Politecnico di Torino

Politecnico di Torino

Master Degree
in
Communication and Computer Networks Engineering
DET

Internet over Satellite: Technologies and Network Performance Comparison

Supervisors:
Prof. Roberto Garello
Ing. Sergio Franco

Author:
Ahmed Mohamed Osman

Abstract

Internet connectivity is a crucial contributor to economic growth and a lifeline for Healthcare systems, schools, hospitals, and other critical services during the COVID-19 pandemic. Moreover, with the rise of digitalization, scientists and research missions worldwide desperately need a connection service beyond the reach of terrestrial assistance. Satellite broadband offers the ability to connect individuals and areas to the Internet that would otherwise be inaccessible using existing wired or wireless technologies. Half of the planet does not have access to ground fiber optic cables that provide reliable Internet connectivity, and that is why satellites has the potential to be a game-changer. Getting our whole world wired with fiber optic cables is complicated and expensive at the same time.

This thesis highlights the basic knowledge of satellites, including satellite orbits and the satellite industry revenues. Furthermore, It contains an overview of the main concepts of satellite communication. It also provides more details about the High Throughput Satellites (HTS) and their technologies, which offer higher throughput than regular satellites by using spot beams to cover many countries using the frequency reuse method. The thesis describes KASAT and KONNECT, two high throughput satellites with KA band and a KU band satellite called Advance KU satellite, all of which are managed and controlled by EUTELSAT.

In addition, the thesis reports the findings of two Network Performance Tests. The first test measures the throughput, jitter, packet loss, number of packets retransmitted in both connection types Transmission Control Protocol (TCP) and User Datagram Protocol (UDP), using a Bash script. The script automates the iperf3 tool. This test measures the performance of KASAT, KONNECT, and Advance KU satellites and a 4G internet connection.

The results of the aforementioned tests were plotted to provide more descriptive explanations for the findings. The network performance test performed, and the results obtained, will help the customers and Internet Service Providers to choose which satellite they want to use based on their requirements.

The second test measures the page load time. It measures the time for the web page to be displayed in an internet browser. The test measures the load time for the most visited websites (Google, Facebook, Instagram, Twitter, and Wikipedia). The page load time has a significant influence on user satisfaction. The speed at which the customer can view a page's contents in a short amount of time generates customer satisfaction for the online experience.

To conclude, This network performance test helps ensure the suitable throughput is delivered to the customer under the satellite beam coverage. In addition, the tests prove to serve as a tool to troubleshoot and understand if there is a network connectivity issue for thousands of User Terminals using KASAT, KONNECT, or Advance KU Satellites.

All Network Performance Tests were performed in collaboration with Skylogic - Eutelsat teleport, located in Turin, Italy.

Acknowledgement

I want to express my deepest gratitude to the Thesis supervisors, Prof. Roberto Garello and Ing. Sergio Franco, for their guidance, constructive feedback, kind support, and advice.

Many thanks to my colleagues at the Broadband Services Operation Department at Skylogic for their continuous encouragement and support.

Last but not least, my warm and heartfelt thanks go to my family and friends for providing me with unfailing support throughout my years of study and through the process of researching and writing this thesis. This accomplishment would not have been possible without them. Thank you.

Contents

Chapter 1

Introduction

Internet is considered one of the most important technologies because it made a significant impact in people's lives. The Internet plays a vital role in our daily life, with the use of the Internet communication between individuals, countries, and the economy became easy. The Internet saves money for different sectors and increases productivity. The opportunities that the Internet provides are unimaginable. Providing Internet service to small cities, regions, and individuals who have no Internet coverage is very important to have the same opportunity.

Fifty percent of the planet is not covered with terrestrial cables such as fiber optic cables. Moreover, connecting the Earth with lines needs a lot of resources, time, and money. Here comes the importance of satellites. Satellites can cover remote locations and large unreachable areas with terrestrial networks with Internet Broadband Services. Satellites also provide Maritime services to ships and oil rigs in seas and oceans. In addition, satellites can provide Internet service to governments and private aircrafts.

This Thesis was conducted in Skylogic-Eutelsat Teleport in Turin and in collaboration with the Broadband Services Operation Department. The Thesis reports the findings of Network Performance Tests performed on three satellites: KASAT, KONNECT, and Advance KU. Both KASAT and KONNECT use KA band while Advance KU uses KU band. In addition to a 4G internet connection, then compares the satellite performances vs 4G connection.

The Network performance test measures the Throughput, Jitter, Packet loss, Number of packets retransmitted in Download and Upload for Transmission Control Protocol TCP and User Datagram Protocol UDP.

The last test is called the Page load test, which measures the time required for a web page to be displayed in a browser.

1.1 Thesis Organization

The thesis is decomposed as follows:

- **Chapter One (Introduction)** gives a brief description of the Thesis.
- **Chapter Two (Literature Review)** highlights the satellite communication system, satellite communication components, Frequencies. More over, It talks about High Throughput satellites and their technology.
- **Chapter Three (KASAT, KONNECT and Advance KU)** contains information about KASAT, KONNECT and Advance KU satellites and their network architecture.
- **Chapter Four (Network Performance Tests)** highlights The tests performed on KASAT, KONNECT and Advance KU satellites and a 4G Internet connection to test their throughput, jitter and packet loss in both TCP and UDP connections, it also contains plots for the results obtained. The last test is called Page Load Test, which measures the time required for a web page to be displayed in a browser.
- **Chapter Five (Internship at Skylogic)** Highlights my Internship experience with the Broadband Services Operation Department.
- **Chapter Six (Results and Conclusion)** contains a summary of the main outcomes of this thesis work.

Chapter 2

Literature Review

2.1 What is a Satellite

A satellite is a natural space body circling another, an entity in space. For instance, the satellite of the earth is the moon. Natural and artificial satellites are the two types of satellites. Artificial satellites are created machines since they are propelled into space by a rocket and maintained thereby in the earth's gravitational attraction, as can be seen in Figure 2.1. Satellites are wireless receivers/transmitters whose primary role is to carry radio frequency waves and the encoded information within them from one end of the globe.[7]

Figure 2.1: Satellite

2.2 Orbits of Satellite

The satellite orbits are described as the following:
GEO:
A satellite in geostationary Earth orbit (GEO) orbits the Earth once every 24 hours on the equator plane. Both onshore and offshore sites can use a single satellite. Any receiving antennas within the beam (the coverage region) get the same signal if the satellite has a specifically designed communications beam focused on those locations. Locations outside the satellite's coverage are usually unable to use it successfully. Several satellite networks allow two-way (full-duplex) communications through the same coverage radius. Between fixed sites on the ground, terrestrial communications technologies provide that capacity, such as fiber optic cable and point-to-point microwave radio. Such systems will be there for a long time (in addition to satellites). Terrestrial communications plus Satellites will increase overall quality, capability, and cost as technology advances.[3]
At an altitude of, 35786 km, GEO satellites should travel at a pace of around 3 km per second. Compared to many satellites, this is a long way from Earth's surface. Most of the world's population and economic activity can be covered by GEO satellites.

LEO:
A low Earth orbit (LEO) is a satellite orbiting near the Earth's surface. It is generally less than 1000 kilometers above Earth's surface, although it might be as low as 160 kilometers, a low height relative to other orbits, but still a long way above the surface. Unlike satellites in geostationary orbit, which must constantly circle over the equator, LEO satellites do not have to follow the same path around the Earth their plane can be inclined. This implies that satellites in LEO have more options for paths, which is why LEO is such a popular orbit. LEO satellites have two distinct benefits over GEO satellites in terms of networking. First, the propagation delay is much reduced because of the shorter ranges involved. As a result, the round trip time is shorter, and considerably less transmit power is required. Second, LEO satellite constellations with on-board processing are used. LEO satellites are not geostationary, and antenna beam switching is necessary when the spot beam pattern travels worldwide.[11]
MEO:
A medium Earth orbit (MEO) is a centered orbit between 2,000 km and 35,786 km above the ground, MEO lies in the middle between GEO and LEO.[10]
An MEO satellite has a significantly more extended period and tends to "hang" for a few hours over a particular place on the Earth. The transmission distance and propagation latency are more than LEO, but still far less than GEO.
Figure 2.2 shows the satellite orbits.

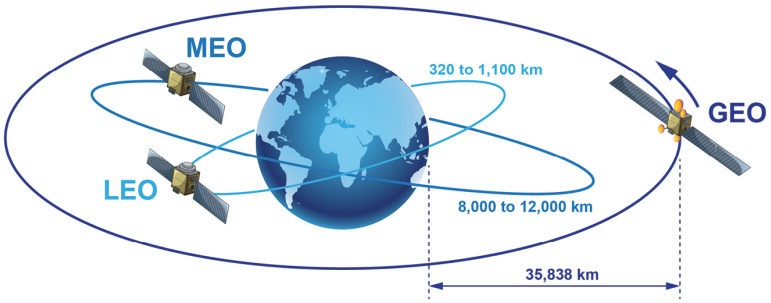


Figure 2.2: Satellite Orbits

2.3 The Communication System of Satellites

The communication system of a satellite is an effective method to link or connect multiple communication sites, and it is composed of two segments:

2.3.1 The Ground Segment

Ground segments represent 50 percent of the satellite communication system. It means all the satellite components located on earth, for instance, Earth station, gateway, terminal or ground station. The primary function of the ground segment is to deliver user communication to the space segment; all the ground segments should be in the line of sight with the satellite to have the

ability to communicate with each other. Figure 2.3 shows EUTELSAT ground infrastructure, the teleport located in Turin boasts 14 earth stations with geostationary visibility from 45° West to 70° East.

Figure 2.3: The Skylogic teleport, located in Turin

The VSAT terminal is connected directly to a Modem using a coaxial cable. The function of the modem is to modulate or demodulate the signals using different techniques for converting; it converts digital data into analog signals normally at IF or L-band, the IF range is 70 MHz or 140 MHz while L-band range 1-2 GHZ. Phase shift keying modulation methods are widely used in the satellite communication field. For example (BPSK, QPSK,8PSK,16PSK,32APSK,64APSK). the signal travels a long distance (more than 71,370 Km). Through a hostile environment (Earth's atmosphere), the data might sometimes arrive at the receiving station with errors. In order to minimize these errors, satellite communications employ a technique called Forward Error Correction (FEC), it is a technique to correct the errors that might have been produced during transmission by adding redundancy to the transmitted information, it allows the receiver to recover any errors, standard FEC rates are 1/2, 2/3, 3/4, 7/8. For example, a 1/2 FEC with 1 Mbps input will have a 2 Mbps output, a 3/4 FEC with 1 Mbps input will have a 1.34 Mbps output. A higher FEC rate is more efficient to carry traffic.
on the satellite, the carrier is composed of pulses attached together to create a signal. every pulse is a symbol. the symbol rate is given by:

$$Symbol\_rate = data\_rate/(M \times FEC) \tag{2.1}$$

M = modulation factor
FEC = Forward Error Correction

$$Bandwidth = symbol\_rate + symbol\_rate \times \alpha/1000 \tag{2.2}$$

$\alpha = roll\_off\_factor$

2.3.2 The Space Segment

The space segment is basically a satellite in the space and the earth station that provides control. The ground station is called the tracking, telemetry. It performs an essential role in controlling and managing the satellite to keep it in the orbit. It is main function is to connect the satellite and the ground stations. [7]

Launching a satellite into orbit takes much effort and keeping it operational for 12 or more years. Contracting with a spacecraft manufacturer and a launch agency and giving them three years to design, build, and launch the satellite is how it gets into orbit. Figure 2.4 shows that EUTELSAT launched its new-generation High Throughput Satellite called KONNECT on January 16, 2020, providing unparalleled operating flexibility. Positioning the satellite in the right orbit goes through multiple procedures. As shown in Figure 2.5. The satellite operator controls the satellite for the remainder of its mission (its lifetime in orbit). When a GEO satellite is retired, a little reserve of fuel is typically used to boost the velocity to elevate the orbit a few hundred kilometers. With its repeater switched off, the retired satellite will stay in orbit indefinitely, posing no threat to the functioning of viable spacecraft in GEO. The decommissioned spacecraft will remain in orbit indefinitely.[3].

Figure 2.4: EUTELSAT KONNECT satellite, built by Thales Alenia Space, successfully launched aboard Ariane 5 rocket

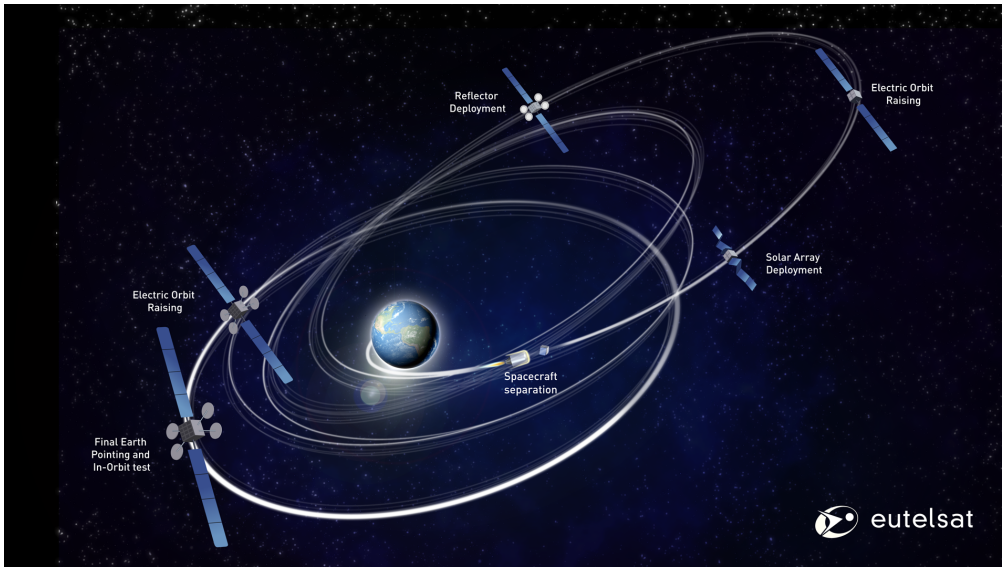


Figure 2.5: Satellite Deployment

2.4 Satellite Frequency Bands

Table 2.1 and 2.2 show the frequency bands and their designations.

Frequency Band Designations	
Designation	Frequency
L Band	1-2 GHz
S Band	2 - 4GHz
C Band	4 - 8 GHz
X Band	8 - 12 GHz
Ku Band	12 - 18 GHz
K Band	18 - 27 GHz
Ka Band	27 - 40 GHz
V Band	40 - 75 GHz

Table 2.1: Letter band frequency designations

Frequency Band Designations			
Designation	Description	Frequency	Band
ELF	Extremely Low Frequency	30=300 Hz	10^4 - $10^3 Km$
LF	Low Frequency	30-300 KHz	10 - 1 Km
MF	Medium Frequency	0.3-3 MHz	1 - 0.1 Km
HF	High Frequency	3-30M Hz	100 - 10 m
VHF	Very High Frequency	30-300 MHz	10 - 1 m
UHF	Ultrahigh Frequency	300-3000 MHz	100 - 10 cm
SHF	Super High Frequency	3-30 GHz	10 - 1 cm
EHF	Extremely High Frequency	30-300 GHz	10 - 1 mm

Table 2.2: Frequency band designations by wavelength

2.5 High Throughput Satellites

2.5.1 Overview

A High Throughput Satellite (HTS) is a satellite of many spot beams and multiple frequency reuse, the HTS satellite can provide higher throughput than a traditional satellite. The traditional satellite covers an entire area with a fixed capacity. It provides service to the ground stations within the satellite coverage. On the other hand, High Throughput Satellite utilizes multiple spot beams or footprints to optimize and increase capacity using the frequency reuse process. Vsat, gateways, and ground stations must be covered by the spot beams to receive service from the satellite.[9]

Multiple Access Techniques

here is a brief discribtion of the multiple access methods which are channel allocation techniques,

for instance Time Division Multiple Access, Frequency Division Multiple Access and Code Division Multiple Access)

- TDMA: it uses a usual broadcast or multicast channel for the connection between two end points by designating time slots to many end users. most satellite communication systems use TDMA as a multiple access technique, in TDMA the bandwidth is shared by all active user, each terminal is allowed to send only in a specific time slot.
- CDMA: it obtained by assigning to different users different code sequence, in CDMA different users are served at the same time on the same band. CDMA allows carriers from multiple stations to utilize the same channel. it can be performed by using larger bandwidth than particular carrier.
- FDMA: it utilizes frequency division to produce synchronuous transmissions in FDMA the whole bandwidth is spilited into separate channels. as a result the end users can exploit a portion of the entire bandwidth.

2.5.2 Spot beam strategy

It is a high-power signal broadcasted from a satellite orbiting around Earth to cover a limited area on the ground. A high throughput satellite with the use of a spot beam can be able to dispatch various data by the use of high power signals with the same frequency, this method overcomes the limitation of frequencies.

With the use of spot beams, the antenna gain of the satellite is increased. On the other hand, the antenna aperture angle decreased. Various spot beams reuse the polarizations or the allocated frequencies. As a result, High Throughput satellites can provide ten times more capacity than the Fixed Satellite Service.[9]

2.6 Satellite Market View

This section uses data collected from various sources to present an overview of the commercial satellite communications business. In 2013, the worldwide satellite manufacture and launch sector produced around US$35 billion.[9] Despite COVID-19, the Satellite Industry Association's "State of the Satellite Industry" report predicted ongoing strength and development in the global space economy in 2020. The industry's investment in technology and innovation has resulted in increased affordability and productivity and the creation of new capabilities and markets. The number of satellites launched by the commercial satellite sector, in particular, reached new highs. From 2019 to 2020, the global space economy increased by 1.4 percent to 371 billion dollars. The satellite business generates 73 percent of the global space economy's profit. Consumer internet, on-the-go connection, and satellite-enabled smartphones and other gadgets drove the ground equipment industry to $135.3 billion in total sales for the year. Thanks to technological advancements that improved data capacity and customer numbers, satellite broadband revenue climbed by 10% to $2.8 billion in 2020.[1]

Chapter 3

KASAT, KONNECT and Advance KU

3.1 KASAT Satellite

KASAT is a Ka-band High Throughput Satellite systems. The KASAT satellite is positioned at 9 degrees east, KASAT provides high-bandwidth internet services to customers outside the reach of fiber optical networks. The KASAT satellite covers 55 countries with 82 spot beams over Europe. The main feature of KASAT satellite is the four-color frequency reuse in Ka-band. The coverage of KASAT can be seen in Figure 3.1 Each location is around 250 kilometers in diameter and covers a relatively circular area. [2]

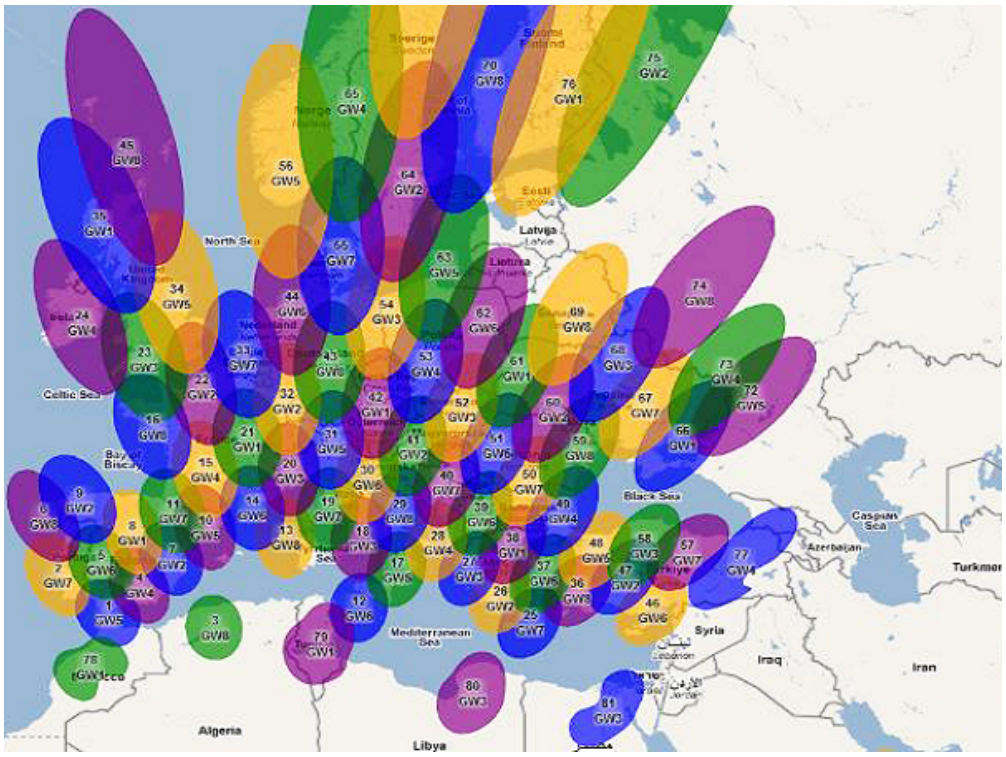


Figure 3.1: KASAT beams Coverage Map

The KASAT system is a fully integrated infrastructure that enables customers and businesses to benefit from internet services. It contains eight gateways that connect the satellite to the Internet exchange points, completing the satellite system's broadband access infrastructure. HTS systems aims to enhance capacity with low fees for the customers. HTS systems have data rates of a few tens of gigabits per second. KASAT, which uses cutting-edge technology, provides a huge increase in capacity of over 90 Gbit/s. An antenna with a multi spot technology is used for the User Service Area to enhance system capacity. The antenna gain per beam is increased by using highly concentrated beams to construct a grid of circular beams over the service region, which improves both uplink and downlink performance. For the downlink, this allows us to either raise the 'Forward Link' capacity, i.e. the capacity from the Gateway to the Users, or lower the RF power of the repeaters. Figure 3.2 shows the KASAT HTS system's Ka-band spectrum. It demonstrates how spectrum is used for uplink and downlink, as well as the communication entity.[5] [6]

A satellite antenna is usually linked with one color in a four-color reuse scheme. Both the Forward and Return Links for KASAT were chosen to have a bandwidth of 250MHz. Each polar-

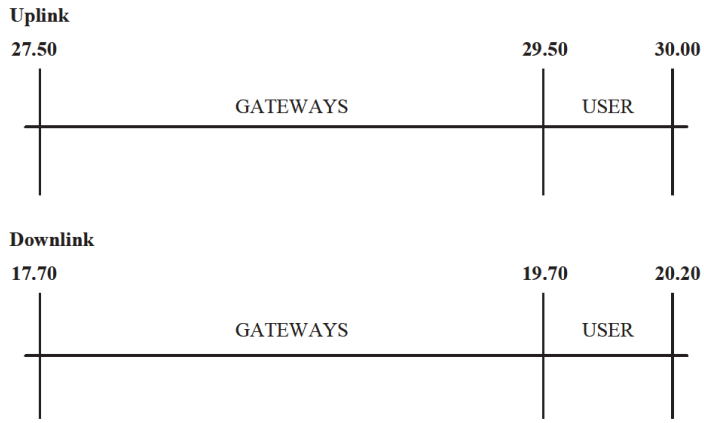


Figure 3.2: Ka-band spectrum allocation for KASAT

ization has a 500MHz spectrum. The spot beam receives 50% of the available bandwidth resource and utilizes Right-hand Circular Polarization or Left-Hand Circular Polarization. Because of fre-

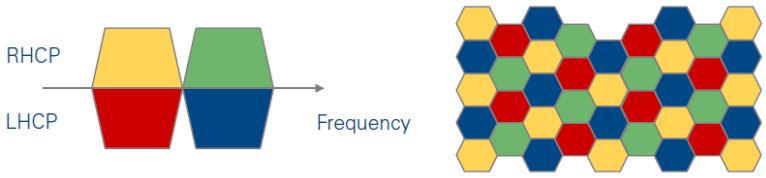


Figure 3.3: Example of a 4-color pattern and allocation of colors to multiple beams providing continuous coverage

quency reuse using orthogonal polarizations, a cluster of four beams has an equivalent bandwidth of double the bandwidth (Bw) assigned to the satellite. As a result, the overall satellite system bandwidth is equal to:

$$Btotal = 2NbBw/Nc$$

where
Nb is the value of beams of the satellite
Nc is the value of colors (here 4) in the cluster
Btotal is the bandwidth in total
Nb/Nc is The frequency reuse factor, it boosts the satellite's capacity (total transmitted bit rate) by the same amount, allowing large capacity improvements across a single beam satellite.[8]

3.1.1 KASAT Gateways

KASAT network comprises eight active gateways with one backup gateway, and the gateways are located in different cities across Europe. Each satellite gateway contains a baseband equipment earth station antenna. The gateways are connected to an Internet Exchange point using fiber-optic

connections and edge routers to router the customers' traffic. Each gateway has redundant fiber optic links to ensure connectivity and load balancing.[4]

3.1.2 KASAT Infrastructure

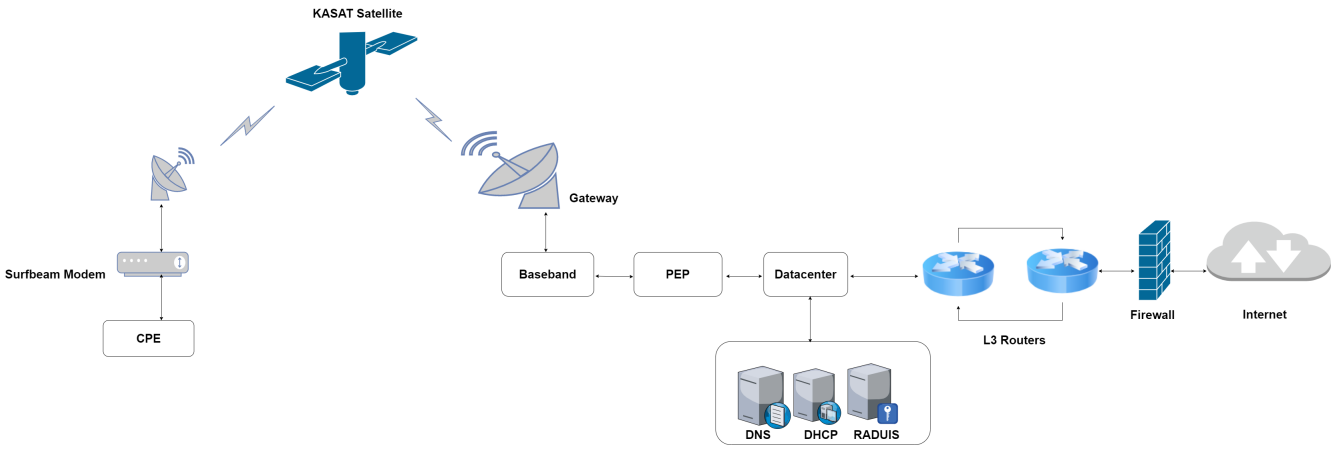


Figure 3.4: KASAT Infrastructure

Datacenter It is composed of network and computing devices, it is function is to manage the flow of information between the user terminal and the internet, establishment of service flow, security and mainly focused on Radio communication.

