UNIVERSITY OF VAASA

SCHOOL OF TECHNOLOGY AND INNOVATIONS

COMMUNICATIONS AND SYSTEMS ENGINEERING

KANNAN SELVAN

GROUND STATION DESIGN FOR LEO'S: IMPLEMENTATION FOR KVARKENSAT

Master's thesis for the degree of Master of Science in Technology submitted for assessment.

Vaasa, December 18, 2019.

Supervisor	Professor Heidi Kuusniemi
Instructor	Professor Mohammed S. Elmusrati

ACKNOWLEDGEMENTS

I would like to take this opportunity to thank God for being my courage and strength to complete this thesis.

I express my sincere gratitude to my thesis supervisor Professor Heidi Kuusniemi for the opportunity to work under her and the valuable guidance during my master's thesis work with her patience, enthusiasm, and immense knowledge.

Besides, I would like to express my deepest gratitude to my instructor, Professor Mohammed S. Elmusrati for giving me continuous support throughout my master's degree program and thesis work. I would like to thank them especially for the faith they had in me and provided me with the right motivation.

I extend my profound gratitude to the University of Vaasa and Finland for giving me a lifetime opportunity to have this wonderful and exciting education. I appreciate my friends and colleagues, near and far, who have shown me love, affection, and support throughout my studies.

Lastly, I would like to thank my family, and my extended family and siblings for always being there for me. Special thanks to my mother Mrs. Rajamani, for all the efforts and struggles in bringing up the family and supporting my career.

Vaasa, 18.12.2019.

Kannan Selvan

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABBREVIATIONS

ADCS	Attitude Determination and Control System
AMOS	Autonomous Marine Operations and Systems
APT	Automatic Picture Transmission
ARM	Advanced RISC Machines
C&DH	Command and Data Handling
CAMS	Copernicus Atmosphere Monitoring Service
CDS	CubeSat Design Specifications
CEMS	Copernicus Emergency Management Services
CLMS	Copernicus Land Monitoring Service
CMEMS	Copernicus Marine Environment Monitoring Service
COMM	Communication System
COTS	Commercial-off-the-shelf
DDE	Dynamic Data Exchange
DGSN	Distributed Ground Station Network
ECMWF	European Center for Medium-Range Weather Forecasts
ELTs	Emergency Locator Transmitters
Envisat	Environmental Satellite
EPS	Electric Power Supply
ESA	European Space Agency
EU	European Union

EUMETSAT	European Organization for the Exploitation of Meteorological Satellites
FMI	Finnish Meteorological Institute
GaAs	Gallium Arsenide
GENSO	Global Educational Network for Satellite Operations
GNSS	Global Satellite Navigation System
GOES	Geostationary Operational Environmental Satellite
GPS	Global Positioning System
GRD	Ground Range Detected
HDSDR	High Definition Software Defined Radio
HRD	Ham Radio Deluxe
HRPT	High-Resolution Picture Transmission
IoT	Internet of Things
ISS	International Space Station
IWW	Inland Waterways
LEO	Low Earth Orbit
LNA	Low Noise Amplifiers
LORAN	Long Range Aid to Navigation
MERIS	Medium Resolution Imaging Spectrometer
MSI	Multispectral Instrument
NASA	National Aeronautics and Space Administration
NDVI	Normalized Difference Vegetation Index

NO2	Nitrogen Dioxide
NOAA	National Oceanic and Atmospheric Administration
NTNU	Norwegian University of Science and Technology
OBC	On-Board Computer
OLCI	Ocean and Land Color Instrument
PASYFO	Personal Allergy Symptom Forecasting
PNDs	Portable Navigation Devices
P-POD	Poly Picosatellite Orbital Deployer
R&D	Research and Development
SAR	Synthetic Aperture Radar
SatNOGS	Satellite Networked Open Ground Station
SDR	Software Defined Radio
SNAP	Sentinel Applications Platform
SNR	Signal to Noise Ratio
SO2	Sulphur Dioxide
SOLAS	Safety of Life At Sea
TLE	Two-Line Element
UCS	Union of Concerned Scientists
UHF	Ultra High Frequency
VHF	Very High Frequency
WFR	Water Full Resolution

Faculty of Technology

Author: Kannan Selvan

Topic of the Thesis: Ground Station Design for LEO's: Implementation for KvarkenSat

Supervisor: Professor Heidi Kuusniemi

Instructor: Professor Mohammed S. Elmusrati

Degree: Master of Science in Technology

Major of Subject: Communication and Systems Engineering

Year of Entering the University: 2015

Year of Completing the Thesis: 2019 **Pages: 123**

ABSTRACT

Exploration of space and the earth over the decades has led to remarkable innovations and developments in the Space industry. The space industry is transitioning from the Old Space era to New Space bringing in tremendous opportunities to develop an infinite number of applications using satellite data. Satellite data provide valuable information that helps businesses, organizations, science, government, people, and the environment in numerous ways. In space missions, apart from the satellite, a ground segment station is an essential element to receive the satellite data. Old Space players used highly expensive sophisticated ground segment stations for receiving the satellite data. Due to the advancement in technology, New Space players such as private companies, organizations, universities, and individuals have built ground stations based on the costs and mission purpose. In this thesis, a low-cost simple ground station is implemented that is capable of receiving telemetry data and payload data from different satellites to serve the forthcoming KvarkenSat small satellite mission. Apart from the ground station received satellite data, through the utilization of open-source satellite data from different providers, value-added information and satellite products that help in different applications were additionally assessed in this work. The simple nature of the ground station implemented in this thesis helps any individual to understand the concepts of satellite communication and showcases the data reception process. The ground station will help in further research on satellite communication and inspire mainly students and researchers to contribute to space technology development and utilization. The contribution to space technologies will offer solutions to strengthen the sustainability of our society and ultimately serve for the betterment of the earth.

KEYWORDS: Software Defined Radio, SatNOGS, Old Space, New Space, Satellite Communication, Space Debris, CubeSats, Google Earth Engine, GNSS, Earth Observation, Commercial-off-the-shelf, miniaturization technology.

1. INTRODUCTION

1.1. Motivation

The interest towards space is perpetual for humans, desiring to explore the unknown objects, planets, solar systems and galaxies. Exploration of space will help us in understanding about our lives on earth and the Universe. Desire in space exploration will help in expanding the space technology and providing new opportunities that benefit the present and future generations. There are remarkable achievements and developments in space technology over several decades. Old Space technology provides the platform to the current New Space industry and the future. Though Old Space brought in major innovations, the transition to New Space has led to various opportunities. The miniaturization technology and commercial-off-the-shelf (COTS) components enabled private organizations, research institutes, universities to be involved in space activities. Likewise, the University of Vaasa enters into space technology to provide a platform for the students and researchers to get involved with space technologies through the KvarkenSat mission. KvarkenSat mission provided an opportunity also to this thesis to research on the existing ground stations, possible satellite data received and different applications through satellite data. It led to the implementation of a reliable and efficient low-cost ground station in this thesis using the available technologies and components.

1.2. Thesis Statement

In general, satellite communication involves transmitting information from a source to the destination located at a different place on the earth. It consists of two segments namely the ground segment and the sky segment. The ground segment consists of a receiving station that acts as a primary element in the satellite missions. The main purpose of the thesis is to implement a low-cost ground station for receiving data from low-earth orbiting satellites using COTS components. The ground station will track and communicate with the open satellites and CubeSats passing over the ground station. Besides, the ground station will operate to track and receive KvarkenSat data that will be launched in the near future. Apart from the ground station received data, other open-access satellite data from various satellite data providers and their applications will be described in detail. The thesis discusses the ground station received data and other open-access satellite data that benefit the local businesses, organizations, students, and citizens in many ways for different applications. Besides, the thesis intends to inspire and interests any individual to get involved with satellite communication by the implementation of KvarkenSat ground station.

1.3. Methodology

To receive space-based data, the implementation of a ground station is essential. The main purpose is to implement a low-cost setup that performs ground station operations. Hence, the ground station uses omnidirectional antennas instead of more sophisticated steerable antennas. Steerable antennas provide a better communication link to the satellite during uplink and downlink. Instead, by using omnidirectional antennas, it is possible to obtain similar results when compared to using a steerable antenna system that is more sophisticated. The components were selected which are low cost but at the same time that perform equal to the components used in advanced ground stations. The system implemented will perform ground station operations tracking the satellites and receiving telemetry data and payload data.

1.4. Thesis Structure

The thesis begins with the introduction chapter that guides through the motivation and objective of the thesis and the methods used. Followed by the introductory chapter, the thesis describes different types of satellites and their essential applications and business opportunities in chapter 2. The role of different satellites and their wide applications in our day-to-day life are discussed. Chapter 3 provides a discussion about the difference between the Old Space and New Space, and the reasons behind the major transition in the space industry to the New Space era. A detailed discussion about opportunities in New Space, different business models in New Space and challenges in New Space economy are provided. Following the transition to New Space Economy, different satellite data products obtained from open satellites and CubeSats, and different open access data from various satellite providers are discussed in chapter 4.

Chapter 5 covers CubeSats, the difference in CubeSats over traditional satellites, classification and design of CubeSats, and qualification testing for CubeSats is also discussed. Chapter 6 is covering the literature review on the different ground stations implemented by other universities and organizations in detail. It summarizes the evolution of the ground segment that communicates with satellites and spacecraft, and limitations of the ground station systems implemented in the past. The chapter will also cover the possible solutions for the ground station using recent technologies. Chapter 7 describes the ground station specifications, software platform and hardware components used. It accomplishes the aim of the thesis by describing the implemented system that tracks and communicates with the low-earth orbit satellites and performs ground station operations. Chapter 8 on KvarkenSat ground station covers in detail the different satellite data obtained by the ground station setup implemented at the University of Vaasa. The chapter also covers accessing different open-source satellite data from different providers and analyses made using their platforms and relevant tools. At the end, chapter 9 covers the future aspects of this thesis along with the highlights of the results achieved through this research work.

2. SATELLITES DIVIDED BY BUSINESS SECTORS

There are multiple applications of satellites and some of those are so significant, that without them modern world will cease to exist. Satellites have a broadcasting feature and due to this characteristic, satellites can be used to cover a wide range of purposes involving transmission and reception of signals. Some of these essential applications include satellite-based communication of radio, television and phones. Weather forecast systems, mapping and navigation also heavily rely on satellites. (Lutz, Bischl, Ernst, Giggenbach, Holzbock, Jahn, & Werner 2004: 2342.)

The way satellites interact with different sectors will be explained in detail in this chapter. There are various types of satellites and each of them has a different purpose, this chapter will discuss three main types of satellites, namely communication satellites, earth observation satellites and navigation satellites, and their business opportunities and application areas.

2.1. Communication Satellites

The main function of a communication satellite is to exchange communication data from the parent to the host through the satellite. The communication satellite is mostly used for services such as the internet, radio, mobile communications and television. The communication satellite reroutes the communication data from one ground station to another station through the help of a transponder in the satellite. The station communicates to the satellite in the form of electromagnetic waves and for this purpose, the station uses a large satellite dish. The satellite redirects the obtained signal to the destination station that receives the signal using a suitable receiver. (Technopedia 2019.) The following **Figure 1** illustrates the communication satellite reception and transmission of the signal from the ground.

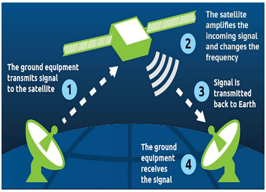

Figure 1. Communication Satellite Signal Transmission & Reception with Ground Station.

Source: https://www.intelsatgeneral.com/satellite-basics/

According to Suparco (2019), "the geostationary orbit is useful for communications applications because ground-based antenna, which must be directed towards the satellite, can operate effectively without the need for expensive equipment to track the satellite's motion. Especially for applications that require a large number of ground antenna (such as direct TV distribution), the savings in ground equipment can more than justify the extra cost and onboard complexity of lifting a satellite into the relatively high geostationary orbit."

2.1.1. Geo-Stationary Satellites & Non-Geostationary Satellites

When referring to satellite communication, there are two types of operational options, geostationary satellite systems and non-geostationary satellite systems. In geostationary satellite systems, due to the fixed nature of satellites with regards to the earth's surface, they are used for Satellite TV reception with the help of satellite dishes. Geostationary satellites are located at an altitude of 35,786 km from earth. Therefore, due to the large distance from the earth, waves suffer from high attenuation in mobile communication. Hence, a geostationary satellite system relies on large receiving antennas. Using non-geostationary satellites for mobile communication, due to the orbiting of the satellite in low or medium orbits around the earth, prevent signal delays. Thus, the performances levels of mobile communication are well achieved with the reduction in signal delays using non-geostationary satellite system. (Lutz et al. 2004: 2342.)

High altitude platform system concepts are being developed, which will be a replacement for the existing communication satellites. These systems will provide the advantages of both the geostationary and Low Earth Orbit (LEO) satellite systems placed at an altitude of 20 km. The main reason behind such concepts is to provide broadband and mobile services. The high wind speeds cause the main threat to the operations of the platform. (Lutz et al. 2004: 2342.)

2.1.2. Future Applications

One of the essential future applications of the communication satellites is to provide broadband services to air passengers. As an example, the recent collaboration between Lufthansa and Boeing in the FlyNet project to provide broadband facility on-board provides a view of the market's potential. Projects like this will help to shape the aeronautical satellite communication, with the help of which passengers do not have to rely on a few kilobytes per second data rates. They will have access to data rates as fast as 100 kilobytes per second or few megabytes per second. In satellite communication, data services will be a major element expected to expand with immense business opportunities and applications through the usage of communication satellites. (Lutz et al. 2004: 2345.)

2.2. Earth Observation Satellites

Earth observation satellites are similar to surveillance or remote sensing satellites designated for non-military usage observing the earth from orbit for the purpose of weather monitoring, environmental study, maps et cetera. The first remote sensing with the help of an earth observation satellite dates back to Sputnik 1, launched by the Soviet Union. The operators in the ground used the radio signals received from Sputnik 1 to study the ionosphere. (Kusnetsov et al. 2014.) Satellites use the onboard radio to receive the radio signal and transfer the data using feeder links to the ground segment (Earth Observation Satellites Transmission Frequencies 2019). Most of the earth observation satellites operate in the altitudes averaging 700-800 kilometers to prevent air drag at lower altitudes. The satellites provide satellite imagery data products of various regions of the earth. (Earth Observation Satellite 2019.)

Satellites intended mainly for weather monitoring helps in monitoring more than just the weather. Apart from clouds and their patterns, these meteorological weather satellites are able to catch the effects of pollution, snow cover, boundaries of oceans, city lights, fires, ash clouds from volcanic mountains et cetera. Similar to weather satellites, the other type of earth observation satellites typically called environmental satellites helps in monitoring the earth's environment. These satellites help in predicting the variations in vegetation, atmospheric gas levels and information on sea, ocean and ice state. (Earth Observation Satellite 2019.)

According to the Union of Concerned Scientists (UCS), 1980 satellites orbit around the earth as of April 2018, and 684 out of them are earth observation satellites or related to earth science. Amongst these 684 earth observation satellites, 338 operate for optical imaging, 49 operate for radar imaging, eight for infrared imaging, 82 for meteorological purposes and other earth observation satellites for specific purposes. Based on the users, earth observation satellites are divided into three main categories such as governmental actors, military activities and civil purposes. All these satellites are controlled by different countries with a major share of the earth observation satellites being owned by the United States. (Pixalytics 2018.)

Earth Observation functionalities vary according to certain features of the spacecraft such as type of orbit, imaging instruments, payload, pixel resolution, sensor characteristics and swath width of sensors. These features are determined even before the time of actual designing of the satellite, according to the type of mission the satellite is going to perform. The altitude and the position of the satellite in orbit also vary according to the application of the satellite mission. For example, a weather satellite needs to cover the whole hemisphere, so it stays in geostationary orbit. Due to high altitude, satellite data with high spatial resolution is difficult to attain. Hence, it is used for applications that do not require high spatial resolution such as tracking the cloud, hurricanes and storms. Sensors with high-resolution properties are used for applications requiring high-resolution images on specific areas such as rivers, map updating, buildings and the aftermath of natural disasters. These type of satellites for capturing high-resolution images needs to be in low altitude such as LEO satellites. Besides, satellites move over the area of interest since they lead a continuous motion relative to the earth. Hence, continuous monitoring of the same area is not possible with these satellites. (ESA Eduspace 2019.)

2.3. Radio Navigation Satellites

The evolution of navigation and positioning began during the 4th century. Magnetic needle compass was the oldest instrument used for navigation. Later, latitude hook kamal, quadrant, astrolabe, and chronometers were used followed by beacon based positioning, Long Range Aid to Navigation (LORAN) system, Navstar Global Positioning System (GPS), GLObal NAvigation Satellite System (GLONASS), Galileo and Compass. (Samama 2007.)

