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A Technical
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On

"STAR LINK"

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Submitted By

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CERTIFICATE

Certified that the Technical Seminar Presentation entitled **“STAR LINK”** carried out by **AFRID PASHA HP(1CE19CS003)** is submitted in partial fulfillment for the award of the **BACHELOR OF ENGINEERING** in **Computer Science and Engineering** from **Visvesvaraya Technological University, Belgaum** during the year **2022-2023**.TheTechnical Seminar report has been approved as it satisfies the academic requirements in respect of the project work prescribed for the said Degree.

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ABSTRACT

Starlink is a satellite constellation development project underway by SpaceX, to develop a low-cost, high-performance satellite bus and requisite customer ground transceivers to implement a new spaceborne Internet communication system. SpaceX plans to build two NGSO constellations, named Starlink, to provide high speed internet to end-users. The system will have global coverage 24/7 by means of launching 4425 satellites on circular low orbits. The possibility of using these satellite emissions as an illuminating source for bistatic real and synthetic aperture radars, assuming a receiver on or near the earth surface, is investigated. The practicality of these systems is discussed for possible applications. This network, Starlink, will be alternative for wire based broadband system. It will give tougher competition to wired based internet connectivity.

Digital connectivity gap in the global south hampered the education of millions of school children during the COVID- 19 pandemic. If not, actions are taken to remedy this problem, future prospects of millions of children around will be bleak. This topic explores the feasibility of using the SpaceX Starlink satellite constellation as a means to alleviate the problem of the digital connectivity divide in the global south. First, we discuss the issues of digital connectivity in education in rural countries in the global south. Then, an introduction to Starlink broadband internet technology and discusses its advantages over traditional technologies. After that, a possible mechanism of adopting Starlink technology as a solution to the rural digital connectivity problem in the global south. Technological, as well as economical aspects of such scheme, are discussed. Finally, challenges that may arise in deploying a system such as Starlink to improve rural digital connectivity in any country in the global south will be discussed with possible remedies.

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CHAPTER 1

INTRODUCTION

In today's digital age, high-speed internet connectivity has become a necessity for individuals, businesses, and governments alike. However, traditional broadband infrastructure is often inaccessible or unreliable in rural or remote areas, leaving millions of people without reliable internet access. To address this problem, private space exploration company SpaceX has launched its ambitious Starlink satellite internet constellation. With over 1,700 satellites in low Earth orbit and plans to launch tens of thousands more, Starlink aims to provide high-speed, low-latency internet connectivity to users all over the world. The system uses advanced satellite technology and ground stations to deliver internet access through small, user-friendly terminals. However, as with any new technology, Starlink faces a number of challenges and controversies. Concerns about space debris, interference with astronomy, and potential impacts on wildlife have been raised by various stakeholders.

With new developments in information and communication technologies (ICTs) and communication-enabled power equipment, the cyber-physical power system (CPPS) is gradually maturing due to the ICT-enabled real-time measurement, dynamic operation and smart control. Applying ICTs to power systems not only requires the upgrade of communication modules installed on the various power equipment such as power electronics converters, but also relies on the communication network infrastructure that can provide fast and stable connection between networking devices even at remote locations. However, the network service is not always reliable in many places such as rural areas and offshore fields, or could even be completely unavailable during severe environmental conditions such as the hurricanes and earthquakes, which makes the stable measurement and smart operation of CPPSs in these places difficult. To provide the globally connected Internet service, SpaceX began the satellite constellation project, called Starlink,in2015. The first two prototype test-flight satellites were launched in February 2018. Up to now, SpaceX has launched nearly 800 satellites. Although it is still at the very initial stage of the entireproject, the final Starlink space network will be composed of nearly 12,000 satellites (with a possible extension to 43000 satellites) when it is completed, where each satellite will circle the Earth at an orbit of 500 km to 1200km overhead.

The numerous satellites could potentially provide all time Internet services with global coverage from relatively low orbits. Despite the extra cost of installing new communication antennas, the space-Internet could achieve even lower transmission latencies than the existing terrestrial fiber networks for long distances. Although there are still many technological challenges to overcome, it may forever change the landscape of the telecom industry if the project could be successfully completed. Since Starlink is based on the space wireless transmission in low orbit without suffering from service quality problems in remote places or under abnormal conditions, it could expose massive potentials in the industrial application of cyber-physical power systems, although the project is still under construction. In this letter, the concept of Starlink space network enhanced CPPS is proposed: the Starlink transmission parameters are first investigated to exploit the capability of space data transmission; then the system structure and implementation techniques are discussed to look into the future applications.

Figure 1.1: Starlink initial phase.

1.1 SPACE INTERNET

Internet access provides through communication satellites System uses satellites in geostationary orbit. This orbit is located at a height of 35,786km (about 22236.39 mi) over the Earth's surface, directly above the Equator, Theoretical data transfers at the speed of light Involves 3 satellite dishes; one at the internet services providers hub, one in space and one attached to your property, in addition to the satellite dish you also need a modem and cables running to and from the dish to your modem. Latency: Average 638 MS, Average uplink rate: 256 kbit/s, Average downlink rate: 1Mbits/satellite Internet generally relies on three primary components: a satellite – historically in geostationary orbit (or GEO) but now increasingly in Low Earth orbit (LEO) or Medium Earth orbit MEO) a number of ground stations known as gateways that relay Internet data to and from the satellite via radio waves (microwave), and further ground stations to serve each subscriber, with a small antenna and transceiver.

Figure 1.2: Satellite image of earth.

