this research study is to develop a new system that will improve the impact of rain specifically on the Ku frequency band for satellite TV transmission.

C. Gau-satcomm Model Design

This section presents the design of the proposed Gau-satcomm model. The study integrated the Feeder Link Channel pre-coding, Vigorous Beam forming for Multibeam Satellite pre-coding and Radio Frequency (RF) User Link Channel Pre-coding when designing the proposed Gau-satcomm model. The transmitter space diversity fading technique was introduced to the RF User Link Channel pre-coded to reduce distinctive aspect of the multibeam SatCom channel caused by the high satellite-side signal correlation. The Gau-satcomm model is proposed to improve the television satellite coverage during bad weather condition such as rain fade, storm, and many more.

1. Feeder Link Channel pre-coding

To improve the Feeder link channel, subsequently the user link is a multi-user multiple input single-output link, the data for various beams are pre-coded at the gateway. The research study considers an analog clear dense wavelength division multiplexing device to preserve low-complexity signal processing on-board the satellite, where the pre-coded RF streams are modulated onto the optical carriers using intensity modulation [9]. The individual optical carriers are then multiplexed into a single fiber by wavelength-division and sent towards the satellite via the telescope. The optical signal receive by a telescope is obtained and demultiplexed in the satellite to obtain the multiplexing carriers of the individual dense wavelength division. The dense wavelength division that multiplexes optical carriers then converts the corresponding RF streams into the electrical signal by direct detection. The received RF signal for the satellite, $y_1 \in \mathbb{C}^{n*1}$ can be articulated as:

$$y_{1=Te+V_1} \tag{1}$$

where e $\in \mathbb{C}^{n*1}$ is the pre-coded signal vector with a total power limit of $C[\boldsymbol{e} \dagger \boldsymbol{e}] \leq D_t$, $V_1 \in \mathbb{C}^{n*1}$ is an additive noise vector consisting of zero-mean and variance Gaussian circularly symmetric complex entries σ_1^2,i.e. $\mathcal{CN}\ (0, \sigma_1^2)$, and T is the channel fading gain recognized as scintillation fading. This scintillation fading is usually modelled by lognormal on the Scintillation Index (SCI) σ_{SCI}^2 = C$[T^2]$ / $C[T]^2-1$ [17]. A simple measure of fading intensity is given by the SCI. This research study assumes that the Scintillation fading $_T$ is accompanied by a lognormal distribution widely used to model weak atmospheric turbulence in feeder SatCom links [19].

2. Vigorous Beam forming Multibeam Satellite Pre-coding

To improve the Multibeam Satellite, this research study uses Vigorous Beam forming multibeam satellite system, where the satellite has a reflector antenna feeding with a total feed represented by D. These feed signals are combined to create a radiation beam pattern represented by P beams that is known to be fixed. The research study assumes that a total number of D_s users are served per beam at the same time (the total number of served users by the satellite is PD_s). In this research study, all beams radiate within the same frequency band ($rep = 1$), and each beam is provided with an instant signal obtained at the $\mu - th$ user terminal as indicated below:

$$y^{(\mu)}=T^{(\mu)}\mathrm{e} + V^{(\mu)}\ ,\ \mu=1, \ldots, D_s \tag{2}$$

where vector $y^{(\mu)} \in \mathbb{C}^{P*1}$ is the vector comprising the μ-th user terminal received signals. ($[y^{(\mu)}]_P$ refers to the signal obtained from the μ-th user terminal on the $P - th$ beam), in comparison, vector $V^{(\mu)} \in \mathbb{C}^{P*1}$ includes each $\mu - th$ user terminal noise terms. $V^{(\mu)}$ entries shall be distinct and distributed in Gaussian with zero mean and unit variance (i.e, $B\ [V^{(\mu)}V^{(\mu)T}\ ] = L_P$, μ=1, …, D_s) . Ultimately, vector e ∈ $\mathbb{C}^{P*1}$ comprises all the signals transmitted.

The matrix of the channel can be defined as:

$$T^{(\mu)} = G^{(\mu)}.T^{\ (\mu)}, \mu=1,\ldots, D_s, \tag{3}$$

where the $(P; V)$- th matrix input $T^{-(\mu)} \in \mathrm{R}^{P*V}$ is

$$T^{-(\mu)}{}_{P,V} = \frac{\sqrt[R]{C_A^P\ C_S^V\ G_{P,V}}}{4\pi\ OF_P\sqrt{K_T\ ST_W}}. \tag{4}$$

Where F_P is the distance between the satellite and the $\mu - th$ user terminal, O is the frequency of the carrier, R is the speed of light, K_T is the constant of Boltzman, S is the noise temperature of the receiver, T_W is the bandwidth of the carrier, C_A^P is the antenna gain at the $\mu - th$ user terminal of the receiver, C_S^V is the antenna gain of the satellite transmission for the $P - th$ beam and $G_{P,V}$ is the normalized radiation gain of the beam between $P - th$ user terminal on board feed and the $\mu - th$ user terminal, therefore the multibeam gain relies on the pattern of antenna radiation and the position of the user terminal. For simplicity, this research study undertakes that each user terminals have an antenna gain, C_A^P = C_A, all satellite feeds have a communal transmitter antenna gain C_S^V= C_S, and the earth's curvature is negligible so that F_P = F. Therefore, it can be simplified as:

$$T^{-(\mu)}{}_{P,V} = \mathcal{E}\sqrt{G_{P,V}}\ \text{, where } \mathcal{E}\ \frac{\sqrt[\mu]{C_A\ C_S}}{4\pi\ OF\sqrt{K_T\ ST_W}} \tag{5}$$

An angle of $\theta\mu$, P will be demarcated between the $\mu - th$ user terminal and the $P - th$ beam, and a 6-dB angle for the $P - th$ beam will be created. Then on board the satellite, for a typical tapered-aperture antenna, the beam gain from the $P - th$ feed to the $\mu - th$ user terminal is estimated by:

$$T^{-(\mu)}{}_{P,V} = \mathcal{E}\left(\frac{\mathrm{P}_1(K_{P,V})}{2\ K_{P,V}} + 36\ \frac{\mathrm{P}_3(K_{P,V})}{K_{P,V}}\right), \tag{6}$$

where the first-kind Bessel functions of order 1 and 3 respectively are $K_{P,V}$ = 2.07123 $\frac{\cos^{-1}(\theta P,V)}{\sin(\theta\ P,6\ dB)}$, P_1 (.) and P_3 (.). Notice that the beam gain for all satellite feed pairs is constant for fixed user terminals on earth, and thus matrix $T^{-(\mu)}$ is decisive.

