CHAPTER I
INTRODUCTION

1.1 Background

The growth of IT and telecommunications is entering the rapidly expanding high-tech sector[1]. High-speed data services are necessary in the fourth industrial revolution[2]. Regional internet data demand in Indonesia is still rising, and high data rates and traffic capacity are required. Since Indonesia is an archipelagic nation with a large geographic area, some residents live unconnected to land network infrastructure through cable or fiber optics, making rural communities vulnerable to the demand for Internet access[1]. All significant islands have installed underwater cables, but the satellite system must keep up with the constantly increasing demand for broadband data. Since the growing demand for 3G and LTE mobile connectivity presents a significant problem in many underserved rural areas, a comprehensive examination of all existing elements is required when creating infrastructure, especially in the 3T area (frontier, outermost, and least development region)[3], [4].

Every year, the increasing number of Internet users represents Indonesia's high need for the Internet. Based on data from APJI (the Indonesian Internet Service Providers Association), the percentage of internet penetration in Indonesia is 78.1% or 215 million users in 2023. Then, in 2024, it increased to 79.5% with 221 million users or an increase of 1.31% from the previous year[5]. Satellite technology is the perfect answer to Indonesia's internet connectivity problem [3]. Over the past few decades, satellite communication systems have garnered increased attention, expanding their use beyond traditional media broadcasting to include data services such as broadband SatComs. The necessity to expand broadband access to underserved areas and the growing demand for more capacity in the areas that are currently covered have been the primary drivers of this change. More precisely, because of the conventional telecommunications infrastructure's limited capacity, the great majority of densely populated urban regions are currently experiencing service and coverage shortages. Furthermore, large exurban areas still lack a dependable infrastructure for communication technologies and the Internet. In this regard, satellite communication systems provide numerous options for boosting coverage and data speeds while aligning with the goals of upcoming communication generations [6].

To reach all distant communities and critical public institutions and increase the penetration of broadband access, the Indonesian government decided to use high-throughput satellites (HTS) to supply broadband services, defined as internet access with guaranteed connectivity. Triple-play capabilities, security, and information durability with a minimum fixed access speed of 2 Mbps[7]. HTS is the outcome of current satellite trends and is characterized by its increased speed and capacity compared to classic satellites. Essential elements of HTS architecture are frequency reuse using the cellular system, which can use the same frequency simultaneously, and the utilization of many spot beams, which can reach a broad area. Deploying HTS is necessary to meet customer requirements, such as adding new apps, increasing the capacity per user (Mbps/user), and putting more people into service. HTS is a mature technology, as evidenced by the many satellite providers that have launched it. Since the spectrum used in HTS technology is too limited, frequency reuse may offer high capacity and maximum quality of service despite the current restrictions[8].

The throughput of current high-capacity GEO satellites ranges from 90 Gb/s to 140 Gb/s. As new services and applications emerge, future communication satellites must expand their capacity to meet the rapidly rising bit rate requirements[9]. The primary obstacle to reaching such high throughput numbers is the restriction of available bandwidth. Additionally, using resource allocation technology, the multibeam satellite communication system may satisfy the growing needs of major communications companies. Multi-beam satellite antenna technology has emerged as a viable solution to mitigate resource scarcity and attain greater satellite throughput than conventional wide-beam satellites due to its benefits of beam space isolation and frequency reuse[10].

Multibeam coverage effectively uses the system's bandwidth, a useful but expensive resource in any communication system. The same frequencies can be reused because HTS multibeams are spatially separated. The overall bandwidth of the system is significantly increased via frequency reuse technology. The system's capacity has risen then [11], which was partly caused by congestion and the United Nations International Telecommunication Union's (ITU) limited spectrum availability for satellites[10]. As a result, the frequency band in the user link needs to be reused numerous times among numerous spot beams[9], [12]. On the other hand, co-channel interference (CCI) between shafts using the same frequency band is an inevitable consequence of the multi-beam antenna's side-lobe effect[11], [9], [13].