Baseband is Based on WiMAX Standard IEEE 802.16e, it provides internet protocol address between KASAT satellite and internet, moreover, provides management of user terminals (Power, Frequency, Timing and return link schedule maps). it Provides MAC and PHY layer functionality between Gateway and User Terminals. Another feature is that it enforces Forward Link and Return Link bandwidth allocation limits on a per-UT basis, as specified in user terminal configuration.

PEP is a Performance Enhancement Proxy defined in RFC 3135, this subsystem allows End-to-end performance to be improved, it overcomes the satellite latency.[14].

DNS Server is a server that have the required information of hostnames and their public Internet Protocol addresses, in addition DNS server converts those names to IP addresses.

RADIUS Server is a Remote Authentication Dial-In User Service, it maintains user profiles in a central database. The client can access the network only after an authentication from the RADIUS.

DHCP Server It is a server that assigned internet protocol addresses to hosts automatically without manual configuration on the host device when it is connected to the network.

Firewall Is a device which provides security for networks it scans and also analyzes incoming and outgoing network packets, and it decides whether specific traffic should be allowed or denied based on a set of security polices configured by a network administrator.

Routers they are devices which connect the ASN gateway to the internet, they provide maximum bandwidth to connect additional routers, the routers use routing protocols in order to route packets to different locations based on the source and destination addresses.

3.2 KONNECT Satellite

3.2.1 Overview

KONNECT is a geostationary communication satellite operated by Skylogic-Eutelsat, it was launched on 16 January 2020, it's 24,000 miles above the Earth ground. The history of satellite Internet for home broadband began in 2012, when Eutelsat launched their first satellite devoted to high-speed Internet, making them the first satellite Internet operator in Europe. Eutelsat provided an Internet connection to hundreds of thousands of households and businesses in the UK and 15 other countries in Europe and North Africa, providing an option to fiber broadband without having to wait for ground or mobile networks to be constructed.

The satellite KONNECT provides Internet services across two continents, which are Europe and Africa. KONNECT has a capacity estimated by 75 Gbps, it provides speeds up to 100 Mbps for both companies and individuals. In Africa, KONNECT will also enable shared Internet access between several users based on the installation of public Wi-Fi terminals. KONNECT is a high throughput satellite, it has 28 spot beams in Europe and 64 spot beams in Africa. Some features of this satellite is that it has semi-flexible payload, moreover the capacity can be reallocated based on business needs. One of the features of KONNECT satellite is that it covers a large area, in addition it supports multiple frequency bands and have multiple transponders. KONNECT provides Broadband connectivity for fixed terminals which can be used for personal or professional use.

3.2.2 KONNECT Coverage Map

KONNRCT satellite uses multi spot beam technology, where different spot beams may have different frequency ranges for signal transmitting and receiving (forward band, return band). to handle carriers from different spot beams, the satellite uses local oscillators. They are two types of spot beams, the gateway spot beam where the gateway resides and the user beam where the VSAT terminals reside. A gateway in a gateway beam can communicate with terminals in multiple user beams.
Figure 3.7 shows KONNECT spot beams around Africa and Europe. [4]

3.2.3 KONNECT Network Architecture

Figure 3.6 illustrates the main component of KONNECT satellite network, below is a brief description of the main components.

Transport Gateway
It receives traffic from the terminals within its user beams and delivers the traffic to the data center. The data center collects traffic from the transport gateway. It performs traffic acceleration, and it can perform transmission control protocol acceleration or web access acceleration, which helps the user of the KONNECT network to have good network performance. Before delivering the data to the customer, the traffic goes through other networking processing such as the traffic shaper (Sandvine shaper is used for KONNECT Network). The traffic shaping is performed only in the

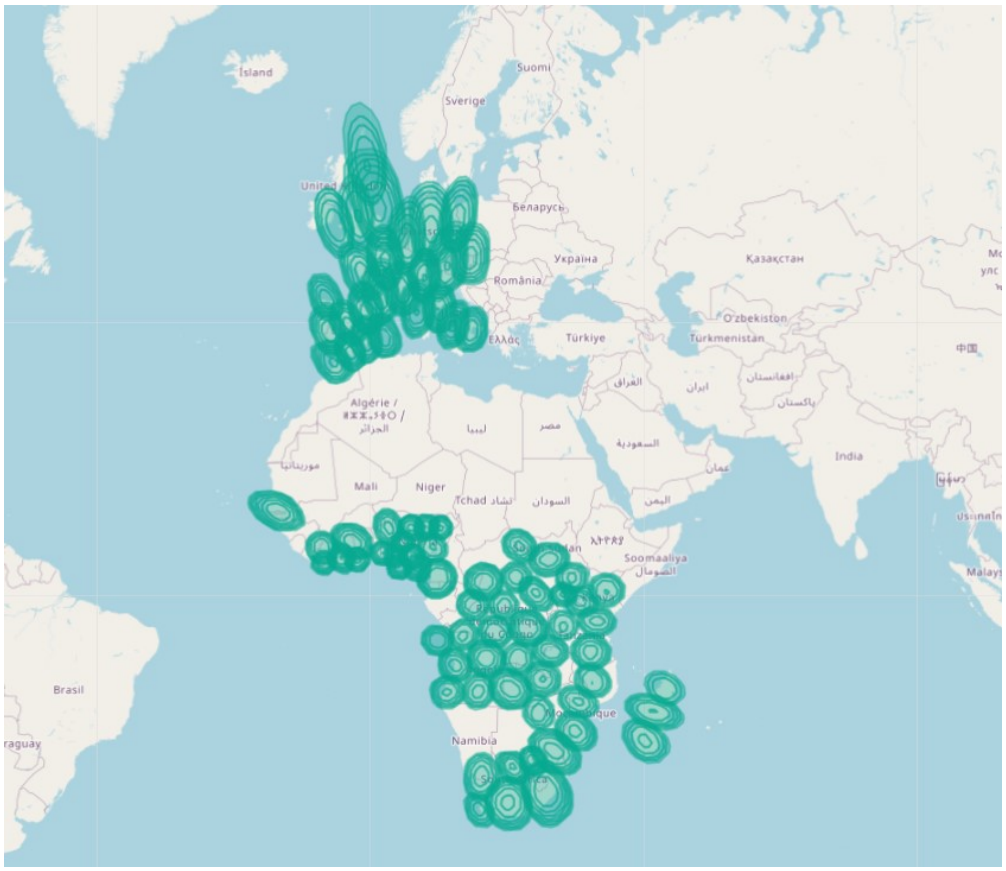


Figure 3.5: KONNECT Coverage Map

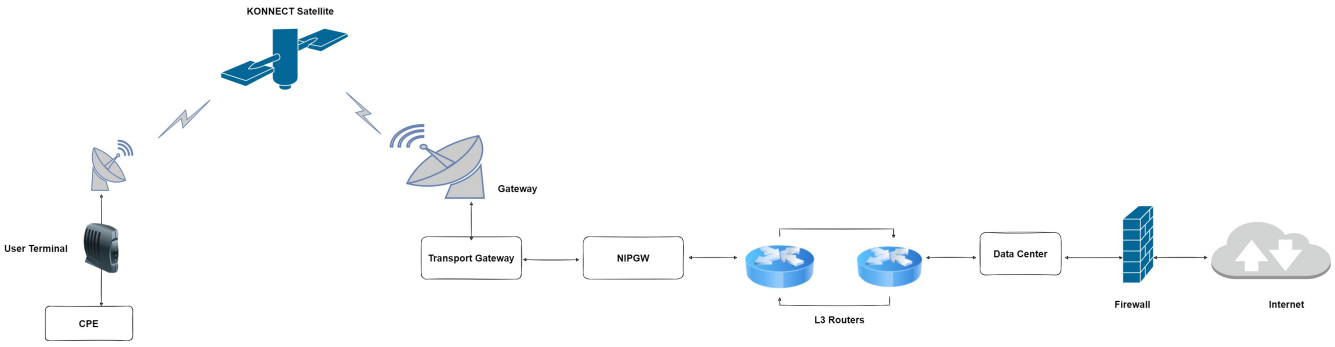


Figure 3.6: KONNECT Network Architecture

download, and the upload traffic is not shaped. The Transport gateway can transmit multiple out routes, and the out route is a high-speed multiplexed signal. Various IP packets are multiplexed into one continuous output stream, and Packets are delivered to different locations based on the destination IP addresses.[4]

NIPGW

Is an acronym for Network IP Gateway, it is a device that exists in the data center, it associates with the terminal for user traffic routing, a terminal associates with the NIPGW during the com-

missioning process, the selection is based on the terminal service plan, IPGW service offerings, IPGW terminal IP address pool, and IPGW loading. A terminal can be re-associated with another network IPGW in the following situations, idle or significant loading difference in IPGW, Failing IPGW, user terminal rebooting, and extended air interface outage.[4]

User Terminal

KONNECT satellite uses Hughes modems to provide an internet connection to the end-user. The terminal needs to associate with network IPGW to access the internet through the KONNECT satellite. The terminal association process starts when a terminal first picks an eligible Network IP gateways pool. The terminal is then associated with a specific NIPGW in the eligible pool based on IPGW loading, and the terminal is free to move between NIPGW while preserving IP addresses. Figure 3.7 shows the HT2010 Hughes modem. It is a high-performance terminal that

Figure 3.7: KONNECT User Terminal

supports a high-speed IP connection for many TCP/IP applications. The modem delivers user IP traffic to and from the gateway through outroute and routes. In addition, the modem has the ability to receive one DVB-S2X outroute and transmit one TDMA inroute at a time.[4]

3.2.4 Access Methods to KONNECT Network

For a terminal to access KONNECT Network, two ways can be used. The first way is that the gateway broadcasts available Aloha channels, any terminal under KONNECT spot beams can choose an Aloha channel randomly to transmit data. The second way is stream access, where bandwidth allocation is required.

3.2.5 Aloha Access

Aloha is a protocol for multiple access, and the Aloha protocol is used in the MAC Medium access control layer. When a user terminal is idle, it needs to send IP packets to the satellite gateway,

and it selects an Aloha channel randomly to send a burst. The user terminal will also establish an in route and an Aloha channel to transmit. If another terminal is transmitting on the same Aloha channel simultaneously, there will be a collision. The terminal will continue to transmit in this mode until it is assigned a stream bandwidth. A bootstrap Aloha channel is a particular Aloha channel. Figure 3.8 shows the Aloha Access method. [4]

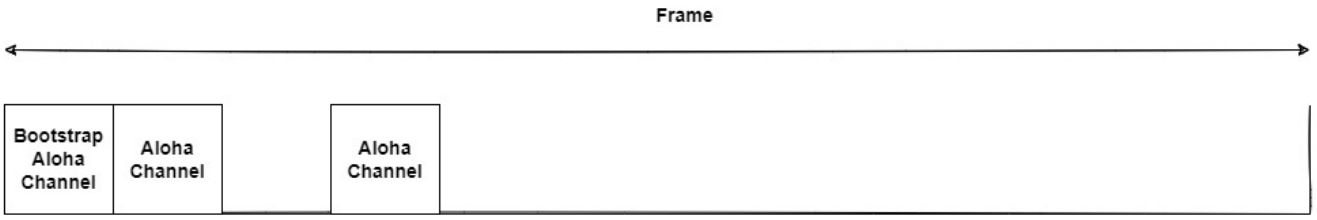


Figure 3.8: Aloha Access

3.2.6 Stream Access

The stream is dynamically allocated by the gateway after it detects an Aloha burst coming from the terminal, the terminal will identify itself in its Aloha burst and indicate its amount of backlogged data. The stream provides periodic transmission opportunities for a terminal, after the queued data is transmitted by the terminal, the gateway will deallocate the stream if the terminal is in idle state for a configurable period of time. Figure 3.10 explains the stream access method.

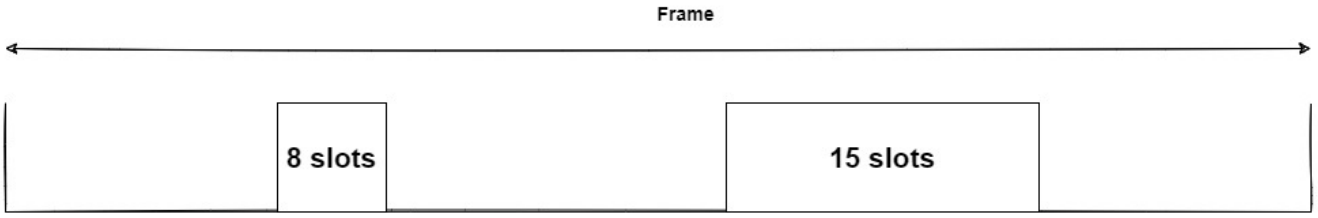


Figure 3.9: Stream Access

3.3 Advance KU

It is a group of EUTELSAT KU-band (12 to 18 GHz) satellites that provide worldwide and full regional coverage, and their primary function is to provide global connectivity and mobility services. Advance KU services are offered over GIPN (Global IP Network) infrastructure.[4]

Advance KU Network Advance KU IP Network is a global project that provides global satellite coverage to services like mobility worldwide. All Advance KU routers are connected to the MPLS backbone. In other words, each node can communicate easily with any other node inside the MPLS backbone.[4]
Main Advance KU elements are:

- Hubs:
  Each HUB is mainly composed by Dialog platform and 2 Edge Routers. These routers are used for platform connection (OSPF sessions) and also for MPLS Skylogic routes exchange. Each HUB is connected to one reference POP. All traffic performed by terminals to Internet is delivered to POP. There aren't Internet access on HUB. Only Internet access provided by reference POP is available.

- POPs
  Each POP is mainly composed of Firewalls and routers. These routers are included on the MPLS Backbone and are used to manage traffic generated by terminals received from HUBs. Firewalls manage ISP Internet access (Primary / Backup) and apply policies to traffic from terminals to Internet (Traffic shaping, NAT etc ..)

- Dialog Platform:
  There is one platform on each HUB. Platform generates DATA and Management traffic. Both traffics are managed by HUBs routers and associated routes are announced to MPLS Backbone.

AKU Network Architecture

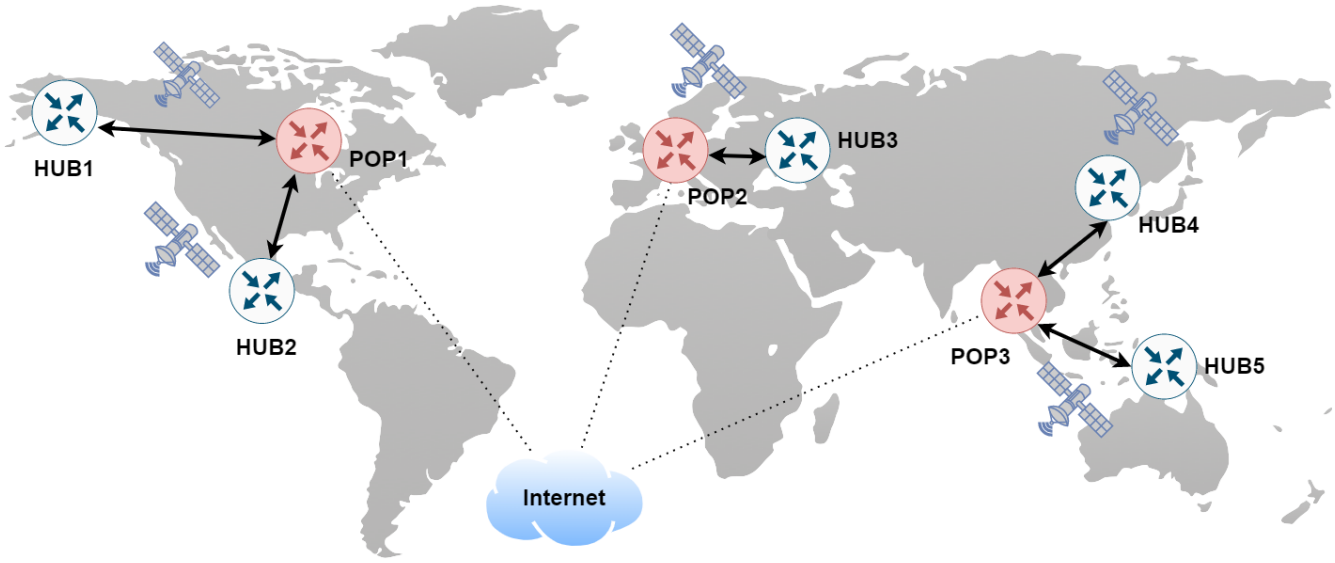


Figure 3.10: GIPN Network Architecture

Advance KU Coverage Map

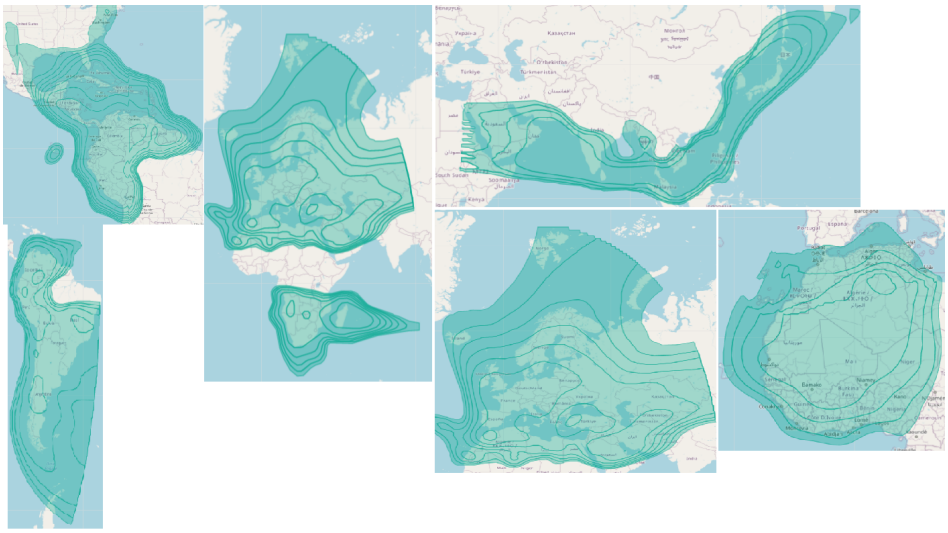


Figure 3.11: Advance KU Coverage Map

Chapter 4

Network Performance Tests

4.0.1 Introduction:

This chapter covers the Network performance tests on different internet connection types. It includes three satellite internet connections and a 4G internet connection. The satellites used for the Network performance tests are KONNECT and KASAT. Both of them use the KA band. The third satellite is Advance KU, which uses the KU band. The last tests were performed using a 4G internet connection. The network performance tests are the following:

- The first test measures and analysis the throughput for download and upload when using Transmission Control Protocol (TCP) and User Datagram Protocol (UDP). As well as the Jitter. a bash script automated iperf3 tool which measures the throughput between a server and a client.
- The second test is the page load test, which measures the time taken to display the content of a specific website. The page load test measured the load speed for the most visited websites.

  KISS principle was used to perform the tests.[13]

4.1 Iperf3

iPerf3 measures the maximum throughput as well as goodput attainable on Internet Protocol networks. Furthermore, it gives each test's bandwidth, loss, and other metrics. Iperf3 provides client and server features, and it can establish a connection to monitor throughput in one or both ways between the two endpoints. User Datagram Protocol (UDP) or Transmission Control Protocol (TCP) data streams can be used (UDP). [12]

4.2 KONNECT Performance Test

Figure (4.1) shows the logical network topology for the network performance test using the KONNECT satellite connection. The network consists of a Client and a Server. The Vsat is in line with the Konnect satellite with a 37,000 Km distance. KONNECT satellite has a space link with a Gateway located in Cagliari, Italy. The gateway directly connects to the MPLS (Multi-Protocol Label Switching) network.

Network Configuration
The Client is a computer running on Linux Operating System (Ubuntu 18.04) connecting the HT2000W Hughes modem with a UTP Ethernet Cat6 cable. Both the Client and Server have public IP addresses. The network interface card on the Client is a full-duplex to allow sending and receiving data simultaneously between server and Client. The speed is 1000Mb per second. Auto-negotiation is on. The Vsat has a 74 cm antenna size and a 1 Watt outdoor unit. The average signal-to-noise ratio is 11.91 and 9.91 dB for download, Upload signal-to-noise ratio. Figure 4.2 shows the SNR values for the Upload and download.

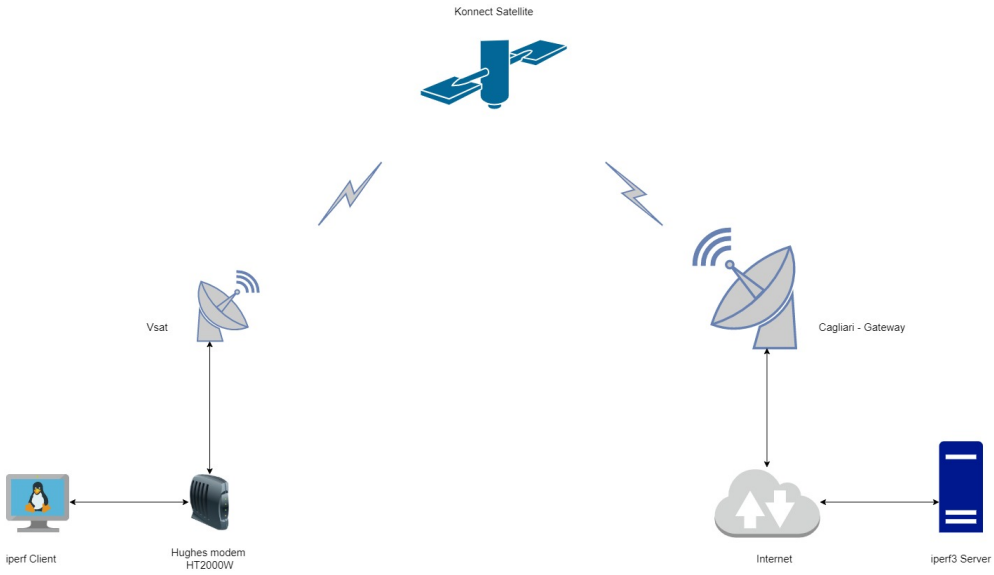


Figure 4.1: Konnect Topology

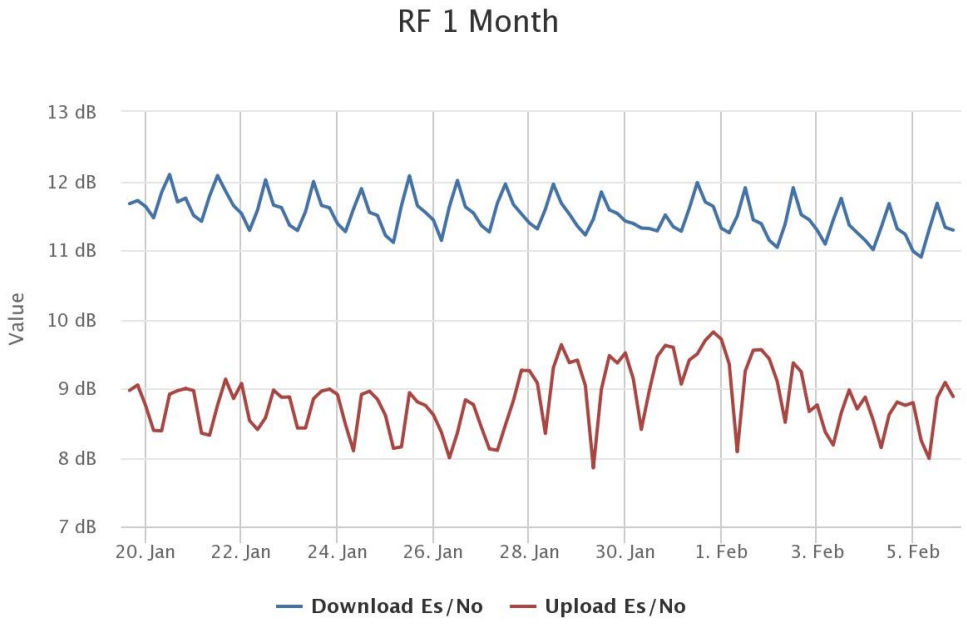


Figure 4.2: Download and Upload SNR

The following parameters were set to configure the modem

HT2000W Parameters	
Parameter	Value
Signal Quality Factor	112
Frequency	19175000 KHz
Symbol rate	235000000 Sps
Transmit Rate	QPSK 4096K
FEC	9/10
Power Attenuation	0.70 dB
Forward Modulation Code	16apsk
Return Modulation Code	QPSK
Transmit Frequency	29700870000

Table 4.1: Downlink and Uplink parameters

The Uplink has Time-division multiple access modes. The modem is connected directly to the Vsat by RF coaxial cable. The Gateway in Cagliari and the iperf3 server are connected to the internet. The ping command tests the connectivity between the iperf server and the client.

KONNECT Download Throughput in TCP
The throughput is the number of packets transmitted successfully between two points per unit time. The first test measures the throughput while using Transmission Control Protocol (TCP) connection. A TCP connection starts between the sender and receiver using the three-way handshake because TCP is connection-oriented. In other words, when the sender wants to create a Transmission control protocol connection, TCP sends SYN to the TCP protocol on the receiver side. The receiver will send back an ACK to acknowledge receiving the segment successfully. The sender will send another ACK then starts to send the data.

Figure 4.3 shows the result of an iperf3 test to measure the download speed. In the beginning, the iperf server was listening on port 5202. Then the client started the connection. The test duration is 60 seconds. Many packets were transferred at different bits rates. In the end, the iperf tool measures the average after the test duration.

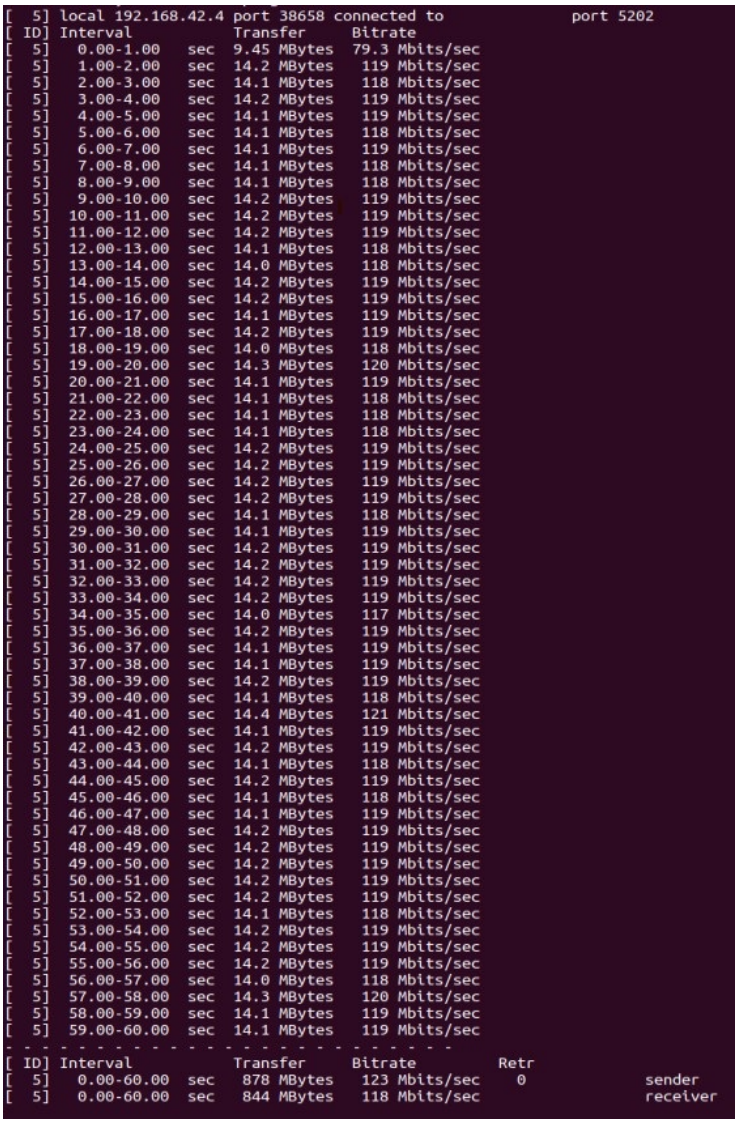


Figure 4.3: Download Test using TCP

Figure 4.4 illustrates the throughput for download, the plot contains information about the segment length in Bytes, the average throughput in (bits per seconds), and the time. During this test, the throughput was high, and it reached 123 Mbits per second for the sender and 118 Mbits per second for the receiver with 0 retransmissions. No retransmission means no packets were dropped or lost between the client and server.