3. Radio Frequency User Link Channel Pre-coding

To improve the RF the transmitter space diversity fading will be introduced to the RF User Link Channel pre-coded in this research study. Where P fixed adjacent beams (single feed per beam) are produced earth by the satellite payload, equipped with an array fed reflector antenna consisting of P feeds. The research study assume that every beam is reused to the same frequency. The signal established at all the user terminals can be weighted into a vector $y_2 \in \mathbb{C}^{p*1}$ expressed as:

$$y_2 = L_{Cs} + p_2 = bkLe + bLp1 + p2 \quad (7)$$

Where $P_2 \in \mathbb{C}^{p*1}$ is the noise vector with elements derived from $\mathcal{CN}$ $(0,1)^4$ and the matrix $L \in \mathbb{C}^{p*p}$ represents the channel gains between the users of the P and the P feeds. It is possible to decay L as [22]:

$$L = FZ, \quad (8)$$

where $F \in \mathbb{C}^{p*p}$ is a random fading matrix containing the coefficients of rain attenuation and phase rotations due to various propagation paths, and $Z \in \mathbb{R}^{p*p}$ models of beam radiation pattern and path losses.

Compared to the terrestrial Multiple-input-multiple-output (MIMO) broadband service, a distinctive aspect of the multibeam SatCom channel is the high satellite-side signal correlation. Therefore, this research study introduces the transmitter space diversity fading technique in to the multibeam system to reduce distinctive aspect of the multibeam SatCom channel caused by the high satellite-side signal correlation. Each user terminal in the user link will have the same phase and the same fading gain between all feeds on-board the satellite antenna, as a common assumption in multibeam satellite channel models. It braced by the fact that the distance between the feeds is very slight relative to the distance between the user terminal and the satellite [11]. As a consequence, diagonal matrices can be modelled as the fading matrix D.

The $P-th$ diagonal component of the channel stage rotation matrix Φ is provided by equation 9.

$$[\Phi]P,P = exp\,(V(\varphi_{MB,P} + \varphi\varphi_{HJ,P})), P \in \cap \quad (9)$$

Where the stage rotation is represented by $\varphi\mathrm{MB,P} = \frac{2\pi}{\lambda} FP$ because of the propagation of the RF (MB) signal, FPdenotes the distance between the user terminal receiver's satellite and the $P-th$ user terminal, and φ HJ,P are attributable to down converters with low noise blocks [12]. It is presumed that the overall channel process is distributed uniformly in [0, 2π) [20].

Let $hP = |hP| exp\,(V\varphi P)$ denotes the $P-th$ diagonal part of the fading matrix D, where the amplitude and phase of the $P-th$ user terminal fading channel are represented by $|hP|$ and φP. This research study consider rain fading to be the dominant cause of Ka and higher frequency band output degradation [21]. The gain amplitude of the rain fading channel $|hP|, P \in \cap$ follows a double-log- ordinary which are given by the Probability Density Function (PDF) and Cumulative Distribution Function (CDF) respectively.

$$O|\mathrm{hP}|(\mathrm{e};\, \text{ӣ}\mathrm{P}, \grave{\mathrm{O}}\mathrm{P}) = -\frac{\left(\frac{\exp\left(-\left(\log(-\log(\mathrm{e}) - \text{ӣ}\mathrm{P})^2\right)\right)}{2\grave{\mathrm{O}}\mathrm{P}^2}\right)}{\sqrt{2\pi}\grave{\mathrm{O}}\mathrm{P}\ \mathrm{e}\log(\mathrm{e})} \quad (10)$$

$$O|\mathrm{hP}|(\mathrm{e};\, \text{ӣ}\mu, \grave{\mathrm{O}}\mathrm{P}) = \mathrm{Y}\left(\frac{\log(-\log(e)) - \text{ӣ}\mathrm{P}}{\grave{\mathrm{O}}\mathrm{P}}\right), \quad (11)$$

where $0 < e < 1, \bar{\mu}P = \mu k + log\,(log\,(10)) - log\,(20))$, the normal logarithm is log(.) and the Gaussian Q-function is O(.) The log-ordinary position parameter μP and the scale parameter ÒP, both expressed in dB, model the magnitude of the attenuation of rain fading [10]. Similarly, the rain fading channel process ÒP is also believed to be distributed uniformly in [0, 2π] [11]. This research study uses $Ye = Y\Phi$ from here onwards for notation aal simplicity, so that Ye is a diagonal matrix with its $P-th$ diagonal part being:

$$[Y]_{P,P} = á_P = |aP|\; exp\,(V(\varphi_{MB,P} + \varphi\varphi_{HJ,P})), P \in \cap \qquad (12)$$

4. Gau-satcomm Algorithm

This research study integrated the feeder link outage prediction algorithm, RF User Link Channel pre-coding and Vigorous Beam forming for Multibeam Satellite pre-coding algorithm with the aim of improving the Satellite coverage during bad weather to provide better Quality of Service (QoS).