Other components of a satellite Internet system include a modem at the user end which links the user's network with the transceiver, and a centralized network operations center (NOC) for monitoring the entire system. Working in concert with a broadband gateway, the satellite operates a Star network topology where all network communication passes through the network's hub processor, which is at the center of the star. With this configuration, the number of ground stations that can be connected to the hub is virtually limitless.

1.2 SATELLITE

Marketed as the centre of the new broadband satellite networks are a new generation of high- powered GEO satellites positioned 35,786 kilometres (22,236 mi) above the equator, operating in K a-band (18.3–30 GHz) mode.[17] These new purpose-built satellites are designed and optimized for broadband applications, employing many narrow spot beams,[18] which target a much smaller area than the broad beams used by earlier communication satellites. This spot beam technology allows satellites to reuse assigned bandwidth multiple times which can enable them to achieve much higher overall capacity than conventional broad beam satellites. The spot beams can also increase performance and consequential capacity by focusing more power and increased receiver sensitivity into defined concentrated areas. Spot beams are designated as one of two types: subscriber spot beams, which transmit to and from the subscriber-side terminal, and gateway spot beams, which transmit to/from a service provider ground station. Note that moving off the tight footprint of a spotbeam can degrade performance significantly. Also, spotbeams can make the use of other significant new technologies impossible, including 'Carrier in Carrier 'modulation. In conjunction with the satellite's spot-beam technology, a bent-pipe architecture has traditionally been employed in the network in which the satellite functions as a bridge in space, connecting two communication points on the ground. The term "bent-pipe" is used to describe the shape of the data path between sending and receiving antennas, with the satellite positioned at the point of the bend. Simply put, the satellite's role in this network arrangement is to relay signals from the end user's terminal to the ISP's gateways, and back again without processing the signal at the satellite. The satellite receives, amplifies, and redirects a carrier on a specific radio frequency through a signal path called a transponder.

Figure 1.3: Starlink Satellite

1.2.1 HISTORY OF STARLINK

- Starlink is a satellite internet constellation developed by SpaceX, founded by Elon Musk.
- The idea for Starlink was first announced in 2015, with the goal of providing high-speed, low-cost internet access to people all over the world.

- The first Starlink satellite was launched in May 2019, with additional satellites launched in batches of 60 at a time.
- As of September 2021, there are over 1,700 Starlink satellites in orbit, with plans to launch tens of thousands more in the coming years.
- In October 2020, SpaceX began public beta testing of the Starlink system, offering internet connectivity to a limited number of users in select areas of the United States and Canada.

Figure 1.4: Multiple Starlink satellites

- In addition to the satellite launches, SpaceX has also been developing ground-based infrastructure, including user terminals and ground stations. Starlink began beta testing in select areas in 2020, with initial speeds ranging from 50 to 150 Mbps.
- By February 2021, SpaceX had launched over 1,000 Starlink satellites, with plans to launch up to 12,000 in total.
- In October 2021, Starlink became the first satellite internet service to achieve 500,000 active users. The Starlink system has faced some controversy and regulatory challenges, including concerns about interference with astronomical observations and the need for additional spectrum licenses.

CHAPTER 2

RELATED WORK

2.1 "Broadband Connectivity for Handheld Devices Via Leo Satellites"

Significant efforts are being made to integrate satellite and terrestrial networks into a unified wireless network. One major aspect of such an integration is the use of unified user terminals (UTs), which work for both networks and can switch seamlessly between them. However, supporting broadband connectivity for handheld UTs directly from low Earth orbit (LEO) satellite networks is very challenging due to link budget reasons. This paper proposes using distributed massive multiple-input multiple-output (DMMIMO) techniques to improve the data rates of handheld devices with a view to supporting their broadband connectivity by exploiting the ultra-dense deployment of LEO satellites and high-speed inter-satellite links. In this regard, we discuss DM-MIMO-based satellite networks from different perspectives, including the channel model, network management, and architecture. In addition, we evaluate the performance of such networks theoretically by deriving closed-form expressions for spectral efficiency and using extensive simulations based on actual data from a Starlink constellation. The performance is compared with that of collocated massive MIMO connectivity (CMMC) and single-satellite connectivity (SSC) scenarios. The simulation results validate the analytical results and show the superior performance of DM-MIMO-based techniques compared to CMMC and SSC modes for improving the data rates of individual users.

2.2 "Temporary Laser Inter-Satellite Links in Free-Space Optical Satellite Networks"

Laser inter-satellite links (LISLs) between satellites in a free-space optical satellite network (FSOSN) can be divided into two classes: permanent LISLs (PLs) and temporary LISLs (TLs). TLs are not desirable in next-generation FSOSNs (NG-FSOSNs) due to high LISL setup time, but they may become feasible in next-next-generation FSOSNs (NNG-FSOSNs). Using the satellite constellation for Phase I of Starlink, we study the impact of TLs on network latency in an

NG-FSOSN (which has only PLs) versus an NNG-FSOSN under different long-distance inter-continental data communications scenarios, including Sydney–Sao Paulo, Toronto–Istanbul, Madrid–Tokyo, and New York–Jakarta, and different LISL ranges for satellites, including 659.5 km, 1,319 km, 1,500 km, 1,700 km, 2,500 km, 3,500 km, and 5,016 km. It is observed from the results that TLs provide higher satellite connectivity and thereby higher network connectivity, and they lead to lower average network latency for the NNG-FSOSN compared to the NG-FSOSN in all scenarios at all LISL ranges. In comparison with the NG-FSOSN, the improvement in latency with the NNG-FSOSN is significant at LISL ranges of 1,500 km, 1,700 km, and 2,500 km, where the improvement is 16.83 ms, 23.43 ms, and 18.20 ms, respectively, for the Sydney–Sao Paulo inter-continental connection. For the Toronto–Istanbul, Madrid–Tokyo, and New York–Jakarta intercontinental connections, the improvement is 14.58 ms, 23.35 ms, and 23.52 ms, respectively, at the 1,700 km LISL range.