In general, satellite positioning was termed as Global Navigation Satellite System (GNSS). It is a group of satellites around the earth, providing automated localization by transmitting time signals from space. The automated location on any point of the earth provided in a certain dimension is known as geo-spatial positioning. The receivers use the time signals and determine the receiver antenna's latitude, longitude, altitude et cetera. GPS and GLONASS by US and Russia respectively were the only two fully functional globally operating satellite navigation system. Europe will launch a complete constellation of 30 satellites by 2020 known as Galileo. China operates a regional navigation system called BeiDou navigation system and will serve globally by 2020 as an alternative to GPS, GLONASS and Galileo with high accuracy in navigating and positioning. (Someswar et al. 2013.) All these GNSSs also function in parallel.

GNSS based satellites offer a wide range of applications for receivers such as in navigation, geo-marketing and advertising, safety and emergency, sports, health, personal tracking and social networking (GNSS Market Report 2019: 26). GNSS provides precise location and time at any point on the earth, provided that there is availability to the signal in space i.e. they are operating typically outdoors. Other parameters such as user speed, acceleration, local time and range measurements are also determined. Zogg (2009) claims that road transportation continues to be the biggest market for GNSS. (Zogg 2009.)

GNSS plays a vital role in the navigation of automobiles, aircraft and ships. Automobiles use built-in GNSS receivers or devices available from the market to be equipped with the vehicles. It displays the navigation information based on the data received from the satellite, allowing the users to navigate and reach faster to the destination. GNSS positioning supports both the pedestrian navigation and road navigation, providing indications systematically for the users and drivers through Portable Navigation Devices (PNDs). (Ramawickrama, Wijesekara, Dharmarathna & Wijesooriya 2016.) Some major cities renovated their public transportation such as trams and buses by using advanced GNSS based receivers. It provides commuters with accurate information on the public buses and its timetables. It is anticipated to be available in most regions of the world in the future. (GNSS Market Report 2019: 36.)

In aviation, certified instruments are used to en-route aircraft for reliable and efficient operations. General aviation aircraft navigate through the GNSS receivers mounted in the cockpit. The aircraft navigation system offers a secured final approach and landing operations of the aircraft as well. Aircraft uses Emergency Locator Transmitters (ELTs) during an emergency situation for search and rescue operations. Upon activation during an emergency, ELTs utilize GNSS to indicate the exact position of the aircraft. Infringement alarms utilize GNSS and provide warning signals to the pilot when the aircraft gets too close to the restricted airspace. (Ramawickrama et al. 2016.)

In maritime, cruise vessels and ships use GNSS to navigate through the rivers, sea and oceans with at most safety. Cruise vessels and cargo ships used for international voyages rely heavily on GNSS for navigation purposes. The installation of Safety of Life At Sea (SOLAS) vessels on the ships provides accurate navigation based on GNSS. Inland Waterways (IWW) utilize GNSS to navigate within rivers, lakes and canals. Besides, monitoring and controlling port operations such as docking, loading and unloading operations, transit progress becomes effortless using GNSS technologies. (Ramawickrama et al. 2016.)

Heavy equipment installed with GNSS receivers are used in precision agriculture and mining (Someswar et al. 2013). Through precision agriculture with the use of various technologies and devices, efficient farming with improved crop yield and minimal environmental damage is possible. Farm machinery guidance helps in avoiding overlapping by assisting the farmers to follow the path using GNSS. Agrichemicals used in farming are more evenly distributed across the fields by using GNSS positioning along with other different sensing devices and digital maps. This process is known as the variable rate application. (Ramawickrama et al. 2016.)

Railway is one of the most widely used transportation by the people in any part of the world. The railway sector aims to offer highly efficient and attractive services to customers through digitalization. GNSS will be used as the standard receiver in the trains offering various services to the end users. The services includes apps for commuting, tracking applications, passenger information in real-time, et cetera. (GNSS Market Report 2019: 71.)

Similar to communication satellites, earth observation satellites, and navigation satellites, also other satellites are serving our society nowadays for various applications. Overall, satellites are widely used for many applications along with other different critical technologies and solutions of our digital society. With the advancement in technologies, demand and utilization of satellite and space technology will continue to grow, emerging new markets with infinite business opportunities.

3. OLD SPACE VERSUS NEW SPACE

The activities related to space emerged during the 20th century known as the space age. The innovation of rockets, satellites, launch stations and other space based models led to remarkable improvement in communicating with space. Old Space refers to the period during which exploration and communication with space began through the innovation of different space technologies and systems. Governmental organizations and big companies were the key players involved in Old Space. They built their own or contracted space center for launching satellites and other operations, accessing the space. Old Space used highly expensive and sophisticated design systems developed by a large team of experts. The components of the systems have high costs and need significant resources to develop into such sophisticated systems, which was out of reach for private companies during Old Space. Any failure in the systems would result in a major catastrophe. Therefore, Old Space players worked only with proved concepts, systems and results. Even though there are several limitations, Old Space players carried out operations successfully for various applications providing platform for the next generation of space industry. (Wandering Alpha 2017.)

Major innovations and developments in Old Space prolonged for over 50 years. The transition in the space industry started to take place during the end of the 20th century, engaging all private companies to reach outer space and create business opportunities called New Space. The private companies and other sectors such as educational institutions will be key players in the New Space, reaching outer earth without major cooperation with governmental space agencies. New Space brought in enormous projects with relatively low cost COTS components available. COTS components reduced the costs drastically, enabling opportunities for smaller space missions, paving way for private companies and other sectors to enter into the space industry. It enabled private companies to seek different approaches and new concepts, even if there is uncertainty in their methodology. The miniaturization technology brought forth not only COTS components but also reduced the size of the sophisticated systems into smaller low cost systems. It enabled the space missions to be simple, faster and frequent. (Poghosyan & Golkar 2016: 59.)

3.1. Difference in Old Space & New Space Economy

In Old Space, design and construction of satellites or any space system requires a large team of experts. While in New Space, design and construction of satellites are easier, quicker and faster at relatively low costs with typically a smaller team of experts. In Old Space, space missions do not focus on a specific business application or societal purpose, while New Space provides an opportunity to create a specific business application or societal purpose based space missions. Old Space missions' limitations include sophisticated systems design and high costs of manufacturing satellites and related systems. New Space missions create business opportunities for the startups, institutes and private companies. With New Space capabilities, the actors involved offer commercialized services through their entry into space with smaller space mission objectives. Overall, New Space players do things much faster and cheaper than the traditional space players do. (Noosphere Ventures 2018.)

3.1.1. Comparison Based on Mission Objectives

The activities involved in Old Space include various space mission objectives for the defense and safeguard of nations and military, growth in the industry, finance and other sectors. There are no productive straightforward cost benefits generated through the Old Space mission projects. On the other hand, New Space involves space mission objectives for specific business applications. New Space missions offer low costs services with productive straightforward costs benefits. Space is a principal source of benefit and value for private companies and non-state players, considering their actions and practice on space mainly as a business. (Paikowsky 2017: 84–88.)

Old Space activities include high-cost long-term projects with large satellites above the earth orbiting for more number of years. Large satellites revolve in various conditions and surroundings, which requires regular support and maintenance from the ground station for the proper functioning of the satellites. Ground station operators do typically not carry out any satellite maintenance operations due to the limitations in technology during Old Space. Overall, the Old Space era failed to take major risks and opportunities in space that produced somewhat conservative results in terms of R&D. In contrast, New Space consists of distinct features and opportunities in terms of research and development (R&D) and finance. New Space activities include small and low costs projects with satellites above the earth orbiting for a minimal lifetime. Due to the COTS components, it is feasible to manufacture small satellites at a faster pace and relatively low costs. Ground station operators carry out support and maintenance operations for the efficient ´functioning of smaller satellites in orbit. Nowadays, tracking of satellite operations and performance from different places in the ground is possible through a monitoring network. Thus, the New Space ecosystem inclines players to take new risks and approaches producing efficient R&D models through innovative solutions. (Paikowsky 2017: 84–88.)

3.1.2. Comparison Based on Satellites Launched

Following the Old Space era, New Space players will be involved with launching more number of satellites to space in recent years than before. The development of the New Space ecosystem helped to launch hundreds of specific business application based CubeSats in higher numbers than large conventional satellites. The year 2017 indicated a significant increase in the total number of application based CubeSats launched by New Space players compared to other space players with about 300 CubeSat launches as illustrated in **Figure 2**. (Alén Space 2019.)

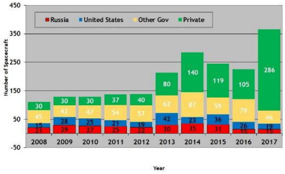

Figure 2. Number of Satellite Launches from 2008 – 2017.

Source: http://claudelafleur.qc.ca/Spacecrafts-index.html

From 2013, New Space players launched CubeSats for the defense and safeguarding of the nations and military purposes in very few numbers. Simultaneously, they launched satellites for specific business applications in large numbers. The emerging players, decrease in technology costs, new fundings and new business opportunities, paved the way for a large number of satellite launches into space. The New Space market anticipates a large number of nanosatellites or CubeSats in orbit with commercialization potential. (Alén Space 2019.)

3.2. Business Models in New Space Economy

The New Space industry mainly functions as a low-cost business paradigm. Miniaturization technology enables the development of small satellites, manufacture subsystems using commercial components, and use the ground segment stations and launching services at lower costs. The prevailing space industry took shape already providing tremendous business opportunities and foreseeing more benefits for the future with commercialization potential. New Space players such as the SpaceX has huge success stories with disruptive business paradigm inspiring other players and startups. One major development by SpaceX being the Falcon 9 rocket from COTS components, used by NASA to carry cargo to International Space Station (ISS) at a lower cost. Globally, the growth in the number of space companies has increased in recent years and expected to be more than multiple thousand companies in the next decade. The growth in space technology will increase considerably in the next thirty years with a major drop in satellite launching services cost and a huge increase in the number of satellite launches. (Noosphere Ventures 2018.)

3.2.1. Open Access Business Models

In recent years, most of the companies business models evolved based on providing resources and services via platform economy such as Uber and Airbnb. Similarly, the New Space economy involves providing open access to enormous amount of data and services to the users. The low costs ground stations integrated through a network allows the user to share and receive data to and from different users in the network. The new launching system helps the New Space players to launch their small satellites along with large satellites together and access the space at feasible costs. Some New Space players provide easy access to satellite data through a platform offering services to users with instant data at an appropriate time. Some examples of such data providers are the commercial Planet labs and the European Commission's Copernicus. Copernicus is providing its data with a free and open policy. Huge amounts of near real-time data is available to students, researchers, governments, and other organizations to access data and create new ideas and innovations based on open satellite data. The main concept of providing resources and services in the New Space economy has agitated the market value of also the conventional space industry. Private companies and other New Space players constricted their business models but broadened their services. Some of them are involved with applications such as Internet of Things (IoT), manufacturing subsystems for CubeSats, data and services, controlling and monitoring of resources and overcoming debris through advanced devices. (Noosphere Ventures 2018.)

3.2.2. Satellite Based Business Models

Recent innovations within technologies has reshaped the way humans communicate with others. A major transition in the space industry took place due to the IoT concept and affordable CubeSats. The topology of small satellites in space and various sensors and devices located in the ground segment produces different kinds of data. Traffic management, self-sufficient transportation, earth observation, tracking, monitoring, and various other applications emerged from the data obtained by the satellites and sensors. New Space players will develop business models and offer services to customers using satellite data. (Alén Space 2019.)

Remote sensing nanosatellites or CubeSats operate specifically for environmental and non-military purposes such as observation of earth from the space, collection of environmental and meteorological data. The data obtained from the remote sensing nanosatellites help in cultivation, mining, and other industries for various purposes. It consists of images on agriculture lands that help in monitoring the fields, irrigation and fertile regions as well as damages caused by environmental factors et cetera. CubeSats provide meteorological data such as information about snow cover, rainfall, floods, clouds, storms, hurricanes and other information. The data received from the CubeSats helps in developing various business models and offer services based on the application and users. (Alén Space 2019.)

CubeSats can help in recognizing objects and elements on land or water. The ship tracking, fleet management and aircraft surveillance are some of the applications considered to be accomplished through data obtained from the CubeSats in the future. In aircraft surveillance, CubeSats can help in transmitting the aircraft location to the ground rather than using the radar signals. Ships can communicate with systems on land and transmit their position from water to the ground using CubeSats. A constellation of CubeSats can help in monitoring natural disasters providing data on the impact levels and the most affected regions. This information from the satellites will help in expediting adequate rescue efforts. Thus, satellite data helps in developing new business models and offer services based on specific applications. (Alén Space 2019.)

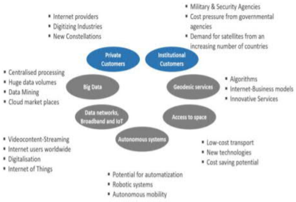

Figure 3. Opportunities in New Space.

Source: https://noosphereventures.com/how-new-business-models-will-disrupt-old-space-industry/

Numerous business opportunities are possible within the New Space economy consisting of a large amount of data obtained from various satellites with lots of applications. Through New Space, the loss of a satellite in a constellation after its lifetime does not affect the services offered by them. Due to the faster and quick manufacturing and development of

CubeSats at low costs, it is feasible to replace it with a new satellite in a shorter period. The space environment creates new business opportunities for entrepreneurs with boundless possibilities in the future. Some of the business models already evolved through the CubeSats creating additional values and boosting profits to all relevant companies and sectors. (Alén Space 2019.) **Figure 3** shows the opportunities in New Space and cross-industry business models.

3.3. Challenges in New Space Economy

The major attraction of New Space ecosystem is the recent significant increase in manufacturing and utilizing small satellites. There is a remarkable improvement in the total number of small satellite launches over the past several years. It comprises a huge portion of total satellites launched annually, meanwhile increasing threats to the protection and sustainability of the space environment, regulation issues and its effects on the New Space industry. The abundant increase of satellites in space constitute to space debris after the shorter lifetime of small satellites. It is one of the primary concerns for the future space environment imposing further danger to operating satellites and satellites with a longer lifetime in orbit. The miniature size, weight and minimal lifetime of the small satellites impose further risk as it does typically not have deorbiting capabilities like large conventional satellites. Non-operational satellites in the space become space debris after their mission lifetime. Due to lack of gravity, satellites at high altitudes are likely to remain in the space as threatening debris to other operating satellites. It is highly essential to establish a reliable and sustainable space environment by all the space players due to the rapid growth of the commercialized space industry. (Paikowsky 2017.) There is no sufficient models and measurements to predict the near earth radiation environment, which affects the satellites and leading it to become space debris. Finnish Centre of Excellence in Research of Sustainable Space plans to build and launch a group of nanosatellites that predicts the near earth radiation environment. By this, the factors affecting the satellites health and leading to space debris will be analyzed and helps in creating a sustainable space for next generation. New Space ecosystem engages space players, private and governmental organizations to pursue a new set of procedures and agreements for a reliable and sustainable space environment, mitigation of space debris and efficient way of operation in the space industry. Regulations and standardization, space debris mitigation using the available technology will ensure greater responsibility by all players in the New Space ecosystem to enable a secure and sustainable space environment for the future. (Paikowsky 2017.)

4. SATELLITE DATA PRODUCTS

Over decades, development in satellite communication led to the exploration of earth and space in several ways. Various applications include connecting people through mobile & internet globally using communication satellites, foretelling & forecasting weather and climatic conditions based on the observation of the atmospheric region of the earth through weather satellites, positioning or navigating to the requested location using navigation satellites. These applications are possible due to different satellites revolving around the earth. Satellites collect and transmit information about the earth known as satellite data. Ground stations use various reception techniques to receive the satellite data obtained using remote sensing technologies from different satellite instruments and sensors. Later, satellite data undergoes various signal-processing techniques resulting in satellite products. (Wonderopolis.)

An enormous amount of satellite products are available based on various types of satellites and their mission objectives. Different organizations and programs provide high-quality satellite imagery products available free of cost to the users. Some of the satellite data providers are ESA's Sentinel missions, NOAA Class, National Aeronautics and Space Administration (NASA), and Earthdata Search (GIS Geography). ¨*Global Satellite Navigation System (GNSS), Sentinel 1, Sentinel 2, Sentinel 3, Sentinel 6, National Oceanic and Atmospheric Administration (NOAA), Geostationary Operational Environmental Satellite (GOES), Landsat and EnviSAT*¨ are different satellites tracked by the satellite data providers with advanced ground stations around the world (GIS Geography). Using advanced reception techniques, satellite data providers and other ground station operators receive satellite data and process the data into products. Through the websites of open satellite data providers, any user can download the products for their application.

The following sub-chapter provides more insight into the satellite data products offered by satellite imagery providers such as the EU’s Copernicus, Google earth engine, commercial service providers such as ICEYE and Planet Labs, open satellite data products such as NOAA satellites and existing CubeSats.