Initialization:

$\mathrm{J, rep, D, P, V, R, O, D_{t,} C_{A\,,} Y_{2\,,} hp = 0}$

1. Radio signal transmission initiated on the feeder link channel using equation (1)
2. If (The received Radio signal is = equation (1)
3. Pre-code the signal vector **e** ⍰ $\mathbb{C}^{n*1}$
4. Pre-code the additive noise vector $\mathrm{D_t,\ V_1} \in \mathbb{C}^{n*1}$
5. Model the scintillation fading using longnormal on the Scintillation Index
6. Else return
7. Radio signal transmission initiated on the feeder link channel
8. End if
9. Multibeam satellite initiate an instant signal to all the beams using equation (2)
10. If (the received instant signal = equation (2))
11. Calculate the channel matrix and matrix input using equation (3 & 4)
12. The satellite Transmit the signal to $\mu -$ th user terminal then to $\mathrm{P} -$ th beam
13. Calculate the earth's curvature and satellite feeds communal transmitter antenna gain using equation (5&6)
14. Else Return to initiate instant signal
15. End if
16. User link establish signal at all the user terminals using equation (7)
17. Transmitter space diversity fading is used to model the $\mathrm{P} -$ th diagonal component of the channel stage rotation matrix Φ.
18. The Transmitter space diversity fading use equation (9) to calculate the distance between the user terminal receiver's satellite and the $\mathrm{P} -$ th user terminal.
19. $\mathrm{hP = |hP| exp\,(V\varphi P)}$ is used to calculate the amplitude and phase of the $\mathrm{P} -$ th & fading matrix D
20. If the amplitude and phase of the $\mathrm{P} -$ th = fading matrix D
21. Calculate the value of CDF and PDF using equation (10 &11) to determine

the log-ordinary position parameter μP and the scale parameter ÒP, to model the magnitude of the attenuation of rain fading

22. The equation (12) is used to calculate the other atmospheric condition rather that rain.
23. Else return Transmitter space diversity fading matrix
24. End If

D. Network Simulators

(1) NS2 - The network simulation software NS2 is free and open source. It includes LEO and Geostationary Earth Orbit (GEO) satellite models, as well as a broad range of network protocols, queuing methods, and node types [31]. The satellite models aren't perfect; for example, the error caused by GEO satellites drifting from their specified locations due to gravitational perturbations isn't considered. Unless it is a key point of analysis, this will rarely be a problem [32].

The simulator comes with all the required tools for simulating a satellite network. It is possible to identify satellite constellations, inter-satellite links (ISL), ground-to-satellite links, and elevation masks (smallest contact angle). In ns2, communication connection hand-off is done natively, and parameters including hand-off times can be set. A centralized routing agent is used for routing. A centralized routing agent decides the global network topology after each topology update, computes new routes for all nodes, and uses the routes to create a forwarding table on each node. This method of abstract routing will result in causality breaches, which is counterintuitive in terms of practical outcomes.

Another downside of ns2 is the time it takes to introduce new models. The simulator provides an Object-Oriented Tool Command Language (OTcl) scripting front-end for configuring the simulation, as well as C++ code for the simulation and modules. To successfully add new modules, very specific C++ file structures are needed, as well as modifications to various header files. After making changes to the source files, the ns2 simulator must be recompiled. To run the ns2 simulator successfully, you must have a thorough understanding of its architectures. The Satellite television interface on NS-2 is shown in Figure 1 below.

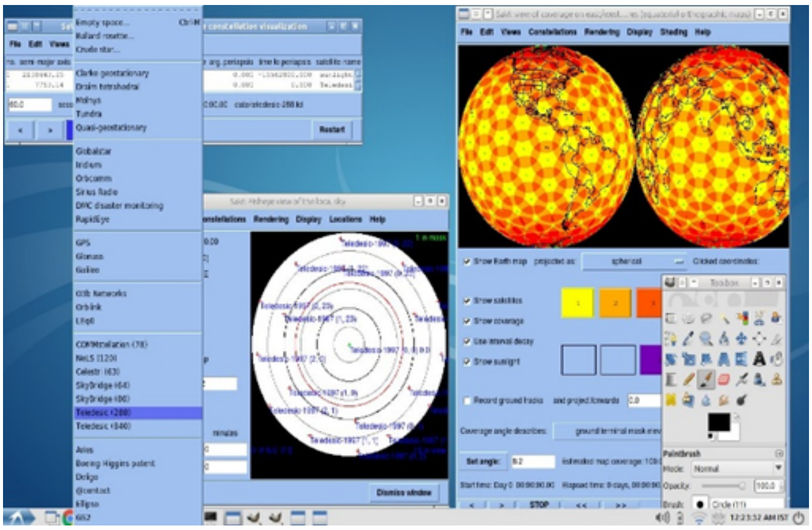

Figure 1. NS2 Satellite television interface

(2) NS3 - is the successor to ns2 and is still in progress. The majority of ns3's emphasis is on internet applications. The satellite modules that are available in the ns2 simulator are currently unavailable in the ns3 simulator. It should be possible to manually port the modules, but this would necessitate a significant amount of effort and testing. To fully comprehend and forecast the simulator's user-friendliness, the software developer must have a detailed understanding of ns3's structures [35].

(3) OPNET Modeller- A commercially available network simulator software kit. The OPNET IT Guru Academic Edition is a free version with a renewable license agreement for academic Institutions [33] (see Figure 2). For a project of this magnitude, the complete commercial version is prohibitively costly. The Academic Edition includes pre-built protocols and devices models. It enables users to model various network topologies. The collection of protocols and devices is fixed, and a user cannot create new protocols or alter existing ones' behavior, though parameters can be changed [33]. Request To Send (RTS) thresholds, packet arrival times, and data rates are some of the variables. The Academic Edition has a total of 50 million events that can be simulated. The reception of a packet or the existence of a timeout are examples of network events. In about 5 minutes of simulation time, a wireless Local Area Network (LAN) network with 10 devices all producing a high load can hit 50 million events. It's worth noting that OPNET was recently acquired by Riverbed Technologies, so the software's focus area can change. Unless a fully approved version can be accessed, OPNET is an insufficient solution due to the limitations and uncertain future of the academic kit.