2.3 "Internet From Sky: Starlink"

The demand of highspeed internet connectivity is in the high demand in the people all overthe world due to ongoing pandemic situation and India is one of the most promising consumer markets of the world. Starlink has given an introductory offer to the customers all over the world including India to have the highspeed internet from the "sky" from satellite, in current situation where all the education and companies are going online for their daily business and there is an acute demand for the highspeed internet connectivity. There is a demand and there is a solution for that, directly from the "sky" but at the same time there are other internet providers like Reliance JIO, Vodafone- Idea, Airtel and others who are into FTTH, Mobile Internet and Internet from Satellite, people are already using Internet but the point of speed of the Internet could be turning point. Another point to ponder the price that is $99 and $499, that could create some hurdles in the market as Indian economy is price sensitive and due to ongoing pandemic situation, many people are struggling to keep up with their jobs. In this research paper the author tries to find out the people view point on the Star link's introductory offer of providing Internet from SKY and other market condition like competition with already established players in the market.

2.4 “A Techno-Economic Framework for Satellite Networks Applied to Low Earth Orbit Constellations: Assessing Starlink, Oneweb and Kuiper”

The emergence of Low Earth Orbit (LEO) satellite systems has been seen as a potential solution for connecting remote areas where engineering terrestrial infrastructure is prohibitively expensive. Despite the hype, we still lack an open-source modeling framework for assessing the techno-economics of satellite broadband connectivity which is therefore the purpose of this paper. Firstly, a generalizable techno-economic model is presented to assess the engineering-economics of satellite constellations. Secondly, the approach is applied to assess the three main competing LEO constellations which include Starlink, Oneweb and Kuiper. This involves simulating the impact on coverage, capacity and cost, as both the number of satellites and quantity of subscribers increases. Finally, a global assessment is undertaken visualizing the potential capacity and cost per user via different subscriber scenarios. The results demonstrate how limited the capacity will be once resources are spread across users in each satellite coverage area. For example, for 0.1 users per km2 (so 1 user per 10 km2), we estimate a mean per user capacity of 24.94 Mbps, 1.01 Mbps and 10.30 Mbps for Starlink, Oneweb and Kuiper, respectively, in the busiest hour of the day. But if the subscriber density increases to 1 user per km2, then the mean per user capacity drops significantly to 2.49 Mbps, 0.10 Mbps and 1.02 Mbps. LEO broadband will be an essential part of the connectivity toolkit.

2.5 “Starlink Space Network-Enhanced Cyber–Physical Power System”

The information and communication technology (ICT) is increasingly involved in the measurement, operation, control and protection of the cyber-physical power system (CPPS). As one of the most promising communication infrastructure projects, Starlink is a satellite Internet constellation being constructed by SpaceX for providing global Internet access, which can benefit the network service supply for the communication-enabled power system equipment in locations where the network access is unreliable, expensive, or completely unavailable. In this letter, the future applications of the Starlink space network in CPPSs are explored: the communication infrastructure and transmission parameters are discussed, and the corresponding test case was emulated in real-time on the heterogeneous co-emulation platform to validate the proposed concept of space network enhanced cyber-physical power system.

CHAPTER 3

PROBLEM STATEMENT

Despite advances in communication technology, there are still many areas around the world that lack reliable, high-speed internet connectivity. Traditional communication infrastructure, such as wired and cellular networks, are often costly and difficult to deploy in remote or underserved areas. This lack of connectivity can have significant social, economic, and educational impacts, hindering development and limiting opportunities.

To address this problem, companies such as SpaceX are developing new satellite communication systems, such as Starlink, which aim to provide low-cost, high-speed internet connectivity to people around the world, particularly in areas that are difficult to reach using traditional infrastructure. While these systems have the potential to revolutionize global connectivity, they also face a number of technical, regulatory, and logistical challenges that must be overcome in order to ensure their success.

Therefore, the problem statement for the Starlink topic is how to design, develop, and deploy a reliable, scalable satellite communication system that can provide affordable and high-speed internet access to people around the world, particularly in underserved or remote areas, while also addressing technical, regulatory, and logistical challenges.

3.1 EXISTING SYSTEM

- **Wired and cellular networks:**

Wired networks, such as cable and fiber-optic networks, are typically used to provide high-speed internet access in urban and suburban areas. However, these networks are costly to deploy and maintain, and are often not feasible in remote or underserved areas. Cellular networks, on the other hand, use mobile towers to provide wireless internet connectivity. While cellular networks have wider coverage than wired networks, they can be costly to access, particularly in areas with limited infrastructure.

- **Other satellite communication systems:**

Satellite communication systems have been used for decades to provide internet connectivity, particularly in remote or underserved areas. These systems typically use geostationary satellites that orbit the Earth at a much higher altitude than Starlink's LEO constellation. However, these systems can suffer from high latency and limited bandwidth, which can make them unsuitable for some applications.