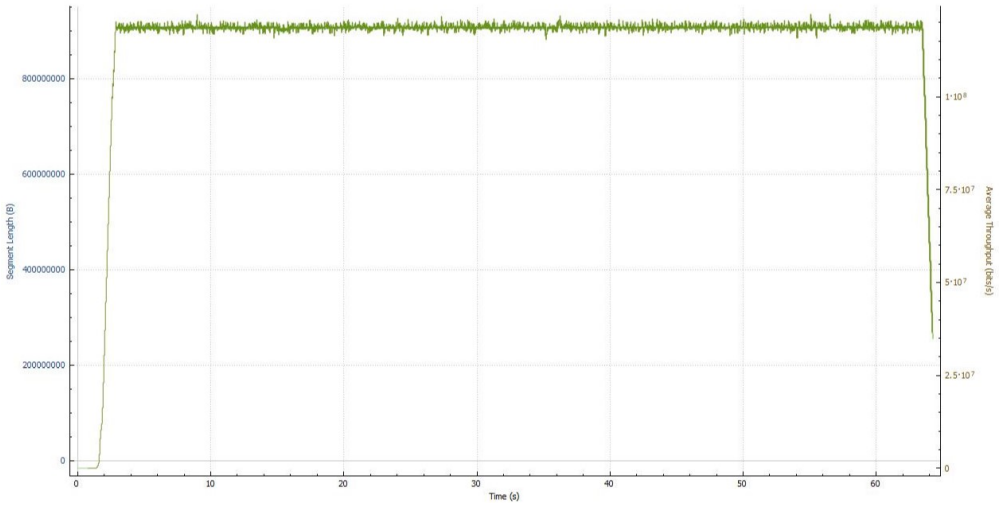


Figure 4.4: Average Throughput vs Time

Sequence Number

It is basically a counter that keeps track of bytes transmitted by a host. For example, when a TCP packet includes X bytes of data, the sequence number is incremented by X after the packet is received. It helps keep track of how much data has been transported and received.

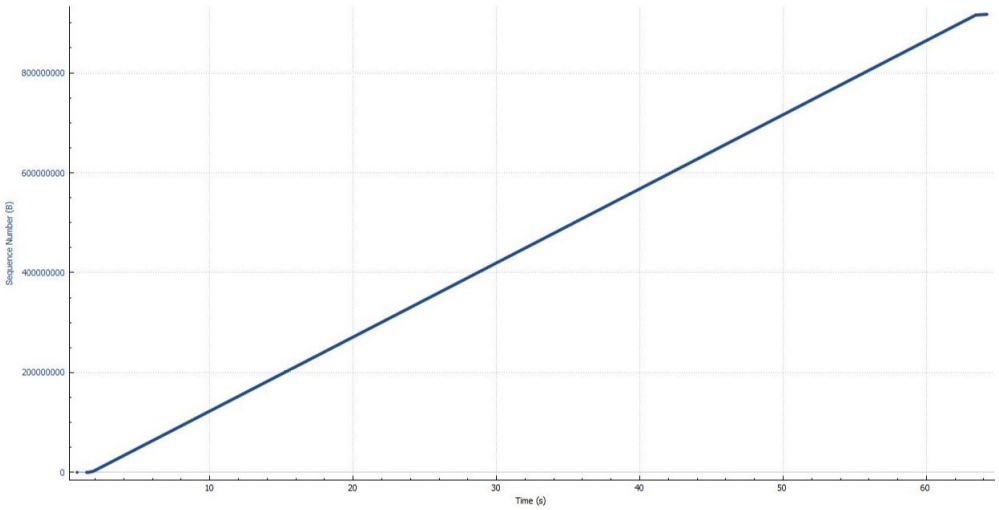
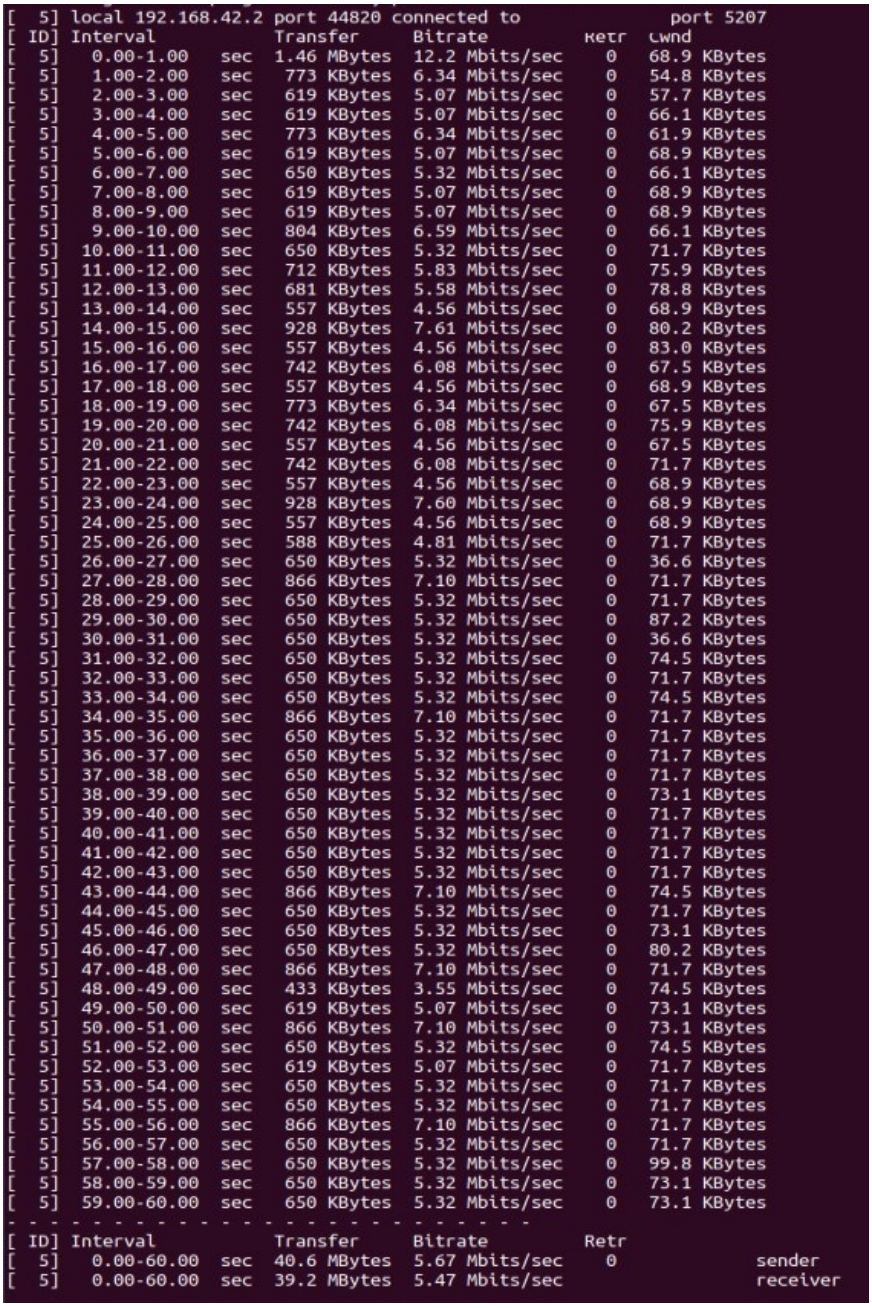


Figure 4.5: Sequence Number

Figure 4.5 shows the sequence number behavior while performing an iperf3 test between the iperf server and the client. The graph shows data in one direction. In this graph, the sequence number was increasing. It means the data moved without interruption, delays, or packet loss.

KONNECT Upload Throughput in TCP

the iperf measures the upload speed for a user terminal that uses KONNECT satellite using a TCP connection for 60 seconds. Figure 4.6 shows the test performed to measure the upload speed in TCP mode while using different Congestion window values. The bit rate for the sender was 5.67 Mbits per second and 5.47 Mbits for the receiver. No retransmissions were detected.



```
[  5] local 192.168.42.2 port 44820 connected to              port 5207
[ ID] Interval           Transfer     Bitrate         Retr  Cwnd
[  5]   0.00-1.00   sec  1.46 MBytes  12.2 Mbits/sec    0   68.9 KBytes
[  5]   1.00-2.00   sec   773 KBytes  6.34 Mbits/sec    0   54.8 KBytes
[  5]   2.00-3.00   sec   619 KBytes  5.07 Mbits/sec    0   57.7 KBytes
[  5]   3.00-4.00   sec   619 KBytes  5.07 Mbits/sec    0   66.1 KBytes
[  5]   4.00-5.00   sec   773 KBytes  6.34 Mbits/sec    0   61.9 KBytes
[  5]   5.00-6.00   sec   619 KBytes  5.07 Mbits/sec    0   68.9 KBytes
[  5]   6.00-7.00   sec   650 KBytes  5.32 Mbits/sec    0   66.1 KBytes
[  5]   7.00-8.00   sec   619 KBytes  5.07 Mbits/sec    0   68.9 KBytes
[  5]   8.00-9.00   sec   619 KBytes  5.07 Mbits/sec    0   68.9 KBytes
[  5]   9.00-10.00  sec   804 KBytes  6.59 Mbits/sec    0   66.1 KBytes
[  5]  10.00-11.00  sec   650 KBytes  5.32 Mbits/sec    0   71.7 KBytes
[  5]  11.00-12.00  sec   712 KBytes  5.83 Mbits/sec    0   75.9 KBytes
[  5]  12.00-13.00  sec   681 KBytes  5.58 Mbits/sec    0   78.8 KBytes
[  5]  13.00-14.00  sec   557 KBytes  4.56 Mbits/sec    0   68.9 KBytes
[  5]  14.00-15.00  sec   928 KBytes  7.61 Mbits/sec    0   80.2 KBytes
[  5]  15.00-16.00  sec   557 KBytes  4.56 Mbits/sec    0   83.0 KBytes
[  5]  16.00-17.00  sec   742 KBytes  6.08 Mbits/sec    0   67.5 KBytes
[  5]  17.00-18.00  sec   557 KBytes  4.56 Mbits/sec    0   68.9 KBytes
[  5]  18.00-19.00  sec   773 KBytes  6.34 Mbits/sec    0   67.5 KBytes
[  5]  19.00-20.00  sec   742 KBytes  6.08 Mbits/sec    0   75.9 KBytes
[  5]  20.00-21.00  sec   557 KBytes  4.56 Mbits/sec    0   67.5 KBytes
[  5]  21.00-22.00  sec   742 KBytes  6.08 Mbits/sec    0   71.7 KBytes
[  5]  22.00-23.00  sec   557 KBytes  4.56 Mbits/sec    0   68.9 KBytes
[  5]  23.00-24.00  sec   928 KBytes  7.60 Mbits/sec    0   68.9 KBytes
[  5]  24.00-25.00  sec   557 KBytes  4.56 Mbits/sec    0   68.9 KBytes
[  5]  25.00-26.00  sec   588 KBytes  4.81 Mbits/sec    0   71.7 KBytes
[  5]  26.00-27.00  sec   650 KBytes  5.32 Mbits/sec    0   36.6 KBytes
[  5]  27.00-28.00  sec   866 KBytes  7.10 Mbits/sec    0   71.7 KBytes
[  5]  28.00-29.00  sec   650 KBytes  5.32 Mbits/sec    0   71.7 KBytes
[  5]  29.00-30.00  sec   650 KBytes  5.32 Mbits/sec    0   87.2 KBytes
[  5]  30.00-31.00  sec   650 KBytes  5.32 Mbits/sec    0   36.6 KBytes
[  5]  31.00-32.00  sec   650 KBytes  5.32 Mbits/sec    0   74.5 KBytes
[  5]  32.00-33.00  sec   650 KBytes  5.32 Mbits/sec    0   71.7 KBytes
[  5]  33.00-34.00  sec   650 KBytes  5.32 Mbits/sec    0   74.5 KBytes
[  5]  34.00-35.00  sec   866 KBytes  7.10 Mbits/sec    0   71.7 KBytes
[  5]  35.00-36.00  sec   650 KBytes  5.32 Mbits/sec    0   71.7 KBytes
[  5]  36.00-37.00  sec   650 KBytes  5.32 Mbits/sec    0   71.7 KBytes
[  5]  37.00-38.00  sec   650 KBytes  5.32 Mbits/sec    0   71.7 KBytes
[  5]  38.00-39.00  sec   650 KBytes  5.32 Mbits/sec    0   73.1 KBytes
[  5]  39.00-40.00  sec   650 KBytes  5.32 Mbits/sec    0   71.7 KBytes
[  5]  40.00-41.00  sec   650 KBytes  5.32 Mbits/sec    0   71.7 KBytes
[  5]  41.00-42.00  sec   650 KBytes  5.32 Mbits/sec    0   71.7 KBytes
[  5]  42.00-43.00  sec   650 KBytes  5.32 Mbits/sec    0   71.7 KBytes
[  5]  43.00-44.00  sec   866 KBytes  7.10 Mbits/sec    0   74.5 KBytes
[  5]  44.00-45.00  sec   650 KBytes  5.32 Mbits/sec    0   71.7 KBytes
[  5]  45.00-46.00  sec   650 KBytes  5.32 Mbits/sec    0   73.1 KBytes
[  5]  46.00-47.00  sec   650 KBytes  5.32 Mbits/sec    0   80.2 KBytes
[  5]  47.00-48.00  sec   866 KBytes  7.10 Mbits/sec    0   71.7 KBytes
[  5]  48.00-49.00  sec   433 KBytes  3.55 Mbits/sec    0   74.5 KBytes
[  5]  49.00-50.00  sec   619 KBytes  5.07 Mbits/sec    0   73.1 KBytes
[  5]  50.00-51.00  sec   866 KBytes  7.10 Mbits/sec    0   73.1 KBytes
[  5]  51.00-52.00  sec   650 KBytes  5.32 Mbits/sec    0   74.5 KBytes
[  5]  52.00-53.00  sec   619 KBytes  5.07 Mbits/sec    0   71.7 KBytes
[  5]  53.00-54.00  sec   650 KBytes  5.32 Mbits/sec    0   71.7 KBytes
[  5]  54.00-55.00  sec   650 KBytes  5.32 Mbits/sec    0   71.7 KBytes
[  5]  55.00-56.00  sec   866 KBytes  7.10 Mbits/sec    0   71.7 KBytes
[  5]  56.00-57.00  sec   650 KBytes  5.32 Mbits/sec    0   71.7 KBytes
[  5]  57.00-58.00  sec   650 KBytes  5.32 Mbits/sec    0   99.8 KBytes
[  5]  58.00-59.00  sec   650 KBytes  5.32 Mbits/sec    0   73.1 KBytes
[  5]  59.00-60.00  sec   650 KBytes  5.32 Mbits/sec    0   73.1 KBytes
- - - - - - - - - - - - - - - - - - - - - - - - -
[ ID] Interval           Transfer     Bitrate         Retr
[  5]   0.00-60.00  sec  40.6 MBytes  5.67 Mbits/sec    0             sender
[  5]   0.00-60.00  sec  39.2 MBytes  5.47 Mbits/sec                  receiver
```

Figure 4.6: TCP Upload Throughput

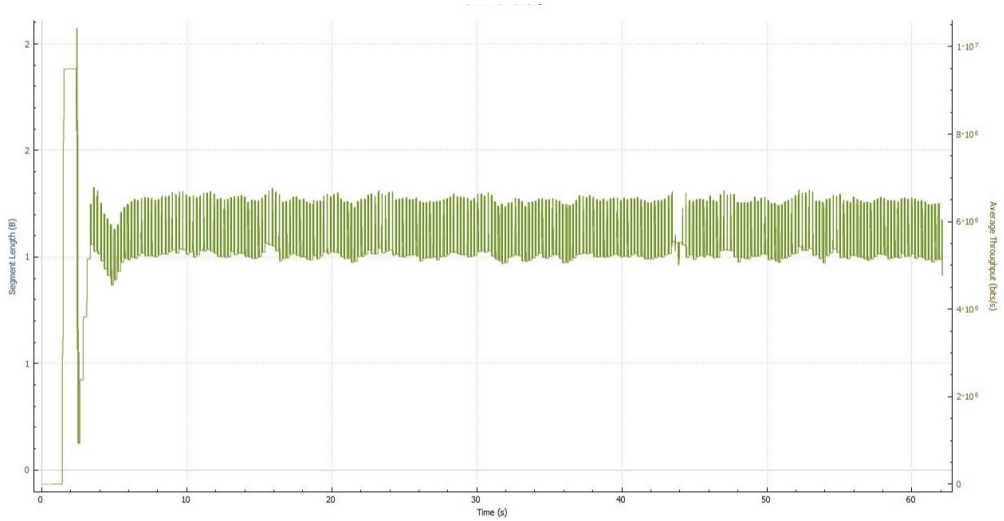


Figure 4.7: Upload Throughput Vs Time

Figure 4.7 explains the throughput behavior during the test of the upload performance, and it is clear that the amount of data transferred varies depending on the bit rate. When the speed is high, more data is transferred, and fewer data is transferred during a low bit rate.

Sequence Number

In Figure 4.8, It is clear that the line is not as sharp as the TCP download sequence number graph. There are many pauses. Each pause means the time when the sequence number was not increasing, which also means that it was a period when the packets were not sent.

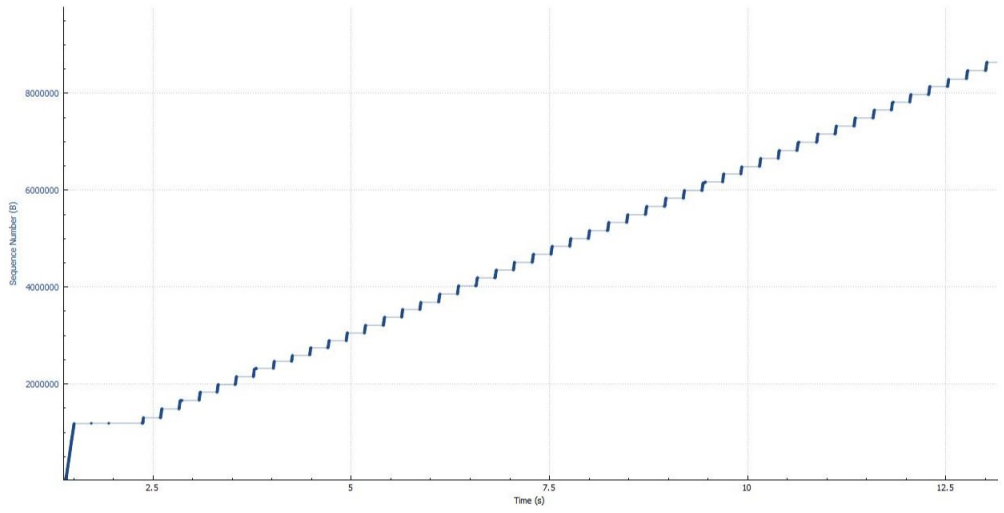


Figure 4.8: Sequence Number during Upload

KONNECT Download Throughput in UDP

The results of this test are from the server-side. The throughput achieved was 120 Mbits per second.

```
[  5] local port 5204 connected to  port 36405
Starting Test: protocol: UDP, 1 streams, 1440 byte blocks, omitting 0 seconds, 60 second test
[ ID] Interval           Transfer     Bandwidth       Total Datagrams
[  5]   0.00-2.00   sec  27.3 MBytes   115 Mbits/sec  19901
[  5]   2.00-4.00   sec  28.6 MBytes   120 Mbits/sec  20832
[  5]   4.00-6.00   sec  28.6 MBytes   120 Mbits/sec  20833
[  5]   6.00-8.00   sec  28.6 MBytes   120 Mbits/sec  20814
[  5]   8.00-10.00  sec  28.6 MBytes   120 Mbits/sec  20847
[  5]  10.00-12.00  sec  28.6 MBytes   120 Mbits/sec  20834
[  5]  12.00-14.00  sec  28.6 MBytes   120 Mbits/sec  20837
[  5]  14.00-16.00  sec  28.6 MBytes   120 Mbits/sec  20819
[  5]  16.00-18.00  sec  28.6 MBytes   120 Mbits/sec  20838
[  5]  18.00-20.00  sec  28.6 MBytes   120 Mbits/sec  20845
[  5]  20.00-22.00  sec  28.6 MBytes   120 Mbits/sec  20835
[  5]  22.00-24.00  sec  28.6 MBytes   120 Mbits/sec  20828
[  5]  24.00-26.00  sec  28.6 MBytes   120 Mbits/sec  20830
[  5]  26.00-28.00  sec  28.6 MBytes   120 Mbits/sec  20838
[  5]  28.00-30.00  sec  28.6 MBytes   120 Mbits/sec  20835
[  5]  30.00-32.00  sec  28.6 MBytes   120 Mbits/sec  20840
[  5]  32.00-34.00  sec  28.6 MBytes   120 Mbits/sec  20823
[  5]  34.00-36.00  sec  28.6 MBytes   120 Mbits/sec  20824
[  5]  36.00-38.00  sec  28.6 MBytes   120 Mbits/sec  20841
[  5]  38.00-40.00  sec  28.6 MBytes   120 Mbits/sec  20837
[  5]  40.00-42.00  sec  28.6 MBytes   120 Mbits/sec  20828
[  5]  42.00-44.00  sec  28.6 MBytes   120 Mbits/sec  20840
[  5]  44.00-46.00  sec  28.6 MBytes   120 Mbits/sec  20843
[  5]  46.00-48.00  sec  28.6 MBytes   120 Mbits/sec  20826
[  5]  48.00-50.00  sec  28.6 MBytes   120 Mbits/sec  20847
[  5]  50.00-52.00  sec  28.6 MBytes   120 Mbits/sec  20828
[  5]  52.00-54.00  sec  28.6 MBytes   120 Mbits/sec  20818
[  5]  54.00-56.00  sec  28.6 MBytes   120 Mbits/sec  20849
[  5]  56.00-58.00  sec  28.6 MBytes   120 Mbits/sec  20836
[  5]  58.00-60.00  sec  28.6 MBytes   120 Mbits/sec  20824
[  5]  60.00-60.69  sec  10.0 MBytes   122 Mbits/sec  7292
- - - - - - - - - - - - - - - - - - - - - - - - -
Test Complete. Summary Results:
[ ID] Interval           Transfer     Bandwidth       Jitter    Lost/Total Datagrams
[  5]   0.00-60.69  sec   867 MBytes   120 Mbits/sec  0.000 ms  0/631362 (0%)
CPU Utilization: local/sender 4.3% (0.5%u/3.8%s), remote/receiver 10.5% (4.0%u/6.5%s)
```

Figure 4.9: UDP Download Throughput

Jitter

It is a packet delay variance or interference in the order of sending data packets. The jitter value was 0.038 ms during the performance test, as shown in Figure 4.10, which is relatively small.

```
[ ID] Interval           Transfer     Bitrate         Jitter    Lost/Total Datagrams
[  5]   0.00-60.00  sec   867 MBytes   121 Mbits/sec  0.000 ms  0/619287 (0%)  sender
[  5]   0.00-60.00  sec   850 MBytes   119 Mbits/sec  0.038 ms  4/619287 (0.00065%)  receiver
```

Figure 4.10: UDP Download Jitter

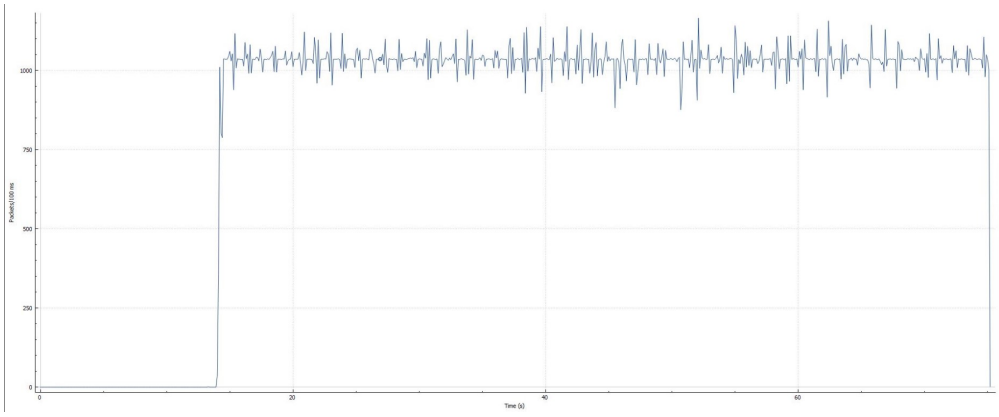
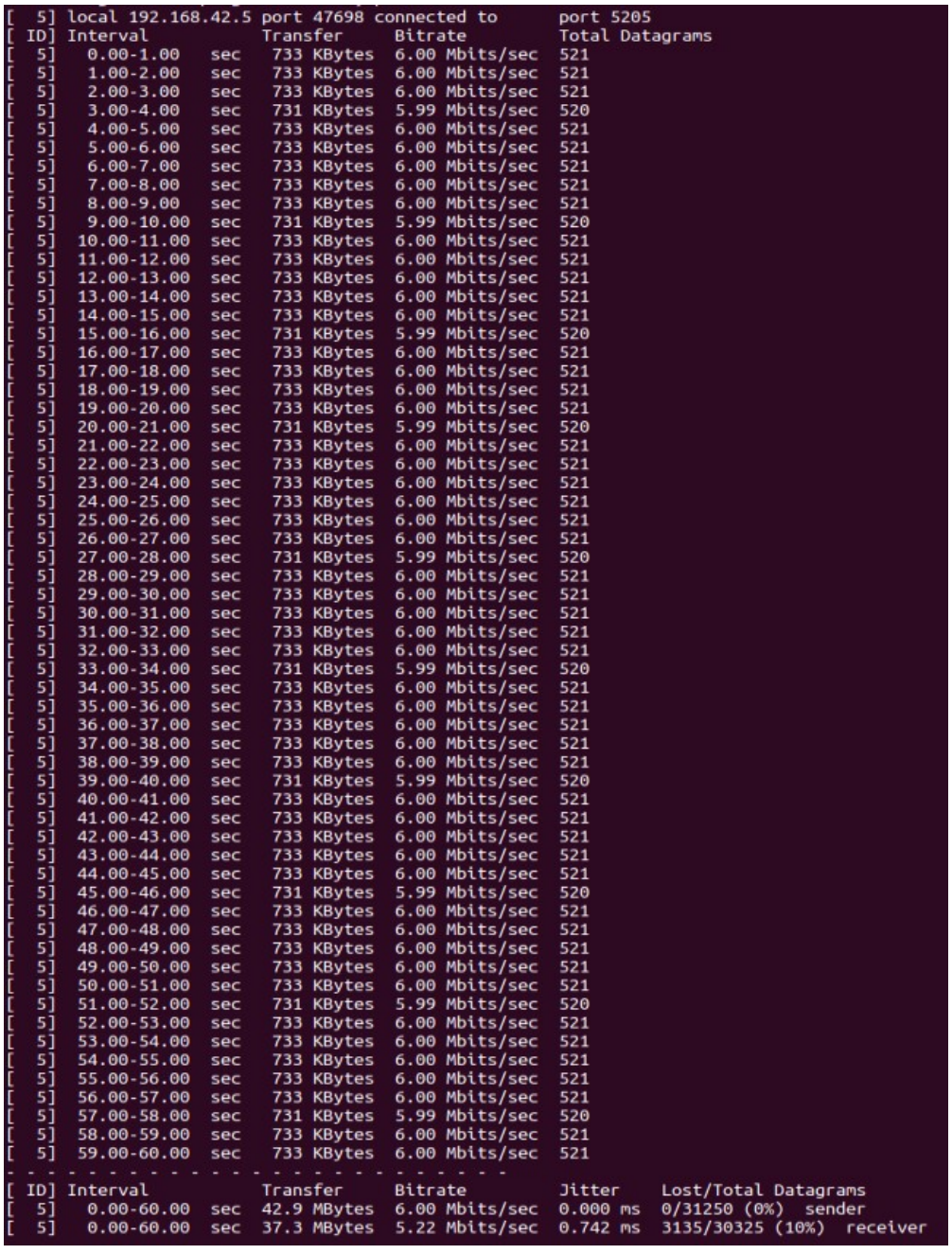