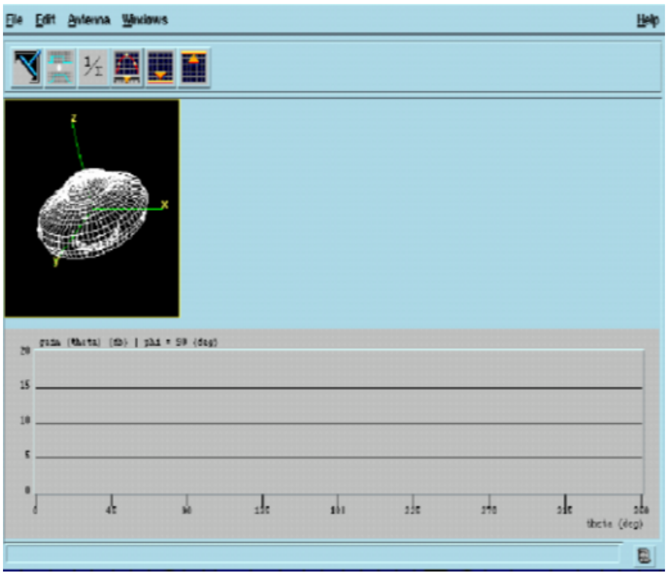

Figure 2. The Satellite television interface on OPNET

(4) MATLAB- Cleve Moler developed a multi-paradigm numerical computing environment and fourth-generation programming language in the 1970s [30]. Moler was the chairman of the University of New Mexico's computer science department, and his work was developed by MathWorks. MATLAB was created by Moler to enable students to use LINPACK and EISPACK (software libraries for numerical linear algebra) without having to learn FORTRAN. MATLAB is written in C++, much

like NS-2, NS-3, and OMNET++, in addition to C++, Python, Java, and FORTRAN. MATLAB can be written in Python, Java, and FORTRAN. There are similar free open-source alternatives to MATLAB, in specific GNU Octave, FreeMat, Julia, etc. Matrix manipulations, function and data plotting, algorithm implementation, and operator interface design are all possible with MATLAB [27]. The MuPAD framework engine is used by MATLAB to provide access to symbolic computing capabilities. MATLAB is a cross-platform programming language that runs on Linux, Microsoft Windows, and Mac Operating System X. Simulink is an add-on kit for dynamics that includes graphical multi-domain simulation and model-based architecture. In addition, the Integer Linear Program (ILP) algorithm is provided by MATLAB, which is used in this research study [27]. Users of MATLAB come from a range of scientific, engineering, and economic backgrounds. Figure 3 depicts the MATLAB command interface.

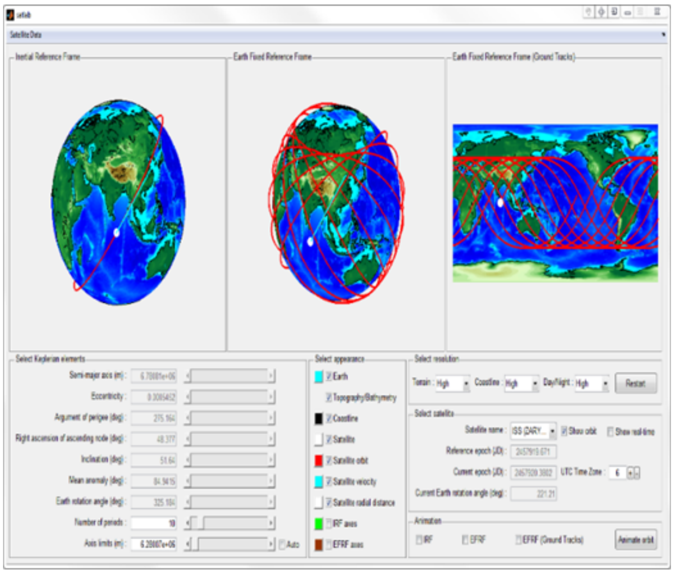

Figure 3. MATLAB Command Interface

E. Discrete Simulation Frameworks

(1) OMNeT++ - C++ programming language is used to create OMNeT++, a discrete-event simulation environment. Its primary application field is the simulation of communication networks, but it has also been successfully used in other fields, such as the simulation of complex IT systems, queuing networks, and hardware architectures, due to its generic and scalable design [34]. OMNeT++ offers an element architecture for models. In a similar manner to ns2, modules are programmed in C++ and then assembled into larger structures and models using a high-level language (NED). While OMNeT++ is not a network simulator in and of itself, it is rapidly gaining popularity in the scientific community as a network simulation platform [34]. Since OMNeT++ is not a dedicated network simulator, study, and testing in it will take some time. For less experienced developers, the complexities involved in modeling networks can pose a challenge. OMNET++ Satellite interface is shown in Figure 4.

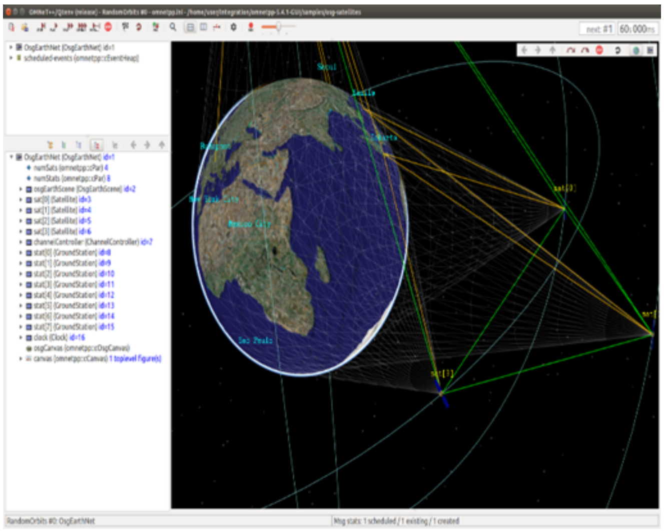

Figure 4. OMNET++ Satellite Interface

(2) SimPy - is a discrete-event simulation application for Python that is object-oriented and process-based. SimPy is a Python application for creating discrete-event simulations. Events are created and put in a chronologically ordered event list. The events are then carried out in order, with new ones being introduced dynamically as the simulation progresses. Python modules offer additional features, such as random variables, which are supported by the basic Python random module [26].