4.1. Copernicus Programme, Services & Use Cases

Copernicus (https://www.copernicus.eu/en) is a European Union's (EU) service programme that aims in delivering real-time satellite data by observing and monitoring the earth and its surroundings. Copernicus programme operations include receiving, storing, analyzing and generating products from the data obtained through satellites and sensors. It uses a group of satellites called Sentinels owned by the EU. EU plans to launch some more dedicated satellites in upcoming years to provide constant satellite products. Their services also depend on the other available commercial and public satellites called as contributing missions apart from dedicated Sentinel satellites. Those contributing missions were operated by the European Space Agency (ESA), European Organization for the Exploitation of Meteorological Satellites (EUMETSAT), EU Member States & other countries and commercial providers. High-resolution consistent satellite products from the contributing missions are available through Copernicus services. Apart from Sentinel and contributing missions, Copernicus uses in-situ systems to collect data and offer satellite products to its users. The in-situ system is a region-based system to measure data using sensors deployed in different regions such as at land or on sea and ocean. The users can search and access the Copernicus datasets from the past and compare with the current datasets for a better understanding of the changes in the environment that helps in predicting the future. The satellite data products are characterized into six categories that are atmosphere, marine, land, climatic change, security, and emergency. The following subsections will discuss a few selected Copernicus categories and the related use cases in detail. (Space 2015: 4–6.)

4.1.1. Atmosphere

The current atmospheric conditions are one of the major issues of interest of the global ecosystem. In order to monitor and control the atmosphere related impacts on the environment, the Copernicus programme offers a service called the Copernicus Atmosphere Monitoring Service (CAMS). European Center for Medium-Range Weather Forecasts (ECMWF) along with other organizations across Europe manages the CAMS. It offers reliable and accurate information on the atmosphere to different users, organizations, and businesses. The service focuses mainly on offering free and authorized data products from satellites and in-situ systems on air contamination levels, atmospheric composition, emissions from the sun, and climatic conditions. It consists of near real-time and forecast data, provided both on a global and regional basis. The service provides information on the quality of air, based on the substances such as aerosols, ozone and other reactive gases present in the atmosphere. The amount of ultraviolet radiation from the sun that reaches the surface of the earth is dependent on the atmospheric ozone distribution. Greenhouse gases and aerosol levels will also have a great impact on the climatic conditions of the earth. Air quality levels, solar radiation, pollen levels are some of the satellite products and information services delivered by CAMS. Therefore, to monitor and control the atmospheric composition of the earth, open access to the satellite data atmospheric related products from CAMS will benefit users comprehensively. (Peuch et al. 2018.)

CAMS analyzes the earth's atmospheric components present at different altitudes from the sea level. The service includes constant air quality measurements for present conditions and projections for a few days ahead. (Space 2016.) The products on European air quality depends on various air quality models used in different parts of Europe. Each individual air quality model across Europe provide information on the concentration of air pollutants. The median value of all the models obtained by using the ensemble model results in the reliable values of the air pollutants concentration. The concentration levels of the atmospheric components on the surface will vary from levels at several thousand meters height. **Figure 4** and **Table 1** provide typical information about index levels based on the concentration of different critical gases and their forecast. (Atmosphere Monitoring Service.)

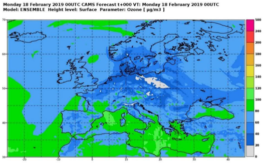

Figure 4. Hourly Forecasts of Ozone Concentration Levels.

Source: (Atmosphere Monitoring Service).

Table 1. Index Value Based on Concentration Levels of Air Pollutants.

Pollutants	Index level (Based on pollutant concentrations in µg/m3)				
	Very Good	Good	Medium	Poor	Very Poor
Ozone (O3)	0-80	80-120	120-180	180-240	240-600
Nitrogen Dioxide (NO2)	0-40	40-100	100-200	200-400	400-1000
Sulphur dioxide (SO2)	0-100	100-200	200-350	350-500	500-1250
Particles less than 10µm PM10	0-20	20-35	35-50	50-100	100-1200

Particles less than 2.5µm PM2.5	0-10	10-20	20-25	25-50	50-800

Source: (Euronews. 2019.)

CAMS along with the cooperation of European Aeroallergen Network provides information on different pollen loads and their severity. It collected data on various types of pollens using several monitoring stations in different parts of Europe for the last several years. Based on the past collected data, the representation of pollen loads in Europe for each month is available to the users in the form of maps, as in **Figure 5**. The current situation and forecasts of the pollen levels for each European country and European basis are also available to the users. (Polleninfo.org.)

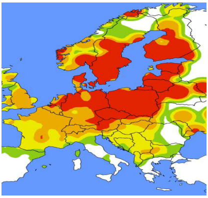

Figure 5. Pollen Load Map of Europe for Birch (Betula) in April 2018.

Source: https://www.polleninfo.org/FI/fi.html

The maps are characterized based on the pollen type and its severity. The colors in the **Figure 5** represent the loads of birch pollen type, where the white area indicates no pollen affected area, green color indicates a low level of birch pollen affected area, yellow indicates intermediate levels of affected region, orange and red indicates high and very high loads of birch pollen present in that region. (Polleninfo.org.)

4.1.2 Marine

Copernicus Marine and Environment Monitoring Service (CMEMS) aims in providing data on marine and ocean-based operations due to the high demand for reliable data on marine and ocean for various applications. Some of the applications include the routing and navigation of ships, predicting climatic changes, identifying vessels and aquatic species, managing coastal areas, ports and the complete aquatic ecosystem. CMEMS achieves this goal with the help of alliances both on a regional and global basis. CMEMS provides satellite-based data on marine and oceans that include temperature, wind, sea ice, waves, salinity and nutrients present in the water. CMEMS provides free and open access data on detailed erudition, composition, and characteristics of the sea and ocean both regionally and globally. (Drevillon et al. 2018: 695–697.)

Observations made by the CMEMS services come from different origins such as satellites, sensors, and in-situ devices. The CMEMS uses satellites such as the Sentinel family of satellites from the ESA, EUMETSAT and NASA satellites for observations on marine and oceans. CMEMS uses in-situ observation data provided by its collaborators. Observation data from the in-situ devices are collected from several regions of Europe such as the arctic region, the Baltic region, North West Europe, Ireland-Biscay-Iberia region, the Mediterranean region, and the Black sea. (Copernicus Marine Environment Monitoring Service.)

Seawater potential temperature, sea ice thickness, sea surface temperature, the area fraction of sea ice, seawater salinity, sea surface height above sea level are the variables measured by CMEMS on a global and regional basis. Based on the hourly mean temperature, CMEMS provides the forecast products on each variable for the next two days. It updates the forecast products twice a day. The satellite uses the infrared or microwave radiometers to measure variables such as seawater potential temperature. **Figure 6** shows the comparison of the seawater potential temperature forecasts during the months of January 2019 and May 2018 in the Baltic Sea. (Copernicus Marine Environment Monitoring Service.)

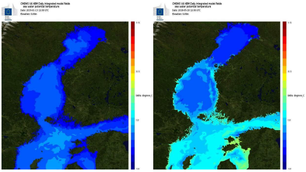

Figure 6. Seawater Potential Temperature Forecasts in Baltic Sea.

Source: (Copernicus Marine Environment Monitoring Service).

Due to the depletion of polar ice, CMEMS monitors the sea ice regularly and collects the data on sea ice thickness, sea ice extent over the Polar Regions. *¨The satellites use various devices and sensors such as microwave radiometers, scatterometers, infrared sensors, SAR sensors, altimeters¨.* These instruments measure sea ice and its thickness level and the extent of sea ice around the region. **Figure 7** illustrates the comparison of the forecasts of sea ice thickness during February 2019 and May 2018 in the Baltic Sea region. (Copernicus Marine Environment Monitoring Service.)

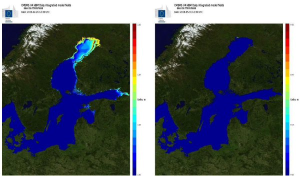

Figure 7. Sea Ice Thickness Forecasts in Baltic Sea.

Source: (Copernicus Marine Environment Monitoring Service).

4.1.3 Land

Satellite images and related processing tools play an important role in land monitoring. Copernicus Land Monitoring Service (CLMS) provides information on land cover and its changes, land use, vegetation state, droughts and floods using satellite data. The service mainly focuses on managing the resources of the environment such as forest, water bodies, soil, agriculture, industries, transportation, et cetera. CLMS consists of different categories, producing various products on a global and regional basis. Systematic monitoring of biophysical parameters provides information on cultivation, agriculture, and water. Land cover and land use mapping is the second category providing information on the land and its features. The other category known as thematic hot-spot mapping focuses on the area that is likely to be affected by environmental conditions. (Copernicus Land Monitoring Service.)

4.1.4 Emergency

Emergency management involves different phases such as mitigation efforts, responding to the disaster and restoring efforts made from the disaster. For this purpose, Copernicus Emergency Management Services (CEMS) provide an exceptional benefit to its users during all phases of disaster management. It is one of the services provided by the Copernicus offering data on the assessment of disaster grade. Satellite and sensor instruments on the ground observe and collect the data. It offers products based on the observation of droughts, heavy rainfall, flood, volcano eruptions, wildfire, cyclones, hurricanes, mining accidents, and explosions. It is possible to minimize the impact of disasters and respond to emergencies based on CEMS products. (Denis et al. 2016: 619–633.)

4.1.5 Use Cases

Copernicus use cases include how satellite data and in-situ collected data products will help their users or customers. The safety of society and the environment is the most essential thing considered before or during a disaster. Therefore, CEMS products help in reacting and responding to disasters quickly and efficiently. One such use case is the forest fire in Brazil, South America. According to United space in Europe (2019), satellite images provided information on the forest fire damages caused in the Amazon region during 2019. The forest fire caused severe damages to the lands, destruction of resources, hectares of forestland, wild animals and species. The results from the satellite data prove that the forest fire increased by four times in 2019 compared to the previous year. Peru, Bolivia, Paraguay are other parts that similarly affected by forest fires apart from Brazil. The main cause for the rainforest region to be sensitive to fire was due to deforestation and global warming. **Figure 8** illustrates the huge plumes of smoke during the forest fire in Brazil captured by Sentinel-3. The Amazon rainforest being the primary source of oxygen for the world released 25 mega tonnes of carbon dioxide into the atmosphere. Copernicus products provide a better understanding of the geometry of the forest fire area that would help in responding quickly to the forest fires. It is possible to take suitable actions and safety measurements to mitigate the effects of disaster based on the information obtained from satellite products. (United space in Europe 2019.)

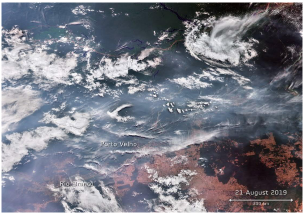

Figure 8. Plumes of Smoke During Forest Fire in Brazil Captured Using Sentinel-3.

Source:
http://www.esa.int/spaceinimages/Images/2019/08/Wildfires_in_Brazil_from_Copernicus_Sentinel-3

Another use case example offered by CEMS includes a product on the flooded region of Myanmar. Due to unprecedented heavy rainfall in the region, the reservoir and river water overflowed into the land cover region, causing severe damages. Through satellite and in-situ data, CEMS provided information about the flood surrounded area, amount of population around the flooded region, damages to the transportation, and so on. The product provides an evaluation of the overall damages caused by the flood as shown in **Figure 9**. Using such information from CEMS on the evaluation of damage caused, relevant safety measurements, and actions to mitigate damage and accelerate rehabilitation is possible. (Copernicus 2015.)

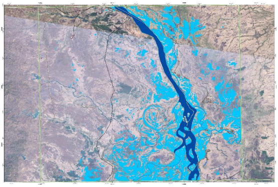

Figure 9. Myanmar Flood Damage Estimation Product by CEMS.

Source: https://emergency.copernicus.eu/

In Europe, due to airborne particles, there is a notable increase in diseases related to the respiratory and immune systems. Pollens are one of the most typical airborne allergy generator caused by air pollution and bad weather. PASYFO (http://pasyfo.lt/) is a pollen symptom forecast tool, which could provide information about the suitable conditions for planning outdoor-based activities or work. It is one such solution for its users, people, and children allergic to pollens and doctors for treating allergic patients. It is available both online as a webpage and as an app for mobile users. The information provided by the PASYFO is useful to people who are working outside for long hours or planning outdoor activities during the pollen season. PASYFO uses the forecasts on the pollen loads, quality of air and atmospheric composition from CAMS as the main source for forecasting the pollen symptoms. Based on these data, PASYFO calculates risk to allergies on a particular day that promotes user's outdoor activities and improves the standard of living as shown in **Figure 10**. (Copernicus.)

Figure 10. Forecasts of Pollen Allergy Symptoms.

Source: https://www.copernicus.eu/en/use-cases/pasyfo-forecasts-personal-allergy-symptoms

4.2 Open Satellites and their Data

Governments and large companies have dealt with most of the space-based projects in the past. Nowadays, private companies, smaller entities, and universities have started to build and launch their own satellites due to reduced costs enabling these new actors to participate in the activities. The goal of these private companies, smaller entities and universities is to engage people, students, and researchers to get involved with space-related activities and naturally to join the New Space industry by developing space-based applications for businesses. Tracking open satellites would be a great start for anyone to involve in space-related activities. Some of the satellites that are available for open access are a series of NOAA weather satellites, the ISS and a few CubeSats.

According to National Oceanic and Atmospheric Administration (2019), the NOAA series consists of four satellites currently in operation in the polar orbit: NOAA 15, NOAA 18, NOAA 19 and NOAA 20. The main mission of these satellites is operational meteorology flying at LEO. These satellites are polar-orbiting satellites that pass through the same region in a day at regular intervals. Due to the low earth orbiting of satellites around the poles, satellites are capable of capturing atmospheric-related data such as cloud patterns. The satellite transmits High-Resolution Picture Transmission (HRPT) and Automatic Picture Transmission (APT) signals. Suitable decoding software will help in decoding the satellite signal into an image. The image depicts high and low clouds, hurricanes, ground station location and other weather-related information. **Figure 11** illustrates an example for a NOAA satellite APT signal decoded into an image. It illustrates high and low clouds, land and sea regions, ground station location, latitudes, longitudes and boundaries. (Hong Kong Observatory 2016.)

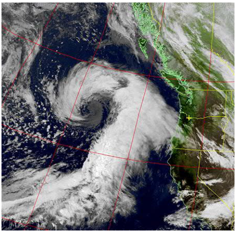

Figure 11. NOAA Satellite APT Signal Decoded Into an Image.

Source: http://www.stargazing.net/david/NOAA/

4.3 Commercial Satellite Data Providers

The evolution of New Space has created opportunities for new business models with commercialization potential (Alén Space 2019). New Space has led to many industries to participate in space-related activities. The business portfolio of these companies involves building and launching satellites for its customers. Companies also engage in receiving the satellite data, process and provide the data to its customers. Using satellite data, the companies are involved with creating new business opportunities and serve customers with commercial products. Some of the commercially available satellite data providers are ICEYE, Planet Labs, et cetera.

ICEYE is a world leader in Synthetic Aperture Radar (SAR) miniaturization technology. It offers timely and reliable earth observation data through SAR technology. SAR instruments capture high-resolution images regardless of weather conditions providing data every square meter. ICEYE launched an ICEYE-X2 satellite with a SAR instrument as a payload. ICEYE-X2 captures the radar image with a resolution of three meters covering several kilometers of land. **Figure 12** illustrates a high-resolution satellite image of the mountains in Spain. (ICEYE 2018.)

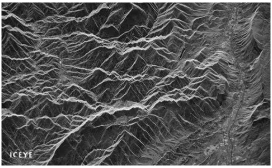

Figure 12. Mountain in Spain Captured Using the ICEYE SAR Instrument.

Source: https://www.iceye.com/satellite-data

ICEYE offers commercial products providing high-resolution information such as monitoring ports, ships, and oil tankers, capturing agricultural lands, oil pipelines, mining regions, and other areas using satellite data. **Figure 13** shows SAR image illustrating industrial port traffic, the difference in sea state, large vessels, Navy museum, Changi airport, vessels with visible wake and jetty with docked vessel respectively.

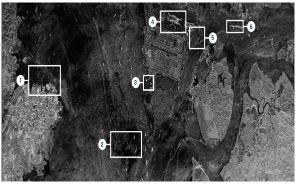

Figure 13. High Resolution SAR Image on Singapore Strait.

Source: https://www.iceye.com/

Similarly, Planet Labs provide high-resolution commercial satellite data through its constellation of satellites. The different constellations of satellites of Planet Labs are PlanetScope, SkySat, and RapidEye. According to Safyan (2015), Planet Labs has the largest fleet of nanosatellites in the world capturing the entire landmass of the earth every day. Due to the smaller size, simple design and construction of CubeSats, Planet Labs launched and operates more than hundreds of CubeSats. It provides satellite data with high spatial resolutions in the range of three-meters, five-meters, and 72 centimeters. The datasets are used for applications such as agriculture, maritime, forests and land use, emergency and disaster management, energy sector et cetera. (Safyan 2015.) **Figure 14** shows the 72-centimeter spatial resolution satellite image from SkySat. It illustrates the port activities and shipping movements of large container ships, tankers in Rotterdam, Netherlands. Such high-resolution data on earth provided commercially by the Planet Labs are used for a wide range of applications.

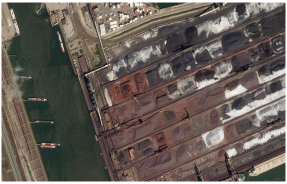

Figure 14. SkySat 72-Centimeter Resolution Image.