Figure 4.11: UDP Packets Vs Time

KONNECT Upload Throughput in UDP

The upload throughput was measured using the User Datagram Protocol (UDP) connection in this test. UDP is connectionless. It divides packets into chunks and sends them. Figure 4.12 shows that the average upload throughput for UDP when using HT2000W modem with KONNECT satellite is 5.22 Mbits per second. the average jitter during the test was 0.742 ms. The total number of datagrams is 30325 the number of datagrams lost is 3135.



```
[  5] local 192.168.42.5 port 47698 connected to      port 5205
[ ID] Interval           Transfer     Bitrate         Total Datagrams
[  5]   0.00-1.00   sec   733 KBytes  6.00 Mbits/sec  521
[  5]   1.00-2.00   sec   733 KBytes  6.00 Mbits/sec  521
[  5]   2.00-3.00   sec   733 KBytes  6.00 Mbits/sec  521
[  5]   3.00-4.00   sec   731 KBytes  5.99 Mbits/sec  520
[  5]   4.00-5.00   sec   733 KBytes  6.00 Mbits/sec  521
[  5]   5.00-6.00   sec   733 KBytes  6.00 Mbits/sec  521
[  5]   6.00-7.00   sec   733 KBytes  6.00 Mbits/sec  521
[  5]   7.00-8.00   sec   733 KBytes  6.00 Mbits/sec  521
[  5]   8.00-9.00   sec   733 KBytes  6.00 Mbits/sec  521
[  5]   9.00-10.00  sec   731 KBytes  5.99 Mbits/sec  520
[  5]  10.00-11.00  sec   733 KBytes  6.00 Mbits/sec  521
[  5]  11.00-12.00  sec   733 KBytes  6.00 Mbits/sec  521
[  5]  12.00-13.00  sec   733 KBytes  6.00 Mbits/sec  521
[  5]  13.00-14.00  sec   733 KBytes  6.00 Mbits/sec  521
[  5]  14.00-15.00  sec   733 KBytes  6.00 Mbits/sec  521
[  5]  15.00-16.00  sec   731 KBytes  5.99 Mbits/sec  520
[  5]  16.00-17.00  sec   733 KBytes  6.00 Mbits/sec  521
[  5]  17.00-18.00  sec   733 KBytes  6.00 Mbits/sec  521
[  5]  18.00-19.00  sec   733 KBytes  6.00 Mbits/sec  521
[  5]  19.00-20.00  sec   733 KBytes  6.00 Mbits/sec  521
[  5]  20.00-21.00  sec   731 KBytes  5.99 Mbits/sec  520
[  5]  21.00-22.00  sec   733 KBytes  6.00 Mbits/sec  521
[  5]  22.00-23.00  sec   733 KBytes  6.00 Mbits/sec  521
[  5]  23.00-24.00  sec   733 KBytes  6.00 Mbits/sec  521
[  5]  24.00-25.00  sec   733 KBytes  6.00 Mbits/sec  521
[  5]  25.00-26.00  sec   733 KBytes  6.00 Mbits/sec  521
[  5]  26.00-27.00  sec   733 KBytes  6.00 Mbits/sec  521
[  5]  27.00-28.00  sec   731 KBytes  5.99 Mbits/sec  520
[  5]  28.00-29.00  sec   733 KBytes  6.00 Mbits/sec  521
[  5]  29.00-30.00  sec   733 KBytes  6.00 Mbits/sec  521
[  5]  30.00-31.00  sec   733 KBytes  6.00 Mbits/sec  521
[  5]  31.00-32.00  sec   733 KBytes  6.00 Mbits/sec  521
[  5]  32.00-33.00  sec   733 KBytes  6.00 Mbits/sec  521
[  5]  33.00-34.00  sec   731 KBytes  5.99 Mbits/sec  520
[  5]  34.00-35.00  sec   733 KBytes  6.00 Mbits/sec  521
[  5]  35.00-36.00  sec   733 KBytes  6.00 Mbits/sec  521
[  5]  36.00-37.00  sec   733 KBytes  6.00 Mbits/sec  521
[  5]  37.00-38.00  sec   733 KBytes  6.00 Mbits/sec  521
[  5]  38.00-39.00  sec   733 KBytes  6.00 Mbits/sec  521
[  5]  39.00-40.00  sec   731 KBytes  5.99 Mbits/sec  520
[  5]  40.00-41.00  sec   733 KBytes  6.00 Mbits/sec  521
[  5]  41.00-42.00  sec   733 KBytes  6.00 Mbits/sec  521
[  5]  42.00-43.00  sec   733 KBytes  6.00 Mbits/sec  521
[  5]  43.00-44.00  sec   733 KBytes  6.00 Mbits/sec  521
[  5]  44.00-45.00  sec   733 KBytes  6.00 Mbits/sec  521
[  5]  45.00-46.00  sec   731 KBytes  5.99 Mbits/sec  520
[  5]  46.00-47.00  sec   733 KBytes  6.00 Mbits/sec  521
[  5]  47.00-48.00  sec   733 KBytes  6.00 Mbits/sec  521
[  5]  48.00-49.00  sec   733 KBytes  6.00 Mbits/sec  521
[  5]  49.00-50.00  sec   733 KBytes  6.00 Mbits/sec  521
[  5]  50.00-51.00  sec   733 KBytes  6.00 Mbits/sec  521
[  5]  51.00-52.00  sec   731 KBytes  5.99 Mbits/sec  520
[  5]  52.00-53.00  sec   733 KBytes  6.00 Mbits/sec  521
[  5]  53.00-54.00  sec   733 KBytes  6.00 Mbits/sec  521
[  5]  54.00-55.00  sec   733 KBytes  6.00 Mbits/sec  521
[  5]  55.00-56.00  sec   733 KBytes  6.00 Mbits/sec  521
[  5]  56.00-57.00  sec   733 KBytes  6.00 Mbits/sec  521
[  5]  57.00-58.00  sec   731 KBytes  5.99 Mbits/sec  520
[  5]  58.00-59.00  sec   733 KBytes  6.00 Mbits/sec  521
[  5]  59.00-60.00  sec   733 KBytes  6.00 Mbits/sec  521
- - - - - - - - - - - - - - - - - - - - - - - - -
[ ID] Interval           Transfer     Bitrate         Jitter    Lost/Total Datagrams
[  5]   0.00-60.00  sec  42.9 MBytes  6.00 Mbits/sec  0.000 ms  0/31250 (0%)  sender
[  5]   0.00-60.00  sec  37.3 MBytes  5.22 Mbits/sec  0.742 ms  3135/30325 (10%)  receiver
```

Figure 4.12: KONNECT Upload Throughput in UDP

4.3 KASAT Performance Test

Figure 4.13 shows the logical topology and the primary devices used for the test. The network performance test was performed using the KASAT satellite. An iperf3 was launched between the iperf server and client multiple times to test the throughput for download and upload for TCP and UDP connections.

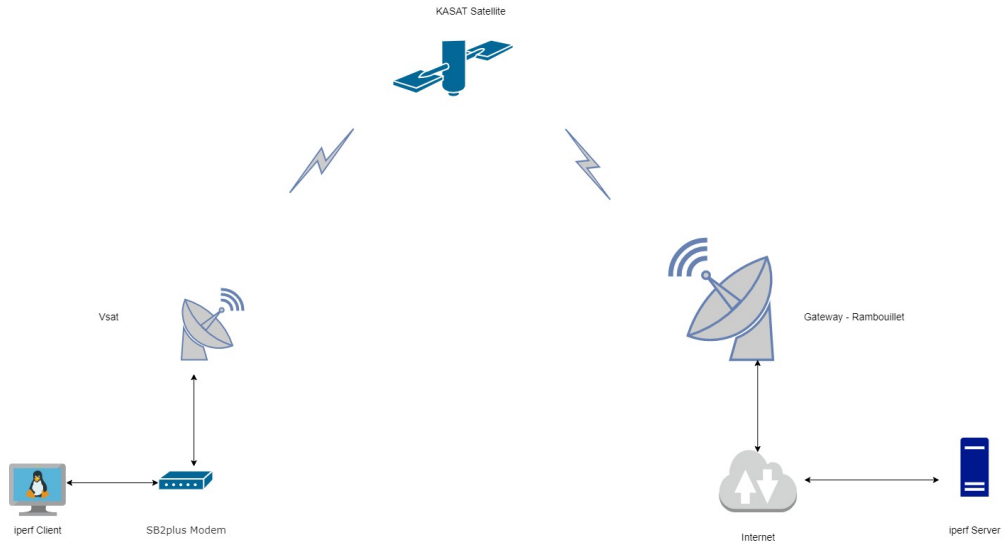


Figure 4.13: KASAT Topology

Network Configuration

The Client is a computer running on Linux Operating System (Ubuntu 18.04) connected to the SB2plus modem with an Ethernet Cat6 cable. The network interface card on the Client is a full-duplex to allow sending and receiving data simultaneously between server and Client, and the speed is 1000Mb per second. Auto-negotiation is on. The Client was assigned a public IP address. The antenna size is 75 cm, the average downstream SNR was 14.40 dB for downstream and 11.81 dB for upstream, as shown in figure 4.13.

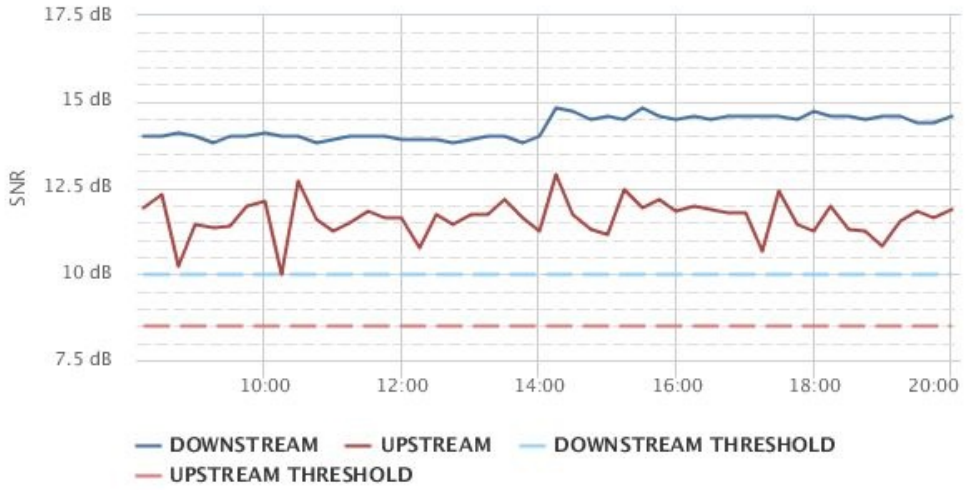


Figure 4.14: Modem SNR

The following parameters were configured on the modem

SB2plus Parameters	
Parameter	Value
Channel Symbol Rate	10000 Ksps
Mod-Cod Return	rlm-8psk-3-4
Mod-Cod Forward	flm-16-apsk-8-9
Return Channel Speed	22500 Kbps

Table 4.2: KASAT Modem Downlink and Uplink parameters

KASAT Download Throughput in TCP

This test was performed between the server and client to measure the download speed while using a TCP connection, and the test duration was 60 seconds. The modem SB2plus ca achieve up to 47.9 Mbits per second for download. The number of retransmission is 704.
Figure 4.15 shows the number of packets transferred and the bit rate.

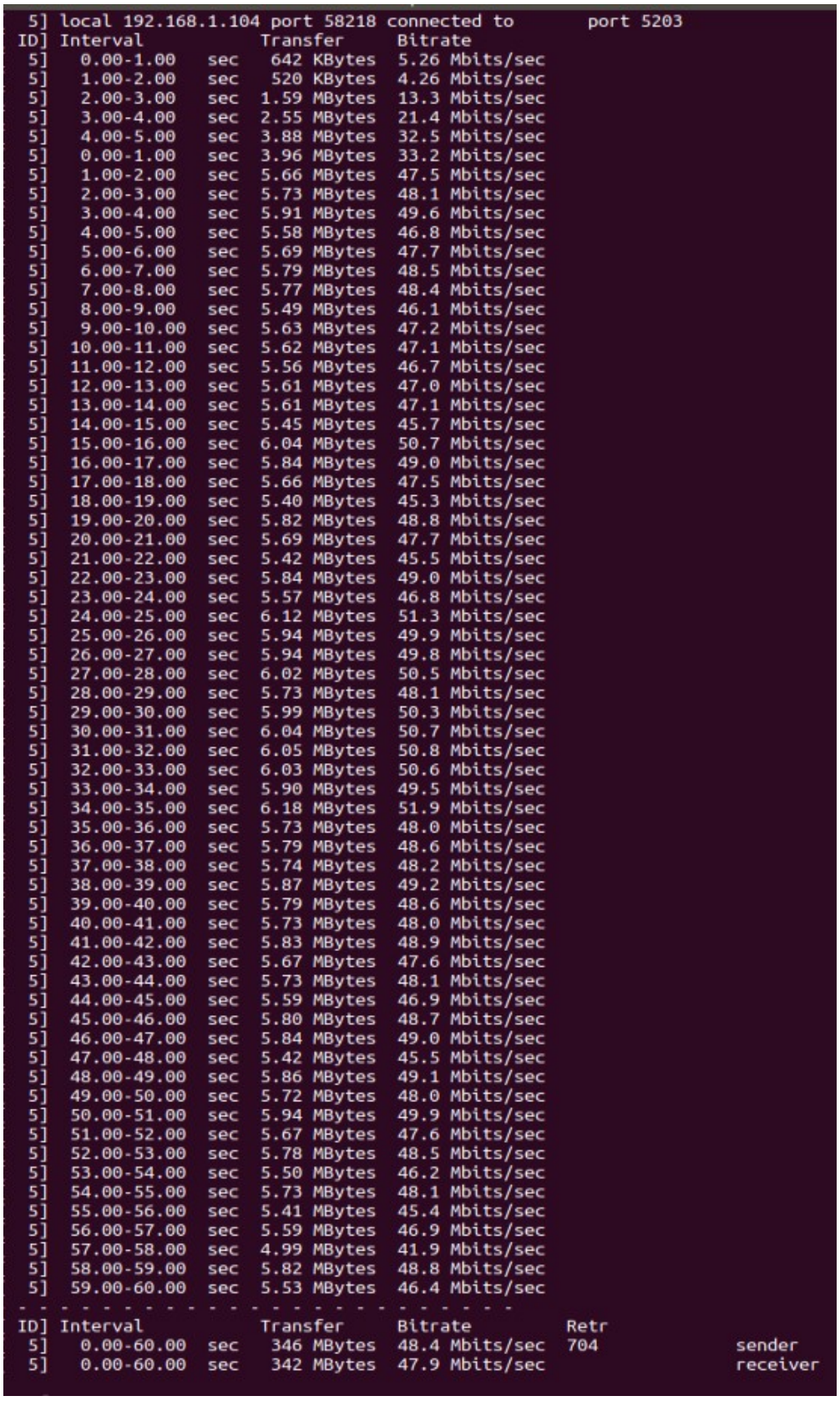


Figure 4.15: TCP Download Throughput

Figure 4.16 explains the throughput vs. time and the segment length in Bytes. In the beginning, we can see that the bit rate is 5.26 Mbits per second, then it goes up to 47.6 Mbits within 1-second.

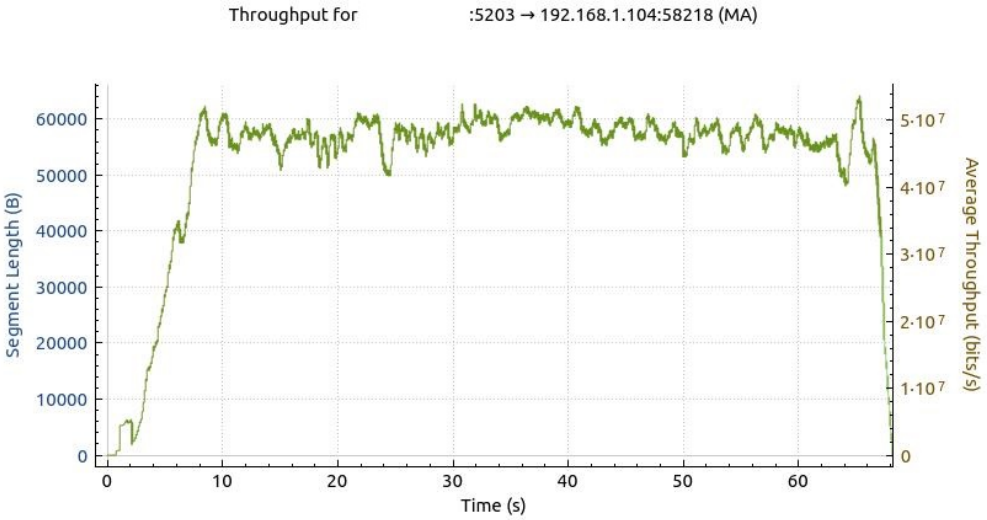


Figure 4.16: Average Throughput vs Time

Sequence Number

Figure 4.17 shows the trend of the sequence number while performing an iperf3 test to measure the download throughput, and it is obvious there was a delay at the beginning of the data transmission between the server and client; after 1 second, the sequence number increased sharply, this shows that the data was moving without any disconnection.

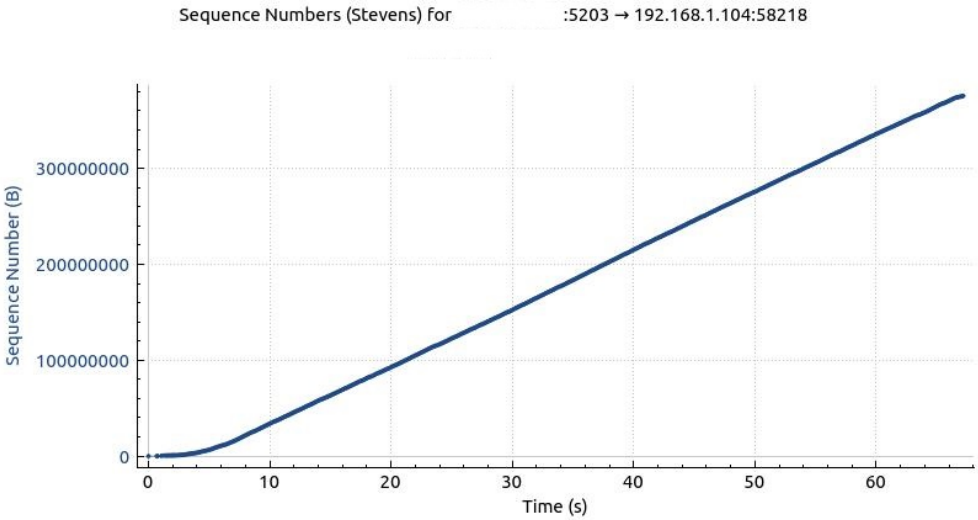


Figure 4.17: Sequence Number

KASAT Upload Throughput in TCP

This test measures the upload speed using a connection-oriented transmission control protocol between the iperf server and the client. The server was listening on iperf port 5203. At the beginning of the test, the bit rate was 5.95 Mbits per second, and the congestion window was 148 KBytes. After that, the sender's average bitrate was 8.76 Mbits per second. The number of retransmission was 1. during the iperf test, large packets were transferred during high bit rates, and a small number of packets were transferred during low bit rates with different congestion windows values.

```
[  5] local 192.168.1.100 port 34094 connected to         port 5203
[ ID] Interval           Transfer     Bitrate         Retr  Cwnd
[  5]   0.00-1.00   sec   727 KBytes  5.95 Mbits/sec    0    148 KBytes
[  5]   1.00-2.00   sec   314 KBytes  2.57 Mbits/sec    0   37.1 KBytes
[  5]   2.00-3.00   sec   314 KBytes  2.57 Mbits/sec    0   57.0 KBytes
[  5]   3.00-4.00   sec   941 KBytes  7.71 Mbits/sec    0   71.3 KBytes
[  5]   4.00-5.00   sec   627 KBytes  5.14 Mbits/sec    0   71.3 KBytes
[  5]   5.00-6.00   sec  1.23 MBytes  10.3 Mbits/sec    0    148 KBytes
[  5]   6.00-7.00   sec  1.23 MBytes  10.3 Mbits/sec    0    108 KBytes
[  5]   7.00-8.00   sec   941 KBytes  7.71 Mbits/sec    0    108 KBytes
[  5]   8.00-9.00   sec  1.23 MBytes  10.3 Mbits/sec    0    108 KBytes
[  5]   9.00-10.00  sec  1.23 MBytes  10.3 Mbits/sec    0    131 KBytes
[  5]  10.00-11.00  sec  1.23 MBytes  10.3 Mbits/sec    0    148 KBytes
[  5]  11.00-12.00  sec  1.23 MBytes  10.3 Mbits/sec    0    148 KBytes
[  5]  12.00-13.00  sec  1.23 MBytes  10.3 Mbits/sec    0    148 KBytes
[  5]  13.00-14.00  sec  1.23 MBytes  10.3 Mbits/sec    0    148 KBytes
[  5]  14.00-15.00  sec   941 KBytes  7.71 Mbits/sec    0    148 KBytes
[  5]  15.00-16.00  sec   627 KBytes  5.14 Mbits/sec    0    148 KBytes
[  5]  16.00-17.00  sec  1004 KBytes  8.23 Mbits/sec    0    153 KBytes
[  5]  17.00-18.00  sec  1.23 MBytes  10.3 Mbits/sec    0    153 KBytes
[  5]  18.00-19.00  sec  1.23 MBytes  10.3 Mbits/sec    0    153 KBytes
[  5]  19.00-20.00  sec   941 KBytes  7.71 Mbits/sec    0    153 KBytes
[  5]  20.00-21.00  sec  1.23 MBytes  10.3 Mbits/sec    0    153 KBytes
[  5]  21.00-22.00  sec  1.23 MBytes  10.3 Mbits/sec    0    153 KBytes
[  5]  22.00-23.00  sec   941 KBytes  7.71 Mbits/sec    0    153 KBytes
[  5]  23.00-24.00  sec  1.29 MBytes  10.8 Mbits/sec    0    153 KBytes
[  5]  24.00-25.00  sec  1004 KBytes  8.22 Mbits/sec    0    153 KBytes
[  5]  25.00-26.00  sec   941 KBytes  7.71 Mbits/sec    0    153 KBytes
[  5]  26.00-27.00  sec  1.23 MBytes  10.3 Mbits/sec    0    153 KBytes
[  5]  27.00-28.00  sec  1.23 MBytes  10.3 Mbits/sec    0    153 KBytes
[  5]  28.00-29.00  sec  1004 KBytes  8.22 Mbits/sec    0    153 KBytes
[  5]  29.00-30.00  sec   941 KBytes  7.71 Mbits/sec    1    153 KBytes
[  5]  30.00-31.00  sec   941 KBytes  7.71 Mbits/sec    0    138 KBytes
[  5]  31.00-32.00  sec  1.29 MBytes  10.8 Mbits/sec    0    138 KBytes
[  5]  32.00-33.00  sec   941 KBytes  7.71 Mbits/sec    0    138 KBytes
[  5]  33.00-34.00  sec  1.23 MBytes  10.3 Mbits/sec    0    138 KBytes
[  5]  34.00-35.00  sec  1.23 MBytes  10.3 Mbits/sec    0    138 KBytes
[  5]  35.00-36.00  sec  1.23 MBytes  10.3 Mbits/sec    0    138 KBytes
[  5]  36.00-37.00  sec   941 KBytes  7.71 Mbits/sec    0    138 KBytes
[  5]  37.00-38.00  sec  1.23 MBytes  10.3 Mbits/sec    0    138 KBytes
[  5]  38.00-39.00  sec  1004 KBytes  8.22 Mbits/sec    0    138 KBytes
[  5]  39.00-40.00  sec   941 KBytes  7.71 Mbits/sec    0    150 KBytes
[  5]  40.00-41.00  sec  1.23 MBytes  10.3 Mbits/sec    0    150 KBytes
[  5]  41.00-42.00  sec   941 KBytes  7.71 Mbits/sec    0    150 KBytes
[  5]  42.00-43.00  sec  1.23 MBytes  10.3 Mbits/sec    0    150 KBytes
[  5]  43.00-44.00  sec  1.23 MBytes  10.3 Mbits/sec    0    150 KBytes
[  5]  44.00-45.00  sec  1.35 MBytes  11.3 Mbits/sec    0    150 KBytes
[  5]  45.00-46.00  sec   941 KBytes  7.71 Mbits/sec    0   74.1 KBytes
[  5]  46.00-47.00  sec  1.29 MBytes  10.8 Mbits/sec    0   74.1 KBytes
[  5]  47.00-48.00  sec  1.23 MBytes  10.3 Mbits/sec    0   97.0 KBytes
[  5]  48.00-49.00  sec   941 KBytes  7.71 Mbits/sec    0   97.0 KBytes
[  5]  49.00-50.00  sec  1.23 MBytes  10.3 Mbits/sec    0    123 KBytes
[  5]  50.00-51.00  sec  1.23 MBytes  10.3 Mbits/sec    0    123 KBytes
[  5]  51.00-52.00  sec   627 KBytes  5.14 Mbits/sec    0    123 KBytes
[  5]  52.00-53.00  sec  1.10 MBytes  9.25 Mbits/sec    0   88.4 KBytes
[  5]  53.00-54.00  sec  1.10 MBytes  9.25 Mbits/sec    0   97.0 KBytes
[  5]  54.00-55.00  sec  1.10 MBytes  9.25 Mbits/sec    0   97.0 KBytes
[  5]  55.00-56.00  sec   753 KBytes  6.17 Mbits/sec    0    117 KBytes
[  5]  56.00-57.00  sec  1.10 MBytes  9.25 Mbits/sec    0    125 KBytes
[  5]  57.00-58.00  sec   753 KBytes  6.17 Mbits/sec    0    128 KBytes
[  5]  58.00-59.00  sec  1.10 MBytes  9.25 Mbits/sec    0    128 KBytes
[  5]  59.00-60.00  sec  1.10 MBytes  9.25 Mbits/sec    0    128 KBytes
- - - - - - - - - - - - - - - - - - - - - - - - -
[ ID] Interval           Transfer     Bitrate         Retr
[  5]   0.00-60.00  sec  62.6 MBytes  8.76 Mbits/sec    1             sender
[  5]   0.00-60.00  sec  61.8 MBytes  8.63 Mbits/sec                  receiver
```

Figure 4.18: TCP Upload Throughput

Figure 4.19 shows the behavior of the throughput vs. time during the TCP upload performance test. Again, the throughput had different values during different times.