Python has a wide group of active developers who build packages to help with scientific techniques, graphical interfaces, and data visualization. Python is a high-level programming language (akin to Java and C++) that is known for its simplicity and ease of use. Python's scripts are compiled into byte codes, so there isn't much of a compilation method [26]. This allows for fast script modifications at the expense of some execution efficiency. This could be a problem if simulations take too long to run. Figure 5 shows the Simulation in Python interface.

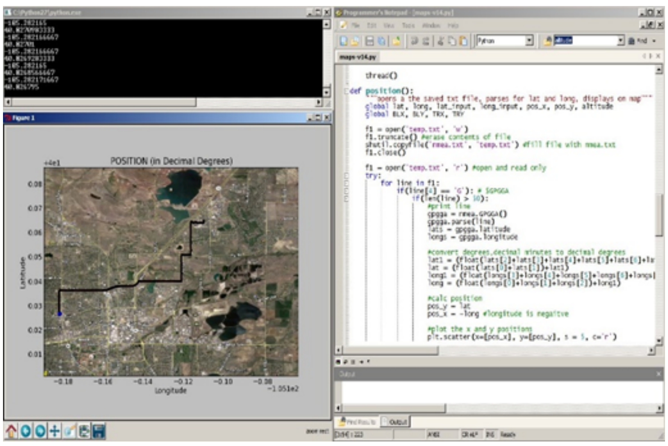

Figure 5. Simulation in Python interface.

F. Simulation Evaluation

We created a simulation Simulink to evaluate the proposed Gau-satcomm model. Scope blocks and scope viewers offer a quick way to visualize simulation data over time. The analyzed results from several simulations were graphically displayed in MATLAB using the plot function and X-graph. In addition, each computed simulation result has been taken from an average of several simulations. characterizes the network simulators and discrete simulation frameworks NS-2 and NS-3 are not very effective at simulating large communication networks and satellite television systems however, it is commonly used by many researchers around the globe, mainly because it is convenient to use, in contrast to MATLAB, OPNET, OMNET++, and SimPy. All the simulators mentioned here are open source (see Table below) and freely available on the Internet. In this research study, the research is intended to design a satellite television topology, which includes beams and user terminals communicating wirelessly. Looking at the features presented in Table 1 below.

Table 1. Simulation Features

Features	**NS-2**	**NS-3**	**OMNET++**	**OPNET**	**Python**	**MATLAB**
Setup	Hard	Hard	Moderate	Moderate	Hard	Easy
Use	Easy	Hard	Moderate	Moderate	Hard	Mod
Scalability	Poor	Poor	High	High	High	High
Large Networks	No	No	Yes		Yes	Yes
Program Language	C++	C++	C & C++	C & C++	Python	C++ C Python
Support Integer Linear Program Algorithm	No	No	No	No	No	Yes
GUI	Yes	Yes	Yes	Yes	Yes	Yes
Dev Continuity	Yes	Yes	Yes	Yes	Yes	Yes
IEEE802.11 protocol	Yes	Yes	Yes	Yes	Yes	Yes
Complications	No	No	No	No	No	No

G. Simulation Set Up

Simulation Set up depicts a simulation scenario in which the Gau-satcom simulation blocks used to simulate the cognitive deficits such as Free space path loss, Doppler error, receiver thermal noise, and Phase noise

https://doi.org/10.33022/ijcs.v14i3.4861

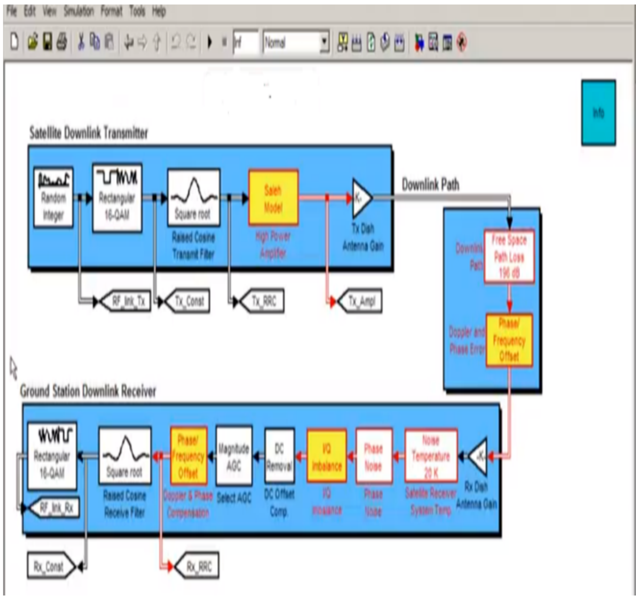

Figure 6. Gau-satcomm model Simulation

The Gau-satcomm model implements link budget calculations that decide whether a downlink can be closed with a given bit error rate by modelling the gains and losses on the link (BER). The data rate that can be tolerated on the connection in an additive Gaussian noise channel is calculated by the gain and loss blocks, which include the Free Space Path Loss block and the Receiver Thermal Noise block (see Figure 6).

The distance between the satellite and the ground station is measured in kilometers. The Free Space Path Loss block is modified when this parameter is changed. 35600 is the default mode. The link's carrier frequency is measured in megahertz (MHz). The Free Space Path Loss block is modified when this parameter is changed. 4000 is the default mode. Transmit and receive antenna diameters transmit antenna diameter is the first element in the vector, and it is used to measure gain in the Dish Antenna Gain block. The receive antenna diameter is represented by the second part, which is used to measure the gain in the Dish Antenna Gain block.

Satellite Downlink Receiver produces a stream of random binary data and maps the data stream to the 16-QAM constellation. The square root raised cosine pulse form is used to up sample and shape the modulated signal in the Raised Cosine Transmit Filter. The Downlink Path decreases the signal and rotates it to model doppler error on the link. Dish Antenna Gain controls the gain of the receiver parabolic dish antenna. The Gaussian noise reflect the receiver's effective system temperature. Random phase perturbations caused by 1/f or phase flicker noise are introduced by phase noise. I/Q Imbalance Causes the signal to have a DC offset, amplitude imbalance, or phase imbalance. High noise amplifier gain is added by the Low Noise Amplifier. Raised Cosine Receive Filter uses the square root raised cosine pulse form to add a matched filter to the modulated signal.