Source: https://www.planet.com/products/planet-imagery/

5. CUBESATS

Numerous innovations have evolved in space industry from the beginning of the space age until the present generation. At the beginning of the space age, governmental organizations and big companies of the space industry built and launched satellites for different applications. Overall, more than thousands of satellites have been launched so far. A comprehensive team of expertise built highly complex satellite models during the conventional space age. NASA, Russian Federal Space Agency Roscosmos and ESA are the very few organizations involved in designing and launching such complex satellite models. There was a notable increase in the mass of the satellite launched. Hence, conventional manufacturers took several measures to reduce the mass of satellites but significant problems persisted during the development stage. In the New Space era, major innovations and developments in technology and space industry in general helped in reducing the mass of satellites to a greater extent. Miniaturization technology is one of the key factors for innovation of CubeSats with COTS components. These components are affordable, quickly available and consume low power. (Poghosyan & Golkar 2016: 59–60.) Thus, the differences between CubeSats over large conventional satellites, classification of satellites based on mass, classification of CubeSats based on volume, CubeSat design and various qualification testing that CubeSats undergo before launching will be discussed in this chapter.

CubeSats are small, low cost, efficient and easy to be built using COTS components for space research purposes. ISS or rockets deploy the CubeSats into space. Rockets carrying satellites use CubeSats as secondary payloads along with primary satellites in big satellite launch missions. Large conventional satellites generally weigh in tonnes, hence damage of any subsystem in a high budget satellite will end up in the failure of the complete space mission. It is not feasible to build and relaunch such large conventional satellites. (Shah & Arshad 2013.) CubeSats are built at relatively low costs based on CubeSat Design Specifications (CDS). CDS includes ¨*information regarding nominal dimensions of the standard, dimensional tolerances, acceptable materials, reference coordinate system, and other* *general information¨* (The CubeSat Program 2014). Hence, some functionalities and operations are limited when compared to conventional satellites. Besides, the imaging capabilities of CubeSats are relatively low when compared to conventional satellites. It requires multiple numbers of CubeSats to cover the field of view captured by a single conventional satellite. (Shah & Arshad 2013.)

In 1999, Stanford and California Polytechnic State Universities proposed the concept of CubeSats. CubeSat is a cube-shaped structure of 10 cm each in cubic units called as a 1U CubeSat. The 1U CubeSat weighs a little more than a kilogram per unit approximately 1.33 kg. A standard 1U CubeSat structure can serve as a single satellite with a minimum payload. For higher payloads, it is possible to consolidate multiple 1U CubeSat into a single large CubeSat. A combination of three standard 1U CubeSat consolidates into three volume of CubeSat known as a 3U CubeSat. Standardization for CubeSats with volumes of 6U, 12U or even higher volumes improves the performance abilities further. It also paved the way for satellite launch vehicle operators to follow the most common deployment system for CubeSats. Satellites in conventional space were classified based on their mass while CubeSats were classified based on the number of volumes. **Table 2** shows the classification of satellites based on the mass while **Figure 15** shows the classification of CubeSats based on the volume. Aluminum was the main source of material used in manufacturing CubeSats in the beginning. The recent innovation of 3D printing technology enhanced developers to build CubeSats using 3D printing as well. (Poghosyan et al. 2016: 59–63.)

Table 2. Classification of Satellites Based on Mass in Kilograms.

Class Name	Kilograms (Kg)
Femto	0.01-0.1
Pico	0.09-1
Nano	1.1-10
Micro	11-200
Mini	201-600
Small	601-1200
Medium	1201-2500
Intermediate	2501-4200
Large	4201-5400

Heavy	5401-7000
Extra Heavy	>7001

Source: http://www.parabolicarc.com/2017/03/06/payloads-launched-2016/

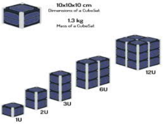

Figure 15. Classification of CubeSats Based on Volume.

Source: https://alen.space/basic-guide-nanosatellites/

5.1 CubeSat Design

The construction of a CubeSat includes designing of the structure, subsystems and payload. Several standard 1U CubeSat structures consolidate into composite CubeSats, allowing to set the maximum size and weight of the subsystems depending on the mission goal. The subsystems include various components for the operations of satellite such as "Attitude Determination and Control System (ADCS), On-Board Computer (OBC), Electric Power Supply (EPS), Communication System (COMM), Command and Data Handling (C&DH), and additional payloads such as sensors and actuators.¨ (Shah et al. 2013.)

5.1.1 Structure

The standard structure of a 1U CubeSat includes rails, beams and panels as shown in **Figure 16**. Rails act as a pillar on four sides of the CubeSats parallel to each other. Beams are used to support and interconnect the rails together forming a cube-shaped structure. Payloads and subsystems are fixed into the CubeSat after designing the structure. CubeSats consists of six panels in total, one on each side forming the exterior design of the CubeSat. Based on the volume of the CubeSat, the structure varies. (Davoli et al. 2019: 3–4.)

Figure 16. 1U CubeSat Structure Showing Rails & Beams.

Source: https://www.isispace.nl/product/1-unit-cubesat-structure/

5.1.2 Propulsion and De-Orbit

The propulsion system is the primary device used for moving the CubeSat in the space. It is used to stabilize or destabilize the CubeSat in the orbit while the de-orbit system is used when the operation of the CubeSat mission ends by de-orbiting satellite away from orbit to avoid space debris. Propulsion and the de-orbit subsystem helps in augmenting the capacity of the CubeSat performance by controlling the position, changing the orbit and de-orbiting. Most of the CubeSats do not have any of these stabilizing or changing the CubeSat orbit system functionalities due to the limited size, capacity and energy of the CubeSat subsystem. Only a limited number of CubeSats have carried this subsystem, which uses different thrusters and an electric sail. Estonian satellite Estcube-1, Finnish student satellite Aalto-1 are few among those CubeSats that carried deorbiting device plasma brake developed by Finnish Meteorological Institute (FMI). Foresail-1 CubeSat by Aalto University will be launched in late 2019 with one payload being the plasma brake from FMI to demonstrate sustainable space mission. Generally, there are three classifications of propulsion systems namely chemical, electric and propellant-less propulsion systems. Of all the three, the propellant-less system does not produce any thrust thus reducing the complications and dimensions of the CubeSat. **Figure 17** illustrates an example of a propulsion system used in CubeSat. (Poghosyan et al. 2016: 63.)

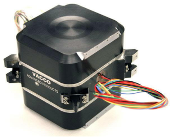

Figure 17. Propulsion System.

Source: https://www.cubesat-propulsion.com/reaction-control-propulsion-module/

5.1.3 Attitude Determination & Control System (ADCS)

Based on the objective of the CubeSat mission, attitude determination and control subsystem controls the CubeSat to adjust, align, and position in the earth's orbit. The sensing instruments present in the subsystem defines the adjustment of the CubeSat while manages to align and position in any direction with the help of actuators. Star trackers, Sun sensors, Earth sensors, and magnetometers used to determine the attitude of CubeSat while actuators such as reaction wheels, magnetorquers, and thrusters maintain and position the CubeSat in the desired direction (Poghosyan et al. 2016: 64). ADC can be classified into active and passive systems where the passive system orientates the CubeSat typically using the space conditions. It consists of magnets, which point one side of the satellite towards the magnetic pole and oscillate the satellite in the geomagnetic field. Active systems use complex systems for orienting the satellite, which consumes an additional increase in the energy. **Figure 18** shows the magnetorquers board used in ADC subsystem. (Davoli et al. 2019: 4.)

Figure 18. Magnetorquer Board.

Source: https://www.isispace.nl/product/isis-magnetorquer-board/

5.1.4 Command & Data Handling (C&DH)

Command and Data Handling subsystem operations collect, verify, and assign commands to other subsystems. Additionally, it accumulates and saves information about CubeSat mission objectives and onboard utilization. The subsystem consists of additional capabilities such as tracking the onboard computer wellness, ensuring safety between connections and timekeeping of the CubeSat. The development of the COTS microcontrollers and processors provide additional functionalities with greater accomplishments. It serves with higher susceptibility to solar radiation as well. The C&DH subsystem consists of highly valuable and powerful microcontrollers and Advanced RISC Machines (ARM) architectures. Usually, onboard computer storage data is relatively low in kilobytes or megabytes. Based on the objectives of the CubeSat mission, it is possible to upgrade using commercial flash memory technologies to gigabyte levels. The storage of onboard computer does not limit the functions of the C&DH subsystem. The main limiting factor of this subsystem is the downlink capabilities. The suitable solution for the limitations of the C&DH subsystem is to improve the downlink capabilities rather than onboard computer storage. **Figure 19** illustrates the example of an onboard computer used in CubeSat. (Poghosyan et al. 2016: 64.)

Figure 19. Onboard Computer.

Source: https://www.isispace.nl/product/cubesat-command-data-bundle/

5.1.5 Power Supply

The two power sources that supply power to the onboard computer and other subsystems of a CubeSat are solar panels and batteries. The outer structure of the CubeSats consists of solar panels made from Gallium Arsenide (GaAs) or silicon as shown in **Figure 20**. GaAs is the most commonly used type of solar panel for CubeSats. It is highly expensive when compared with silicon solar cells while providing a higher transformation of the rate of solar energy. Most of the CubeSats launched revolve the earth in the sun-synchronous orbit. Hence, a CubeSat generates power using solar panels, which is used for mission operations. Due to the smaller size of the CubeSat, solar panels generate a very low power and are attached to the CubeSat outer layer. Additional power for satellite operations was required when CubeSats do not get exposure to sunlight. Hence, batteries replace solar panels for storing additional power and helps in satellite operations when solar panels do not receive any sunlight. Thus, non-rechargeable batteries provide power during the elliptical phase of the satellite. The development of rechargeable batteries such as lithium-ion replaces non-rechargeable batteries due to energy storage capabilities. (Davoli et al. 2019: 4.)

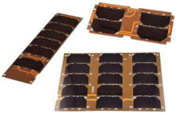

Figure 20. CubeSat Solar Panels

Source: https://www.isispace.nl/product/isis-cubesat-solar-panels/

5.1.6 Communication

A CubeSat consists of antennas for receiving and transmitting purposes. It receives control commands for the CubeSat and transfers it to the onboard computer while transmitting the telemetry data and payload data to the ground. It consists of the transceiver and deployable antennas for data uplink and downlink functions. Most of the onboard computer power consumption takes place when the satellite is in the line of sight to the ground station consuming more than 50% of the power. The power consumption of the satellite occurs during the function of a downlink from satellite to the ground station. Due to variation in the availability of the communication link between the satellite and the ground station during each pass, there are limitations in establishing the link with the ground station for a longer time. **Figure 21** illustrates the antenna system used in CubeSats. (Davoli et al. 2019: 4–5.)

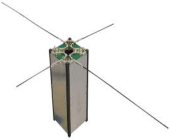

Figure 21. CubeSat Antenna System.

Source: https://www.isispace.nl/product/dipole-antenna-system/

5.1.7 Deployers

Most of the big satellite launch missions include CubeSats as secondary payloads. A deployer is a tool used for putting the satellites into the orbit from the rocket as shown in **Figure 22**. It acts as a protective medium for the satellites during the launch of the rocket and deploys a satellite into space when the rocket reaches the time for deployment. One of the innovations of the California Polytechnic State Universities is a CubeSat deployer called Poly Picosatellite Orbital Deployer (P-POD) (http://www.cubesat.org/). It is a CubeSat ejecting device made of aluminum in the form of a box. It consists of openings for the CubeSat to be thrown into space using a non-explosive release mechanism. Due to the openings in the CubeSat deployer, it minimizes the shock to both the rocket and CubeSat. It also protects all the essential individual components in the launch vehicle from any disturbances. Thus, CubeSat deployers ensure safety to the CubeSats, increasing the access to space for CubeSats. It provides secure deployment of each individual CubeSats carried by a rocket. (Davoli et al. 2019: 4–5.)

Figure 22. CubeSat Deployer.

Source:https://commons.wikimedia.org/wiki/File:Poly_Picosatellite_Orbital_Deployer_-_post_deployement.jpg

5.2 CubeSat Qualification Testing

Qualification testing involves CubeSat to undergo different tests to ensure CubeSat design to be acceptable and for efficient functioning in the space environment. It is carried out after manually testing the working conditions of each subsystem assembled earlier. It will ensure if CubeSat will withstand during the deployment phase. The CubeSats will undergo the following tests. (Debes et al. 5.)

1. Vibration testing.
2. Thermal testing.

5.2.1 Vibration Testing

After testing each hardware functionality and integration, the qualification testing takes place. In the first phase of the qualification testing, CubeSats will undergo random vibration testing. P-Pod or Test-Pod is a device, which creates random vibrations. An object placed inside the P-Pod experiences vibrations randomly and from all three axes. Based on the results obtained, comparison with the base profile analysis is made to figure out the damages or broken parts of the CubeSat. Thus, the testing will ensure the capability of CubeSat to withstand any disturbances and agitations. (Debes et al. 5.)

5.2.2 Thermal Testing

After the vibration test, a CubeSat will undergo thermal vacuum testing. The testing will ensure whether a CubeSat will operate in space and does not overheat during the launch. CubeSats are placed in a vacuum chamber at different temperature cycles for an hour. The testing undergoes a standard temperature cycle range of minus 10° Celsius to plus 40° Celsius. After each temperature cycle, CubeSats undergo a functional verification test. In rare cases, additional qualification testing such as shock and acoustic testing is carried out.

Modifications after testing will not ensure the proper functioning of the CubeSat. In case of any modifications, it undergoes qualification testing again. (Debes et al. 5.)

6. GROUND STATION SCHEMES

According to NASA (2014), a satellite is an object revolving the earth in an orbit that helps in studying and understanding the nature of the earth and space. The satellites that are orbiting and facing the earth helps in monitoring and providing various information on the earth such as clouds, water bodies, land and ice. It is used to monitor environmental impacts such as volcano eruptions, windstorms, forest fires and other applications such as measuring different gases in the atmosphere. Satellites facing the space helps in providing information such as rays emitted from the sun, exploring asteroids, comets and history of stars. Also, they are used for exploring other planets as well. The information or the data from the satellite is received by the operators on the ground. The receiver and all other essential receiving components equipped together to function as a ground station receiving system. Therefore, an efficient ground station system is required to receive the information and control the satellite effectively. (NASA 2014.)

The primary goal of the ground control station is to communicate with the space crafts and satellites i.e. sending control commands to the spacecraft or satellites and receiving information back. They are the primary source of interaction with the satellites. The Russian Federal Space Agency Roscosmos had its own ground control stations in function even before the launch of Sputnik 1, the first satellite launched to space in 1957. Zak (2018) in his analysis stated that, during that time, for the Russian Federal Space Agency Roscosmos, constructing control stations that give commands to the missiles and observation stations to be built around the missiles' target region was challenging. The implementation of such a huge network of ground control stations and observation stations by the government in the uninhabitable region was challenging and expensive. (Zak 2018.)

Sputnik 1 was a remarkable event in the development of space related activity, which also led to implementing ground stations to track and control projectiles launched into space, along with the rockets which launched them. Only a few of the ground stations were implemented and operated before this launch. During those days, ground station operators relied on other inputs from optical sensors, larger telescopes and radars, due to the technological inability to track the flight of the rocket that launched the satellites in real-time. These methods do not have higher range (typically 1700 km) to track the satellite, but were able to track satellite at a distance close to several hundred kilometers. Due to the limitations of the ground based tracking systems, most of the ground station controllers had to rely on the telemetry data from a Tral radio telemetry system (Zak, 2018) to verify that the satellite has indeed reached its orbit. But the Sputnik ground station was not equipped with a Tral radio telemetry system, which was not available those days making it the most basic of ground stations established. However, the Russian Federal Space Agency Roscosmos made a remarkable contribution to space technology and upgraded the ground station system in the coming years. Information about the limitations in the Sputnik satellite communication technology for the ground station was not shared. (Zak 2018.)

Electropeadia (2005) stated that the launch of the first satellite Sputnik 1 led to more opportunities to explore space technology for engineers. However, some technical problems needed to be resolved. Sputnik 1 satellite had four radio antennas for the transmitting function but without any receiver to communicate with the ground station. Electropeadia (2005) concluded that due to the lack of receiver, the satellite had no specific mission other than portraying the capability of Russia in space technology. (Electropeadia 2005.)

According to Harrison & Schwuttke (2000), numerous innovations have been made in the field of satellite technology after the launch of the Sputnik 1 satellite. It was enhanced to implement a more significant ground station by the operators. In the early stages, the operators used to control and monitor only one or two satellites from the ground stations. The ground station operations required a large team even for monitoring and controlling one or two satellites. After a few years, the demand for communication technology across the world was strongly growing which resulted in launching more satellites. Thus the complexity of operations increased in the ground station due to the monitoring of additional satellites at the same time. (Harrison et al. 2000.)