In comparison, the Starlink system is designed to overcome many of the limitations of existing satellite communication systems, by using a large constellation of low-orbitingsatellites that can provide high-speed, low-latency internet connectivity to users around the world. By leveraging advanced technology, such as phased-array antenna technology, the Starlink systemaims to provide a reliable and affordable internet connectivity solution to underserved areas

3.1.1 STAR LINK

Figure 3.1: Starlink Constellation

The "Starlink" is a SpaceX project to build a broadband network to provide space internet (i.e., satellite-based) to the remotest corner of the world. This project is the most ambitious of three active initiatives to begin beaming data transmissions from space.

The Starlink project by SpaceX aims to create a broadband network using a collection of thousands of circling spacecrafts. The Starlink satellites are equipped with Hall thrusters, which are used to maneuver in orbit, maintain altitude, and guide the spacecraft back into the atmosphere after their missions. Hall thrusters generate an impulse using electricity and krypton gas. The goal of the project is to create a low-cost, satellite-based broadband network that can provide global internet access. 42,000 satellites will eventually be part of the Starlink network. In Low Earth Orbit, the Starlink satellites will be placed in an altitude range between 350km and 1,200 km (LEO). Up to 2,000 kilometers are covered by the LEO. Reduced latency between a user seeking data and the server transmitting that data is the key benefit of placing satellites in LEO for space-based Internet.

However, LEO has a significant drawback. They are less tall; therefore, their signals only reach a small region. To send signals to every corner of the world, a lot more satellites are therefore required. Once operational, space-based Internet networks are expected to change the face of the Internet.

3.2 SIGNIFICANCE OF SPACE INTERNET

- Uninterrupted Internet: To guarantee that Internet services are dependable, unbroken, and capable of providing a wide range of public services to people all over the world that are globally accessible.
- Access to the Internet: Due to existing methods of distributing the internet via fiber optics and wireless networks, which cannot convey it everywhere on the earth, around half of the world's population lacks access to dependable Internet networks.
- Geographical barrier: In many remote areas, or places with difficult terrain, it is not feasible or viable to set up cables or mobile towers.
- Industrial revolution: The Internet of Things (IoT) may be incorporated into practically any household, whether urban or rural and is predicted to revolutionize services like autonomous vehicle driving.
- Global Connectivity: Space internet has the potential to provide internet connectivity to people in remote or underserved areas, regardless of their location on the planet. This can have a significant impact on economic development, education, and social connectedness.

- High-speed internet: Space internet systems such as Starlink have the potential to provide high-speed internet connectivity to users, even in remote areas. This can facilitate faster communication, online education, remote working, and other applications that require high-speed internet.
- Low latency: Space internet systems can offer low latency connections, which are particularly important for applications such as gaming, video conferencing, and remote work.
- Resilience: Space internet can provide a resilient communication network, which can be used as a backup system in case of natural disasters or other disruptions to traditional communication infrastructure.
- Improved access to information: Space internet can help to bridge the digital divide by providing access to information and resources that were previously unavailable to people in remote or underserved areas

3.3 SERVICES OF STARLINK

- Satellite Internet: Starlink provides satellite-based internet connectivity to underserved areas of the planet, as well as competitively priced service in more urbanized areas.
- Satellite Cellular Services: For a future service, T-Mobile US and SpaceX are partnering to add satellite cellular service capability to Starlink satellites. It will provide dead-zone cell phone coverage across the US using existing mid band PCS spectrum that T-Mobile owns. Cell coverage will begin with messaging and expand to include voice and limited data services later, with testing to begin in 2023.
- Star Shield Program: In December 2022, SpaceX announced Star shield, a program to incorporate military or government entity payloads on board a customized satellite bus. These satellites are heavier, with twice the area as a single Starlink v1.5 and have two pair of solar arrays as opposed to one on Starlink Block v1.5. While Starlink is designed for consumer and commercial use, Star shield is designed for US government use, with an initial focus on three areas, namely, earth observation, communications and hosting payloads.

CHAPTER 4

SYSTEM DESIGN

The Starlink system is made up of a constellation of thousands of small, low-orbiting satellites that communicate with ground stations and user terminals to provide internet connectivity. The satellites are designed to operate in a unique, low Earth orbit (LEO) at an altitude of around 550 km (340 miles), which is much closer to Earth than traditional communication satellites. This allows for faster data transmission and lower latency, as signals don't have to travel as far.

The Starlink satellites are relatively small, with a mass of around 260 kg (570 lb.) each, and are powered by solar panels. They are designed to be modular, so that they can be easily replaced or upgraded as needed. The satellites communicate with each other using a laser inter-satellite link (ISL) system, which allows for high-speed data transfer between satellites in the constellation. On the ground, users connect to the Starlink network using a small, flat antenna called a user terminal. The terminal is designed to automatically track the Starlink satellites as they pass overhead, ensuring a reliable connection. The terminal communicates with the Starlink satellites using phased-array antenna technology, which allows for fast, low-latency data transfer.In addition to the satellites and user terminals, the Starlink system also includes a network of ground stations that are used to communicate with the satellites and connect them to the wider internet. These ground stations are strategically located around the world, and are connected to theinternet backbone using high-speed fiber optic cables.

4.1 SYSTEM ARCHITECTURE

The architecture of the Starlink system is shown in Figure. Ground stations or Starlink Gateways are in constant communication with the satellites. They provide internet access and control information to user terminals. User-Satellite communication uses Ku band and Ground Station-Satellite communication uses Ku band for downlink and Ka band for uplink. SpaceX’s satellites generate ultra-small spot-size beams due to the fact that they are much closer to the earth compared to geostationary satellites. Close proximity to the earth provides higher speed and lower latency. The estimated total bandwidth throughput at the start of the commercial deployment is 23.7 Tbps.