The proposed model and algorithm were compared numerically to two other algorithms, namely ITU-R and SAM model using a variety of parameters in terms of end-to-end Constellation, Bit error rate (BER) display, and Power Spectrum. Because of its performance in numerical computations and efficient simulation, the tool was used to test the design efficiency parameters. Table 2 below shows simulation parameters.

Table 2. Simulation Parameters

Parameter	**Specification**
Simulator	MATLAB 2022
Dimension	1 to 100 km
Protocol	S-MAC
Packet size	1024 bytes
Execution radius	15 runs
Time Run	60s
Connection radius	1 unit
Initialization	Arbitrary

The research study chose Sensor MAC (S-MAC) protocol that tries to reduce energy consumption due to overhearing, idle listening, and collision. In this protocol every node also has two states, sleep state and active state. S-MAC contributes in these ways; reduction of idle listening (as nodes sleep and not stay in idle state), collision and overhearing avoidance by using Request to Send (RTS) and Clear to Send (CTS), and saving energy and time, by sending a series of fragments of a long message together, rather than going for contention after sending every fragment. RTS and CTS are the optional mechanism used by wireless networking protocol to reduce frame collisions introduced by the hidden node problem.

H. Findings and Discussions

In this Section, in this study, we compared Gau-satcomm with ITU-R and SAM algorithms. The simulation has been run fifteen times to ensure that the results are reliable. We analyzed the following performance metrics: (1) Bit Error Rate (BER) – is defined as the rate at which errors occur in a transmission system. This can be directly translated into the number of errors that occur in a string of a stated number of bits [29]. The definition of BER can be translated into a simple formula:

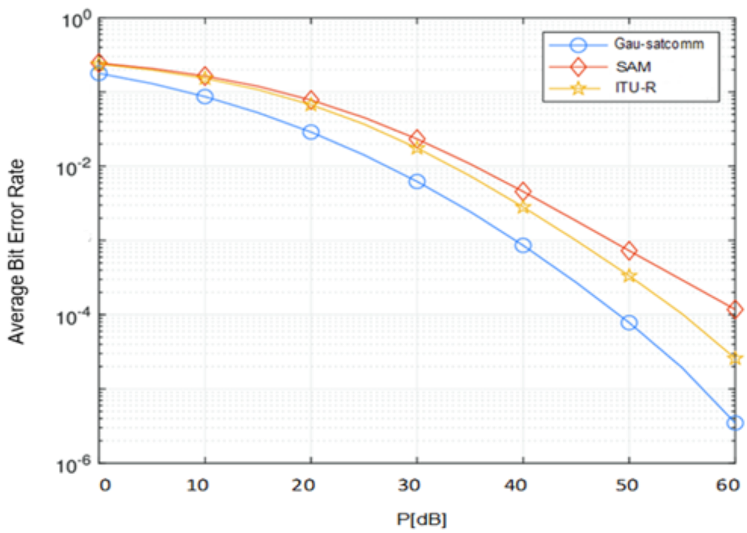

Figure 7. Comparison of BER of performance of three models.

BER = number of errors / total number of bits sent

This simple relationship is the basis for all BER measurements and specifications. It assumes that all transmitted bits were sent error free. BER is usually specified as several times 10 raised to a large negative exponent. Common requirements for serial links are generally in the range of 1x10-6 to 1x10-15. BER numbers by themselves do not represent any period. They are only a ratio of numbers of bits sent and received.

(2) Average Attenuation – also known as transmission loss, is the reduction in intensity of the light beam (or signal) with respect to distance travelled through a transmission medium. Attenuation coefficients in optical fibers usually use units of dB/km through the medium due to the relatively high transparency quality of modern optical transmissions. The medium is typically a fused silica fiber that confines the incident light beam inward. Attenuation is an important factor that limits the transmission of a digital signal over long distances. Therefore, much research has been devoted to both limiting the attenuation and maximizing the gain of the optical signal. Empirical studies have shown that attenuation in optical fibers is mainly caused by scattering and absorption.

(3) Outage probability – is defined as the point at which the receiver power value falls below the threshold (where the power value relates to the minimum SNR within a cellular), one can say that the receiver is out of the range of Base Station (BS) in cellular communications. Outage probability is the probability that an outage will occur within a specified time.

In this study, we compared Gau-satcomm with ITU -R and SAM algorithms as mentioned in section 2. The SAM and ITU-R algorithms were primary selected because they both operate above 10 GHz. Our choice of the ITU-R model was since it expresses rain attenuation at a given frequency and rain rate. This model is widely used in satellite television. To prevent harmful interference between radio stations of different countries, the ITU-R is obliged to allocate frequencies and register them in their statute. Furthermore, both ITU-R and SAM models are commonly used as reference models for developing hydrometeor damping models. In the literature review, it is claimed that both the ITU-R and SAM models are capable of accurately predicting rain attenuation. The purpose of this comparison was to see if our proposed Gau-Satcomm model could outperform the existing models.

1. Average Bit Error Rate

Figure 7 shows the BER average for three algorithms when the signal frequency is above 10 GHz at 100 km path distance and 100 mm/h rain rate. The proposed Gau-Satcomm algorithm, ITU-R model and SAM model experienced an average BER of 5%, 8%, and 10%, respectively, and assuming a path distance of 100 km and a signal frequency over 10 GHz. The average BER of the proposed algorithm is only 5% and therefore outperforming ITU-R and SAM.

2. Average Attenuation

Using Figure 8 we compared the average attenuation for the three algorithms at frequencies over 10 GHz, elevation angles varying from 0 to 90 degrees, path length of 100 km, and rainfall rate of 100 mm/h. In the results, it is revealed that the most severe attenuation effects occur at higher frequencies during rainfall.