Harrison et al. (2000) claim that after launching more number of satellites in the LEOs and geostationary orbits, demand for efficient and low-cost ground stations and demand for the number of operators increased rapidly. Hence, one possible way to minimize the cost is from the operation of the ground station. He proposed a new way of reducing the cost by visually monitoring data. The visual data monitoring approach is a simple and efficient way of operations for the satellite operators in the ground station for data monitoring and controlling more satellites at the same time. Building such data monitoring and controlling systems to different earth orbit satellites were easily available. From this standpoint, the author conveys effective ways of handling ground station operations. However, low-cost hardware components for visual ground stations were far from reality. (Harrison et al. 2000.)

Antwi (2001) did his work on latest and trending space-related technologies. He stated that the most delicate part of satellite communication is the ground station. When there is a higher sensitivity in the ground station, the communication link that exists between the ground and the satellite is higher, while the communication link is lower when the sensitivity of the ground station is low. For such design and implementation of a highly sensitive ground station to enable a good communication link between satellite and ground, suitable solutions or alternatives have to be implemented. Hence, replacing the existing hardware of the ground station with software defined radio (SDR) receivers (E-Systems Inc. 1984) can provide a highly portable, low cost and flexible solution enabling a highly sensitive ground station with a good communication link. (Antwi 2001.)

Dascal, Dolea, Cristea & Palade (2013) mention that new concepts are being developed in the ground segment sector in recent years. From the understanding of Electropaedia (2005) and Harrison et al. (2000) perspectives, the specifications of hardware components are tightened and lose flexibility in the overall conventional ground station. While Dascal et al. (2013) claim that SDR techniques provide a higher level of flexibility, replacing traditional ground stations into a low cost and efficient ground station for satellite communication. (Dascal et al. 2013.)

A review of the different data reception and transmission operations of ground stations implemented by various universities to communicate with the LEO satellites for various applications are discussed in the following section.

Wickramanayake (2007: 1–2) implemented a student ground station for Luleå University of Technology that operates mainly in the Very High Frequency (VHF) and Ultra High Frequency (UHF) bands. Uplink and downlink performance analysis on the LEO satellites such as the Tokyo University CubeSat XI-IV, CUTE-1 and XI-V were carried out. The ground station is unique and highly influential due to its geographic location having more polar satellite passes. The population around the ground station is very limited thereby enabling very few chances for interference by electromagnetic waves or nearby buildings. Until the launch of Luleå's own CubeSat, experiments and operations of the ground station were carried out on other CubeSats at a higher data downloading and decoding rate. The high gain antennas in the VHF and UHF bands enables the ground station to send telecommand to the satellites. Thus, the higher data downloading rate and sending telecommand to satellite enables a fully functional ground station. (Wickramanayake 2007: 1–2.)

The ground stations implemented by Luleå University is focused mainly on communicating CubeSats due to their characteristics and frequency band. CubeSats made by universities weigh only a few kilograms and are operated from the ground station in the VHF and UHF uplink and downlink frequencies. Compared to traditional satellites, CubeSats are small in size and easy to be built thereby reducing the cost of launching the satellite. CubeSat programs play a significant role in providing students with more openness to space, satellite construction and satellite communication creating opportunities for research and education purposes. (Wickramanayake 2007: 7–8.)

A comparison of the ground station systems used by different universities is made and the Luleå University of Technology ground station with the latest equipment is looked into more closely. The ground station consists of an antenna system that can communicate with the satellite in the VHF and UHF amateur radio bands. The block diagram of the ground station architecture similar to that of the Luleå University of Technology is shown in **Figure 23**. (Wickramanayake 2007: 35–43.)

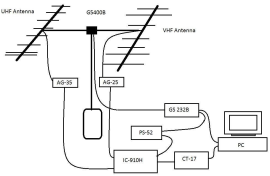

Figure 23. Block Diagram Similar to That of the Luleå Ground Station.

Source: (Wickramanayake 2007: 35).

The ground system consists of CUE DEE 15 X 144 and CUE DEE 17 X 432 antennas that are used to communicate with the satellite in VHF and UHF frequencies respectively. The antennas are connected to the ICOM IC-910H transceiver. The transceiver is connected to the computer using the ICOM CT-17 interface. The Yaesu 5400-B rotator between the antennas provides azimuth and elevation angle control based on the commands received from the computer through the GS-232B interface. Overall, the Luleå ground station setup consists of VHF and UHF antennas along with a traditional transceiver radio to transmit and receive the data from the satellite with suitable rotor controllers and interfaces. (Wickramanayake 2007: 1–43.)

The transceiver ICOM IC910-H does not serve the actual purpose and has its own advantage and disadvantages as well. The SDR receivers have more advantages when compared with the traditional ICOM transceiver models. The traditional receivers or transceivers use their components to sense the signal while SDR processes the digitally converted signal in a computer. Also, from Electropaedia (2005) and Harrison et al. (2000), compared to transceiver ICOM IC910-H, the overall performance of the ground station is improved using the SDR receiver increasing the flexibility in the overall system and reducing the complexity. (Electropaedia 2005.)

Wickramanayake (2007: 55–56) conducted experiments to analyze the overall performance of the ground station by calculating the preliminary link budget and overall data decoding ratio. The minimum power required for uplink and downlink performance gives the overall performance of the ground station. The information about the products obtained from the satellite was not shared, instead, the capacity of downloading the data was measured. The result shows that the downloading capacity of the ground station is double than that of the University of Tokyo station. Overall, the ground station has better uplink and downlink performance from the results of link budget calculation while no information is further provided on the satellite products obtained from CubeSats. (Wickramanayake 2007: 55–56.)

Rochester Institute of Technology developed a ground station to communicate with the satellites in the amateur radio band especially the FUNcube-1 CubeSat. FUNcube-1 project by the Rochester Institute of Technology aimed in making the students acquire knowledge in satellite applications and involve them in space research and innovations. The FUNcube-1 satellite helped students with tracking and receiving data from the satellite. Velayudhan (2017: 1) in her thesis developed a low-cost ground station with simple architecture to communicate with the FUNcube-1 CubeSat and other satellites, and post-process the data through Matlab and decoding it using certain decoding software. The main objective of the author was to explore the SDR in space related applications, as the space industry is becoming more popular in recent years after the innovation of small satellites. (Velayudhan 2017: 1–50.)

The author compared different ground stations that existed and proposed a simple low cost and portable ground station architecture for communicating with satellites in the VHF and UHF frequency band. Hence a handheld Yagi Uda antenna, low noise amplifier and Funcube SDR dongle was used. In the ground station, the conventional radio receiver was replaced with a new SDR receiver that connects the antenna and the computer. The SDR covers the frequency range in the amateur radio band. Due to several applications of SDR in terms of performance and flexibility, the conventional radio receiving technology was replaced by the new software based devices. The block diagram of the portable ground station architecture similar to that of the Rochester Institute of Technology is shown in **Figure 24**. (Velayudhan 2017: 32–50.)

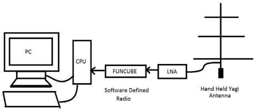

Figure 24. Funcube Architecture Similar to Rochester Institute of Technology Ground Station.

Source: (Velayudhan 2017: 35).

The ground station is used for tracking satellites such as FUNcube-1, NOAA and ISS using tracking software and receive data using the Funcube receiver dongle. The signals are then post-processed and decoded using certain decoding software to obtain the results. Major innovation and advancement in communication technology have led to the production of reliable equipment at much lower costs. The author focused mainly on the cost reduction of the ground station. Due to the existing reliable low cost products, implementation of the ground station has become easy and affordable. (Velayudhan 2017: 32–75.)

Though the low cost and portable components of the ground station have advantages, there are limitations in the SDR selected. The Funcube dongle SDR is not capable to perform additional functions. The SDR can only receive the satellite data while transmitting capabilities such as sending control commands from the ground station to the satellite for in-orbit operations are not possible with the Funcube dongle. There are SDR transceivers (Peter Hoeher and Helmuth Lang, 1988) available at an affordable price that can perform various functions and are used for both receiving and transmitting capabilities. From the overall aspects, a SDR transceiver that is affordable and reliable would have enhanced the ground station performance. (Velayudhan 2017: 32–75.)

The data products obtained by the Rochester Institute of Technology ground station consist of received satellite data decoded into images using WXToImg decoding software. The data from the NOAA satellite image consists of the atmospheric composition such as high and low clouds, latitudes, longitudes and ground station location. **Figure 25** shows the NOAA 18 satellite data received from the ground station and its decoded audio file as an image using WXToImg. (Velayudhan 2017: 61–63.)

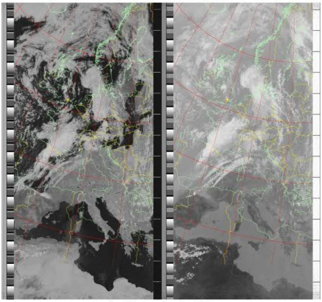

Figure 25. Image Decoded by the Funcube Author Using WXToImg.

Source: (Velayudhan 2017: 61).

The received data from the satellite is not only decoded using WXToImg. The Funcube author has decoded the audio data received from the satellite using APT decoder and Matlab software as well. The NOAA satellite data consists of the atmospheric composition showing weather-related data. More information on the other products obtained besides weather-related data from the satellites such as telemetry decoding is not provided. Instead, focus is given on various decoding software such as the APT decoder and Matlab that are used to convert the satellite audio files into images. **Figure 26** shows the image that is processed and decoded using the APT decoder instead of WXToImg decoding software. (Velayudhan 2017: 61–63.)

Figure 26. Image Decoded by the Funcube Author Using APT Decoder.

Source: (Velayudhan 2017: 63).

Norwegian University of Science and Technology (NTNU) has developed a ground station that can communicate with the satellites in the frequency range of VHF and UHF frequency band (Karlsen 2017:1). Autonomous Marine Operations and Systems (AMOS) is one of the key research projects of the NTNU that focuses on launching small satellites for operations and surveillance in the arctic region. Karlsen (2017: 1) claims that coverage of the small CubeSats is better than a geostationary satellite in the northern hemisphere. Hence, AMOS-Sat is a program developed by the NTNU which aims to launch a number of CubeSats into space for the automation of the Norwegian marine and ocean operations. (Karlsen 2017: 1.)

It is challenging for the single ground station to operate efficiently when the number of small satellite launches increases. The renting of ground station costs more and it is complicated to implement additional ground stations. Since no satellites were launched at that time by NTNU when they built their ground station, it will help in assisting other institutions and third parties with their CubeSat related research. This is done by having an open ground station network. With an open ground station network, the exchange of more satellite data is possible between the ground stations and can help to integrate and provide access to the other ground stations as well. The concept of developing an open network ground station was started early in 2006 by Global Educational Network for Satellite Operations (GENSO). By 2017, other concepts of open network ground stations were established such as ¨Satellite Networked Open Ground Station (SatNOGS), Distributed Ground Station Network (DGSN), ThumbNet and GENSO 2.0¨. (Karlsen 2017: 1–2.)

After a comparison of the existing ground stations available, the NTNU implemented a ground station system to communicate with the satellite in the VHF and UHF frequency band. The advantage of the ground system is the implementation of SDR transceivers instead of traditional radio receivers. The SDR implemented in the ground station for NTNU has the capabilities of both uplink and downlink performance. The ground system is designed to communicate with the future AMOS-Sat that is to be launched. Until the successful launch of their own smaller satellites, the ground station will communicate with other satellites and support other satellite missions and third parties. The satellites developed with higher payloads will communicate with the ground station in the UHF and low SHF bands. The ground station similar to that of the NTNU is shown in **Figure 27** as follows. (Karlsen 2017: 2–10.)

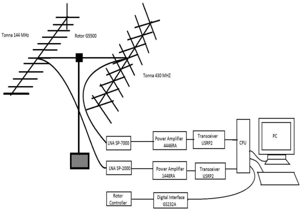

Figure 27. Block Diagram of a Ground Station Similar to the NTNU Station.

Source: (Karlsen 2017: 10).

The NTNU Ground station consists of the two USRP SDRs used for both the VHF antenna and the UHF antenna separately. The antenna system consists of two crossed Yagi antenna that operates in the VHF and UHF bands. The antenna is supported with a rotor G5500 to track the satellite at a desired azimuth and elevation angle. The two USRP receivers have very little output power in the range of 1mW to 100mW. Hence two power amplifiers are used to amplify the output power of the SDR. Thus, by obtaining the desired output power, better uplink and downlink performance is carried out. The low noise amplifiers (LNAs) are connected to the VHF and UHF antennas for improved signal and minimum noise. (Karlsen 2017: 9–12.)

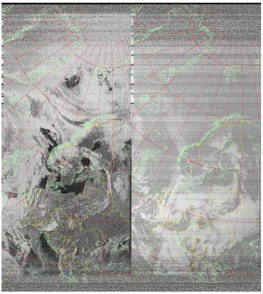

Figure 28. Satellite Image Decoded by NTNU Team Using WXToImg.

Source: (Karlsen 2017: 35).

The calculation of the uplink and downlink link budget for both the VHF and UHF antennas are conducted. The ground station was able to track and receive some of the satellite data such as NOAA satellite images. **Figure 28** illustrates the NOAA 15 satellite data received and the decoded audio file as an image using the WXToImg decoding software. (Karlsen 2017: 35–38.)

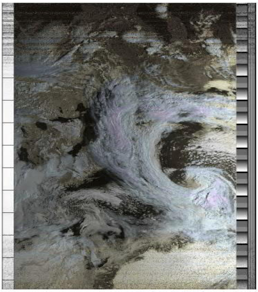

Figure 29. NOAA 15 Image Collected From a Different Ground Station Using SatNOGS.

Source: (Karlsen 2017: 35).

The open network ground station is capable of gathering data from other ground stations as well. Through SatNOGS satellite data collected from a different ground station can be transferred to the NTNU ground station through the network. The data is then processed and decoded into an image as shown in **Figure 29**. (Karlsen 2017: 35–38.)

From the above perspectives, the NTNU ground station presented consists of a more advanced and sophisticated system increasing the overall cost. Implementing a low cost ground station with COTS components can however produce results similar to an advanced ground station system. For that, VHF and UHF yagi antennas used in the NTNU ground station can be replaced with low costs turnstile antennas. Using these omnidirectional antennas does not need the use of rotators and controllers. Thus, it reduces the costs, complexity and improves the flexibility of the ground station. There is no information further provided by NTNU team on decoding telemetry data from different satellites, other open-source satellite data available and the processing or analysis.

Therefore, to implement a low cost ground station, the implementation of a SDR transceiver in ground stations is very essential in the present satellite communication systems. Using a high-quality affordable software radio based transceiver system such as the HackRf One (https://greatscottgadgets.com/hackrf/one/), the overall performance of the ground station can be improved. The VHF and UHF Winkler turnstile antennas will be suitable candidates to perform tasks similar to the yagi antennas in VHF and UHF bands. Flexibility of the overall system is increased by reducing the complexity in ground stations and enabling more opportunities for future innovation and development.

7. KVARKENSAT GROUND STATION

The primary goal of ground stations is to communicate with spacecraft and satellites. They are the main source of interaction with the satellite to transmit control commands to the satellites and receive back satellite data. Hence, the ground station plays an important role in any satellite related operations. A functional ground station consists of hardware components such as antennas, low-noise amplifiers, receivers, computer and essential software to track the satellite, decode telemetry data, view the waterfall of the received signal et cetera. The main purpose of this thesis is to implement an operational ground station at the University of Vaasa. The following chapter will provide details about the implemented ground station – its specifications, software platform and the hardware components used.

7.1 Ground Station Specifications

Table 3 presents the basic pieces of information about the implemented ground station at the University of Vaasa.

Table 3. Ground Station Specifications.

Ground Station Name	Kvarken Ground Station
University	University of Vaasa
City/Country	Vaasa/Finland
Altitude	30 meter
Latitude and Longitude	63°104 N and 21°593 E
Operating Frequencies	137- 152 MHz and 435 MHz
Antenna	Winkler turnstile VHA and UHF antennas
Preamplifier	RTLSDR Blog Wideband LNA
Bandstop filter	RTLSDR bandstop filter

Cables	RG-58 cable
Transceiver	HackRf One
PC	HP, Intel i5, 1.80GHz, 16 GB RAM, 60 TB HDD and raspberry Pi 3 Model B+
Operating System	Debian, Raspbian, Windows 10

7.2 Ground Station Software

To understand the concepts of the ground station system practically, it is good to implement a simple receiving unit tracking open weather satellites such as the NOAA 15, NOAA 18 and NOAA 19. A handheld VHF antenna or V-dipole antenna is connected to the SDR through a small three-meter coaxial cable. The SDR receiver from the antenna is connected directly to the computer. This setup is capable of functioning as a ground station with reception capabilities for weather satellites only. The ground station setup apart from hardware requires additional software for tracking the weather satellite pass, visualizing the waterfall of the signal and weather image decoders are presented in the following.

7.2.1 Orbitron

A satellite tracking system is a software used by the ground station operators, radio amateurs, meteorological experts and astronomers for tracking satellites efficiently. One such satellite tracking system used by different users is Orbitron as shown in **Figure 30**. The tracking system provides information about the satellite orbit at any moment both in real-time and satellite cross over time. It uses a two-line element (TLE) consisting of encoded data of the orbital parameters of the satellite and provides information on the satellite pass over a particular region.