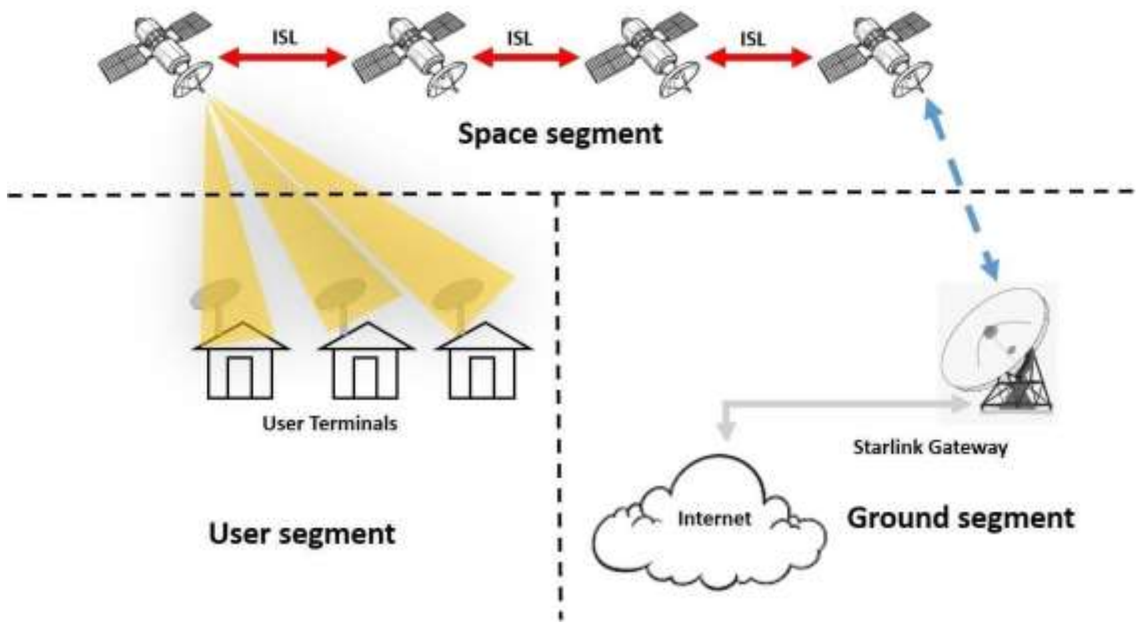

Figure 4.1: Starlink System Architecture.

The Starlink system architecture can be divided into three main components: the satellites, the ground stations, and the user terminals.

- Satellites:

The Starlink satellite constellation consists of thousands of small satellites in low Earth orbit. The satellites communicate with each other using a laser inter-satellite link system, which enables high-speed data transfer between the satellites. The Starlink satellites are also equipped with antennas that communicate with the user terminals on the ground.

- Ground Stations:

The Starlink ground station network is made up of several gateway stations that are strategically located around the world. The ground stations are connected to the internet backbone using high-speed fiber optic cables. These ground stations are used to communicate with the satellites in orbit and to provide internet connectivity to the user terminals.

- User Terminals:

The Starlink user terminals are small, flat antennas that are installed on the user's premises. The user terminals automatically track the Starlink satellites as they pass overhead, maintaining a reliable connection. The user terminals use phased-array antenna technology to communicate with the satellites in orbit, enabling fast, low-latency data transfer.

4.1.1 DIGITAL CONNECTIVITY

Presents the conceptual idea of a rural off-grid digital connectivity center. In this center, internet connectivity is provided via Starlink and is powered by solar energy. First, let’s do an approximate power requirement calculation. Assume that this center is equipped with 5 desktop computers and 5 laptops. Additionally, 40 tablets can be simultaneously used in this location. The physical structure of the center can either be constructed for the purpose or it may be a re-purposed existing building. The primary objective of the digital connectivity center would be to enhance the educational opportunities of children via reliable digital connectivity. Additionally, resources could be used by adults for e-commerce in the evening and at night provided that there is sufficient energy storage. For a grid-connected digital connectivity center, a solar energy generation system is optional.

It would be useful to consider the economic viability of such a center with respect to the connectivity cost. Here, three possible utilization schemes are considered. In scheme 1, each user gets to use the center for a 4-hour time slot per day. Considering 8-hour daytime usage, 100 users can use the center per day. In scheme 2, each user gets to use the center for a 3-hour time slot per day. Considering 9-hour daytime usage, 150 users can use the center per day. In scheme 3, each user gets to use the center for a 2-hour time slot per day. Considering 8-hour daytime usage, 200 users can use the center per day. These number can be decided considering the ground situation such as number of students and the area of service.

