# CHAPTER I
# INTRODUCTION

## 1.1 Background

Information and communication technology has become one of the most important resources in this current time. Broadband networks, fiber optics and satellites have become such an important tool to fulfill the needs of information exchange around the world. Driven by the rapid expansion of several Internet-based services and applications, which has led to a constant rise in the need for connections that are high-speed, diverse, highly reliable, and low latency can be a key component in meeting this demand because of their special qualities and technological advancements in the industry, whether used as an integrated satellite-terrestrial network or as a stand-alone solution [1].

Traditionally, Geostationary Orbit (GSO) satellite is used as a main option of satellite communications. GSO orbits at 35.786KM above the earth and maintains a constant position relative to earth's surface, this can happen because GSO has 23 hours, 56 minutes, and 4 seconds of orbital period in its first implementation GSO serving using only one wide beam. Due to its stationary position, GSOs are usually used to provide communication, navigation, and environmental monitoring services. In recent years multibeam GSO systems have been implemented to allow efficient frequency reuse and high throughput rates across the coverage area, these systems called High Throughput Satellite (HTS). However, because of its altitude, GSO has some limitations especially in terms of high latency that can reach 600ms

To address GSO limitations, there is a shift in trend with a high level of interest in the development of non-GSO (Non-Geostationary) satellites. This technology can deliver reliable high throughput and low latency communication services throughout the globe. By forming a mega constellation of satellites in Low Earth Orbit (LEO). In these past few years, government and private companies have competed to develop their own non-GSO constellations. The massive increase in the use of non-GSO satellites can be seen from SpaceX with its Starlink launching 5,500 satellites and 5,442 that are currently operating and already have its FCC approval for 12,000 satellites. Other big players such as Amazon with the Amazon Kuiper Project have launched two prototypes and plant to launch 3,252 satellites with a deadline set by the FCC are in 2029 [2]. All these development efforts have the main goal of fulfilling the need for satellite capacity across the earth's surface.

However, the growth of non-GSO satellite technology has given us a whole new set of challenges to solve. Besides the advantages mentioned above, the main issue of concern is the possibility of interference, Figure 1. 1 describes the occurrence of the interferences. This problem is already being addressed by the International Telecommunication Union (ITU) in ITU-R article 22. This article mentions that non-GSO shall not cause unacceptable interference to GSO satellite networks and shall not claim protection from GSO satellite network [3]. Such interference restrictions for non-GSO networks in down, up, and inter-satellite directions are defined in this article. ITU limits the Equivalent Power-Flux Density (EPFD) value, EPFD is a metric used to make sure that GSO earth stations and satellites remain safe from harmful interference from non-GSO systems [4]. EPFD is the aggregate emission (or Power Flux Density) of all non-GSO satellites towards any GSO earth station, taking into consideration the GSO antenna directivity. ITU also mentions a detail of method to perform interference calculations for all three directions and confirm conformance to Article 22 limits through its recommendation ITU-R S,1503.