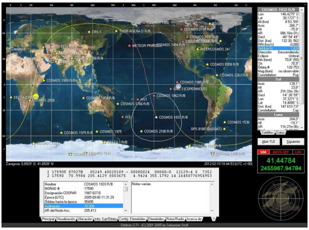

Figure 30. Orbitron Software Showing the Satellite Orbit.

Source: https://imag.malavida.com/mvimgbig/download-fs/orbitron-10200-1.jpg

The software is free to use, displaying the world map and the satellite's orbit in real-time. In the simulation phase, simulation of the satellite pass shows the orbit of the satellite over a region even before the actual pass of the satellite. The software comes with additional functionality such as Dynamic Data Exchange (DDE) support for adjusting the Doppler shift, communicates with the rotators to control the azimuth and elevation angle of the antenna along with the satellite. There are also other satellite tracking systems and websites such as n2yo.com, Nova for windows et cetera. These tracking systems provide information on the satellite orbit, azimuth and elevation angle, uplink and downlink frequencies, beacon frequency, latitude, longitude, altitude et cetera.

7.2.2 SDR Sharp

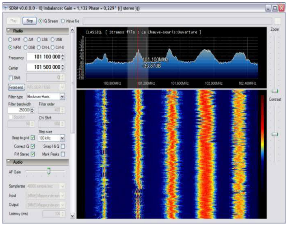

Figure 31. SDR Sharp Displaying Waterfall of an FM Signal.

Source: https://www.pe0sat.vgnet.nl/sdr/sdr-software/sdrsharp/

SDR Sharp is a simple digital signal processing application used for SDR. It provides hands-on experience in digital signal processing (DSP) techniques visualizing information on the received signal through the waterfall chart as shown in **Figure 31**. It is compatible with most of the SDR receivers, such as RTLSDR (https://www.rtl-sdr.com/), AirSpy (https://www.rtl-sdr.com/), Funcube Dongle (http://www.funcubedongle.com/), Hackrf One et cetera. A traditional radio receiver provides information only about the tuned in frequency while SDR uses communication software such as SDR Sharp, Ham Radio

Deluxe (HRD) and High Definition Software Defined Radio (HDSDR) to display information on the received signal. The software displays the waterfall chart of the received signal. It supports various SDRs and connects a satellite tracking application such as the Orbitron, Gpredict along with the SDR Sharp. (Amateur Radio – PEØSAT 2015.)

7.2.3 WxToImg

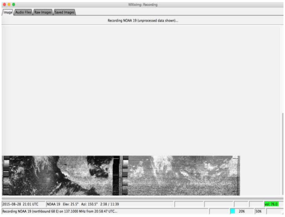

Figure 32. WxToImg Decoding Weather Satellite into Image.

Source: http://www.planetary.org/blogs/jason-davis/2015/20150921-how-to-download-weather.html

WxToImg is a software used for recording, decoding, and editing weather satellite data. The application records the audio signal received from the satellite in the form of an APT file, and converts them into an image as shown in **Figure 32**. It provides users with image processing techniques and supports a wide range of picture enhancements, map overlays, 3D images, temperature display et cetera. The application can be installed in any operating system and available free from the internet. There are many software applications available for free to decode the APT signal received from the weather satellites such as the APT decoder, Wxsat and Matlab.

7.2.4 SatNOGS

The simple receiving unit suggested above will act as a ground station only for receiving weather satellite data. An enhanced or upgraded ground station is needed to track and obtain other satellite data apart from weather satellites. It is possible to obtain various other open satellite payloads and telemetry data using the enhanced or upgraded ground station. The ground station will be a low cost and flexible ground station with less complexity that can operate similarly to that of an advanced ground station. Using a simple receiving unit, there are limitations in tracking the number of possible satellites. In addition, the process of tracking the satellite, visualizing the spectrum of the received signal and decoding the weather satellite data requires manual operation for each observation. Through enhanced setup, it is possible to track different satellites and operate the ground station autonomously to decode satellite data.

An enhanced setup of a ground station is implemented in the University of Vaasa premises based on a comparison made of other ground stations and the SatNOGS documentation. The ground station operates autonomously through the platform provided by the SatNOGS and decodes the satellite data. SatNOGS is a Satellite Network of Ground Stations that works on a community-based approach. Radio amateurs, universities or individuals implemented ground stations based on SatNOGS for a deeper understanding of satellite communication. It is an open-source platform consisting of multiple ground stations accessed through a web page by different users in the network. The platform consists of four segments, namely satellites, ground stations, global management network and users as shown in **Figure 33**. The major part of the SatNOGS platform is the global management network, which integrates different ground stations from various locations through the web site. Different satellites are tracked and possible data from the satellites are decoded by each ground station autonomously. Through the website, the user can access the satellite data received and share the data with other users in the network.

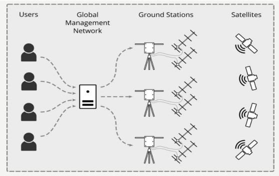

Figure 33. Segments of SatNOGS.

Source: https://wiki.satnogs.org/Main_Page

7.3 Ground Station Hardware

The ground station hardware consists of various units implemented based on the block diagram of a SatNOGS ground station as shown in **Figure 34**. The ground stations can be either an enhanced setup with omnidirectional antennas or a more sophisticated system with rotator controllers using directional antennas, which depends entirely on the user.

The main ideology behind this thesis is to implement a low-cost efficient model with high flexibility suitable to track available open satellites, decode possible payload and telemetry data, analyze data obtained from other open-source platforms and perform ground station operations. Using directional antennas with rotator controller increases the costs and complexity of the system. It requires higher maintenance and reduces the flexibility of the ground station. Hence, the enhanced setup will be a suitable model for achieving such goals. The enhanced setup includes omnidirectional antennas with the filters, LNA and receiver connected to a raspberry pi (https://www.raspberrypi.org/) device. The components are interconnected using low loss cables. The raspberry pi runs the SatNOGS client that connects the ground station to the network.

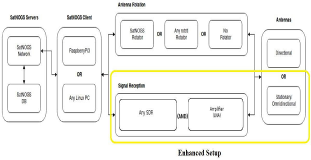

Figure 34. Block Diagram of a SatNOGS Ground Station.

Source: https://wiki.satnogs.org/Build

7.3.1 Tower & Antennas

Antennas implemented consist of conductors in a certain pattern connected to the receiving or transmitting circuit. The antenna radiates the electric currents received from the transmitter in the form of electromagnetic waves to space. The receiver antenna intercepts electromagnetic waves from space and sends them to the receiver in the form of electric currents. (Antenna (radio) 2019.)

Figure 35. Winkler Turnstile VHF and UHF Antennas at the University of Vaasa Premises.

The antenna tower implemented consists of a three-meter high aluminum tower mounted with VHF and UHF Winkler turnstile antennas as shown in **Figure 35**. The Winkler turnstile antennas operates in the VHF frequency band from 135 MHz to 152 MHz and UHF frequency band at 435 MHz. The VHF Winkler turnstile antenna consists of cross dipoles used for the reception of LEO satellite data and weather satellite data with gain up to 4 dB. The UHF Winkler turnstile antenna consists of cross dipoles used for the reception of satellite data and transmitting commands for smaller CubeSats such as the KitSat (https://kitsat.fi/).

7.3.2 Transceivers

Figure 36. Hackrf One Software Defined Radio Transceiver.

Source: https://en.wikipedia.org/wiki/HackRF_One

Radio communication systems comes in different shapes and sizes from highly sophisticated traditional radio to a small advanced multi-mode SDR device. A traditional radio includes a radio communication system implemented using different hardware components used only for a certain task. For performing other tasks, it is necessary to replace traditional radio hardware components according to the requirements. On the other hand, SDR consists of essential hardware parts of the system replaced by the software using a desktop or an embedded system. SDR performs different tasks consisting of both transmitting and receiving units in one single device known as a transceiver. Most of the low-cost SDRs consist of only receiving capabilities while the Hackrf One is one such radio device, which acts as a transceiver that performs both transmitting and receiving capabilities on a frequency range of 1MHz to 6 GHz as shown in **Figure 36.** (Software-defined radio 2019.)

7.3.3 Preamplifiers

Figure 37. RTLSDR Blog Wideband Low Noise Amplifier.

Source: https://www.rtl-sdr.com/product/rtl-sdr-blog-wideband-lna-bias-tee-powered/

Most of the CubeSats transmits a low power signal while weather satellites transmit strong signals. Hence, using an amplifier the received low power signal from the CubeSats is amplified. In general, an amplifier is an electronic device not only capable of amplifying the low power input signal, but it amplifies the noise along with it. While a low noise amplifier was designed only to increase the power of the input signal and minimize the noise present in it, that is amplifying the signal without degrading the signal to noise ratio (SNR). Hence, a low noise amplifier (LNA) would be suitable as a general amplifier in the receiving unit for the amplification process. The RTLSDR Blog is a wideband mast preamplifier with a frequency range of 50 MHz to 4000 MHz as shown in **Figure 37**. It is suitable for many applications with a low noise figure of less than 1 dB and large signal rejection. In the implemented ground station, the LNA is connected close to the antenna using a weatherproof enclosure along with the FM bandstop filter. (Low-noise amplifier 2019.)

7.3.4 Bandstop Filter

Figure 38. Broadcast FM Block Filter.

Source: https://www.amazon.com/Broadcast-FM-Block-Filter-88/dp/B01LE9LRPM

A bandstop filter is used to reject the signals in the frequency modulation band. Any FM transmitters close to the ground station broadcast FM signals, which overload the SDR resulting in a weak signal from the nearest bands. Hence, the FM bandstop filter prevents the SDR from overloading of the FM signal and improve the performance of reception of other frequency band signals. **Figure 38** illustrates the bandstop filter used in the ground station. (RTL-SDR.com 2016.)

7.3.5 Cables

The ground station uses cables to interconnect the receiving or transmitting unit. Low loss coaxial cables with varying lengths combine the components from antenna until the transceiver. The ground station includes 50 ohms RG 58 low loss coaxial cable. The cable length of the receiving unit is six meters in total, which includes three-meter RG 58 cable from the LNA to the Hackrf One transceiver and three-meter USB extension cable from the Hackrf One to the raspberry pi.

7.3.6 Raspberry Pi

Figure 39. The Raspberry Pi Utilized in the Implemented Ground Station.

Raspberry Pi is a low-cost single board small sized computer running with Linux suitable for certain applications, such as home automation and smaller projects based on programming. The Hackrf One transceiver is connected to the raspberry pi using the three-meter USB extension cable to keep the receiver away enough from the raspberry pi and thus avoiding electrical interference. **Figure 39** illustrates the raspberry pi connected to the Hackrf One transceiver through the USB extension cable.

7.3.7 Monitor

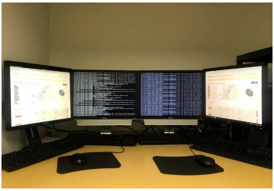

Figure 40. SatNOGS Station Web Page & SatNOGS Client Running on Raspberry Pi in the Implemented Ground Station at the University of Vaasa.

The monitor is used to visualize the operations ongoing in the ground station as shown in **figure 40.** Two monitors display the SatNOGS web page with possible satellite pass predictions for the ground station in the VHF and UHF bands. Other two monitors displays the SatNOGS client running every one minute to check for any new observation scheduled by the user for VHF and UHF separately. The client kicks off the observation and uploads the data to the network after the end of the satellite pass. Apart from pass predictions, the web page contains information about the ground station, details about each observation made and possible data obtained from it.

7.3.8 Hardware Connection

The following **Figure 41** illustrates the whole hardware connection of the ground station setup implemented in University of Vaasa running SatNOGS platform with the help of raspberry pi.

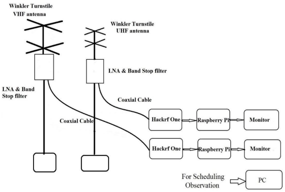

Figure 41. Hardware Connection of the Implemented Ground Station.

8. GROUND STATION IMPLEMENTATION RESULTS & SATELLITE DATA ANALYSIS

The KvarkenSat ground station setup is implemented after a review of other similar ground stations and available low cost COTS components. The ground station tracks various "open" satellites and CubeSats operating in the VHF and UHF range. The signals received from the satellites are processed using various platforms and relative tools to produce valuable data for various purposes. Since the ground station does not have a dedicated satellite on its own at present to focus on, other available open satellites and CubeSats were tracked. Most of the operations by the implemented ground station involved receiving weather satellite payloads and various CubeSat telemetry data. This chapter explains the telemetry data from different CubeSats received and open satellite payloads received using the SatNOGS platform. Besides, other satellite data from satellite data providers like Planet Labs and Copernicus were accessed and analyzed using several software platforms and tools.

8.1 Ground Station Implementation Results

This section presents the data received with the implemented ground station at the University of Vaasa.

8.1.1 Telemetry Data

The implemented ground station runs the SatNOGS client through a raspberry pi and thereby connects the station to the SatNOGS network. The user can log in to the SatNOGS network through the webpage and navigate to the ground station or other ground stations in the network. After navigating to the ground station webpage, the SatNOGS platform illustrates the tracks of all the satellites that pass through the ground station region and suggests pass predictions based on the type of ground station implemented as shown in

Figure 42. Upon the selection of any of the satellite passes, a new observation page opens in the browser.

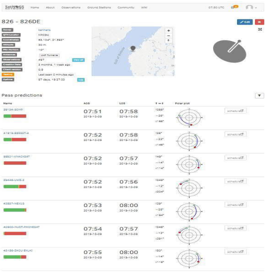

Figure 42. SatNOGS Platform Illustration with the Implemented Ground Station Suggesting Various Pass Predictions.

Source: https://satnogs.org/, https://network.satnogs.org/stations/826/

The new observation page consists of the satellite and its time of pass over the ground station, different signals and the mode of transmission. Some satellites have one or more signal to transmit, for example, UNISAT-6 uses only a FSK mode to transmit a telemetry beacon signal while an open satellite like the NOAA 18 uses payload beacon to transmit the payload data and a CW mode to transmit the telemetry signal to the ground station. Most of the CubeSats are not open satellites, hence the satellite's own ground station operator only has access to the payloads while other ground station operators can access the satellite beacon. The ground station at the University of Vaasa communicates with different satellite beacons and its efficiency on how well it can communicate with a satellite is evaluated via experimentation. The user can schedule any satellite pass through the ground station for observation and the type of signal of interest to be received as shown in **Figure 43**. For open satellites, the payload beacon itself can be selected to receive the payload data.

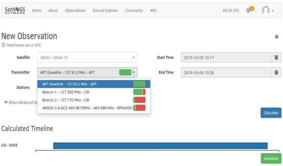

Figure 43. Scheduling Observation of NOAA 18 Satellite & Selecting the Signal of Interest.

Source: https://satnogs.org/, https://network.satnogs.org/observations/new/?norad=28654&ground_station=826&start=2019/10/09%2010:17&end=2019/10/09%2010:27

After scheduling an observation, when the scheduled satellite is in line of sight to the ground station, the SatNOGS client activates the SDR to the desired frequency of the satellite to receive the signal. Once the satellite pass is over, SatNOGS uploads the waterfall, audio, and telemetry or payload data to the network on the observation page as shown in **Figure 44**. The decoded data can be either payload data such as weather satellite images or the telemetry data from the satellite beacon. To receive any other satellite data apart from weather-related data, typically, it is necessary to know the technical details of the satellite in question or to use data provided by some of the organizations like EU's Copernicus or the commercial Planet Labs.

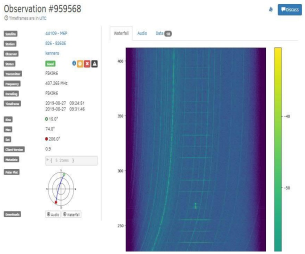

Figure 44. Waterfall, Audio and Data Uploaded on the Observation Page.

Source: https://satnogs.org/, https://network.satnogs.org/observations/959568/

The SatNOGS client looks for more observation of the satellite scheduled by the user as shown in **Figure 45**. If there are other satellites scheduled, it activates the SDR again, repeats the process and uploads the relevant data to the network. The user of the ground station in the network can access the data obtained from each observation scheduled or publicly access the data observed from other ground stations in the network. The different ground stations in the network receive and share the data through the website perpetually.

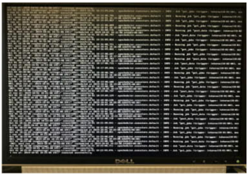

Figure 45. SatNOGS Client Looking for Next Observation.

The implemented ground station tracked different satellites in the VHF and UHF range. The following **Figure 46** illustrates the different satellites such as the M6P, UNISAT-6 and AALTO-1 and in particular the satellite waterfall consisting of a beacon signal transmitted in the FSK9k6, 9k6 FSK TLM and CW transmission mode respectively. The waterfall of the signal will give a clear indication of all possible signals received by the receiving unit. It will help to visualize if the ground station receives just the satellite signal or any nearby stationary radio signals or interferences. If there are any other signals present along with the actual satellite signal, suitable modifications in the receiving unit will help in eliminating the unwanted signals.