Moreover, the proposed Gau-Satcomm algorithm, SAM model, and ITU-R model experienced an average attenuation of 4%, 9 %, and 11 % respectively.

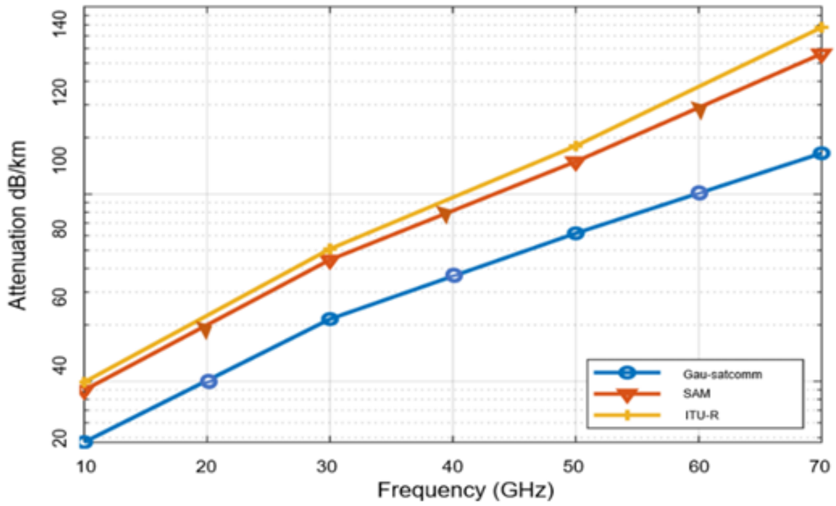

Figure 8. Comparison of average attenuation of three models

We compared the average outage probability for the three algorithms at frequencies over 10 GHz, path length of 100 km, and rainfall rate of 100 mm/h using Figure 9. The proposed Gau-satcomm algorithm, the ITU-R algorithm, and the SAM algorithm minimized outages by 10%, 7%, and 5%, respectively. Our proposed Gau-satcomm experiences a lower outage probability than conventional ITU-R and SAM models.

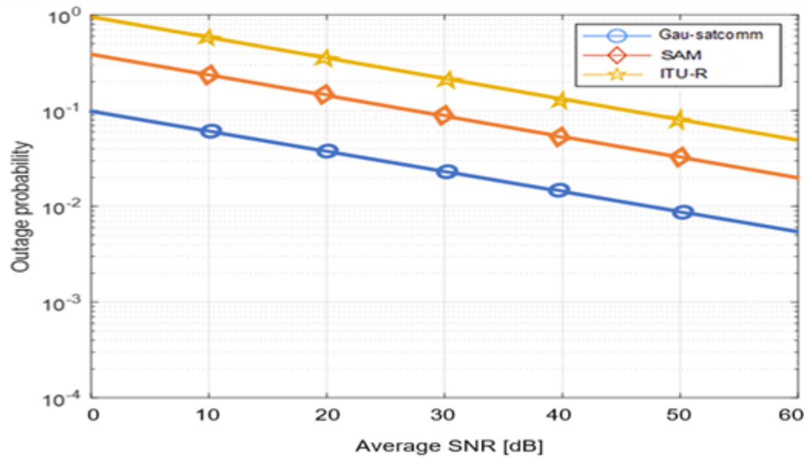

Figure 9. Comparison of outage probability versus SNR of the three models.

I. Conclusions

In conclusion, this study presents a novel solution to one of the most pressing challenges in satellite television broadcasting: signal degradation caused by rain fade. The proposed Gau-Satcomm model leverages advanced signal processing techniques to significantly enhance transmission quality at high frequencies. Through rigorous simulation using MATLAB and Simulink, the model has been proven to reduce bit error rates, minimize attenuation, and lower outage probabilities when compared to standard ITU-R and SAM models. The implications of this work extend beyond theoretical contribution, it offers a practical and scalable approach to improving satellite communication reliability, particularly in weather-vulnerable regions. Future work could explore real-time implementation and optimization of the Gau-Satcomm model on commercial satellite platforms to further validate and expand its applicability.

J. Acknowledgment

The authors would like to thank the Tshwane University of Technology for financial support. The authors declare that there is no conflict of interest regarding the publication of this paper. Coster Baloyi is acknowledged for assisting with the formatting of the paper.

K. References

[1] Silva, R., 2019.The difference between digital and analogue TV
[2] Murray, S. 2003. Global digital television, 3rd edition. London: Informa Media
[3] Papathanassopoulos, S.,2008 “Satellite Television." The International Encyclopedia of Communication. Donsbach, Wolfgang (Ed). Blackwell Publishing,
[4] Woodford, C., 2022. Satellites. Available at https://www.explainthatstuff.com/satellites.html (Accessed 20 September 2022)
[5] Isabelle, D., Philippe, A., Nicolas, A., and Bouchra, B. 2018. Rain Attenuation Prediction Model for Satellite Communications Based on The Météo-France Ensemble Prediction System PEARP
[6] Barthes L. And Mallet C. Rain fall measurement from the opportunistic use of an earth-space link in the Ku band. Atmospheric measurement technique Volume 6, 2181-2193, 2013. Doi:10 5194/amt-6-2181-2013.
[7] Athanasios D, Charilaos, K., Panagopoulos, D. 2014, Outage performance of dual branch diversity in broadband fixed wireless access networks
[8] Akobra S, Diawuo K. and Gyasi-Agyele A, 2012 IEEE 4th international conference on Adaptive science and technology (ICAST) 25-27 October 2012. Doi 10;1109/CASTTech 2012. 6381058 Kumasi Ghana.
[9] l-Shalaby, Noha & Zainud-Deen, Saber & Malhat, Hend. (2019). Broadband Transmitarray for Satellite Applications in Ku Band. Wireless Personal Communications.
[10] Hussien, A.A. and Ali, A.H., 2020. Comprehensive investigation of coherent optical OFDM-RoF employing 16QAM external modulation for long-haul optical communication system. International Journal of Electrical and Computer Engineering, 10(3), pp.2607-2616.
[11] Ahmad, I., Nguyen, K.D., Letzepis, N. and Lechner, G., 2020. On the Next-Generation High Throughput Satellite Systems with Optical Feeder Links. IEEE Systems Journal.
[12] Schwarz, R.T., Delamotte, T., Storek, K.U. and Knopp, A., 2019. MIMO applications for multibeam satellites. IEEE Transactions on Broadcasting, 65(4), pp.664-681.