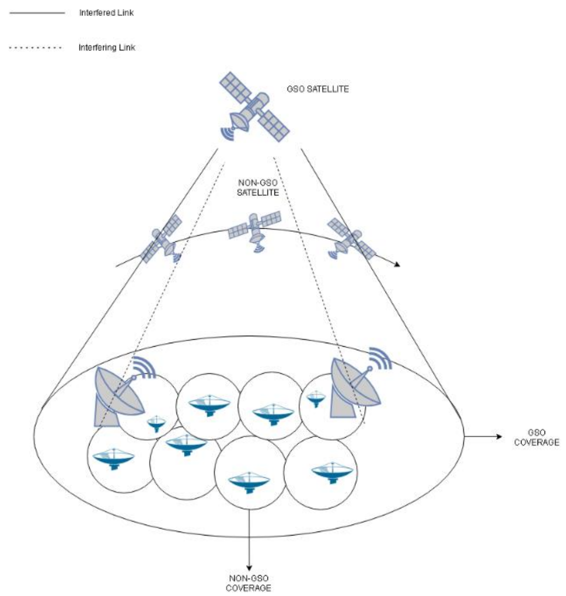


Figure 1. 1 Interference Scenario

Article 22 of the ITU Radio Regulations and Recommendation ITU-R S.1503 collectively address interference management between GSO and non-GSO satellite systems, to ensure efficient and fair spectrum use. Article 22 sets regulatory limits on EPFD to protect GSO systems from harmful interference caused by non-GSO systems, detailing limits on emissions, orbital station maintenance and antenna alignment accuracy. In addition, the EPFD defines operational requirements to ensure compatibility among satellite networks sharing a frequency band. Complementing this, ITU-R Recommendation S.1503 provides a technical framework for calculating the EPFD, emphasizing the use of the Worst-Case Geometry (WCG) algorithm to determine the highest level of interference. The WCG algorithm identifies configurations of non-GSO satellites, GSO satellites, and ground stations that result in maximum EPFD by considering factors such as satellite positions, antenna gain patterns, and propagation losses. By simulating these extreme scenarios, WCG ensures robust protection for GSO systems under all possible operating conditions. Furthermore, ITU-R Recommendation S.1503 incorporates the implementation of PFD masks and aggregation techniques to evaluate the cumulative interference effects of non-GSO systems. Together, these provisions protect GSO operations while enabling the continued coexistence of GSO and non-GSO satellite constellations in a shared spectrum environment.

The WCG algorithm, as implemented in ITU-R Recommendation S.1503 to evaluate compliance with EPFD, has been discovered to be unable to capture the potential for actual interference from non-GSO systems. Studies conducted by Viasat submitted to ITU working party 4A show that the WCG algorithm shows inconsistencies in its simulation performance [5]. This was obtained by Viasat who simulated other geometries besides WCG. Viasat made two observations, the first observation was made by selecting a combination of earth stations located in Fuchsstadt, Germany [6]. The second observation was made on a combination of earth station geometry located in Chandigath, India [7]. From both observations, it was found that the combination used by Viasat in its observations produced greater interference than the geometry combination determined by the WCG algorithm. The suspicion of inconsistency in the WCG algorithm is reinforced by research conducted by Triana Fika who conducted research on the USASAT-NGSO-3X satellite filling using ITU-BR GIBC Software [8]. Fika Triana found that there is inconsistency in the results obtained, by comparing the results of aggregate simulation and individual orbital simulation it is found that the WCG algorithm has failed to provide the worst possible interference.

Motivated by the problem, the author proposed to do an analysis on the use of WCG methods on the EPFD validation. With focus on the WCG algorithm that has been used in ITU-BR GIBC software. This research will be conducted by analyzing how the WCG algorithm works and also analyzing the parameters that are key in simulating EPFD calculations, namely the PFD mask. EPFD validation also will be conducted to validate the analysis results. In addition, this thesis will only focus on the EPFD downlink scenario. This research will also refer to the ITU-R Recommendation S.1503-2 document because this regulation is the basis of the WCG algorithm used in the ITU-BR GIBC Software and will use USASAT-NGSO-3X satellite filling as an object of observation.

## 1.2 Problem Identification

The rapidly increasing risk of interference caused by non-GSO systems to GSO systems has reached concerning levels, posing a significant threat to the performance and reliability of GSO networks. The WCG algorithm, currently the primary method used to assess interference levels, has demonstrated inconsistencies under various conditions, raising questions about its reliability in ensuring accurate evaluations.

Viasat stated that the WCG algorithm currently used to simulate the EPFD calculation, which benchmarks the degree of interference caused by non-GSO constellations to GSO satellite services, fails to provide the worst possible interference results. This is stated in the ITU working party's document 4A/94-E. Viasat derived this result from its study “Viasat analysis of geometries beyond the WCG”. In this study Viasat performed two analyses of possible combinations of GSO earth station and GSO satellite geometries. The geometry combination was done by selecting an earth station located in Fuchsstadt, Germany (50.118°N, 9.924°E) that communicates with a satellite located at 17.6°E and communicates on Ku and Ka-band frequencies. The second geometry combination chosen was an earth station located in Chandigarh, India (30.77°N, 76.78°E) with a GSO satellite serving the Indian region on an orbit of 111.5°E and communicating utilizing Ku and Ka-bands frequencies. This study uses starlink satellite fillings STEAM-1 and STEAM-2 as observation objects.

Both studies show a clear result that WCG fails to provide the geometry combination with the worst possible interference result. In both analyses, higher interference probability values were obtained when compared to the geometry combinations selected by the WCG algorithm (ES: 4.41°N, 2.78°E, GSO: 1.45°E). Where, the results of the geometry combination selected by the WCG algorithm state that there is no interference caused by the STEAM-1 and STEAM-2 starlinks. Viasat also stated in ITU working party's document 4A/94-E that there is a possibility of manipulation performed on the PFD mask data, this forces the algorithm to choose an inappropriate geometry combination. This manipulation is done by increasing the PFD value at a latitude close to the equatorial line (0°). This point corresponds to the GSO ground station which is in the vicinity of the equator and points to the satellite in a high elevation state as it illustrates in Figure 1. 2. Since the algorithm relies on PFD mask data to estimate interference from each direction. Therefore, the algorithm will select this geometry as the worst possible interference. This is not the geometry that causes the highest interference. The possibility of high interference at points close to the equator is difficult because usually non-GSO satellites have a high inclination, so they should not often pass through the main beams of GSO satellite antennas or GSO earth stations.