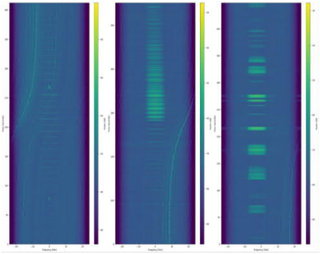

Figure 46. Waterfall of the Telemetry Beacon from M6P, UNISAT-6 and Aalto-1 CubeSats.

Source: https://satnogs.org/, https://network.satnogs.org/stations/826/

Apart from the waterfall, the audio and telemetry data or payload data uploaded to the observation page are available to be downloaded and stored on the local computer as well. Depending on the satellite pass, the number of data transmitted by each satellite varies. If the satellite passes through the horizon, chances of getting data from the satellite are less while a satellite pass above the ground station transmits more number of data. The M6P satellite's demodulated telemetry data obtained by the ground station is illustrated in **Figure 47** that consists of 18 data packets transmitted by the satellite. SatNOGS is fully autonomous in that it automatically demodulate the telemetry data or payload data and uploads it to the observation page of the particular satellite scheduled.

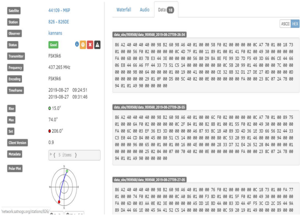

Figure 47. Demodulated Telemetry Data of the M6P Satellite.

Source: https://satnogs.org/, https://network.satnogs.org/observations/959568/

The demodulated data is decoded using suitable online telemetry decoding software to obtain the digital values of the telemetry data. The telemetry data gives information about the status of the satellite throughout its pass over the ground station. The information about different subsystems and payload were provided by the telemetry data such as voltage and current of the battery, the temperature of different sensors and onboard computer, onboard computer, magnetometer and gyroscope values, a payload state, orbital velocity, orbital position et cetera. Based on these telemetry values, suitable commands to the satellite are transmitted for efficient operation, functioning and monitoring of the satellite. The following **Figure 48** illustrates the telemetry data decoded from the demodulated data obtained by using a suitable telemetry decoder. It shows the digital values on each sensor and subsystem of the BugSat-1 and a graphical value on the battery current throughout its pass.

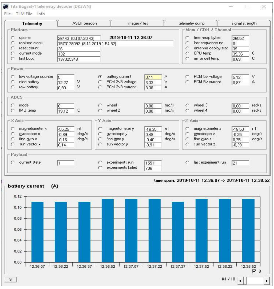

Figure 48. Telemetry Data Decoded Using an Online Telemetry Decoder.

8.1.2 Open Satellite Data

In the case of weather satellites such as the NOAA, the actual payload is automatically decoded by SatNOGS and is uploaded to the observation page. It does not need any other decoder software as SatNOGS already decodes the payload data such as the APT signal into an image and uploads it directly to the observation page. The following **Figure 49** shows the NOAA weather satellite image received with the VHF antenna implemented, and then decoded and uploaded to the observation page by the SatNOGS.

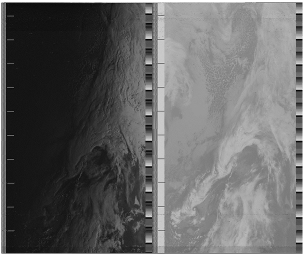

Figure 49. NOAA Satellite Payload Data Received Using a VHF Antenna.

Source: https://satnogs.org/, https://network.satnogs.org/observations/1116072/

The decoded weather image from NOAA 19 satellite provides information about the cloud patterns, precipitation, storms, hurricanes, and other meteorological data. Besides, the APT signal received in the form of an audio signal is loaded into a decoding software such as the WxToImg to make additional enhancements to the data for better visualization and understanding. The following **Figure 50** provides much more information in differentiating the land, sea, dark and light clouds, boundaries, ground station location, et cetera. There are several other enhancements to the received image, possible through software such as the WxToImg.

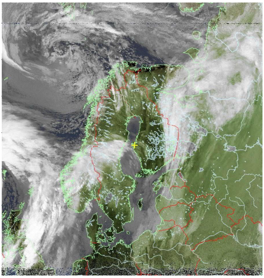

Figure 50. NOAA Satellite Data Enhancement Using WxToImg.

8.2 Satellite Data Analysis

Apart from the ground station received satellite data, other satellite data providers are using a constellation of satellites to monitor the Earth, and receive and share the data through their websites. Using such free open source data, a geospatial analysis was made for various applications. For thesis purpose, Planet Labs, Google Earth Engine and Copernicus platforms and their data for different applications are next discussed.

8.2.1 Planet Labs

a) Search, Download & Merge:

Figure 51. PlanetScope Data Searched, Downloaded & Merged.

Source Code Applied from: https://developers.planet.com/tutorials/search-download-with-the-data-api/, https://developers.planet.com/planetschool/creating-a-mosaic-in-python/

Planet Labs offers 3-meter resolution per pixel satellite data through their PlanetScope satellite constellation. There are other satellite constellations as well apart from PlanetScope. The user can search and download high-quality images of the area of interest. One such example is the **Figure 51** which illustrates the PlanetScope 3 meter resolution data over the Söderfjärden impact crater in the Vaasa region. Two adjoining tiles of satellite data are searched based on the area of interest, filtering the specific time of observation and other details. Each adjoining tiles of the area of interest are downloaded and merged into a composite image. The composite image gives a better understanding of the data providing information on the geographical structure, land patterns, borders, urban classification, water bodies and other details over the Vaasa region.

b) Vegetation Index

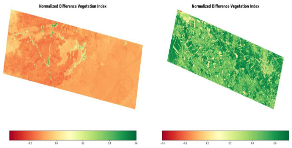

Figure 52. Vegetation of the Sahara Desert and the Vaasa Region Using PlanetScope Data.

Source Code Applied from: https://medium.com/analytics-vidhya/satellite-imagery-analysis-with-python-3f8ccf8a7c32

Planet Labs satellite imagery serves for applications such as forest monitoring, crop classification, vegetation estimation, vessel detection and temporal analytics for creating essential products. For example, the vegetation index in a region can be estimated using satellite data. The sensors in the satellite capture the reflected light from the trees providing information on the vegetation. The vegetation is categorized into dense vegetation, sparse vegetation and no vegetation based on the index range. The following **Figure 52** illustrates the normalized difference vegetation index (NDVI) for the two tiles of the PlanetScope data on Sahara desserts and Vaasa region respectively. The vegetation index value for the Sahara desserts is less than 0.1 while the Vaasa region averages around 0.4 indicating areas of no vegetation and sparse vegetation region respectively.

8.2.2 Google Earth Engine

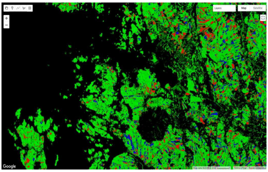

Figure 53. Forests Change in Vaasa Region from 2000 to 2014.

Source Code Applied from: https://developers.google.com/earth-engine/tutorial_forest_01

Google Earth Engine allows the user to compute different satellite data and create value-added information through their platform. For observation of the forest change from 2000 to 2014, the time series analysis of the Landsat images on the forest data was considered here as an analysis example. Satellite data helps in analyzing the changes accurately using simple computations. The following **Figure 53** illustrates the forest change globally with red representing forest loss, blue representing forest gain and pink representing both loss and gain in forests. The forest change information helps in estimating the deforested areas. Likewise, more similar analysis using satellite data will provide information that benefits the various businesses, the environment, and society at large.

8.2.3 Copernicus

The EU's Copernicus program offers a wide range of data on various environmental parameters and the required tools to process the data and create value-added informative products. MERIS level two product from Environmental satellite (Envisat) was considered in this analysis as an example. MERIS is a Medium Resolution Imaging Spectrometer that acquires imaging over the land, ocean, and atmosphere. The water quality can be measured using various parameters such as temperature, salinity, dissolved oxygen, algae, et cetera. The various water quality parameters were analyzed and visualized using the Sentinel Applications Platform (SNAP). For example, the chlorophyll concentration in water gives an indication of algae that affects the water quality.

Figure 54 illustrates the chlorophyll concentration in the water bodies of the Scandinavian region. The green lines indicate the coastlines, grey color indicating land and white color indicating the clouds. The blue color indicates very small concentration of chlorophyll, red indicates average values and yellow indicates high concentrations of chlorophyll. The higher chlorophyll concentrations indicate bad water quality levels. Thus, satellite data will help us in assessing the water quality levels. These satellite data are available free to use from the satellite data provider of the European Commission.

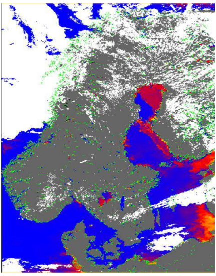

Figure 54. Chlorophyll Content in Water Bodies over Scandinavian Regions.

Source Code Applied from**:** https://www.youtube.com/watch?v=Yl5EJ8oNijU

Similarly, chlorophyll concentrations can be mapped using EU's Copernicus Sentinel-2 Multispectral Instrument (MSI) L1C product or Sentinel-3 Ocean and Land Color Instrument (OLCI) OL_2_WFR product. Both Sentinel-2 level-1 product and Sentinel-3 level-2 product was considered in this analysis as an example. **Figure 55** indicates the visualization comparison of chlorophyll concentration in the water bodies of Turku region from Sentinel-2 and Sentinel-3 satellite data. The black, blue and yellow color indicates low, medium and high levels of chlorophyll concentrations respectively while grey color indicating land region. The resolution of Sentinel-2 product is 10 meter per pixel while Sentinel-3 product is 300-meter resolution. Due to the variation in the resolution, chlorophyll concentration mapped using Sentinel-2 MSI level-1 product gives better visualization than the Sentinel-3 OLCI product.

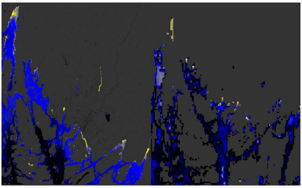

Figure 55. Chlorophyll Concentration from Sentinel-2 & Sentinel-3 Data over Turku Region.

Source Code Applied from**:** https://vimeo.com/368506227

Oil is an important commodity in the Baltic Sea region, with large volumes transported through the Baltic Sea. Increase in the volume of oil transportation through the sea leads to risks of spills of oil and other hazardous substances. It is necessary to analyze the intensity and extent of oil spill and respond immediately. Therefore, EU's Copernicus Sentinel-1 Ground Range Detected (GRD) product was considered in the analysis of detecting oil spill as an example. **Figure 56** illustrates an example of oil spill detected from sentinel-1 GRD product processed using SNAP. It visualizes the impact of the oil spill over Bay of Bengal in 2017. The red color in the figure indicates the extent of oil spills over several kilometers in the Sea. (Holt et. al 2013: 4–8.)

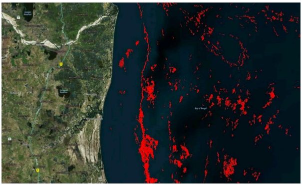

Figure 56. Oil Spill Detection Using Sentinel-1 GRD Product over Bay of Bengal.

Source Code Applied from: https://rus-copernicus.eu/portal/wp-content/uploads/library/education/training/OCEA03_OilSpill_Kuwait_Tutorial.pdf

Overall, using satellite data and analyzing them with different platforms and tools provides hundreds of essential information or products for various purposes. As discussed earlier, tracking the satellite telemetry data, weather satellite data, forests change, vegetation estimation, water quality are some of the applications assessed in this work. The ground station built at the University of Vaasa will operate and serve for such applications. It will track and collect data from the KvarkenSat CubeSat that will be launched in the near future while simultaneously also being able to track other CubeSats and possible open satellites.

Besides, in addition to data received with the implemented ground station, in the continuation of this work, Copernicus and other open-source data will be processed and analyzed using several platforms and tools to obtain essential products that support the businesses, organizations, students and local citizens around the Kvarken region close to Vaasa.

9. CONCLUSIONS & FUTURE WORK

In this thesis, the KvarkenSat ground station implemented operates in the amateur radio band. The ground station receives signals from various satellites in the VHF and UHF. Telemetry data from CubeSats such as Aalto-1, M6P, JY1Sat, CubeSat XI-IV, BUGSAT-1, SOMP and payload data from weather satellites such as NOAA 15, NOAA 18, and NOAA19 were received. Open access satellite data were retrieved from various platforms such as Planet Labs, Google Earth Engine and Copernicus; and analyzed using relevant tools. Through such satellite data analysis, value-added products or information were obtained such as the geographical structure of an area, forest change, vegetation calculation, water quality, air quality, pollen levels. These value-added products or information will bring added benefits in many ways for different applications. Besides, the components of the ground station were chosen based on the available low cost COTS components, component's performance, and specifications. The relatively low cost setup of the ground station and the open-source autonomous software platform design were the main highlights and contributions of the thesis. This type of implementation is affordable and gives easy access for any research institute or university or an individual to space technologies.

The thesis work on the KvarkenSat ground station paved the way for already the next steps for improving the station in many different ways. As seen from the results, there are some stationary radio signals present in the background of the waterfall obtained for some observations. Therefore, adding additional filters such as a bandpass filter will allow the signal of interest alone to pass through the receiving unit, eliminating any other frequency signal to be received. The ground station was able to track and receive telemetry data from different satellites and CubeSats. Only payload data from weather satellites such as the NOAA were however received. Until the launch of the KvarkenSat, as part of the Kvarken Space Center project (www.kvarkenspacecenter.org), accessing different CubeSat payloads will be necessary and help in testing other potential sources of data that can be received by the implemented ground station.

Though the entire ground station setup is weatherproofed, long-term operations in different weather conditions require regular maintenance. A permanent weatherproof setup will make sure that the station functions properly at any weather conditions without the need for any additional maintenance costs or repair costs. The limitations of the ground station using omnidirectional antennas is that the antennas are low gain and difficult to point the antennas to the satellite for transmission of control commands. A fully efficient transmission option using a custom omnidirectional antenna without rotator controllers needs to be implemented in the future that performs equal to the advanced steerable antenna systems. Due to the half-duplex nature of the Hackrf One transceiver, it is capable of either transmitting or receiving at a single time. Low cost of a full duplex transceiver will fulfill the limitations on the performance of the transceiver.

The ground station uses an open-source software platform for the entire chain of operations through SatNOGS such as tracking, pass predictions, demodulating and decoding. Customizing the software platform in the future would add additional value to the ground station setup. SatNOGS ground station operations are autonomous once the satellite pass is scheduled, from receiving, demodulating, decoding and uploading the signal to the network. At the same time, manual tracking and decoding the signal from satellites using customized satellite tracking and decoding software might be of interest and motivate working with the ground station operations for further progress.

The future work of this thesis work will focus on the different satellite missions. In general, ground stations were implemented based on the actual primary and secondary payloads of a satellite mission. Each satellite mission requires a ground segment to operate. Some satellite mission requires less sophisticated systems while other missions require advanced ground station systems. The future work will focus on developing advanced system capable of operating for any satellite mission operations. In addition, future work includes designing and developing efficient hardware components and software modules used in the ground segment. Developing efficient products and software platforms for the ground segment create various opportunities and business ideas in the future.

The KvarkenSat ground station is unique in the Vaasa region, providing the foundations and opportunities for students, researchers, businesses, and locals to understand the concepts of satellite communication, satellite data, and its applications and benefits. Since the aim of the thesis was to build a less sophisticated simple ground station at low cost, it attracts and interests any individual to get involved and contribute to space-based technologies. Space-based technologies offer solutions to strengthen the sustainability of the society in addition to providing economic potential. Space can serve to the betterment of the Earth. The educational institutions such as the University of Vaasa will be left out of the tremendous opportunities the New Space economy has to offer unless the initiation for the ground station implementation did not take place, as now implemented in this thesis.