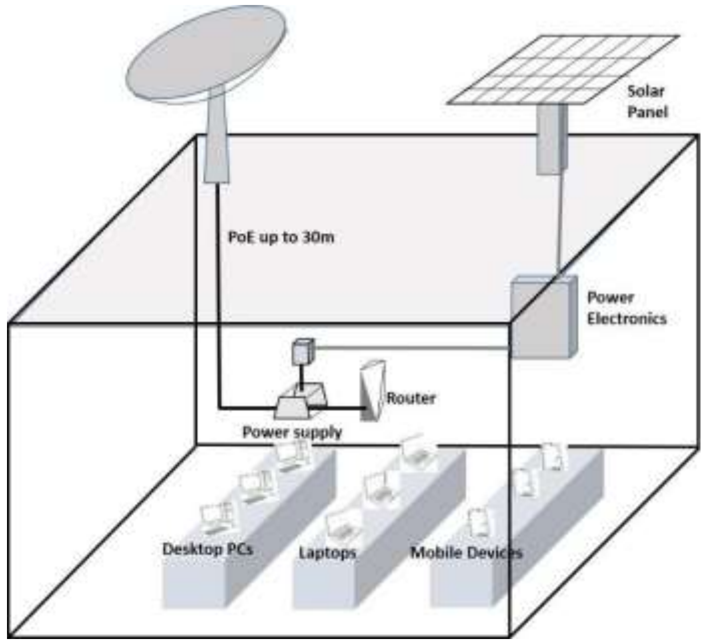

Figure 4.2: Proposed Rural Digital Connectivity Center

The Starlink system architecture is designed to be highly modular and scalable. The satellite constellation can be expanded or upgraded easily, and new ground stations can be added as needed to provide coverage to new areas. Overall, the system architecture of Starlink is highly innovative and represents a significant advance in satellite communication technology. It has the potential to provide high-speed, low-cost internet access to people all over the world, particularly in underserved or remote areas. However, it also faces challenges related to regulatory and technical issues, which will need to be addressed in order to ensure its long-term viability and success. It is reasonable to assume that a desktop PC with an LED display consumes approximately 150 W of power and a laptop consumes 60W of power. Additionally, a tablet consumes approximately 10 W of power. So, all the devices combine consume approximately 1.45 kW. Considering all the other requirements a 3-kW solar energy system would suffice to power up such a center.

CHAPTER 5

IMPLEMENTATION AND EVALUATION

In CPPSs, the real-time measurement and control are achieved via the data packet-based connection between the communication modules installed on various power equipment. The transmission can be wired in fiber or wireless in vacuum, as long as the transmission latency could meet the performance requirements and the economic cost is reason- able. Fortunately, due to the low orbit (550 km altitude) and fast transmission speed in vacuum, the propagation delaydifference between the SpaceX's Phase I Starlink constellation and the terrestrial optical fiber network is small, and the delay of space propagation could be even smaller when the hop distanceis longer than 2500 km. Therefore, the Starlink network could be exploited in the CPPS for wide area measurement, protection and control (WAMPAC) applications in the areas with weaknetwork connections. The proposed space network enhanced cyber-physical power system is shown, where the space network layer is added to the existing two-layer CPPS architecture.

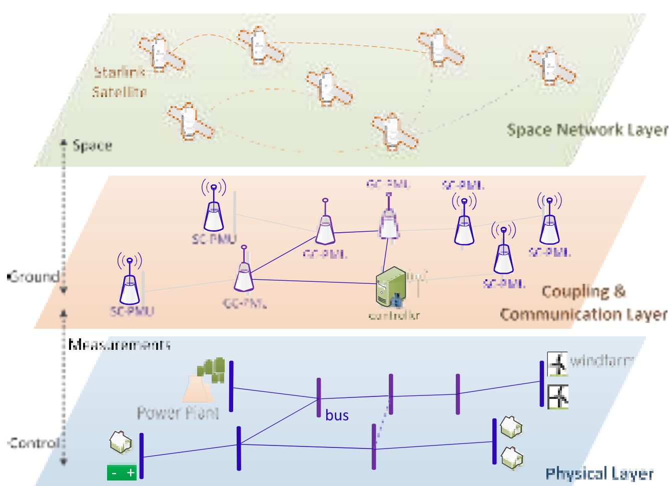

Figure 5.1: Proposed space network enhanced cyber-physical power system architecture

The physical layer contains the power generation, distribution, transmission, storage, conversion, consumption, and protection equipment, where the renewable energies such as the windfarm generation and solar power generation are also included in the system.

The basic network component in the cyber layer is the sampling and reporting device installed on the power equipment or processing buses, and the commonly used device is the phasor measurement unit (PMU). A PMU is responsible to measure the electrical quantities and report the corresponding phasor values to the phasor data concentrator (PDC) that collects the measurements from the PMUs in the area or the controller that makes decisions for global control. In addition to the traditional physical and cyber layers, the third layer - space network layer, is proposed in this letter.

The space network layer is utilized to provide fast and reliable connection services for the areas where the ground-based network service is not good. Assume that some PMUs (called space communication-based PMU, SC- PMU) are located at higher elevations or offshore places and no stable links can be connected, which are different from the traditional ground communication-based PMUs (GC-PMU). Then their operations are based on the space communication between the PMUs, PDCs and controllers. As estimated by the transmission delay for a 5000 km distance could be smaller than 20ms, which is quite significant to meet the delay requirements of PMU connections. In fact, the time requirement of the phasor measurement-based detection and control action is on the order of 200-300ms and the transmission delays are insignificant to impact the overall operation time of wide-area control scheme.