[13] Hong, W., Jiang, Z.H., Yu, C., Zhou, J., Chen, P., Yu, Z., Zhang, H., Yang, B., Pang, X., Jiang, M. and Cheng, Y., 2017. Multibeam antenna technologies for 5G wireless communications. IEEE Transactions on Antennas and Propagation, 65(12), pp.6231-6249
[14] Chung, K.L., Li, W., Li, Y., Liu, R. and Zhang, P., 2019. Chinese character-shaped artistic patch antenna. IEEE Antennas and Wireless Propagation Letters, 18(8), pp.1542-1546.
[15] Liu, S., Zhang, Y.D., Shan, T. and Tao, R., 2018. Structure-aware Bayesian compressive sensing for frequency-hopping spectrum estimation with missing observations. IEEE Transactions on Signal Processing, 66(8), pp.2153-2166]
[16] Kumru Berfin Emre Cetin (2018) Television and the making of a transnational Alevi identity, National Identities, 20:1, 91-103, DOI: 10.1080/14608944.2016.1247260.
[17] Barrios, R., 2020. Fading loss for Earth-to-space lasercom affected by scintillation and beam wander composite channel. Optical Engineering, 59(5), p.056103.
[18] Cooke, K., 2021. How Does Weather Affect Internet Service. Available from: https://www.satelliteinternet.com/resources/does-weather-affect-internet/. Accessed Online. 19 April 2019
[19] Nunes, F.D. and Sousa, F.M.G., 2018. Generalized gamma fading simulation of scintillation disturbed GNSS signals. IEEE Transactions on Aerospace and Electronic Systems, 54(4), pp.2025-2034
[20] Wu, Q. and Zhang, R., 2019, May. Beamforming optimization for intelligent reflecting surface with discrete phase shifts. In ICASSP 2019-2019 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP) (pp. 7830-7833). IEEE
[21] Lee, Y. and Choi, J.P., 2019. Performance evaluation of high-frequency mobile satellite communications. IEEE Access, 7, pp.49077-49087.
[22] Zhou, Z., Ge, N., Wang, Z. and Hanzo, L., 2020. Joint transmits precoding and reconfigurable intelligent surface phase adjustment: A decomposition-aided channel estimation approach. IEEE Transactions on Communications
[23] Liu, S., Zhang, Y.D., Shan, T. and Tao, R., 2018. Structure-aware Bayesian compressive sensing for frequency-hopping spectrum estimation with missing observations. IEEE Transactions on Signal Processing, 66(8), pp.2153-2166
[24] Letafati, M., Kuhestani, A., Behroozi, H. and Ng, D.W.K., 2020. Jamming-resilient frequency hopping-aided secure communication for Internet-of-Things in the presence of an untrusted relay. IEEE Transactions on Wireless Communications, 19(10), pp.6771-6785.
[25] M. El-Hajjar and L. Hanzo, "A Survey of Digital Television Broadcast Transmission Techniques," in IEEE Communications Surveys & Tutorials, vol. 15, no. 4, pp. 1924-1949, Fourth Quarter 2013, doi: 10.1109/SURV.2013.030713.00220.
[26] Ramasubramani, V., Dice, B.D., Harper, E.S., Anderson, A. and Glotzer, S.C., 2020. freud: A software suite for
[27] high throughput analysis of particle simulation data. Computer Physics Communications, 254, p.107275.

[28] Gheisari, M., Panwar, D., Tomar, P., Harsh, H., Zhang, X., Solanki, A., Nayyar, A. and Alzubi, J.A., 2019. An optimization model for software quality prediction with case study analysis using MATLAB. IEEE Access, 7, pp.85123-85138.
[29] Liu, S., Zhang, Y.D., Shan, T. and Tao, R., 2018. Structure-aware Bayesian compressive sensing for frequency-hopping spectrum estimation with missing observations. IEEE Transactions on Signal Processing, 66(8), pp.2153-2166.
[30] Basudewa, M.I., Bagaskara, Z.H., Damita, S.S.A., Putra, R.F. and Ahmadi, D., 2020, May. Bit error rate performance analysis for free space optic communication. In IOP Conference Series: Materials Science and Engineering (Vol. 850, No. 1, p. 012056). IOP Publishing.
[31] Radjapov, D.S., 2020. Organizing and testing QPSK (quadrature phase shift keying) signals in telecommunication technologies sphere in MATLAB programme. Modern Science, (7-2), pp.296-300.
[32] Laurin, S.P.B.M., 2018. Development of Deployable Antennas for Advanced Maritime Communication and Monitoring withSmall Satellites (Doctoral dissertation, University of Toronto (Canada)).
[33] Lokhande, D.G. and Mohsin, S.A., 2017, October. Internet of things for ubiquitous smart home system. In 2017 1st International Conference on Intelligent Systems and Information Management (ICISIM) (pp. 314-320). IEEE
[34] ZHANG, J., YANG, Q.W. and Dong, C.H.E.N., 2018. Influence Analysis of Typical Operational Environment on the Use of Projectile-carried Communication Jammer on the OPNET Platform. DEStech Transactions on Computer Science and Engineering, (msota)
[35] Laassiri, F., Moughit, M. and Idboufker, N., 2017, December. Evaluation of the QoS parameters in different SDN architecture using Omnet 4.6++. In 2017 18th International Conference on Sciences and Techniques of Automatic Control and Computer Engineering (STA) (pp. 690-695). IEEE
[36] Ilčev, S.D., 2018. Global Broadcasting Satellite System (GBSS). In Global Mobile Satellite Communications Applications (pp. 203-304). Springer, Cham.