Other transmitters in other beams using the same channel (i.e., the same polarization and carrier) at the same time are the most significant source of interference at the beam receiver (on the satellite) compared to cross-polarization interference, adjacent channel interference, and other interferences [14], this interference has a more dominant position in the overall system interference. Although antenna technology has advanced, unwanted side lobes remain a complicated issue in geostationary satellite communications because co-channel beam interference can significantly impact the user terminal's ability to receive the desired signal, limiting the potential for capacity increases. This is especially true for ground stations using small antennas, where increased interference can penalize the link throughput or availability[12]. Because forward downlink and return uplink are seen as more traditional and entail high-frequency reuse in the user terminal, intrasystem interference, such as CCI in HTS, occurs on these channels[14]. Then, download and streaming services result in high data rates in the forward downlink direction; the user downlink is more significant than the user uplink in data rates[9].

In previous related research on HTS and CCI, Hector Fenech analyzed CCI on Ka-Sat and Eutelsat HTS with a 4-color scheme system. The communication performance of users in the service area is evaluated on the forward downlink using *EIRP* distribution and on the return uplink using *G/T* distribution, including uplink *C/I* and downlink *C/I*. In the forward downlink and return uplink, interference in the wanted beam and interferer beam is represented by *C/(N+I),* which is a function of *C/N* and *C/I*, where *C/I* is a function of the contributions from copolar and cross-polar components of interfering beams relative to the victim beams. Additionally, the forward downlink and return uplink capacity in each user cell depends on the *C/(N+I)* of the downlink and uplink[15], [16]. This study provides formulas for both user uplink and downlink. However, it does not analyze the degradation result caused by the impact of interference on the technical aspects, such as the reduction in *C/N* and capacity. Additionally, it does not examine the effect of interference on economic and regulatory aspects.

A study to determine the feasibility of implementing Ka-band HTS technology in Indonesia based on technical aspects of link budget and capacity analysis was conducted by Ignatius Daru Kristiadi. The link budget was calculated for forward uplink, forward downlink, return uplink, and return downlink based on *C/N*. Subsequently, capacity calculations were performed using the Shannon Theorem with the *C/N* values under clear sky and rain conditions. The results indicate that implementing the HTS system in Indonesia is predicted to be feasible for both clear skies and rainy environmental conditions[17].

This research analyzes the CCI of multibeam from Indonesian HTS-A at Ku-band frequency techno-economic and regulatory. By examining factors like *C/N, C/I*, and *C/(N+I)* and the effect of interference on capacity decrease, the technical conduct concentrates on the user side of both forward downlink and return uplink communications. The economic analysis analyzes the decremental revenue based on link capability before and after interference, including BHP analysis and additional economic comparative through Ku-band and C-band, which will be linked to the economy through capacity reduction. Technical considerations: The angle of interference is based on Rec. ITU-R S.1855 for the gain of the radiation pattern of the earth station antenna used in forward downlink and Rec. ITU-R S.672-4 analyzes the satellite antenna gain used in return uplink.

As part of the development of this research, the results have been presented and published at the 2024 IEEE Asia-Pacific Conference on Geoscience, Electronics and Remote Sensing Technology (AGERS) which shows significant contributions to this field.

1.2 Problem Identification

As an archipelago country separated by islands, Indonesia finds it challenging to implement telecommunications network infrastructure, especially in areas outside Java, while internet needs in Indonesia are increasing yearly. HTS is the right technological solution for broadband access in Indonesia, especially in 3T areas, which are difficult to cover by terrestrial and fiber optic networks. HTS has the main advantages, namely multibeam and a frequency reuse system, which will save bandwidth as a limited and expensive resource. However, on the other hand, HTS also experiences CCI caused by beams that use the same channel (both frequency, polarization, and carrier). This interference can reduce signal quality and affect satellite capacity. So, through this research, an analysis will be carried out on several of these primary problems, including:

1. The technical evaluation of CCI, such as link budget and capacity, includes frequency and polarization between spot beams using the same channel.
2. Economic analysis due to CCI is based on capacity before and after interference.
3. Regulatory analysis on CCI as a reference of the interference angle based on Rec. ITU-R S.1855 to find earth station gain antenna and Rec. ITU-R S.672-4 to calculate satellite gain antenna.