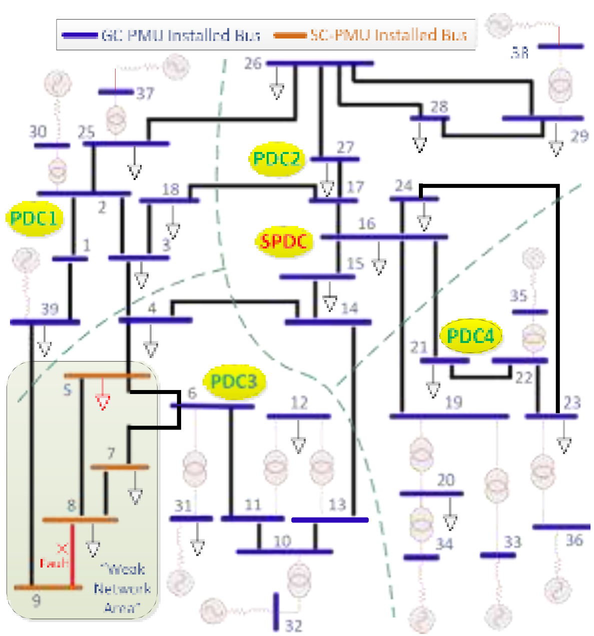

Figure 5.2: bus test power system and cyber-layer configuration

Therefore, it can be expected that the global power system measurement and control can be achieved with the space network layer involved in the cyber layer. For the implementation of the Starlink space network enhanced cyber physical power system, SC-PMU is the key component since the construction of space network is the task of Starlink. The SC-PMU can be customized by installing a user terminal to enable the space data transmission via the satellites: according to the size of the flat user terminal is like a pizza box, which has phased array antennas and can track the satellites. The terminals can be mounted anywhere, as long as they can see the sky. With the technology development and mass production, the terminal price can be very low. Another implementation issue is the communication protocols, since it is not practical and economical to customize the Starlink satellites for pure CPPS applications. Fortunately, except for the local communication networks within a substation where the protocols are customized based on MAC address, in wide area communication of CPPS the transmission standards such as the IEC 61850 are all based on the IP address, which means the CPPS communication network can directly use the Starlink Internet service for its own applications.

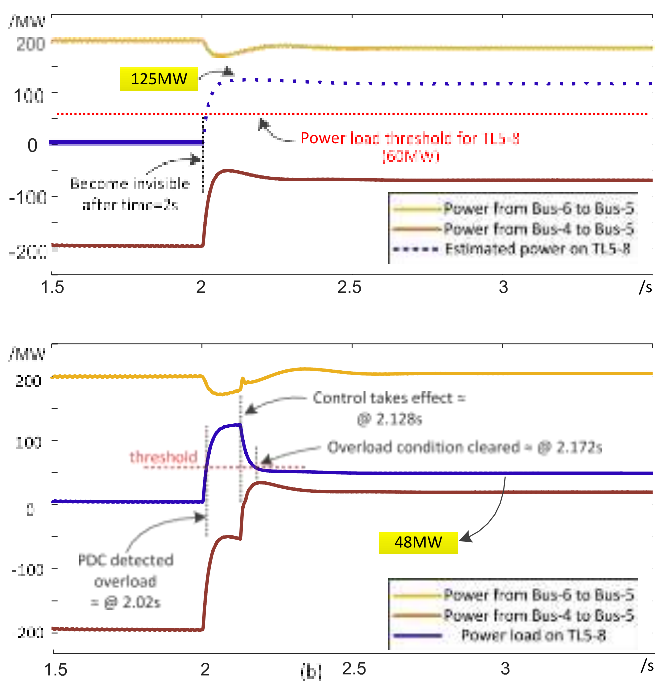

Figure 5.3: Emulation results of active power flows in the two cases: a) ground-based networking; b) space-based communication case.

CHAPTER 6

FEATURES

6.1 STAR TRACKER

Figure 6.1: Star Tracker

A star tracker is an optical device that measures the positions of stars using photocells or a camera. As the positions of many stars have been measured by astronomers to a high degree of accuracy, a star tracker on a satellite or spacecraft may be used to determine the orientation (or attitude) of the spacecraft with respect to the stars. In order to do this, the star tracker must obtain an image of the stars, measure their apparent position in the reference frame of the spacecraft, and identify the stars so their position can be compared with their known absolute position from a star catalog. A star tracker may include a processor to identify stars by comparing the pattern of observed stars with the known pattern of stars in the sky.

6.2 AUTONOMOUS COLLISION AVOIDANCE

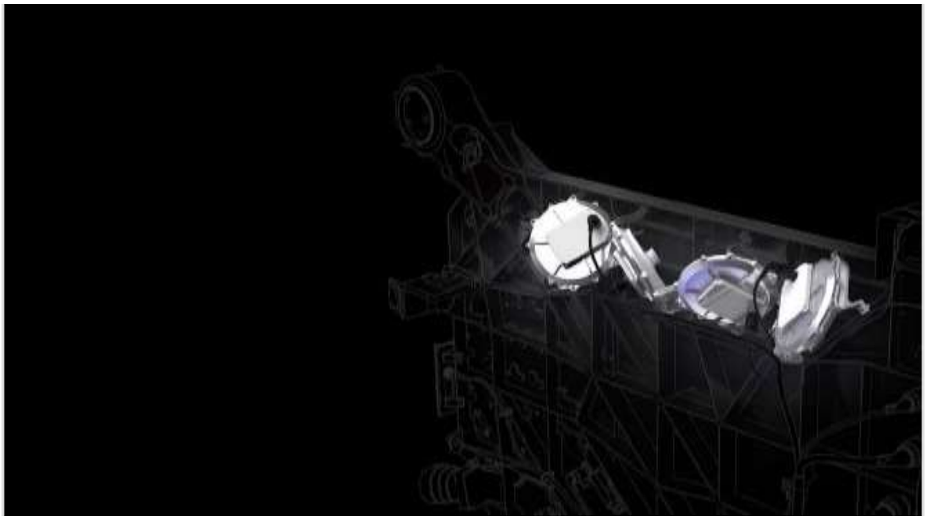

Figure 6.2: Spacecraft Collision Avoidance.