REFERENCES

Alén Space (2019). *Space Business,* How to Do Business in Space? [online]. [Cited 10 April 2019]. Available from Internet: <URL: https://alen.space/space-business/>

Amateur Radio – PEØSAT (2015). *Information about Amateur Radio – Satellite Experiments* [online]. [Cited 20 April. 2019]. Available from Internet: <URL: https://www.pe0sat.vgnet.nl/sdr/sdr-software/sdrsharp/>

Antenna (radio) (2019). *Wikipedia* [online]. [Cited 20 April. 2019]. Available from Internet: <URL: https://en.wikipedia.org/wiki/Antenna_(radio)>

Antwi, Aaron Yankey (2001). *The Use of Software Defined Radios (SDR) in Ground-Station Design* [online]. All Nations University College [Cited 05 Dec. 2018]. Available from Internet: <URL: http://www.unisec-global.org/pdf/UNIGLO2_studentreps/Ghana_a.pdf>

Atmosphere Monitoring Service. *European Air Quality – About the Project* [online]. [Cited 25 Feb. 2018]. Available from Internet: <http://www.regional.atmosphere.copernicus.eu/index.php?category=documentation&subensemble=macc_raq_project>

Atmosphere Monitoring Service. *European Air Quality – Ensemble Hourly Forecasts and Analysis* [online]. [Cited 25 Feb. 2018]. Available from Internet: <http://macc-raq-op.meteo.fr/index.php?category=ensemble&subensemble=hourly_ensemble&date=LAST&calculation-model=ENSEMBLE&species=o3&level=SFC&offset=000>

Copernicus (2015). *Monyo – MYANMAR Flood - 01/08/2015* [online]. [Cited 25 Feb. 2018]. Available from Internet:

<https://emergency.copernicus.eu/mapping/system/files/components/EMSR130_09MONYO_DELINEATION_OVERVIEW-MONIT03_v2_100dpi.jpg>

Copernicus Land Monitoring Service. *Land* [online]. [Cited 25 Feb. 2018]. Available from Internet: <https://www.copernicus.eu/en/services/land>

Copernicus Marine Environment Monitoring Service. *Baltic Sea Physics Analysis and Forecast* [online]. [Cited 25 Feb. 2018]. Available from Internet: <http://marine.copernicus.eu/services-portfolio/access-to-products/?option=com_csw&view=details&product_id=BALTICSEA_ANALYSIS_FORECAST_PHY_003_006>

Copernicus Marine Environment Monitoring Service. *Observation* [online]. [Cited 25 Feb. 2018]. Available from Internet: <http://marine.copernicus.eu/training/education/observation/>

Copernicus Marine Environment Monitoring Service. *Sea Ice* [online]. [Cited 25 Feb. 2018]. Available from Internet: <http://marine.copernicus.eu/training/education/ocean-parameters/sea-ice/>

Copernicus Marine Environment Monitoring Service. *Temperature* [online]. [Cited 25 Feb. 2018]. Available from Internet: <http://marine.copernicus.eu/training/education/ocean-parameters/temperature/>

Copernicus. *PASYFO:forecasts of personal allergy symptoms* [online]. [Cited 25 Feb. 2018]. Available from Internet: <https://www.copernicus.eu/en/use-cases/pasyfo-forecasts-personal-allergy-symptoms>

Dascal, Vlad, Paul Dolea, Octavian Cristea & Tudor Palade (2013). *Low-Cost SDR-Based Ground Receiving Station for LEO Satellite Operations* [online]. [Cited 05 Dec. 2018].

Available from Internet: <URL: https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=6704456>

Davoli, Franco, Charilaos Kourogiorgas, Mario Marchese, Athanasios Panagopoulos & Fabio Patrone (2019). *Small satellites and CubeSats: survey of structures, architectures, and protocols* [online]. International Journal of Satellite Communications and Networking. [Cited 07 Mar. 2019]. Available from Internet: <URL: https://www.researchgate.net/publication/327685874_Small_satellites_and_CubeSats_Survey_of_structures_architectures_and_protocols>

Debes, Joshua, Nathan Howard, Ryan Harrington, Richard Cobb & Jonathan Black. *Rapid Build and Space Qualification of CubeSats* [online]. Air Force Institute of Technology. 25th Annual AIAA/USU Conference on Small Satellites [Cited 07 Mar. 2019]. Available from Internet: <URL: https://digitalcommons.usu.edu/cgi/viewcontent.cgi?article=1148&context=smallsat>

Denis, Gil, Helene de Boissezon, Steven Hosford, Xavier Pasco, Bruno Montfort & Franck Ranera (2016). *The evolution of Earth Observation satellites in Europe and its impact on the performance of emergency response services* [online]. Acta Astronautica 127 (2016) 619-633 [Cited 25 Feb. 2018]. Available from Internet: <https://ac.els-cdn.com/S0094576515303337/1-s2.0-S0094576515303337-main.pdf?_tid=b9c88b6d-62b8-497f-b83e-9405927e40c2&acdnat=1551189017_601bbc7f2a081d9be9da437c74a53403>

Drevilon, Marie, Pierre Bahurel, David Bazin, Mounir Benkiran, Jonathan Beuvier, Laurence Crosnier, Yann Drillet, Edmee, Durand, Michele Fabardines, Isabel Garcia Hermosa, Cedric Giordan, Elodie Gutknecht, Fabrice Hernandez, Stephane Law Chune, Pierre-Yves Le Traon, Jean-Michel Lellouche, Bruno Levier, Angelique Melet, Dominique Obaton, Julien Paul, Mathieu Peltier, Diane Peyrot, Elizabet Remy, Karina von

Schuckmann & Cecile Thomas-Couroux (2018). *Learning about Copernicus Marine Environment Service ¨CMEMS¨: A Practcal Introduction to the Use of the European Operational Oceanography Service* [online]. Florida State University Libraries [Cited 25 Feb. 2018]. Available from Internet: <https://fsu.digital.flvc.org/islandora/object/fsu%3A602117>

Earth Observation Satellite (2019). *Wikipedia* [online]. [Cited 25 May 2019]. Available from Internet: <URL: https://en.wikipedia.org/wiki/Earth_observation_satellite>

Earth Observation Satellites Transmission Frequencies (2019). *Wikipedia* [online]. [Cited 25 May 2019]. Available from Internet: <URL: https://en.wikipedia.org/wiki/Earth_observation_satellites_transmission_frequencies>

Electropaedia (2005). *Satellite Technologies* [online]. [Cited 05 Dec. 2018]. Available from Internet: <URL: https://www.mpoweruk.com/satellites.htm>

ESA Eduspace (2019). *Earth Observation Satellites - Introduction* [online]. [Cited 25 May 2019]. Available from Internet: <URL: http://www.esa.int/SPECIALS/Eduspace_EN/SEM7YN6SXIG_0.html>

Euronews. (2019). *Air quality index* [online]. [Cited 25 Feb. 2018]. Available from Internet: <https://www.euronews.com/weather/copernicus-air-quality-index>

GIS Geography. *15 Free Satellite Imagery Data Sources* [online]. [Cited 25 Feb. 2018]. Available from Internet: <https://gisgeography.com/free-satellite-imagery-data-list/>

GIS Geography. *The Big Satelilte List. 50 Satellites. 30 Words or Less* [online]. [Cited 25 Feb. 2018]. Available from Internet: <https://gisgeography.com/satellite-list/>

GNSS Market Report (2019). Issue 6, European Global Navigation Satellite Systems Agency. [online]. [Cited 25 May 2019]. Available from Internet: <URL: https://www.gsa.europa.eu/system/files/reports/market_report_issue_6.pdf>

Harrison, Irving & Ursula Schwuttke (2000). *Optimising Satellite, Network, and Ground Station Operations with Next Generation Data Visualization* [online]. [Cited 05 Dec. 2018]. Available from Internet: <URL: https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=878251>

Holt, Julie Ring-Hansen, Christina Pharkhomenko, Hermanni Backer, Johanna Laurila & Laura Meksi (2013). *Risks of Oil and Chemical Pollution in the Baltic Sea* [online]. Information office of the Nordic Council of Ministers in Kaliningrad [Cited 05 Dec. 2019]. Available from Internet: <URL: http://www.helcom.fi/Lists/Publications/BRISK-BRISK-RU_SummaryPublication_spill_of_oil.pdf>

Hong Kong Observatory (2016). *What is a Meteorological Satellite?* [online]. [Cited 25 Feb. 2018]. Available from Internet: <https://www.hko.gov.hk/education/article_e.htm?title=ele_00196>

http://www.emgo.cz/www_profi_137/sw/WXtoIMG/WXtoImg_reference_manual_gb.pdf

https://orbitron.software.informer.com/

https://satnogs.org/about/

https://www.helsinki.fi/en/researchgroups/finnish-centre-of-excellence-in-research-of-sustainable-space/about

https://www.iceye.com/hubfs/img/pdf/ICEYE-X1-Example-SAR-Imagery-Set-01-2018.pdf

ICEYE (2018). *First Radar Image from ICEYE-X2 Published Only A Week After Launch* [online]. [Cited 25 Feb. 2018]. Available from Internet: <https://www.iceye.com/press/press-releases/first-radar-image-from-iceye-x2-published-only-a-week-after-launch>

Karlsen, Oyvind (2017). *Ground Station Considerations for the AMOS Satellite Programme* [online]. Norwegian University of Science and Technology [Cited 28 Dec. 2018]. Available from Internet: <URL: http://daim.idi.ntnu.no/masteroppgaver/017/17128/masteroppgave.pdf>

Kuznetsov, V.D, V. M. Sinelnikov & S. Alpert (2014). *Sputnik 1 and the First Satellite Ionospheric Experiment.* [online]. [Cited 28 October 2019]. Available from Internet: <URL: https://www.researchgate.net/publication/309858564_Sputnik_1_and_the_First_Satellite_Ionospheric_Experiment>

Low-noise amplifier (2019). *Wikipedia* [online]. [Cited 20 April. 2019]. Available from Internet: <URL: https://en.wikipedia.org/wiki/Low-noise_amplifier>

Lutz, Erich, Hermann Bischl, Harald Ernst, Dirk Giggenbach, Matthias Holzbock, Axel Jahn & Markus Werner (2004). *Development and Future Applications of Satellite Communications* [online]. [Cited 25 May 2019]. Available from Internet: <URL: https://ieeexplore-ieee-org.proxy.uwasa.fi/stamp/stamp.jsp?tp=&arnumber=1368738>

NASA (2014). *What is a satellite?* [online]. [Cited 05 Dec. 2018]. Available from Internet: <URL: https://www.nasa.gov/audience/forstudents/5-8/features/nasa-knows/what-is-a-satellite-58.html>

National Oceanic and Atmospheric Administration (2019). *Satellite and Information Service.* Currently Flying [online]. [Cited 18 Nov. 2018]. Available from Internet: <https://www.nesdis.noaa.gov/content/currently-flying>

Noosphere Ventures (2018). *Next Big Thing,* How New Business Models will Disrupt Old Space Industry [online]. [Cited 10 April 2019]. Available from Internet: <URL: https://noosphereventures.com/how-new-business-models-will-disrupt-old-space-industry/>

Paikowsky, Deganit (2017). *What is New Space? The Changing Ecosystem of Global Space Activity* [online]. 67th International Astronautical Congress, Mary Ann Liebert, Inc. [Cited 10 April 2019]. Available from Internet: <URL: https://www.liebertpub.com/doi/pdf/10.1089/space.2016.0027>

Peuch, Vincent-Henri, Richard Engelen, Melanie Ades, Jerome Barre, Antje Inness, Johannes Flemming, Zak Kipling, Anna Agusti-Panareda, mark Parrington, Roberto Ribas, Martin Suttie & the CAMS international team (2018). *The Use of Satellite Data in the Copernicus Atmosphere Monitoring Service (CAMS)* [online]. European Centre for Medium-Range Weather Forecasts, Reading, United-Kingdom. 1594–1596. [Cited 25 Feb. 2018]. Available from Internet: <https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=8518698>

Pixalytics (2018). *How many Earth Observation Satellites are in Space in 2018?* [online]. [Cited 25 May 2019]. Available from Internet: <URL: https://www.pixalytics.com/eo-satellites-in-space-2018/>

Poghosyan, Armen & Alessandro Golkar (2016). *Progress in Aerospace Sciences,* CubeSat evolution: Analyzing CubeSat capabilities for conducting science missions [online]. Skolkovo Institute of Science and Technology, Russia [Cited 07 Mar. 2019]. Available from Internet: <URL: https://www.sciencedirect.com/science/article/pii/S0376042116300951>

Poghosyan, Armen & Alessandro Golkar (2016). *Progress in Aerospace Sciences,* CubeSat evolution: Analyzing CubeSat capabilities for conducting science missions [online]. Skolkovo Institute of Science and Technology, Russia [Cited 07 Mar. 2019]. Available from Internet: <URL: https://www.sciencedirect.com/science/article/pii/S0376042116300951>

Polleninfo.org. *Pollen Load Map of Europe* [online]. Medizinische Universitat Wien [Cited 25 Feb. 2018]. Available from Internet: <https://www.polleninfo.org/FI/en/current-data/pollen-load-map-of-europe.html>

Ramawickrama, Yasith, Jude Wijesekara, Rohan Dharmarathna & Hiruni Wijesooriya (2016). *The Future of GNSS in the Next Ten Years,* [online]. [Cited 25 May 2019]. Available from Internet: <URL: https://www.researchgate.net/publication/309575401_The_Future_of_GNSS_in_the_next_Ten_years>

RTL-SDR.com (2016). RTL-SDR.com Broadcast FM Band-Stop Filter (88-108 MHz Reject) Now for Sale + RTL-SDR V3 Dongle Availability [online]. [Cited 30 June. 2019]. Available from Internet: <https://www.rtl-sdr.com/rtl-sdr-com-broadcast-fm-band-stop-filter-88-108-mhz-reject-now-for-sale/>

Safyan, Mike (2015). Overview of the Planet Labs Constellation of Earth Imaging Satellites. In Space to Help Life on Earth [online]. [Cited 25 Feb. 2018]. Available from Internet: <https://www.itu.int/en/ITU-R/space/workshops/2015-prague-small-sat/Presentations/Planet-Labs-Safyan.pdf>

Samama, Nel (2007). *A Brief History of Navigation and Positioning* [online]. [Cited 25 May 2019]. Available from Internet: <URL: https://onlinelibrary.wiley.com/doi/pdf/10.1002/9780470241912.ch1>

Shah, Syed Afaq Ali & Usman Arshad (2013). *General System Design of CubeSAT in LEO for IR Imaging* [online]. Institute of Space Technology, Pakistan. 2013 International Conference on Aerospace Science & Engineering (ICASE) [Cited 07 Mar. 2019]. Available from Internet: <URL: https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=6785552>

Software-defined radio (2019). *Wikipedia* [online]. [Cited 20 April. 2019]. Available from Internet: <URL: https://en.wikipedia.org/wiki/Software-defined_radio>

Someswar, Manoj G., T. P. Surya Chandra Rao & Dhanunjaya Rao Chigurukota (2013). *Global Navigation Satellite Systems and Their Applications,* International Journal of Software and Web Sciences (IJSWS) [online]. [Cited 25 May 2019]. Available from Internet: <URL: http://www.unoosa.org/documents/pdf/icg/ISWI/IJSWS12-326.pdf>

Space (2015). *Copernicus: Europe's Eye on Earth* [online]. European Commission, Belgium. [Cited 25 Feb. 2018]. Available from Internet: < https://www.copernicus.eu/sites/default/files/documents/Copernicus_brochure_EN_web_Oct2017.pdf> ISBN 978-92-79-45666-4.

Space (2016). *Atmosphere Monitoring Service, European Commission* [online]. [Cited 25 Feb. 2018]. Available from Internet: <https://www.copernicus.eu/sites/default/files/documents/Copernicus_AtmosphereMonitoring_Feb2017.pdf>

Suparco (2019). *Pakistan Space & Upper Atmosphere Research Commission,* Applications of Satellites [online]. [Cited 25 May 2019]. Available from Internet: <URL: http://www.suparco.gov.pk/pages/applications-satellite.asp>

Techopedia (2019). *Communications Satellite* [online]. [Cited 25 May 2019] Available from Internet: <URL: https://www.techopedia.com/definition/6567/communications-satellite>

The CubeSat Program (2014). *Poly Picosatellite Orbital Deployer Mk. III Rev. E User Guide* [online]. California Polytechnic State University. [Cited 27 Nov. 2019]. Available from Internet: <URL: https://static1.squarespace.com/static/5418c831e4b0fa4ecac1bacd/t/5806854d6b8f5b8eb57b83bd/1476822350599/P-POD_MkIIIRevE_UserGuide_CP-PPODUG-1.0-1_Rev1.pdf>

United space in Europe (2019). *Fires Ravage the Amazon*, ESA [online]. [Cited 07 Oct. 2019]. Available from Internet: < https://www.esa.int/Our_Activities/Observing_the_Earth/Copernicus/Sentinel-3/Fires_ravage_the_Amazon>

Velayudhan, Sneha (2017). *A low, Cost Portable Ground Station to Track and Communicate with Satellites in VHF Band* [online]. Rochester Institute of Technology [Cited 28 Dec. 2018]. Available from Internet: <URL: https://scholarworks.rit.edu/cgi/viewcontent.cgi?referer=&httpsredir=1&article=10845&context=theses>

Wandering Alpha (2017). *New Space and Old Space* [online]. [Cited 10 April. 2019]. Available from Internet: <URL: https://wanderingalpha.com/new-space-vs-old-space/>

Wickramanayake, Anura (2017). *Design, Development and Operation of a Student Ground Station* [online]. Lulea University of Technology [Cited 28 Dec. 2018]. Available from Internet: <URL: http://www.diva-portal.se/smash/get/diva2:1023378/FULLTEXT01.pdf>

Wonderopolis. *What Can Satellites Do?* [online]. [Cited 25 Feb. 2018]. Available from Internet: <https://wonderopolis.org/wonder/what-can-satellites-do>

Zak, Anatoly (2018). *Russian Ground Control and Tracking Network* [online]. [Cited 05 Dec. 2018]. Available from Internet: <URL: http://www.russianspaceweb.com/kik.html>

Zogg, Jean-Marie (2009). *GPS,* Essentials of Satellite Navigation, Compendium [online]. [Cited 25 May 2019]. Available from Internet: <URL: http://zogg-jm.ch/Dateien/GPS_Compendium(GPS-X-02007).pdf>