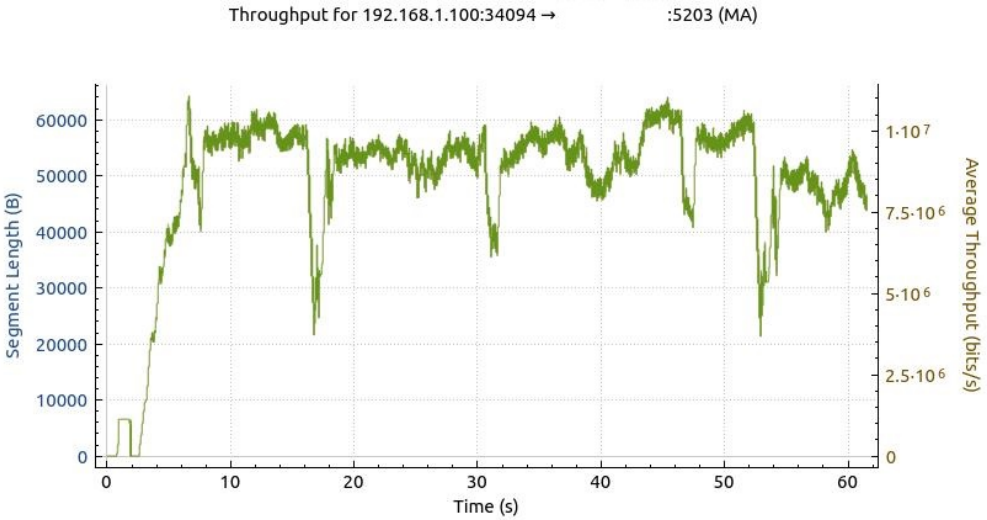


Figure 4.19: Throughput vs Time

Sequence Number

During the data transfer, the sequence number had a couple of interruptions because of delay and bit rate variations, as can be shown in Figure 4.20.

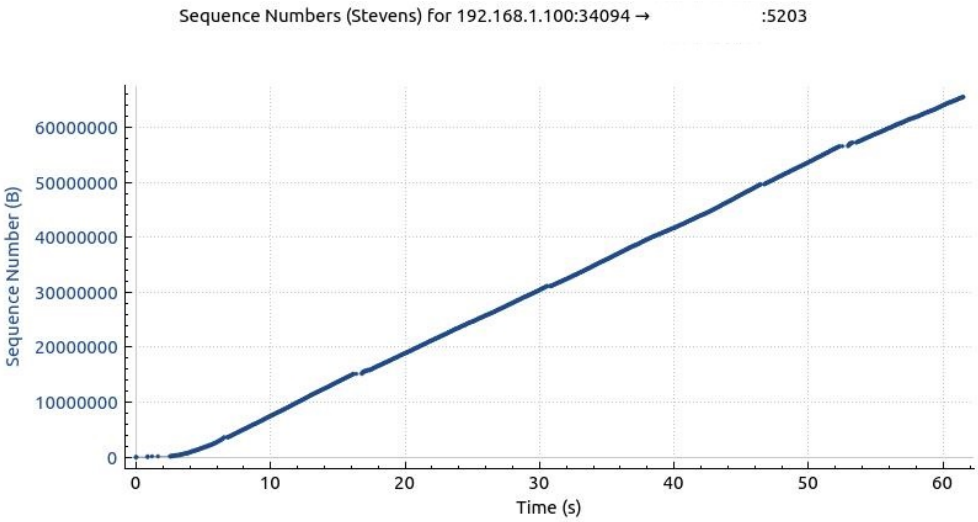


Figure 4.20: Throughput vs Time

KASAT Download Throughput in UDP

The download throughput was measured using a UDP connection for the SB2plus modem using the KASAT satellite. UDP does not require connection establishment or termination. Instead, it divides packets into chunks of a reasonable size that can be sent instantly. The bit rate achieved during the beginning of the test was 47.6 Mbits per second, then it increased up to 50 Mbits per second, no packet loss was detected.

```
Accepted connection from       , port 35212
      Cookie: 5742pls7wpp2ipcnzcexkifp6u6ns5tcnrdt
[  5] local  port 5205 connected to          port 39486
Starting Test: protocol: UDP, 1 streams, 1460 byte blocks, omitting 0 seconds, 60 second test
[ ID] Interval           Transfer     Bandwidth       Total Datagrams
[  5]   0.00-2.00   sec  11.4 MBytes  47.6 Mbits/sec  8153
[  5]   2.00-4.00   sec  11.9 MBytes  50.0 Mbits/sec  8561
[  5]   4.00-6.00   sec  11.9 MBytes  50.0 Mbits/sec  8562
[  5]   6.00-8.00   sec  11.9 MBytes  50.0 Mbits/sec  8561
[  5]   8.00-10.00  sec  11.9 MBytes  50.0 Mbits/sec  8560
[  5]  10.00-12.00  sec  11.9 MBytes  50.0 Mbits/sec  8563
[  5]  12.00-14.00  sec  11.9 MBytes  50.0 Mbits/sec  8562
[  5]  14.00-16.00  sec  11.9 MBytes  50.0 Mbits/sec  8561
[  5]  16.00-18.00  sec  11.9 MBytes  50.0 Mbits/sec  8562
[  5]  18.00-20.00  sec  11.9 MBytes  50.0 Mbits/sec  8562
[  5]  20.00-22.00  sec  11.9 MBytes  50.0 Mbits/sec  8560
[  5]  22.00-24.00  sec  11.9 MBytes  50.0 Mbits/sec  8564
[  5]  24.00-26.00  sec  11.9 MBytes  50.0 Mbits/sec  8561
[  5]  26.00-28.00  sec  11.9 MBytes  50.0 Mbits/sec  8559
[  5]  28.00-30.00  sec  11.9 MBytes  50.0 Mbits/sec  8564
[  5]  30.00-32.00  sec  11.9 MBytes  50.0 Mbits/sec  8562
[  5]  32.00-34.00  sec  11.9 MBytes  50.0 Mbits/sec  8561
[  5]  34.00-36.00  sec  11.9 MBytes  50.0 Mbits/sec  8561
[  5]  36.00-38.00  sec  11.9 MBytes  50.0 Mbits/sec  8563
[  5]  38.00-40.00  sec  11.9 MBytes  50.0 Mbits/sec  8560
[  5]  40.00-42.00  sec  11.9 MBytes  50.0 Mbits/sec  8564
[  5]  42.00-44.00  sec  11.9 MBytes  50.0 Mbits/sec  8561
[  5]  44.00-46.00  sec  11.9 MBytes  50.0 Mbits/sec  8561
[  5]  46.00-48.00  sec  11.9 MBytes  50.0 Mbits/sec  8563
[  5]  48.00-50.00  sec  11.9 MBytes  50.0 Mbits/sec  8561
[  5]  50.00-52.00  sec  11.9 MBytes  50.0 Mbits/sec  8561
[  5]  52.00-54.00  sec  11.9 MBytes  50.0 Mbits/sec  8561
[  5]  54.00-56.00  sec  11.9 MBytes  50.0 Mbits/sec  8561
[  5]  56.00-58.00  sec  11.9 MBytes  50.0 Mbits/sec  8563
[  5]  58.00-60.00  sec  11.9 MBytes  50.0 Mbits/sec  8562
[  5]  60.00-60.59  sec  3.58 MBytes  50.5 Mbits/sec  2568
- - - - - - - - - - - - - - - - - - - - - - - - -
Test Complete. Summary Results:
[ ID] Interval           Transfer     Bandwidth       Jitter    Lost/Total Datagrams
[  5]   0.00-60.59  sec   361 MBytes  49.9 Mbits/sec  0.000 ms  0/259008 (0%)
CPU Utilization: local/sender 3.7% (0.6%u/3.1%s), remote/receiver 1.6% (0.2%u/1.3%s)
```

Figure 4.21: UDP Download Throughput

KASAT Jitter in UDP

The value of the jitter was measured as well during the test. The value recorded was 0.153 ms on the receiver. Figure 4.22 shows the amount of jitter measured during the test.

```
[ ID] Interval           Transfer     Bitrate         Jitter    Lost/Total Datagrams
[  5]   0.00-60.00  sec   361 MBytes  50.4 Mbits/sec  0.000 ms  0/256425 (0%)  sender
[  5]   0.00-60.00  sec   333 MBytes  46.5 Mbits/sec  0.153 ms  17451/256425 (6.8%)  receiver
```

Figure 4.22: KASAT Jitter in UDP Download

Figure 4.23 shows the trend of the packets transmitted vs. time during UDP connection.

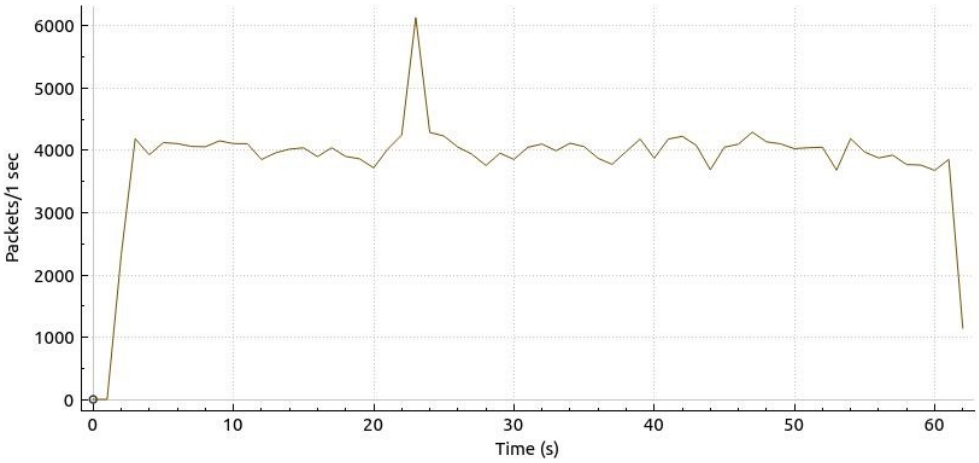


Figure 4.23: Packets vs Time

KASAT Upload Throughput in UDP

An iperf3 command was launched to measure the upload speed while using a UDP connection between the server and the client. During the UDP connection, datagrams of 856 and 857 have been transferred between server and client. The average throughput measured was 8.86 Mbits per second with a jitter of 1.956 ms. the total number of datagrams sent was, 51365 the number of datagrams lost was 5865, representing 11 percent of the total number. Figure 4.24 shows the measured values of the average throughput and the jitter.

```
[  5] local 192.168.1.100 port 54419 connected to  port 5208
[ ID] Interval           Transfer     Bitrate         Total Datagrams
[  5]   0.00-1.00   sec  1.19 MBytes  10.0 Mbits/sec  856
[  5]   1.00-2.00   sec  1.19 MBytes  10.0 Mbits/sec  856
[  5]   2.00-3.00   sec  1.19 MBytes  10.0 Mbits/sec  856
[  5]   3.00-4.00   sec  1.19 MBytes  10.0 Mbits/sec  856
[  5]   4.00-5.00   sec  1.19 MBytes  10.0 Mbits/sec  857
[  5]   5.00-6.00   sec  1.19 MBytes  10.0 Mbits/sec  856
[  5]   6.00-7.00   sec  1.19 MBytes  10.0 Mbits/sec  856
[  5]   7.00-8.00   sec  1.19 MBytes  10.0 Mbits/sec  856
[  5]   8.00-9.00   sec  1.19 MBytes  10.0 Mbits/sec  856
[  5]   9.00-10.00  sec  1.19 MBytes  10.0 Mbits/sec  856
[  5]  10.00-11.00  sec  1.19 MBytes  10.0 Mbits/sec  857
[  5]  11.00-12.00  sec  1.19 MBytes  10.0 Mbits/sec  856
[  5]  12.00-13.00  sec  1.19 MBytes  10.0 Mbits/sec  856
[  5]  13.00-14.00  sec  1.19 MBytes  10.0 Mbits/sec  856
[  5]  14.00-15.00  sec  1.19 MBytes  10.0 Mbits/sec  856
[  5]  15.00-16.00  sec  1.19 MBytes  10.0 Mbits/sec  856
[  5]  16.00-17.00  sec  1.19 MBytes  10.0 Mbits/sec  857
[  5]  17.00-18.00  sec  1.19 MBytes  10.0 Mbits/sec  856
[  5]  18.00-19.00  sec  1.19 MBytes  10.0 Mbits/sec  856
[  5]  19.00-20.00  sec  1.19 MBytes  10.0 Mbits/sec  856
[  5]  20.00-21.00  sec  1.19 MBytes  10.0 Mbits/sec  856
[  5]  21.00-22.00  sec  1.19 MBytes  10.0 Mbits/sec  856
[  5]  22.00-23.00  sec  1.19 MBytes  10.0 Mbits/sec  857
[  5]  23.00-24.00  sec  1.19 MBytes  10.0 Mbits/sec  856
[  5]  24.00-25.00  sec  1.19 MBytes  10.0 Mbits/sec  856
[  5]  25.00-26.00  sec  1.19 MBytes  10.0 Mbits/sec  856
[  5]  26.00-27.00  sec  1.19 MBytes  10.0 Mbits/sec  856
[  5]  27.00-28.00  sec  1.19 MBytes  10.0 Mbits/sec  856
[  5]  28.00-29.00  sec  1.19 MBytes  10.0 Mbits/sec  857
[  5]  29.00-30.00  sec  1.19 MBytes  10.0 Mbits/sec  856
[  5]  30.00-31.00  sec  1.19 MBytes  10.0 Mbits/sec  856
[  5]  31.00-32.00  sec  1.19 MBytes  10.0 Mbits/sec  856
[  5]  32.00-33.00  sec  1.19 MBytes  10.0 Mbits/sec  856
[  5]  33.00-34.00  sec  1.19 MBytes  10.0 Mbits/sec  856
[  5]  34.00-35.00  sec  1.19 MBytes  10.0 Mbits/sec  856
[  5]  35.00-36.00  sec  1.19 MBytes  10.0 Mbits/sec  857
[  5]  36.00-37.00  sec  1.19 MBytes  10.0 Mbits/sec  856
[  5]  37.00-38.00  sec  1.19 MBytes  10.0 Mbits/sec  856
[  5]  38.00-39.00  sec  1.19 MBytes  10.0 Mbits/sec  856
[  5]  39.00-40.00  sec  1.19 MBytes  10.0 Mbits/sec  856
[  5]  40.00-41.00  sec  1.19 MBytes  10.0 Mbits/sec  857
[  5]  41.00-42.00  sec  1.19 MBytes  10.0 Mbits/sec  856
[  5]  42.00-43.00  sec  1.19 MBytes  10.0 Mbits/sec  856
[  5]  43.00-44.00  sec  1.19 MBytes  10.0 Mbits/sec  856
[  5]  44.00-45.00  sec  1.19 MBytes  10.0 Mbits/sec  856
[  5]  45.00-46.00  sec  1.19 MBytes  10.0 Mbits/sec  856
[  5]  46.00-47.00  sec  1.19 MBytes  10.0 Mbits/sec  856
[  5]  47.00-48.00  sec  1.19 MBytes  10.0 Mbits/sec  857
[  5]  48.00-49.00  sec  1.19 MBytes  10.0 Mbits/sec  856
[  5]  49.00-50.00  sec  1.19 MBytes  10.0 Mbits/sec  856
[  5]  50.00-51.00  sec  1.19 MBytes  10.0 Mbits/sec  856
[  5]  51.00-52.00  sec  1.19 MBytes  10.0 Mbits/sec  856
[  5]  52.00-53.00  sec  1.19 MBytes  10.0 Mbits/sec  856
[  5]  53.00-54.00  sec  1.19 MBytes  10.0 Mbits/sec  857
[  5]  54.00-55.00  sec  1.19 MBytes  10.0 Mbits/sec  856
[  5]  55.00-56.00  sec  1.19 MBytes  10.0 Mbits/sec  856
[  5]  56.00-57.00  sec  1.19 MBytes  10.0 Mbits/sec  856
[  5]  57.00-58.00  sec  1.19 MBytes  10.0 Mbits/sec  856
[  5]  58.00-59.00  sec  1.19 MBytes  10.0 Mbits/sec  856
[  5]  59.00-60.00  sec  1.19 MBytes  10.0 Mbits/sec  857
- - - - - - - - - - - - - - - - - - - - - - - - -
[ ID] Interval           Transfer     Bitrate         Jitter    Lost/Total Datagrams
[  5]   0.00-60.00  sec  71.5 MBytes  10.0 Mbits/sec  0.000 ms  0/51370 (0%)  sender
[  5]   0.00-60.00  sec  63.4 MBytes  8.86 Mbits/sec  1.965 ms  5865/51365 (11%)  receiver
```

Figure 4.24: KASAT Upload Throughput in UDP

Figure 4.25 shows the packets sent vs time.

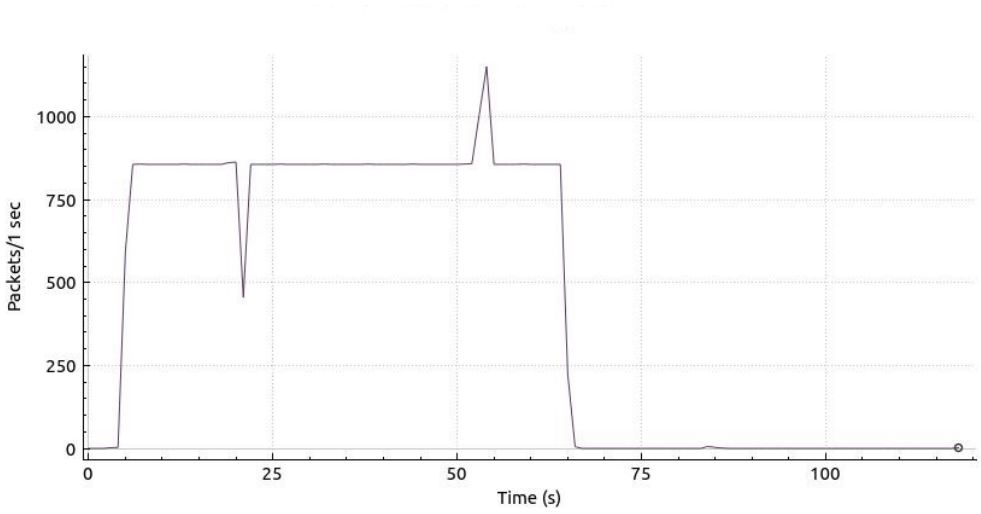


Figure 4.25: packets sent vs Time

4.4 Advance KU Network Performance Test

This section shows the Network Performance Test performed on Advance KU (AKU), which used the KU band. The script measures the throughput, Jitter, Packet loss for download and upload between an iperf3 server and client using Transmission Control Protocol and User Datagram Protocol. The traffic between the iperf3 client and server was captured and analyzed by Wireshark.

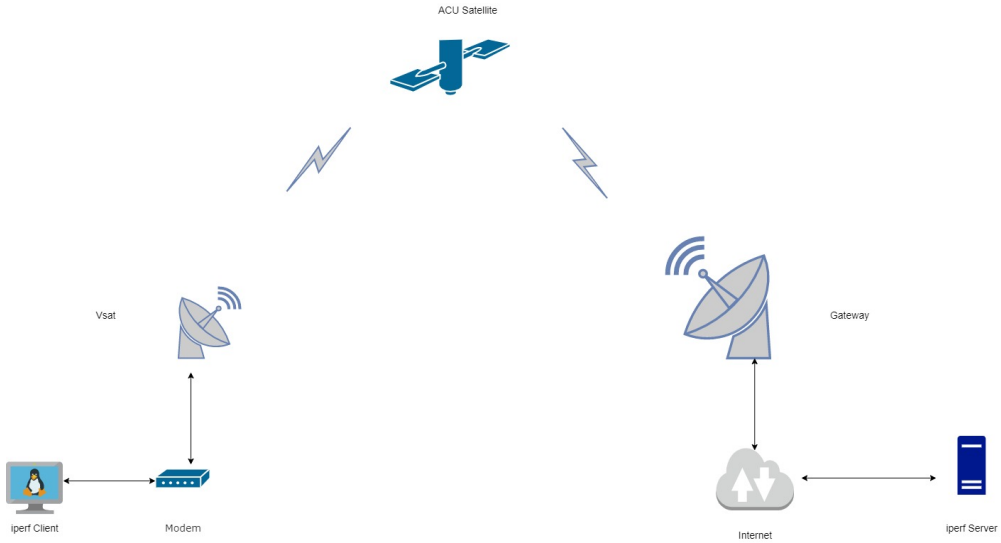


Figure 4.26: AKU Test Topology

Network Configuration Figure 4.26 shows the main devices used for the test, the iperf3 client is a computer running on Linux operating system, the client reaches the iperf3 server through Ad-

vance KU satellite. AKU uses Ku-band (12–18 GHz).

AKU Download Throughput in TCP The script which automates iperf3 tool measures the speed of download in the client which is connected to the iperf3 server through AKU satellite. iperf3 measures the throughput in Download in TCP through port 5205. the test duration were 60 seconds, the average bit rate measured is 1.46 Mbits/sec for the receiver.

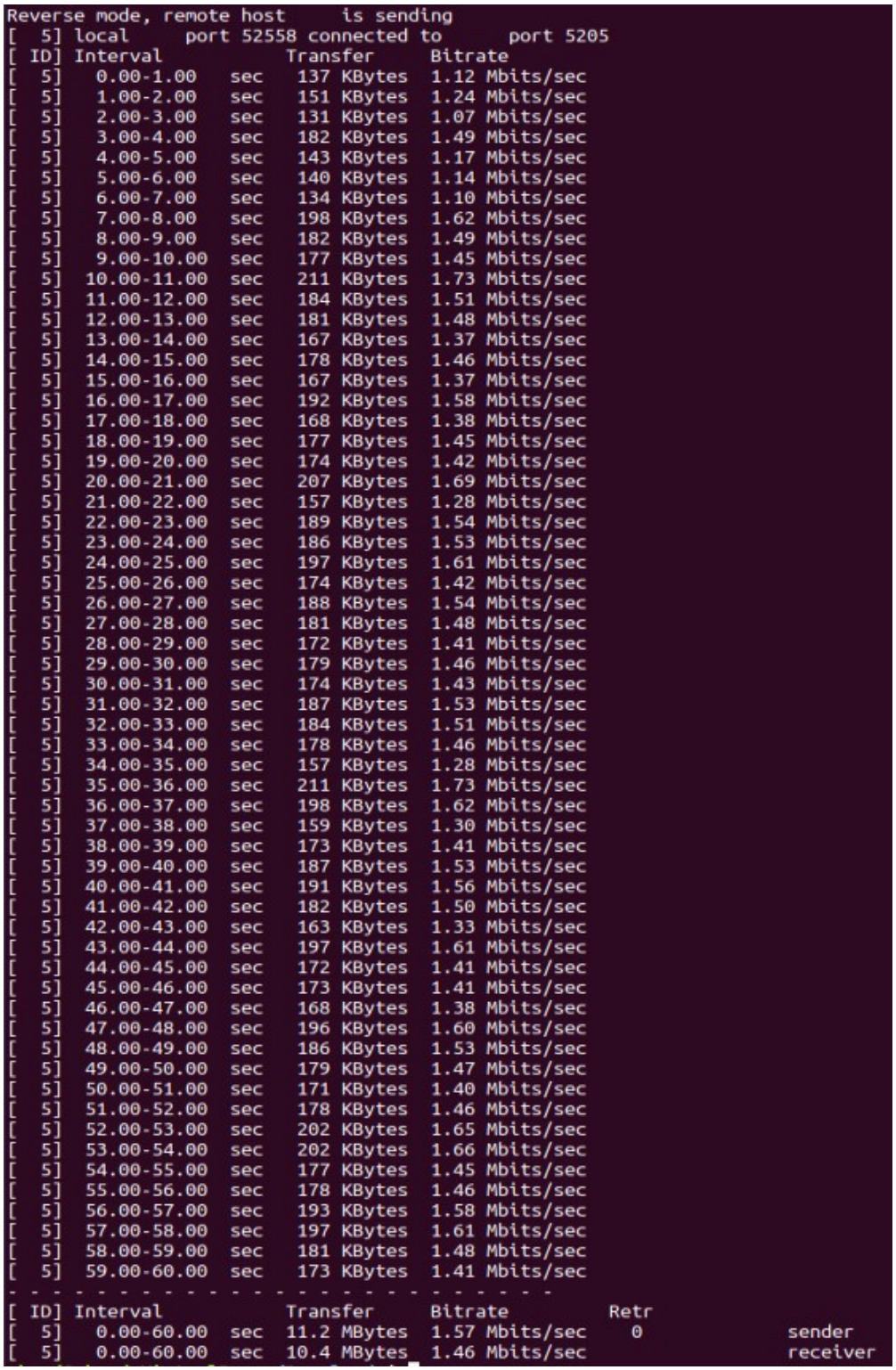


Figure 4.27: AKU Download Throughput

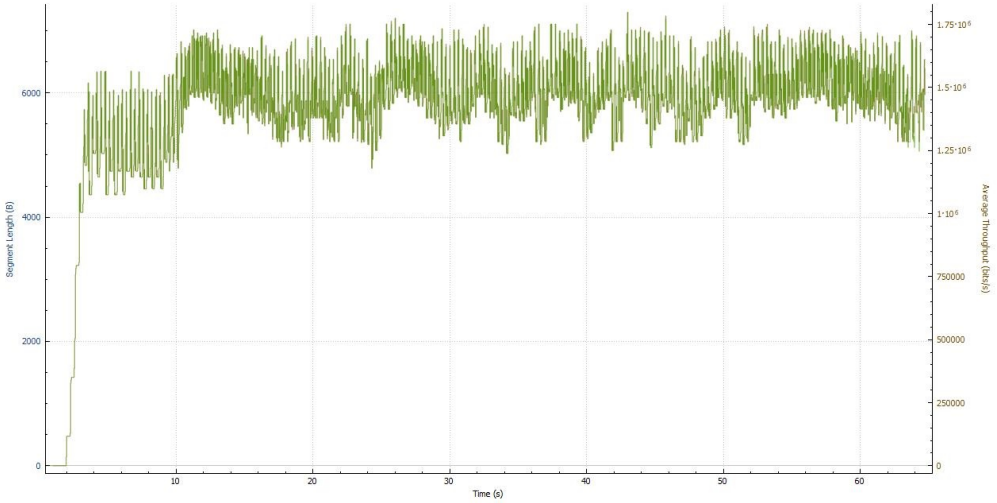


Figure 4.28: AKU Download Throughput in TCP vs Time

Sequence Number

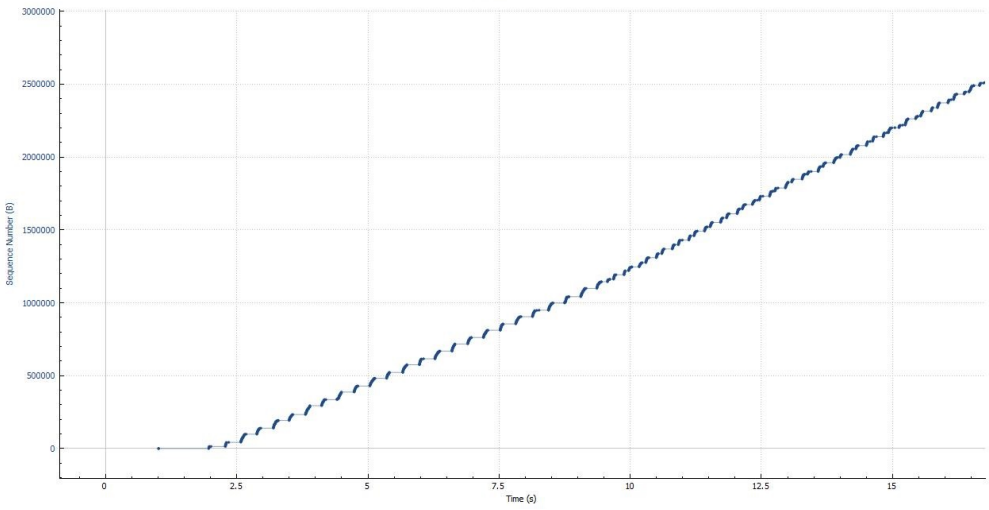


Figure 4.29: AKU Download Throughput in TCP Sequence Number

AKU Upload Throughput in TCP iperf3 measures the speed of upload in TCP, the average throughput obtained is 264 Kbits/sec. Wireshark's analysis shows TCP congestion window has a limited size of, 64240 Bytes. The average upload speed calculated is 252 Kbits/sec.