Spacecraft collision avoidance is the implementation and study of processes minimizing the chance of orbiting spacecraft inadvertently colliding with other orbiting objects. The most common subject of spacecraft collision avoidance research and development is for human-made satellites in geocentric orbits. The subject includes procedures designed to prevent the accumulation of space debris in orbit, analytical methods for predicting likely collisions, and avoidance procedures to maneuver offending spacecraft away from danger. Orbital speed around large bodies (like the Earth) are fast, resulting in significant kinetic energy being involved in on-orbit collisions. For example, at the Low Earth orbital velocity of ~7.8km/s, two perpendicularly colliding spacecraft would meet at ~12.2 km/s. Almost no known structurally solid materials can withstand such an energetic impact. Most of the satellite would be instantly vaporized by the collision and broken up into myriad pieces ejected at force in all directions. Because of this, any spacecraft colliding with another object in orbit is likely to be critically damaged or completely destroyed.

6.2.1 COLLISION PREDICTION METHODS

Most impact risk predictions are calculated using databases of orbiting objects with orbit parameters like position and velocity measured by ground-based observations. The United States Department of Defense Space Surveillance Network maintains a catalog of all known orbiting objects approximately equal to a softball in size or larger. Information on smaller articles of space debris is less accurate or unknown. Once the exact orbit of an object is accurately known, the DoD's SSN publishes known parameters for public analysis on the DoD's space-track.org and NASA's Space Science Data Coordinated Archive. The object's orbit can then be projected into the future, estimating where it will be located and the chance it will have a close encounter with another orbiting object. Long-term orbit projections have large error bars due to complicated gravitational effects that gradually perturb the orbit (akin to those of the Three-body problem) and the measurement errors of ground tracking equipment. For these reasons, methods for more precise measurement and estimation are an active field of research. NASA conducts orbital projections and assesses collision risk for known objects larger than 4inches (10 cm). For critical assets like the International Space Station, evaluations are made for the risk that any object will traverse within a rectangular region half a mile (1.25 km) above/below and 15 miles (25 km) ahead/behind in orbit and to either side of the spacecraft. This high-risk zone is known as the “pizza box" because of the shape it resembles.

6.2.2 Collision avoidance methods

- Spacecraft with onboard propulsion.
- Docking aborts.
- Spacecraft without onboard propulsion.
- Complicating factors.
- Effects on launch windows.

6.3 SOLAR ARRAY

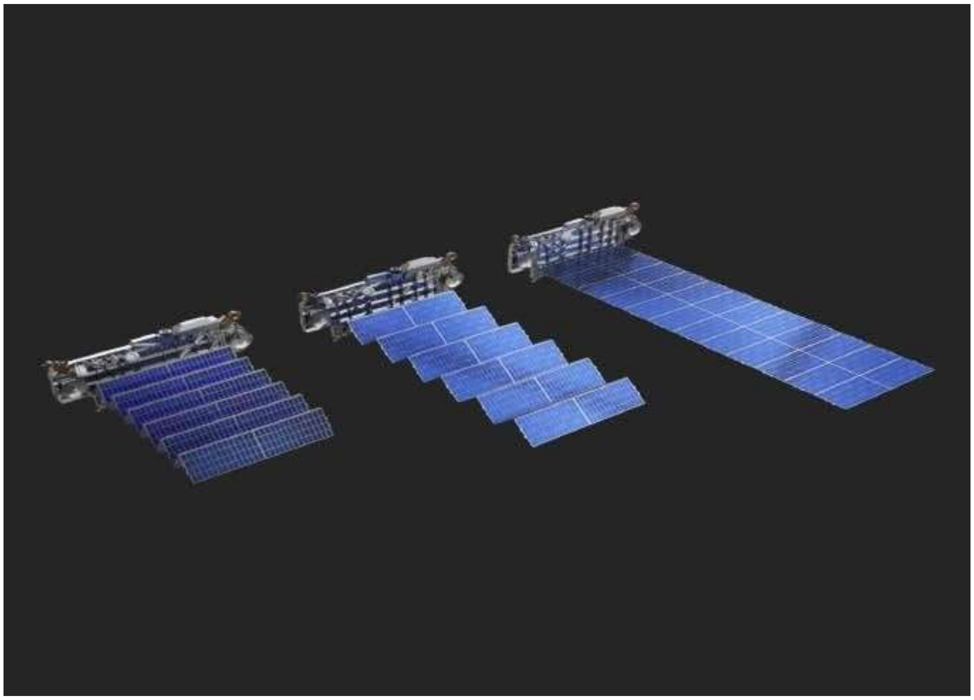

Figure 6.3: Solar Array

Space solar arrays must survive in the hostile space environment. The most dangerous space solar array environmental interaction is spacecraft charging, which can lead to potentially disabling arcing. In this chapter we discuss why solar arrays are often the spacecraft components most likely to arc and how this is related to electrical charging of the spacecraft. The basic charging equations are given. Factors involved in charging and arcing are enumerated. How charging is related to the space plasma environment is discussed. The different types of charging are given, and how they may lead to arcing on the solar arrays. Transient arcs and sustained arcs are differentiated. We describe the effects of arcing and give examples. Standards related to charging and arcing are listed and described, and mitigation strategies (both passive and active) are surveyed. Because charging and arcing are driven by the space environment, models of the space plasma environment and charging models are listed and described. Finally, we make the case for the necessity of laboratory measurements of arcing voltage thresholds, both for primary and sustained arcs.