1.3 Objective

Based on the background and problem identification that underlies this thesis research, its objective can be described as follows.

1. Conduct the technical aspects analysis of CCI Ku-band GSO Indonesian HTS-A in forward downlink and return uplink.
2. Analyzing the economic impact based on capacity affected by CCI, including incremental and decremental revenue before and after interference.
3. Regulatory analysis is used to find the antenna gain from a certain interference angle based on Rec. ITU-R S.1855 for ES gain antenna and Rec. ITU-R S.672-4 for satellite gain antenna.

1.4 Scope of Work

To avoid the spreading direction of the discussion in this study, several limitations of the problem will be given.

1. The research was carried out on CCI on the Indonesian HTS-A multibeam satellite, which operates on the Ku-band frequency and has a coverage area in Indonesia.
2. Technical analysis to determine the CCI produced based on *C/N, C/I*, and *C/(N+I)* link budget calculations.
3. An economic analysis was performed to determine how capacity reduction affects satellite operator's revenue due to CCI without comparing capital expenditures (CAPEX) and operational expenditures (OPEX) against revenue before and after interference.
4. Based on the capacity reduction, an economic analysis was conducted to ascertain the revenue impact that CCI would have on satellite operators.

5. Regulatory analysis of CCI on multibeam as a reference gain on certain interference angles from Rec. ITU-R S.1855 and Rec. ITU-R S.672-4.
6. CCI calculations are performed using a 4-color scheme on 8 beams.
7. CCI research is calculated on the affected user communications, consisting of forward downlink and return uplink before and after interference.
8. The position of the earth station is represented by the *C/I* calculation in the forward downlink via satellite *EIRP*, and the location of the earth station is represented by the *G/T* calculation in the return uplink.
9. Interference on the return uplink is calculated without a probability distribution and is predicated on the location of the interferer and the earth station being known.
10. The research was conducted for CCI on the Indonesian HTS-A as an internal system and was not compared with interference from external systems, including other GSOs and NGSOs.

1.5 Hypothesis

HTS does offer high throughput capacity and advantages in the concept of multibeam and frequency reuse. However, frequency reuse into multibeam intended to save and reduce bandwidth can cause interference between systems called CCI. This is a significant problem in HTS communications because it can cause various problems, significantly reducing the quality of the signal the user receives. This can seriously impact HTS communications first because the antenna gain is reduced due to the effects of side lobes in the beam interferer and the antenna radiation pattern. Because of a decrease in gain, the *EIRP* in downlink communications and the antenna gain in the *G/T* uplink. Then, CCI will have an impact on decreasing the Carrier-to-Noise Ratio *(C/N)*, Carrier-to-Interference Ratio *(C/I)*, and Carrier-to-Noise plus Interference Ratio *C/(N+I),* also reduce the capacity and revenue of satellite operators.

1.6 Research Methodology

The methodology used in the thesis research is as follows.

1. Literature Study

   A literature study was carried out to examine theories from textbooks, journals, and ITU recommendations that support research based on CCI problems on multibeam HTS, starting from technical, economic, and regulatory discussions.

2. Collecting Data

   Collect data from satellite operators, textbooks, research journals, and appropriate ITU recommendations relating to parameters used in technical analysis of satellite, gateway, earth station, and carrier parameters related to CCI on multibeam HTS.

3. Technical Analysis

   Technical analysis was used to identify the effect of multibeam CCI on the signal quality and capacity of the HTS based on the *C/(N+I)* forward and return link budget calculation.

4. Economic Analysis Regulatory Analysis

   Economic analysis determines a satellite operator's revenue impact, and BHP analysis is based on the loss capacity caused by CCI on the Indonesian HTS-A multibeam.

5. Regulatory Analysis

   In technical calculations, regulatory analysis finds a gain antenna at certain interference angles.

6. Conclusion

   The results of this research are intended to answer the identification of problems discussed previously. In the future, this research can be used as a recommendation for satellite operators and the Indonesian government to implement HTS in Indonesia.