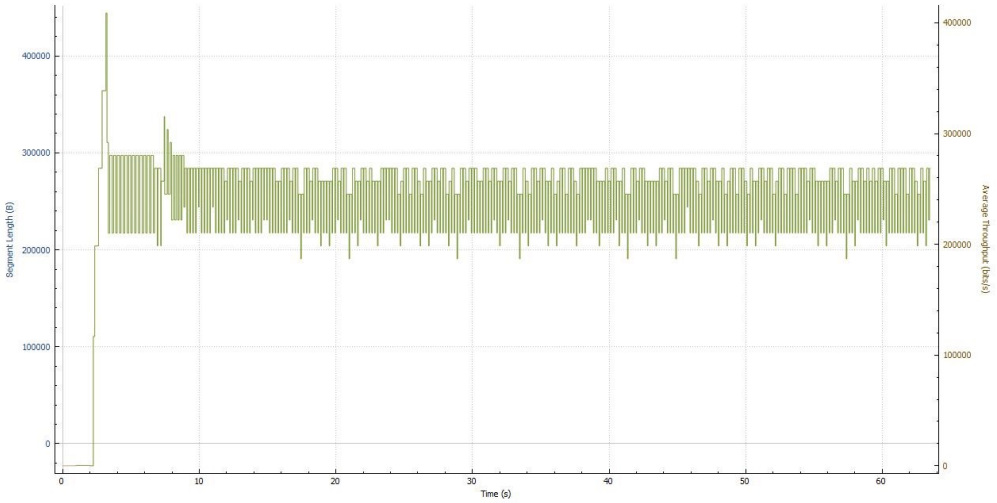


Figure 4.30: AKU Upload Throughput in TCP

Sequence Number

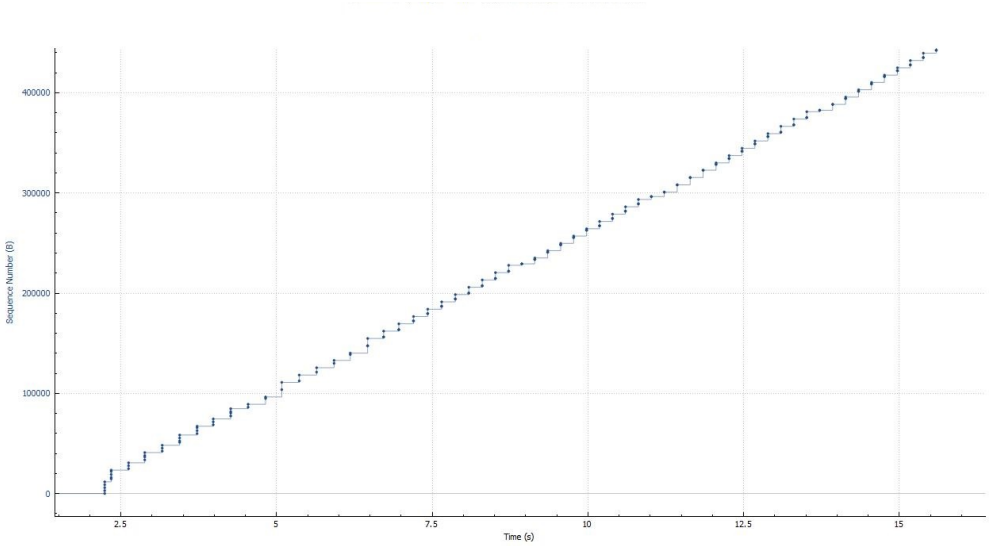
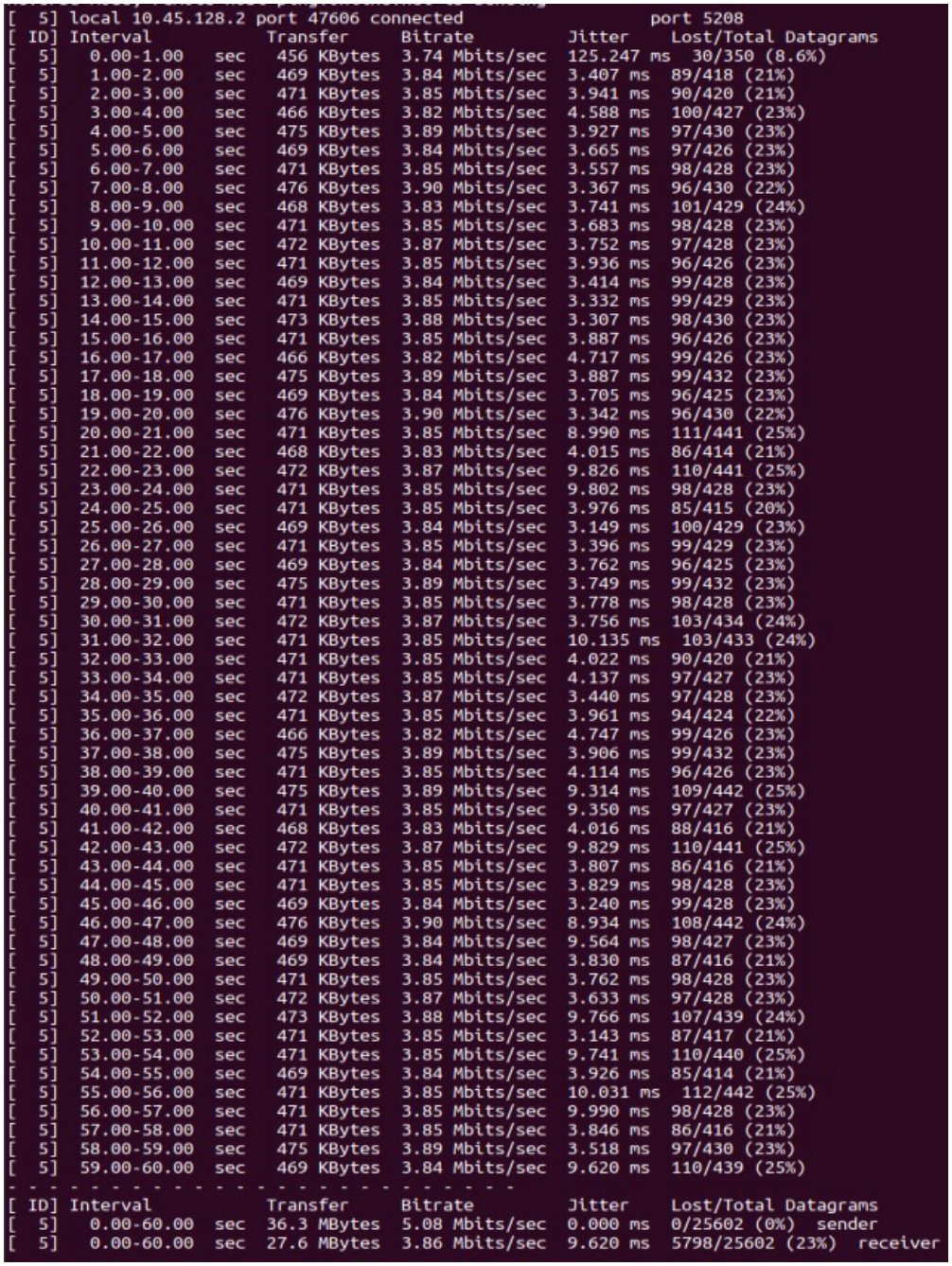


Figure 4.31: AKU Upload Throughput in TCP Sequence Number

AKU Download Throughput in UDP

The test measures the download throughput in UDP. 23 percent of the UDP data grams were lost. The jitter measure was 9.620 ms. Figure 4.32 shows the packets Vs Time.



```
[  5] local 10.45.128.2 port 47606 connected                    port 5208
[ ID] Interval           Transfer     Bitrate         Jitter    Lost/Total Datagrams
[  5]   0.00-1.00   sec   456 KBytes  3.74 Mbits/sec  125.247 ms  30/350 (8.6%)
[  5]   1.00-2.00   sec   469 KBytes  3.84 Mbits/sec  3.407 ms  89/418 (21%)
[  5]   2.00-3.00   sec   471 KBytes  3.85 Mbits/sec  3.941 ms  90/420 (21%)
[  5]   3.00-4.00   sec   466 KBytes  3.82 Mbits/sec  4.588 ms  100/427 (23%)
[  5]   4.00-5.00   sec   475 KBytes  3.89 Mbits/sec  3.927 ms  97/430 (23%)
[  5]   5.00-6.00   sec   469 KBytes  3.84 Mbits/sec  3.665 ms  97/426 (23%)
[  5]   6.00-7.00   sec   471 KBytes  3.85 Mbits/sec  3.557 ms  98/428 (23%)
[  5]   7.00-8.00   sec   476 KBytes  3.90 Mbits/sec  3.367 ms  96/430 (22%)
[  5]   8.00-9.00   sec   468 KBytes  3.83 Mbits/sec  3.741 ms  101/429 (24%)
[  5]   9.00-10.00  sec   471 KBytes  3.85 Mbits/sec  3.683 ms  98/428 (23%)
[  5]  10.00-11.00  sec   472 KBytes  3.87 Mbits/sec  3.752 ms  97/428 (23%)
[  5]  11.00-12.00  sec   471 KBytes  3.85 Mbits/sec  3.936 ms  96/426 (23%)
[  5]  12.00-13.00  sec   469 KBytes  3.84 Mbits/sec  3.414 ms  99/428 (23%)
[  5]  13.00-14.00  sec   471 KBytes  3.85 Mbits/sec  3.332 ms  99/429 (23%)
[  5]  14.00-15.00  sec   473 KBytes  3.88 Mbits/sec  3.307 ms  98/430 (23%)
[  5]  15.00-16.00  sec   471 KBytes  3.85 Mbits/sec  3.887 ms  96/426 (23%)
[  5]  16.00-17.00  sec   466 KBytes  3.82 Mbits/sec  4.717 ms  99/426 (23%)
[  5]  17.00-18.00  sec   475 KBytes  3.89 Mbits/sec  3.887 ms  99/432 (23%)
[  5]  18.00-19.00  sec   469 KBytes  3.84 Mbits/sec  3.705 ms  96/425 (23%)
[  5]  19.00-20.00  sec   476 KBytes  3.90 Mbits/sec  3.342 ms  96/430 (22%)
[  5]  20.00-21.00  sec   471 KBytes  3.85 Mbits/sec  8.990 ms  111/441 (25%)
[  5]  21.00-22.00  sec   468 KBytes  3.83 Mbits/sec  4.015 ms  86/414 (21%)
[  5]  22.00-23.00  sec   472 KBytes  3.87 Mbits/sec  9.826 ms  110/441 (25%)
[  5]  23.00-24.00  sec   471 KBytes  3.85 Mbits/sec  9.802 ms  98/428 (23%)
[  5]  24.00-25.00  sec   471 KBytes  3.85 Mbits/sec  3.976 ms  85/415 (20%)
[  5]  25.00-26.00  sec   469 KBytes  3.84 Mbits/sec  3.149 ms  100/429 (23%)
[  5]  26.00-27.00  sec   471 KBytes  3.85 Mbits/sec  3.396 ms  99/429 (23%)
[  5]  27.00-28.00  sec   469 KBytes  3.84 Mbits/sec  3.762 ms  96/425 (23%)
[  5]  28.00-29.00  sec   475 KBytes  3.89 Mbits/sec  3.749 ms  99/432 (23%)
[  5]  29.00-30.00  sec   471 KBytes  3.85 Mbits/sec  3.778 ms  98/428 (23%)
[  5]  30.00-31.00  sec   472 KBytes  3.87 Mbits/sec  3.756 ms  103/434 (24%)
[  5]  31.00-32.00  sec   471 KBytes  3.85 Mbits/sec  10.135 ms  103/433 (24%)
[  5]  32.00-33.00  sec   471 KBytes  3.85 Mbits/sec  4.022 ms  90/420 (21%)
[  5]  33.00-34.00  sec   471 KBytes  3.85 Mbits/sec  4.137 ms  97/427 (23%)
[  5]  34.00-35.00  sec   472 KBytes  3.87 Mbits/sec  3.440 ms  97/428 (23%)
[  5]  35.00-36.00  sec   471 KBytes  3.85 Mbits/sec  3.961 ms  94/424 (22%)
[  5]  36.00-37.00  sec   466 KBytes  3.82 Mbits/sec  4.747 ms  99/426 (23%)
[  5]  37.00-38.00  sec   475 KBytes  3.89 Mbits/sec  3.906 ms  99/432 (23%)
[  5]  38.00-39.00  sec   471 KBytes  3.85 Mbits/sec  4.114 ms  96/426 (23%)
[  5]  39.00-40.00  sec   475 KBytes  3.89 Mbits/sec  9.314 ms  109/442 (25%)
[  5]  40.00-41.00  sec   471 KBytes  3.85 Mbits/sec  9.350 ms  97/427 (23%)
[  5]  41.00-42.00  sec   468 KBytes  3.83 Mbits/sec  4.016 ms  88/416 (21%)
[  5]  42.00-43.00  sec   472 KBytes  3.87 Mbits/sec  9.829 ms  110/441 (25%)
[  5]  43.00-44.00  sec   471 KBytes  3.85 Mbits/sec  3.807 ms  86/416 (21%)
[  5]  44.00-45.00  sec   471 KBytes  3.85 Mbits/sec  3.829 ms  98/428 (23%)
[  5]  45.00-46.00  sec   469 KBytes  3.84 Mbits/sec  3.240 ms  99/428 (23%)
[  5]  46.00-47.00  sec   476 KBytes  3.90 Mbits/sec  8.934 ms  108/442 (24%)
[  5]  47.00-48.00  sec   469 KBytes  3.84 Mbits/sec  9.564 ms  98/427 (23%)
[  5]  48.00-49.00  sec   469 KBytes  3.84 Mbits/sec  3.830 ms  87/416 (21%)
[  5]  49.00-50.00  sec   471 KBytes  3.85 Mbits/sec  3.762 ms  98/428 (23%)
[  5]  50.00-51.00  sec   472 KBytes  3.87 Mbits/sec  3.633 ms  97/428 (23%)
[  5]  51.00-52.00  sec   473 KBytes  3.88 Mbits/sec  9.766 ms  107/439 (24%)
[  5]  52.00-53.00  sec   471 KBytes  3.85 Mbits/sec  3.143 ms  87/417 (21%)
[  5]  53.00-54.00  sec   471 KBytes  3.85 Mbits/sec  9.741 ms  110/440 (25%)
[  5]  54.00-55.00  sec   469 KBytes  3.84 Mbits/sec  3.926 ms  85/414 (21%)
[  5]  55.00-56.00  sec   471 KBytes  3.85 Mbits/sec  10.031 ms  112/442 (25%)
[  5]  56.00-57.00  sec   471 KBytes  3.85 Mbits/sec  9.990 ms  98/428 (23%)
[  5]  57.00-58.00  sec   471 KBytes  3.85 Mbits/sec  3.846 ms  86/416 (21%)
[  5]  58.00-59.00  sec   475 KBytes  3.89 Mbits/sec  3.518 ms  97/430 (23%)
[  5]  59.00-60.00  sec   469 KBytes  3.84 Mbits/sec  9.620 ms  110/439 (25%)
- - - - - - - - - - - - - - - - - - - - - - - - -
[ ID] Interval           Transfer     Bitrate         Jitter    Lost/Total Datagrams
[  5]   0.00-60.00  sec  36.3 MBytes  5.08 Mbits/sec  0.000 ms  0/25602 (0%)  sender
[  5]   0.00-60.00  sec  27.6 MBytes  3.86 Mbits/sec  9.620 ms  5798/25602 (23%)  receiver
```

Figure 4.32: AKU Download Throughput in UDP

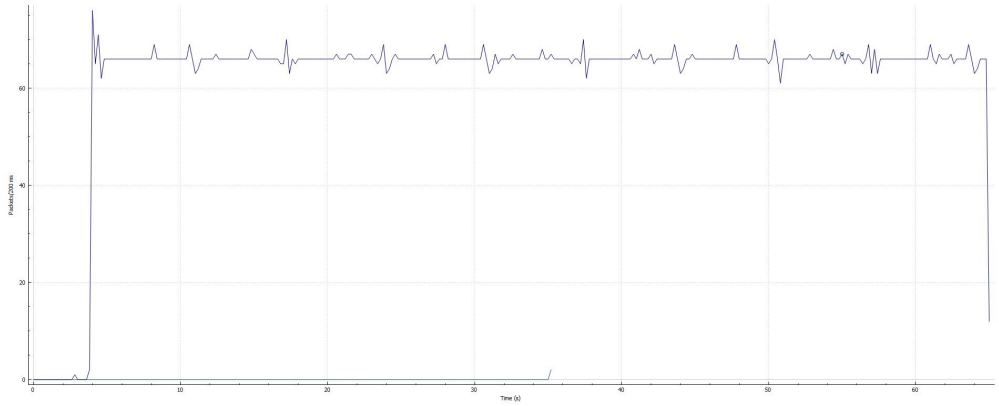
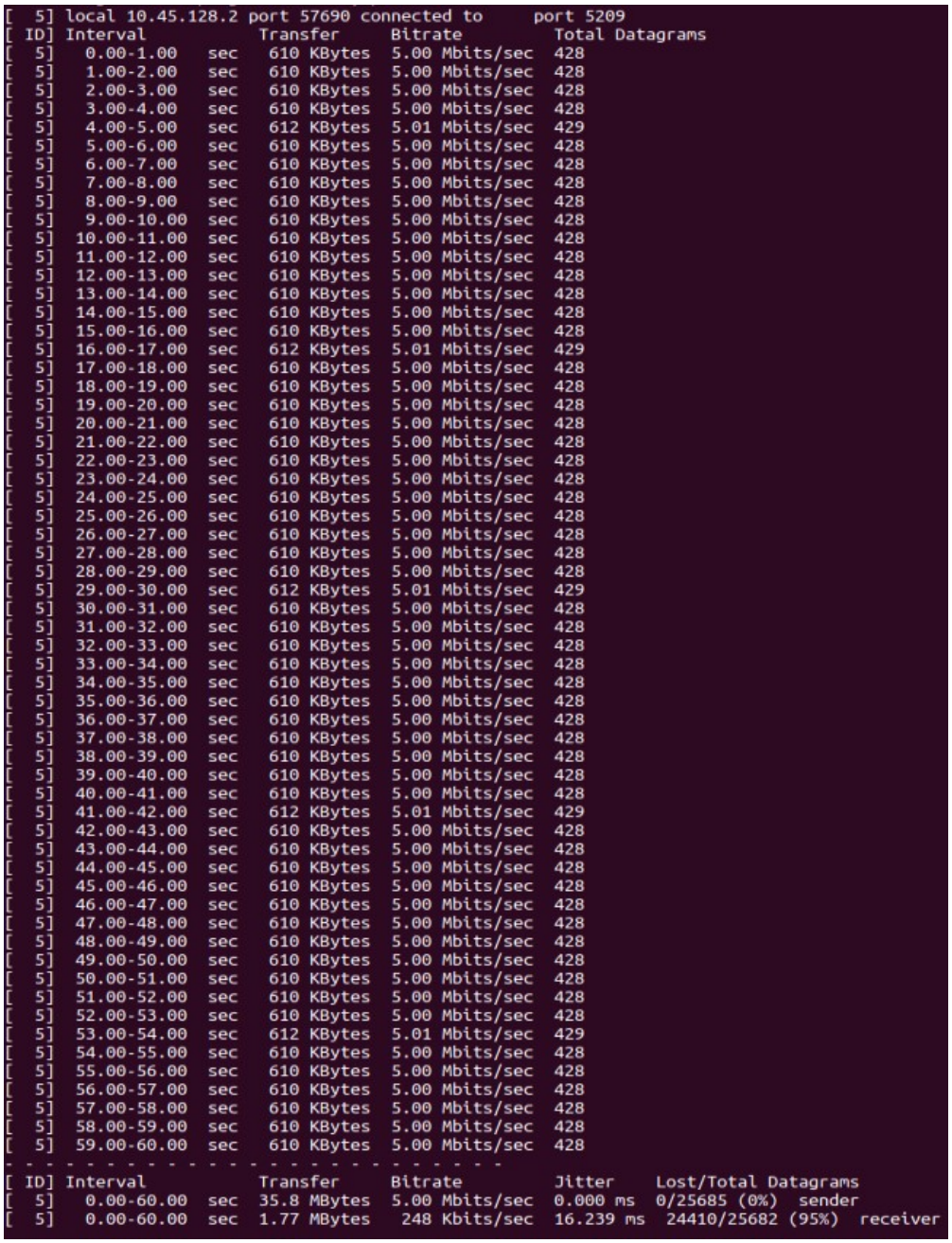


Figure 4.33: AKU Packets Vs Time in UDP

AKU Upload Throughput in UDP The Upload speed measured is 248 Kbits/s in UDP, the Jitter calculated is 16.239 ms.



```
[  5] local 10.45.128.2 port 57690 connected to     port 5209
[ ID] Interval           Transfer     Bitrate         Total Datagrams
[  5]   0.00-1.00   sec   610 KBytes  5.00 Mbits/sec  428
[  5]   1.00-2.00   sec   610 KBytes  5.00 Mbits/sec  428
[  5]   2.00-3.00   sec   610 KBytes  5.00 Mbits/sec  428
[  5]   3.00-4.00   sec   610 KBytes  5.00 Mbits/sec  428
[  5]   4.00-5.00   sec   612 KBytes  5.01 Mbits/sec  429
[  5]   5.00-6.00   sec   610 KBytes  5.00 Mbits/sec  428
[  5]   6.00-7.00   sec   610 KBytes  5.00 Mbits/sec  428
[  5]   7.00-8.00   sec   610 KBytes  5.00 Mbits/sec  428
[  5]   8.00-9.00   sec   610 KBytes  5.00 Mbits/sec  428
[  5]   9.00-10.00  sec   610 KBytes  5.00 Mbits/sec  428
[  5]  10.00-11.00  sec   610 KBytes  5.00 Mbits/sec  428
[  5]  11.00-12.00  sec   610 KBytes  5.00 Mbits/sec  428
[  5]  12.00-13.00  sec   610 KBytes  5.00 Mbits/sec  428
[  5]  13.00-14.00  sec   610 KBytes  5.00 Mbits/sec  428
[  5]  14.00-15.00  sec   610 KBytes  5.00 Mbits/sec  428
[  5]  15.00-16.00  sec   610 KBytes  5.00 Mbits/sec  428
[  5]  16.00-17.00  sec   612 KBytes  5.01 Mbits/sec  429
[  5]  17.00-18.00  sec   610 KBytes  5.00 Mbits/sec  428
[  5]  18.00-19.00  sec   610 KBytes  5.00 Mbits/sec  428
[  5]  19.00-20.00  sec   610 KBytes  5.00 Mbits/sec  428
[  5]  20.00-21.00  sec   610 KBytes  5.00 Mbits/sec  428
[  5]  21.00-22.00  sec   610 KBytes  5.00 Mbits/sec  428
[  5]  22.00-23.00  sec   610 KBytes  5.00 Mbits/sec  428
[  5]  23.00-24.00  sec   610 KBytes  5.00 Mbits/sec  428
[  5]  24.00-25.00  sec   610 KBytes  5.00 Mbits/sec  428
[  5]  25.00-26.00  sec   610 KBytes  5.00 Mbits/sec  428
[  5]  26.00-27.00  sec   610 KBytes  5.00 Mbits/sec  428
[  5]  27.00-28.00  sec   610 KBytes  5.00 Mbits/sec  428
[  5]  28.00-29.00  sec   610 KBytes  5.00 Mbits/sec  428
[  5]  29.00-30.00  sec   612 KBytes  5.01 Mbits/sec  429
[  5]  30.00-31.00  sec   610 KBytes  5.00 Mbits/sec  428
[  5]  31.00-32.00  sec   610 KBytes  5.00 Mbits/sec  428
[  5]  32.00-33.00  sec   610 KBytes  5.00 Mbits/sec  428
[  5]  33.00-34.00  sec   610 KBytes  5.00 Mbits/sec  428
[  5]  34.00-35.00  sec   610 KBytes  5.00 Mbits/sec  428
[  5]  35.00-36.00  sec   610 KBytes  5.00 Mbits/sec  428
[  5]  36.00-37.00  sec   610 KBytes  5.00 Mbits/sec  428
[  5]  37.00-38.00  sec   610 KBytes  5.00 Mbits/sec  428
[  5]  38.00-39.00  sec   610 KBytes  5.00 Mbits/sec  428
[  5]  39.00-40.00  sec   610 KBytes  5.00 Mbits/sec  428
[  5]  40.00-41.00  sec   610 KBytes  5.00 Mbits/sec  428
[  5]  41.00-42.00  sec   612 KBytes  5.01 Mbits/sec  429
[  5]  42.00-43.00  sec   610 KBytes  5.00 Mbits/sec  428
[  5]  43.00-44.00  sec   610 KBytes  5.00 Mbits/sec  428
[  5]  44.00-45.00  sec   610 KBytes  5.00 Mbits/sec  428
[  5]  45.00-46.00  sec   610 KBytes  5.00 Mbits/sec  428
[  5]  46.00-47.00  sec   610 KBytes  5.00 Mbits/sec  428
[  5]  47.00-48.00  sec   610 KBytes  5.00 Mbits/sec  428
[  5]  48.00-49.00  sec   610 KBytes  5.00 Mbits/sec  428
[  5]  49.00-50.00  sec   610 KBytes  5.00 Mbits/sec  428
[  5]  50.00-51.00  sec   610 KBytes  5.00 Mbits/sec  428
[  5]  51.00-52.00  sec   610 KBytes  5.00 Mbits/sec  428
[  5]  52.00-53.00  sec   610 KBytes  5.00 Mbits/sec  428
[  5]  53.00-54.00  sec   612 KBytes  5.01 Mbits/sec  429
[  5]  54.00-55.00  sec   610 KBytes  5.00 Mbits/sec  428
[  5]  55.00-56.00  sec   610 KBytes  5.00 Mbits/sec  428
[  5]  56.00-57.00  sec   610 KBytes  5.00 Mbits/sec  428
[  5]  57.00-58.00  sec   610 KBytes  5.00 Mbits/sec  428
[  5]  58.00-59.00  sec   610 KBytes  5.00 Mbits/sec  428
[  5]  59.00-60.00  sec   610 KBytes  5.00 Mbits/sec  428
- - - - - - - - - - - - - - - - - - - - - - - - -
[ ID] Interval           Transfer     Bitrate         Jitter    Lost/Total Datagrams
[  5]   0.00-60.00  sec  35.8 MBytes  5.00 Mbits/sec  0.000 ms  0/25685 (0%)  sender
[  5]   0.00-60.00  sec  1.77 MBytes   248 Kbits/sec  16.239 ms  24410/25682 (95%)  receiver
```

Figure 4.34: AKU Upload Throughput in UDP

4.5 4G Network Performance Test

This section describes the network performance test using a 4G internet connection, and the test was performed with a computer running on Linux operating system. The computer has a 4G SIM card. iperf3 tool measures the throughput of 4G connection using both connections TCP and UDP.

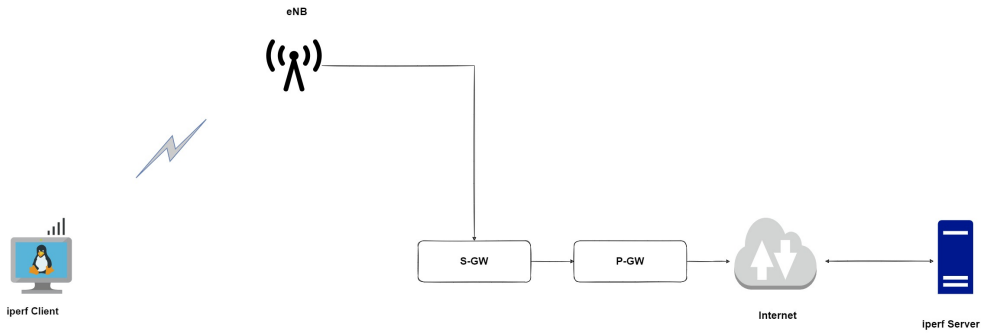


Figure 4.35: 4G Topology

4G Download Throughput in TCP

This test measures the download speed using a transmission control protocol connection between the iperf server and the client through iperf3 port 5203. At the beginning of the connection, 520 KBytes were transmitted at 4.23 Mbits per second bit rate. At the second 1.01, the bit rate was 11.7 Mbits per second. The average throughput measured in download is 16.5 Mbits per second. No packets retransmitted. Figure 4.36 the test results of the download speed in TCP connection mode.

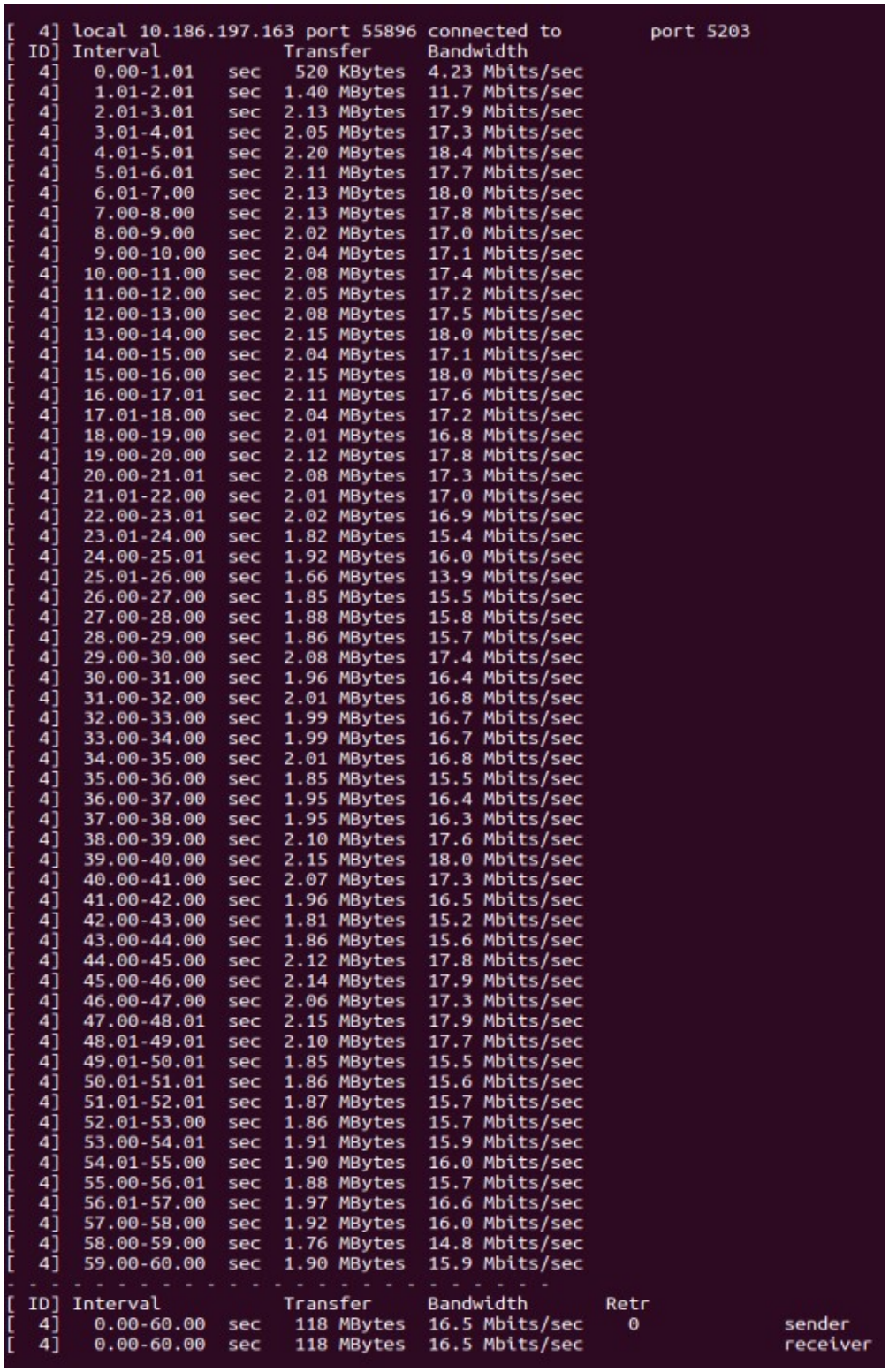


Figure 4.36: 4G Download Throughput in TCP test results

Figure 4.37 illustrates the average throughput vs. the time.

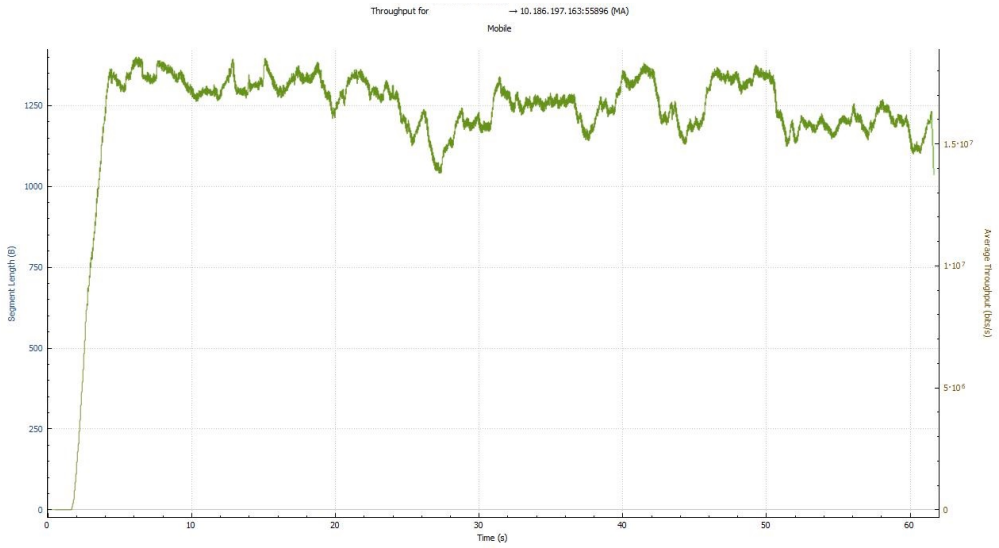


Figure 4.37: 4G Download Throughput in TCP Graph

Sequence Number

Figure 4.38 shows the sequence number. It grows sharply without disconnections. It means no delay or packet drop.

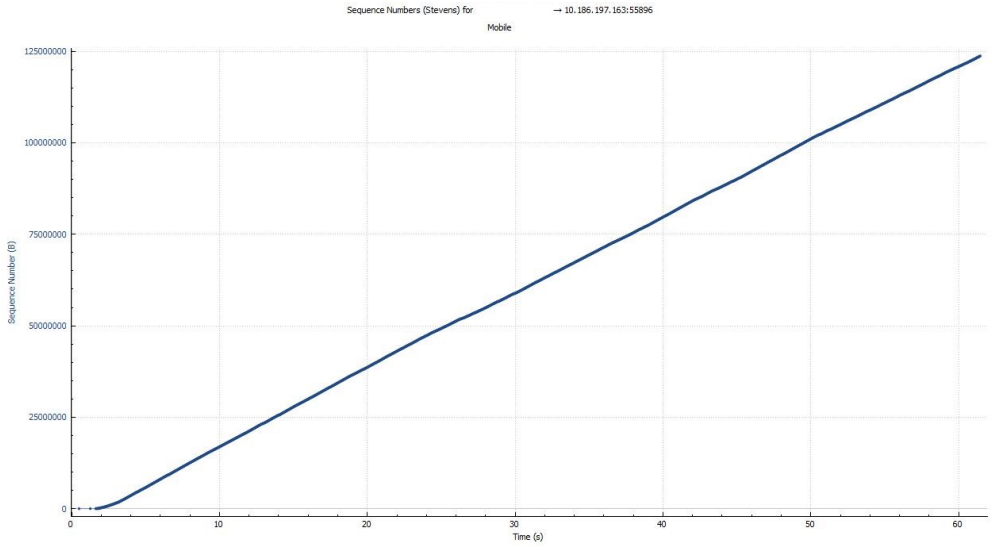


Figure 4.38: 4G Download Throughput in TCP Sequence Number

4G Upload Throughput in TCP

Figure 4.39 explains the throughput obtained during the upload speed test in TCP connection mode.

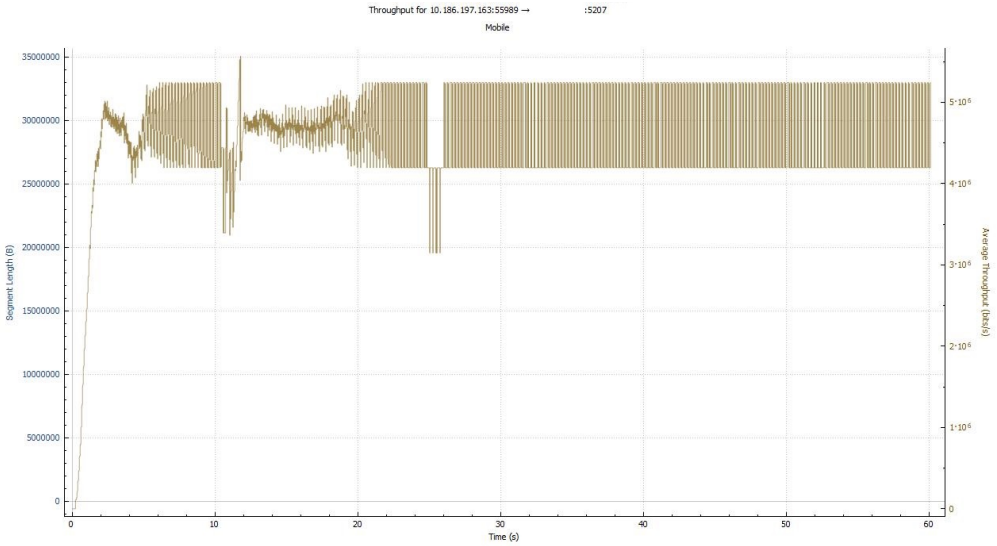


Figure 4.39: 4G Upload Throughput in TCP

Sequence Number

There are small pauses in the sequence number, as shown in Figure 4.40. The pauses in sequence number mean a delay during packets transfer between the server and the client.

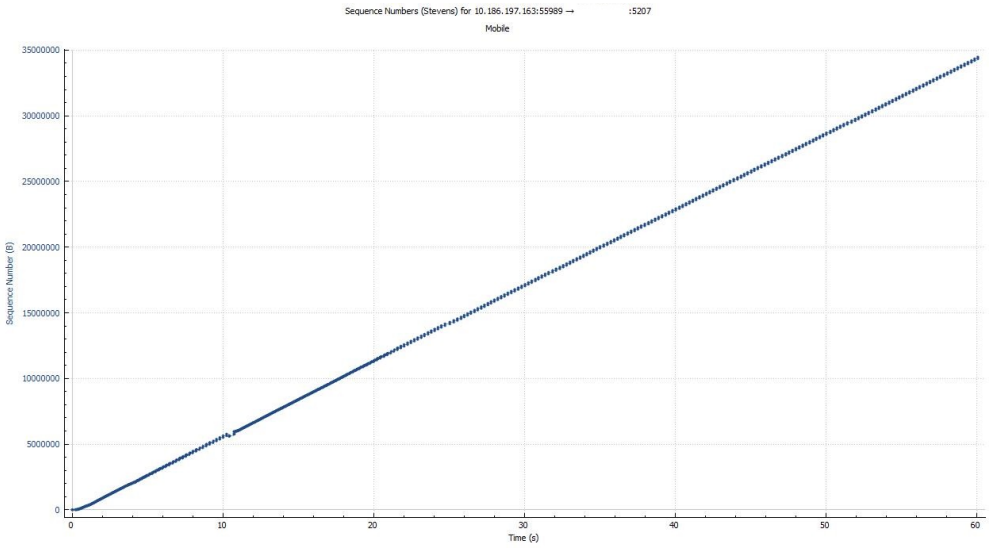


Figure 4.40: 4G Upload Throughput in TCP Sequence Number

4G Download Throughput in UDP

During the test of measuring the download speed in UDP connection mode, many packets were received out of order, there are multiple reasons for the out-of-order packets which are:

- This issue appears in stateless connections such as UDP, moreover, the absence of flow control mechanism which prevents out of order packets.
- Multiple Paths for data stream.
- Queuing out of order packets can occur when a queuing device does not forward packets in a first-in/first-out (FIFO) order.

2.5 percent of the datagrams were lost during 60 seconds. The Jitter equals 7.761 ms.

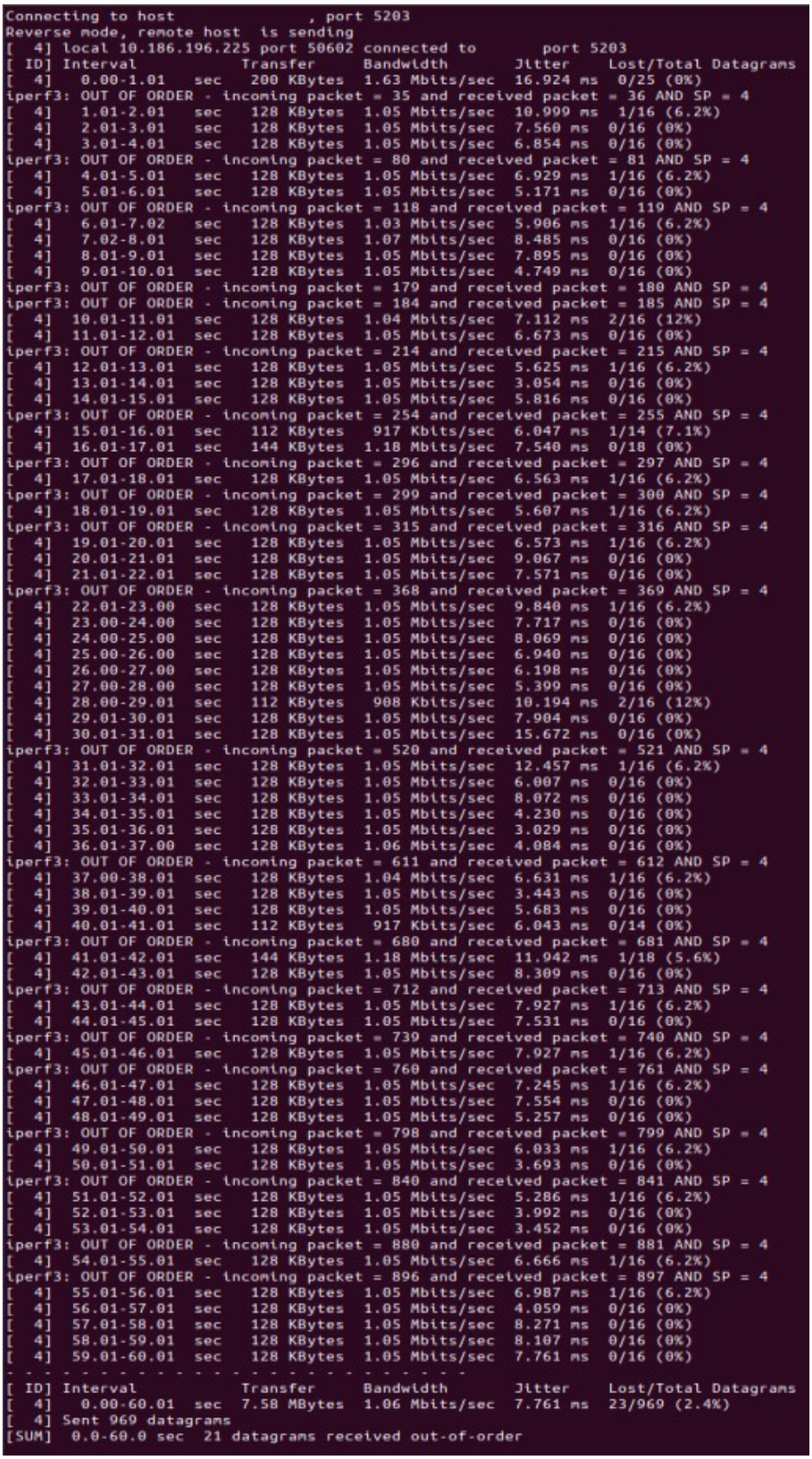


Figure 4.41: 4G Upload Throughput in UDP

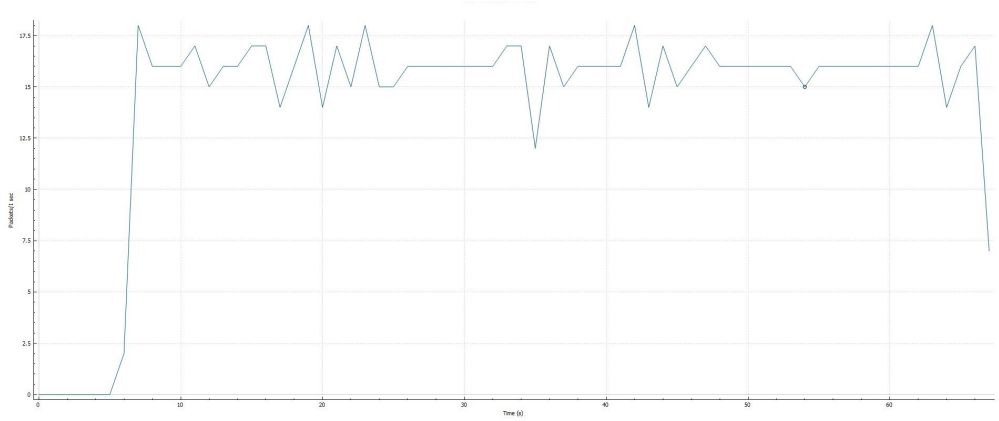
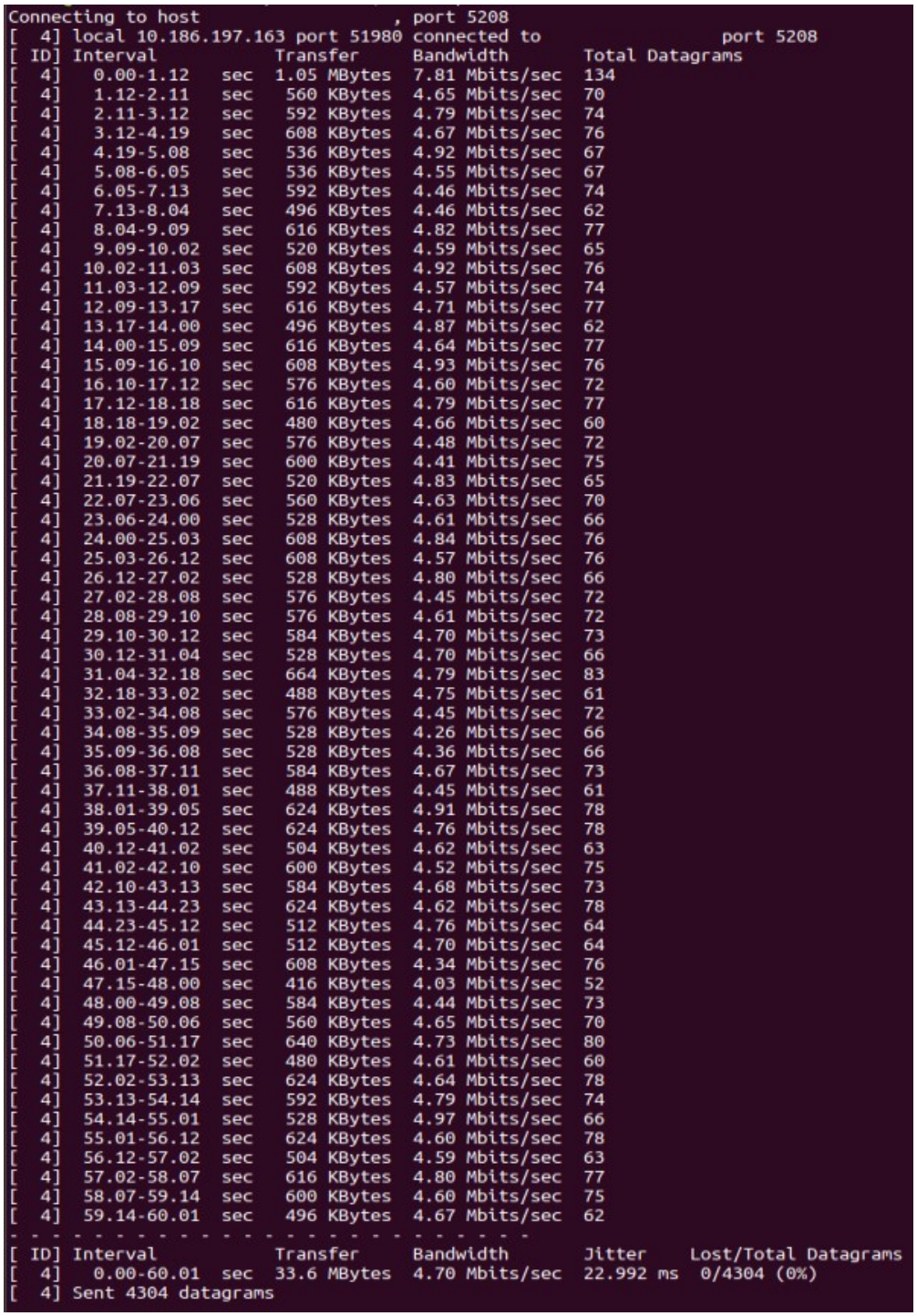


Figure 4.42: 4G Download Throughput in UDP

4G Upload Throughput in UDP



```
Connecting to host                , port 5208
[  4] local 10.186.197.163 port 51980 connected to                port 5208
[ ID] Interval           Transfer     Bandwidth       Total Datagrams
[  4]   0.00-1.12   sec  1.05 MBytes  7.81 Mbits/sec  134
[  4]   1.12-2.11   sec   560 KBytes  4.65 Mbits/sec  70
[  4]   2.11-3.12   sec   592 KBytes  4.79 Mbits/sec  74
[  4]   3.12-4.19   sec   608 KBytes  4.67 Mbits/sec  76
[  4]   4.19-5.08   sec   536 KBytes  4.92 Mbits/sec  67
[  4]   5.08-6.05   sec   536 KBytes  4.55 Mbits/sec  67
[  4]   6.05-7.13   sec   592 KBytes  4.46 Mbits/sec  74
[  4]   7.13-8.04   sec   496 KBytes  4.46 Mbits/sec  62
[  4]   8.04-9.09   sec   616 KBytes  4.82 Mbits/sec  77
[  4]   9.09-10.02  sec   520 KBytes  4.59 Mbits/sec  65
[  4]  10.02-11.03  sec   608 KBytes  4.92 Mbits/sec  76
[  4]  11.03-12.09  sec   592 KBytes  4.57 Mbits/sec  74
[  4]  12.09-13.17  sec   616 KBytes  4.71 Mbits/sec  77
[  4]  13.17-14.00  sec   496 KBytes  4.87 Mbits/sec  62
[  4]  14.00-15.09  sec   616 KBytes  4.64 Mbits/sec  77
[  4]  15.09-16.10  sec   608 KBytes  4.93 Mbits/sec  76
[  4]  16.10-17.12  sec   576 KBytes  4.60 Mbits/sec  72
[  4]  17.12-18.18  sec   616 KBytes  4.79 Mbits/sec  77
[  4]  18.18-19.02  sec   480 KBytes  4.66 Mbits/sec  60
[  4]  19.02-20.07  sec   576 KBytes  4.48 Mbits/sec  72
[  4]  20.07-21.19  sec   600 KBytes  4.41 Mbits/sec  75
[  4]  21.19-22.07  sec   520 KBytes  4.83 Mbits/sec  65
[  4]  22.07-23.06  sec   560 KBytes  4.63 Mbits/sec  70
[  4]  23.06-24.00  sec   528 KBytes  4.61 Mbits/sec  66
[  4]  24.00-25.03  sec   608 KBytes  4.84 Mbits/sec  76
[  4]  25.03-26.12  sec   608 KBytes  4.57 Mbits/sec  76
[  4]  26.12-27.02  sec   528 KBytes  4.80 Mbits/sec  66
[  4]  27.02-28.08  sec   576 KBytes  4.45 Mbits/sec  72
[  4]  28.08-29.10  sec   576 KBytes  4.61 Mbits/sec  72
[  4]  29.10-30.12  sec   584 KBytes  4.70 Mbits/sec  73
[  4]  30.12-31.04  sec   528 KBytes  4.70 Mbits/sec  66
[  4]  31.04-32.18  sec   664 KBytes  4.79 Mbits/sec  83
[  4]  32.18-33.02  sec   488 KBytes  4.75 Mbits/sec  61
[  4]  33.02-34.08  sec   576 KBytes  4.45 Mbits/sec  72
[  4]  34.08-35.09  sec   528 KBytes  4.26 Mbits/sec  66
[  4]  35.09-36.08  sec   528 KBytes  4.36 Mbits/sec  66
[  4]  36.08-37.11  sec   584 KBytes  4.67 Mbits/sec  73
[  4]  37.11-38.01  sec   488 KBytes  4.45 Mbits/sec  61
[  4]  38.01-39.05  sec   624 KBytes  4.91 Mbits/sec  78
[  4]  39.05-40.12  sec   624 KBytes  4.76 Mbits/sec  78
[  4]  40.12-41.02  sec   504 KBytes  4.62 Mbits/sec  63
[  4]  41.02-42.10  sec   600 KBytes  4.52 Mbits/sec  75
[  4]  42.10-43.13  sec   584 KBytes  4.68 Mbits/sec  73
[  4]  43.13-44.23  sec   624 KBytes  4.62 Mbits/sec  78
[  4]  44.23-45.12  sec   512 KBytes  4.76 Mbits/sec  64
[  4]  45.12-46.01  sec   512 KBytes  4.70 Mbits/sec  64
[  4]  46.01-47.15  sec   608 KBytes  4.34 Mbits/sec  76
[  4]  47.15-48.00  sec   416 KBytes  4.03 Mbits/sec  52
[  4]  48.00-49.08  sec   584 KBytes  4.44 Mbits/sec  73
[  4]  49.08-50.06  sec   560 KBytes  4.65 Mbits/sec  70
[  4]  50.06-51.17  sec   640 KBytes  4.73 Mbits/sec  80
[  4]  51.17-52.02  sec   480 KBytes  4.61 Mbits/sec  60
[  4]  52.02-53.13  sec   624 KBytes  4.64 Mbits/sec  78
[  4]  53.13-54.14  sec   592 KBytes  4.79 Mbits/sec  74
[  4]  54.14-55.01  sec   528 KBytes  4.97 Mbits/sec  66
[  4]  55.01-56.12  sec   624 KBytes  4.60 Mbits/sec  78
[  4]  56.12-57.02  sec   504 KBytes  4.59 Mbits/sec  63
[  4]  57.02-58.07  sec   616 KBytes  4.80 Mbits/sec  77
[  4]  58.07-59.14  sec   600 KBytes  4.60 Mbits/sec  75
[  4]  59.14-60.01  sec   496 KBytes  4.67 Mbits/sec  62
- - - - - - - - - - - - - - - - - - - - - - - - -
[ ID] Interval           Transfer     Bandwidth       Jitter    Lost/Total Datagrams
[  4]   0.00-60.01  sec  33.6 MBytes  4.70 Mbits/sec  22.992 ms  0/4304 (0%)
[  4] Sent 4304 datagrams
```

Figure 4.43: 4G Upload Throughput UDP

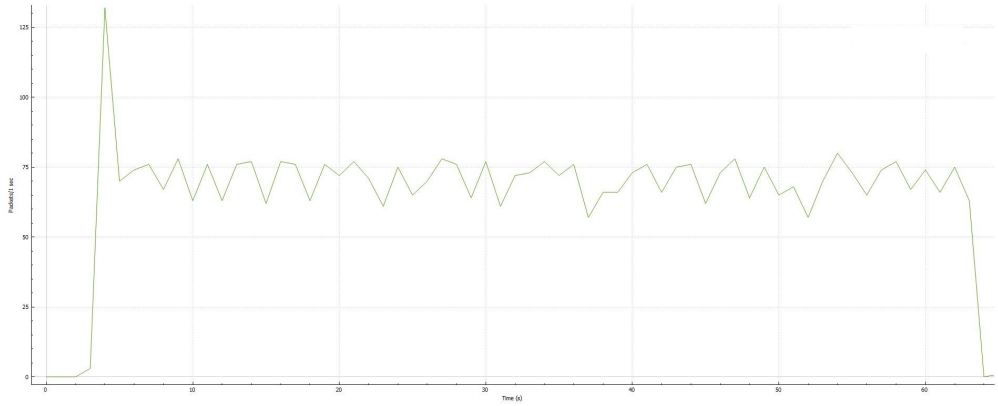


Figure 4.44: 4G Upload Throughput in UDP

4.6 Page Load Time

The time required to download and view all web page content in an internet browser is page load time. It is measured when a user accesses a web page using a URL or clicks a link to a website. The page load speed is calculated in seconds when a page is fully loaded. The internet connection plays an important rule in the page load time.

Network and Server Time

Server time and Network depend on the internet connection throughput and how text and photos are displayed.

Importance of Page Load Time

In this era, especially for the popularity of social media, a fast page load time is essential. The page load time has a significant influence on user satisfaction. The speed at which the customer can view a page's contents in a short amount of time generates customer satisfaction for the online experience. In addition, a pleasant experience can generate positive feedback, and increasing the popularity of the internet connection used can indirectly increase internet connection sales.

Page load process

Here are the main steps required in the loading of web pages.

1. The process begins with an initial request. It starts when a user types a URL in a browser or clicks a link.
2. The initial request arrives at the application for processing.
3. After the application completes processing, it transmits an acknowledgement.
4. The browser receives the response then starts the document object model (DOM)
5. The DOM completes loading, and then the browser starts to render the page.
6. The page completes rendering in the internet browser, and the browser load event starts.

4.7 Web Page Load Tests

This section contains information about the page load test performed using different internet connection types.

- The first internet connection used was a satellite internet connection. The satellite used was KONNECT.
- The second web page load test was performed using KASAT satellite.
- The third test was performed using Politecnico di Torino WiFi.
- The last web page load test was performed using a 4G internet connection.

The web load test was focused mainly on the most visited websites, for example (Google, Facebook, Twitter, Instagram, YouTube, and Wikipedia). The tools used to perform the test were a PC running on Windows operating system, Firefox browser with load time add-on.

Parameters Tested

- Page load time: is the time required to display a specific website.
- Response Time: is the time required to receive first acknowledgement from the server.
- Time to First Byte: corresponds to the time taken by a browser to receive the first byte of response from the server.
- DOM processing Time: is the time required for parsing HTML into a DOM and retrieve or execute scripts.

4.8 KONNECT Page Load Test

www.google.com	
Parameter	Value
Page Load Test	3.90 s
Redirect	n/a
Domain Lookup	1 ms
Connect	1.77 s
Wait for Response	916 ms
Response	208 ms
DOM Processing	862 ms
Parse	186 ms
Wait for Sub Resources	631 ms
Load Event	1 ms

Table 4.3: Google Page Load Test-KONNECT

www.wikipedia.com	
Parameter	Value
Page Load Test	1.78 s
Redirect	n/a
Domain Lookup	0 ms
Connect	0 s
Wait for Response	704 ms
Response	1 ms
DOM Processing	944 ms
Parse	891 ms
Wait for Sub Resources	38 ms
Load Event	1 ms

Table 4.4: Wikipedia Page Load Test-KONNECT

www.facebook.com	
Parameter	Value
Page Load Test	8.02 s
Redirect	n/a
Domain Lookup	4 ms
Connect	2.09 s
Wait for Response	795 ms
Response	0 ms
DOM Processing	4.98 s
Parse	4.23 s
Wait for Sub Resources	590 ms
Load Event	23 ms

Table 4.5: Facebook Page Load Test-KONNECT

www.youtube.com	
Parameter	Value
Page Load Test	8.40 s
Redirect	n/a
Domain Lookup	1 ms
Connect	763 s
Wait for Response	714 ms
Response	0 ms
DOM Processing	6.64 s
Parse	6.64 s
Wait for Sub Resources	0 ms
Load Event	2 ms

Table 4.6: YouTue Page Load Test-KONNECT

www.twitter.com	
Parameter	Value
Page Load Test	10.74 s
Redirect	n/a
Domain Lookup	630 ms
Connect	1.60 s
Wait for Response	880 ms
Response	174 ms
DOM Processing	7.40 s
Parse	3.48 s
Wait for Sub Resources	3.92 s
Load Event	3 ms

Table 4.7: Twitter Page Load Test-KONNECT

www.instagram.com	
Parameter	Value
Page Load Test	8.57 s
Redirect	n/a
Domain Lookup	595 ms
Connect	1.39 s
Wait for Response	943 ms
Response	27 ms
DOM Processing	5.53 s
Parse	1.52 s
Wait for Sub Resources	4.01 s
Load Event	2 ms

Table 4.8: Instagram Page Load Test-KONNECT

4.9 KASAT Page Load Test

www.google.com	
Parameter	Value
Page Load Test	9.66 s
Redirect	n/a
Domain Lookup	1 ms
Connect	2.07 s
Wait for Response	683 ms
Response	0 ms
DOM Processing	6.62 s
Parse	526 ms
Wait for Sub Resources	6.09 s
Load Event	37 ms

Table 4.9: Google Page Load Test-KASAT

www.wikipedia.com	
Parameter	Value
Page Load Test	1.87 s
Redirect	n/a
Domain Lookup	0 ms
Connect	0 s
Wait for Response	643 ms
Response	0 ms
DOM Processing	968 ms
Parse	906 ms
Wait for Sub Resources	16 ms
Load Event	1 ms

Table 4.10: Wikipedia Page Load Test-KASAT

www.facebook.com	
Parameter	Value
Page Load Test	5.76 s
Redirect	n/a
Domain Lookup	10 ms
Connect	700 ms
Wait for Response	760 ms
Response	156 ms
DOM Processing	4.02 s
Parse	2.45 s
Wait for Sub Resources	1.51 s
Load Event	35 ms

Table 4.11: Facebook Page Load Test-KASAT

www.youtube.com	
Parameter	Value
Page Load Test	15.35 s
Redirect	n/a
Domain Lookup	24 ms
Connect	811 ms
Wait for Response	8.63 s
Response	0 ms
DOM Processing	13.39 s
Parse	4.75 s
Wait for Sub Resources	8.63 s
Load Event	2 ms

Table 4.12: YouTue Page Load Test-KASAT

www.twitter.com	
Parameter	Value
Page Load Test	8.68 s
Redirect	n/a
Domain Lookup	0 ms
Connect	0 s
Wait for Response	782 ms
Response	160 ms
DOM Processing	7.64 s
Parse	3.96 s
Wait for Sub Resources	3.67 s
Load Event	1 ms

Table 4.13: Twitter Page Load Test-KASAT

www.instagram.com	
Parameter	Value
Page Load Test	9.24 s
Redirect	n/a
Domain Lookup	623 ms
Connect	1.33 s
Wait for Response	1.11 s
Response	31 ms
DOM Processing	6.09 s
Parse	1.61 s
Wait for Sub Resources	4.48 s
Load Event	2 ms

Table 4.14: Instagram Page Load Test-KASAT

4.10 Polito WiFi Page Load Test

This test was performed using Politecnico di Torino WiFi.

www.google.com	
Parameter	Value
Page Load Test	739 ms
Redirect	n/a
Domain Lookup	0 ms
Connect	45 ms
Wait for Response	84 ms
Response	9 ms
DOM Processing	545 ms
Parse	123 ms
Wait for Sub Resources	162 ms
Load Event	3 ms

Table 4.15: Google Page Load Test-WiFi

www.wikipedia.com	
Parameter	Value
Page Load Test	461 ms
Redirect	n/a
Domain Lookup	0 ms
Connect	0 s
Wait for Response	38 ms
Response	0 ms
DOM Processing	391 ms
Parse	356 ms
Wait for Sub Resources	9 ms
Load Event	1 ms

Table 4.16: Wikipedia Page Load Test-WiFi

www.youtube.com	
Parameter	Value
Page Load Test	2.24 s
Redirect	n/a
Domain Lookup	4 ms
Connect	46 ms
Wait for Response	50 ms
Response	0 ms
DOM Processing	2.05 s
Parse	2.04 s
Wait for Sub Resources	0 ms
Load Event	1 ms

Table 4.17: YouTue Page Load Test-WiFi

www.twitter.com	
Parameter	Value
Page Load Test	1.06 s
Redirect	n/a
Domain Lookup	2 ms
Connect	104 ms
Wait for Response	181 ms
Response	145 ms
DOM Processing	700 ms
Parse	681 ms
Wait for Sub Resources	14 ms
Load Event	1 ms

Table 4.18: Twitter Page Load Test-WiFi

www.instagram.com	
Parameter	Value
Page Load Test	1.89 s
Domain Lookup	0 ms
Connect	0 s
Wait for Response	608 ms
Response	29 ms
DOM Processing	1.20 s
Parse	407 ms
Wait for Sub Resources	788 ms
Load Event	8 ms

Table 4.19: Instagram Page Load Test-WiFi

4.11 4G Web page load Test

www.google.com	
Parameter	Value
Page Load Test	3.16 s
Redirect	n/a
Domain Lookup	0 ms
Connect	438 ms
Wait for Response	201 ms
Response	0 ms
DOM Processing	2.36 s
Parse	166 ms
Wait for Sub Resources	640 ms
Load Event	11 ms

Table 4.20: Google Page Load Test-4G

www.wikipedia.com	
Parameter	Value
Page Load Test	1.45 s
Redirect	n/a
Domain Lookup	1 ms
Connect	276 ms
Wait for Response	186 ms
Response	0 ms
DOM Processing	739 ms
Parse	699 ms
Wait for Sub Resources	19 ms
Load Event	1 ms

Table 4.21: Wikipedia Page Load Test-4G

www.youtube.com	
Parameter	Value
Page Load Test	7.11 s
Redirect	n/a
Domain Lookup	0 ms
Connect	648 ms
Wait for Response	125 ms
Response	0 ms
DOM Processing	6.04 s
Parse	6.04 s
Wait for Sub Resources	1 ms
Load Event	2 ms

Table 4.22: YouTue Page Load Test-4G

www.twitter.com	
Parameter	Value
Page Load Test	3.78 s
Redirect	n/a
Domain Lookup	60 ms
Connect	307 ms
Wait for Response	219 m
Response	144 ms
DOM Processing	3.11 s
Parse	1.57 s
Wait for Sub Resources	1.53 s
Load Event	1 ms

Table 4.23: Twitter Page Load Test-4G

www.instagram.com	
Parameter	Value
Page Load Test	4.29 s
Domain Lookup	2 ms
Connect	307 ms
Wait for Response	608 ms
Response	137 ms
DOM Processing	3.08 s
Parse	1.37 s
Wait for Sub Resources	1.71 s
Load Event	46 ms

Table 4.24: Instagram Page Load Test-4G

Chapter 5

Internship

5.1 Introduction

Skylogic-Eutelsat was the main source for the development of this thesis, below is a brief description of Skylogic and my training experience.

5.2 Skylogic-Eutelsat

It was founded in March 2006, it is one of the leading broadband satellite communication service provider in Europe, it provides Broadband services in Europe, Africa, the Middle East and the Americas for users who do not have access to fiber optic networks. Eutelsat owns Skylogic, Eutelsat is one of the biggest satellite operators. Some great assets of Skylogic is their Teleports, they have two teleports one is located in Turin, it is called Skypark, the other one is located in Cagliari which is called Skylogic Mediterraneo. Skypark is connected to different terrestrial Internet Backbone providers, the terrestrial interconnection to over 70 PoPs and Internet Exchanges in Europe and to PoPs in US. During my internship, I was enrolled in the Broadband Services Operation Department.

Broadband Services Operation
This department is the main core of Skylogic, it manages and maintains the satellite network access to thousands of users in Africa and Europe. it prevents outages and service degradation in the satellite network by monitoring end-to-end system performance. Furthermore, the broadband Services Operation department provides Layer 2 and Layer 3 technical support to the customers, by maintaining day-to-day platform components, tools and databases because the goal is to improve the service, also to achieve high user satisfaction. Moreover, managing the available bandwidth in the satellite network is very crucial, this department controls and analysis the bandwidth in order to optimize the bandwidth.

The Role of Broadband Services Operation Engineer

Manage and maintain satellite access network systems, applications. Provide technical service through Layer 2 and Layer 3 on VSAT. Monitor the end-to-end system performance and prevent outages or service degradation. Contribute to company problem and change management processes, so to maintain and optimize customer production services and related infrastructures. Mange platform incidents in order to ensure service availability. Manage the bandwidth optimization process, analyzing and controlling the performance test results and design solution for testing and reporting on bandwidth management.

What I have learned

During my internship at Skylogic-Eutelsat I have learned and acquired new skills, I learned how to use several tools which are useful for analyzing, searching for data generated by machines in real-time. detection of network and server outages and protocol failures, monitoring the infrastructure and log analytics. In addition, I have learned how to detect the root cause of any service outage or service degradation for the user terminals in KASAT and KONNECT satellite networks.

Chapter 6

Results and Conclusion

6.1 KONNECT Network Performance Test Results

The results illustrate that the download throughput can reach a high speed with 0 retransmissions. This means no packet loss because if a packet loss was detected while using a TCP connection, the lost packet must be retransmitted, showing that TCP is more reliable and ensures packets delivery. On the other hand, it can be seen that the download speed while using a UDP connection is higher than the speed in TCP because UDP is connectionless and does not retransmit lost packets. The jitter value is essential for time-sensitive data such as real-time audio and video the jitter tests results are shallow and do not affect sensitive data. The sequence number increased sharply during the download throughput test in TCP, which proves that there was no delay or packet loss. During the upload, it can be seen that the bit rate had multiple values during the test and different packets size, as shown in Figure 4.7. The sequence number during upload had pauses because some packets were not sent.

KONNECT Network Performance Test Results		
Test Performed	Results	Notes
TCP Download Throughput	118 Mbits/sec	0 retransmission
UDP Download Throughput	126 Mbits/sec	0 loss, Jitter = 0.038 ms
TCP Upload Throughput	5.47 Mbits/sec	0 retransmission
UDP Upload Throughput	5.22 Mbits/sec	0 loss, Jitter = 0.742 ms

Table 6.1: KONNECT Network Performance Test Results

6.2 KASAT Network Performance Test Results

Table 5.2 shows that the download speed of the KASAT network is less than the download speed of the KONNECT network. On the contrary, the upload speed of the KASAT network is higher than the KONNECT network due to multiple reasons, which were discussed in chapter 3. During the download speed test, the number of retransmissions detected was 704, while there was only one retransmission for download. The Jitter in the KASAT network is higher than the KONNECT network but still acceptable, and it does have a negative impact on sensitive data applications.

During the download in TCP, a few packets were transferred at low bit rates at the beginning of the connection between the client and server. Then the bit rate started to increase within time and the data transfer. Figure 4.16 shows the trend of the throughput vs. time. The sequence number started to increase sharply after the 4th second from the beginning of the connection. At the end of the connection and data transfer, the sequence number stops growing.

KASAT Network Performance Test Results		
Test Performed	Results	Notes
TCP Download Throughput	47.9 Mbits/sec	704 retransmissions
UDP Download Throughput	49.9 Mbits/sec	0 loss, Jitter = 0.153 ms
TCP Upload Throughput	8.63 Mbits/sec	1 retransmission
UDP Upload Throughput	8.86 Mbits/sec	11% loss, Jitter = 1.965 ms

Table 6.2: KASAT Network Performance Test Results

6.3 Advance KU Network Performance Test Results

Table 6.3 contains the results of the Network Performance Test performed using Advance KU as a satellite link between the iperf3 server and the client. The results show that the download speed when using Transmission Control Protocol is 1.46 Mbits/sec with 0 retransmissions. The download speed in User Datagram Protocol is higher than the download speed in TCP. The throughput for download in UDP is 3.86 Mbits/sec. 23% of the datagrams were lost because UDP does not ensure packets delivery between two points. The Jitter measures during the UDP download test equals 9.620 ms. The throughput in the upload is low in both TCP and UDP connections. For example, 95% of the packets were lost during the UDP upload throughput test.

Advance KU Network Performance Test Results		
Test Performed	Results	Notes
TCP Download Throughput	1.46 Mbits/sec	0 retransmissions
UDP Download Throughput	3.86 Mbits/sec	23% loss, Jitter = 9.620 ms
TCP Upload Throughput	252 Kbits/sec	0 retransmission
UDP Upload Throughput	248 Kbits/sec	95% loss, Jitter = 16.239 ms

Table 6.3: Advance KU Network Performance Test Results

6.4 4G Network Performance Test Results

Table 6.4 shows the results obtained for the Network Performance Test performed using a 4G Internet connection.

4G Network Performance Test Results		
Test Performed	Results	Notes
TCP Download Throughput	16.5 Mbits/sec	0 retransmissions
UDP Download Throughput	1.06 Mbits/sec	2.4% loss, Jitter = 7.761 ms
TCP Upload Throughput	4.60 Mbits/sec	0 retransmission
UDP Upload Throughput	4.70 Mbits/sec	0% loss, Jitter = 22.992 ms

Table 6.4: 4G Network Performance Test results

6.5 Conclusion

This thesis aimed to test the network performance of two Ka-band satellites which are KONNECT and KASAT, as well as a Ku-band satellite which is called Advance KU, in addition to a 4G internet connection.
By analyzing the results obtained, KONNECT proved to have a high performance in the download throughput with no retransmission; It means KONNECT can provide good quality internet service for video streaming services in real-time for numerous users. Furthermore, the amount of jitter measured does not impact sensitive data applications such as VOIP, The main reason is that KONNECT has higher performance in download throughput is because it has more download bandwidth compared to KASAT and Advance KU. The web page test shows that KONNECT can provide good browsing speed

From the tests I performed, it appears that KASAT has a high performance in the upload throughput compared to KONNECT, the reason is that upload bandwidth of KASAT is higher than KONNECT, also it could be that KASAT and KONNECT networks use different type of accelerations, moreover the congestion window of KASAT is different from KONNECT. The TCP download throughput test reported high packet retransmissions that impact the overall performances

Advance KU has the lowest performance because of the use of the KU-band, moreover Advance KU network has a low congestion window (14.3 KBytes). On the other hand, Advance KU is more resilient to interference and rain fading. more performance tests should be performed on Advance KU network.

Internet over satellite has a better performance compared to 4G internet connection in terms of download, upload throughput, and jitter despite the long distance between the satellite and Earth.

This network performance test helps ensure the suitable throughput is delivered to the customer under the satellite beam coverage. In addition, the tests prove to serve as a tool to troubleshoot and

understand if there is a network connectivity issue for thousands of User Terminal using KASAT, KONNECT, or Advance KU Satellites. The results are related to the scenarios I have tested, and it's not general. All Network Performance Tests were performed in collaboration with Skylogic - Eutelsat teleport, located in Turin, Italy.

6.6 Future Work

Due to the lack of time, many experiments and tests have been left for the future, for example testing the performance of VoIP when using the Internet over satellite. Furthermore, It would be much better to improve the performance test of broadband networks. in other words, the thesis talks about the idea to design a suit of tests to measure the performances of networks and also to allow a general comparison of performances from an End to End point of view. It can be enhanced by designing a tool that integrates several tests and measurements, collects different metrics and provides a synthetic result to provide indications about the "Overall customer experience" using different networks and a score related to the performances not all on the specific metric (e.g. jitter, or packet loss, or RTT) Moreover, it would be useful to repeat the tests in different scenario (such as time of the day, weather conditions, different coverages, different products and terminals) In future more research is needed to test Advance KU satellite and to find a way to enhance its network performance.

Bibliography

[1] Satellite Industry Association. *State of the Satellite Industry Report*. June 2021. URL: https://sia.org/news-resources/state-of-the-satellite-industry-report/.

[2] crystop. https://crystop.de/en/satellite-systems/satellite-systems-for-professionals/eutelsat/. 2022.

[3] Bruce R Elbert. *Introduction to satellite communication*. Artech House, 2008.

[4] Skylogic Eutelsat. https://www.eutelsat.it/home.html. 2022.

[5] H Fenech et al. "KA-SAT and future HTS systems". In: *2013 IEEE 14th International Vacuum Electronics Conference (IVEC)*. IEEE. 2013, pp. 1–2.

[6] Hector Fenech et al. "Eutelsat HTS systems". In: *International Journal of Satellite Communications and Networking* 34.4 (2016), pp. 503–521.

[7] Louis J Ippolito Jr. *Satellite communications systems engineering: atmospheric effects, satellite link design and system performance*. John Wiley & Sons, 2017.

[8] Arthur D Little. "High throughput satellites: Delivering future capacity needs". In: *white paper* (2015).

[9] Daniel Minoli. *Innovations in satellite communications and satellite technology: the industry implications of DVB-S2X, high throughput satellites, Ultra HD, M2M, and IP*. John Wiley & Sons, 2015.

[10] Holli Riebeek. *Catalog of Earth Satellite Orbits*. https://earthobservatory.nasa.gov/features/OrbitsCatalog/page1.php. May 2021.

[11] Dennis Roddy. *Satellite communications*. McGraw-Hill Education, 2006.

[12] Wikipedia contributors. *Iperf — Wikipedia, The Free Encyclopedia*. https://en.wikipedia.org/w/index.php?title=Iperf&oldid=1069509764. [Online; accessed 5-February-2022]. 2022.

[13] Wikipedia contributors. *KISS principle — Wikipedia, The Free Encyclopedia*. https://en.wikipedia.org/w/index.php?title=KISS_principle&oldid=1070136871. [Online; accessed 10-February-2022]. 2022.

[14] Wikipedia contributors. *Performance-enhancing proxy — Wikipedia, The Free Encyclopedia*. https://en.wikipedia.org/w/index.php?title=Performance-enhancing_proxy&oldid=1067504543. [Online; accessed 12-February-2022]. 2022.

List of Figures

List of Tables