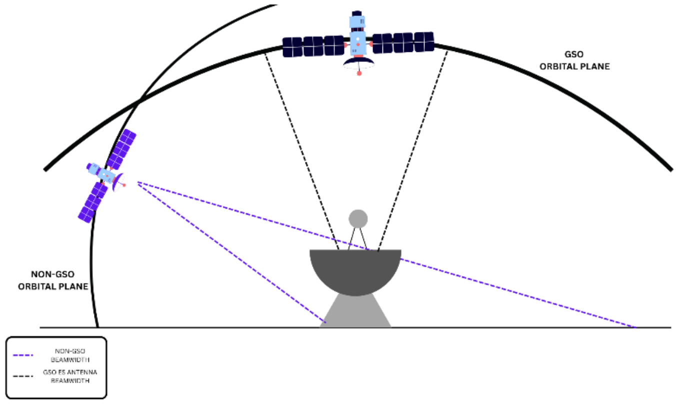


Figure 1. *2* non-GSO satellite with non-zero inclination angle

The possibility of irregularities in the PFD mask was also found in a study conducted by Fika Triana in her study entitled “USASAT-NGSO-3X Filing Analysis Using ITU-BR GIBC Software for Various Orbital Shells”. Triana Fika simulated EPFD calculations using many combinations of orbital shells, starting from the entire orbital shell to individual shells in the satellite filling. The results showed that when the simulation was carried out on the USASAT-NGSO-3X satellite filling with the scenario of all orbital shells, orbital shells 350, 604, and 614 resulted in no interference occurring. However, when simulations were performed on orbital shells 340, 345, 360, 525, 530, and 535, there was interference caused by the USASAT-NGSO-3X Starlink to the GSO satellite system. This emphasizes that the WCG algorithm cannot provide accurate and consistent results in its implementation.

An in-depth analysis of the WCG algorithm is essential to gain a comprehensive understanding of its functionality. This analysis involves examining the algorithm flow provided in Recommendation ITU-R S.1503-2, which serves as the primary reference for the operation of the ITU-BR GIBC software. A thorough understanding of the algorithm is essential to ensure that the tool used to evaluate interference between Non-GSO and GSO systems accurately represents the actual interference scenario. It is also necessary to analyze the PFD mask, as this data is key to the simulation calculations. This is critical to maintaining optimal performance of both systems and meeting the growing demand for satellite communication services.

### 1.3 Objectives

These Following points below are the objectives that this research is aiming to achieve:

1. Conduct a technical examination of the WCG algorithm to fully comprehend its mechanisms and principles.
2. Investigate the influence of PFD mask data particularly from the USASAT-NGSO-3X filing on the outcome of the WCG algorithm in calculating EPFD levels and assess whether the observed results support the concerns raised by previous studies regarding potential data irregularities.
3. Propose enhancements to improve WCG algorithm based on the analysis results that conducted in this thesis.

### 1.4 Scope Of Works

To avoid the spreading direction of the discussion in this study, there are several limitations of the problems as it mentions below:

1. This research focuses on conducting an in-depth analysis of the WCG algorithm, specifically in the context of EPFD downlink assessments.
2. The analysis will adhere to the guidelines and requirements outlined in Article 22 of the ITU Radio Regulations to ensure compliance with predetermined standards.
3. ITU-R Recommendation S.1503-2 will serve as the primary reference for the study, as the ITU-BR GIBC software used for EPFD validaton is developed based on this recommendation.
4. This study will utilize data of USASAT-NGSO-3X on Ku-Band downlink frequency (10,7 – 11.7 GHz) as an object of observation.

## 1.5 Hypothesis

This research hypothesizes that the PFD mask data used in the USASAT-NGSO-3X satellite filing may have been compiled in such a way as to cause the WCG algorithm to incorrectly identify the worst-case interference geometry. This includes a possible increase in PFD values near equatorial latitudes, which could lead to a misrepresentation of the worst-case conditions and undermine the accuracy of the EPFD compliance evaluation performed using the ITU-BR GIBC software. This is continuous with the inaccuracies experienced by the WCG algorithm in determining the worst-case geometry scenario. This is also due to the lack of assertiveness of ITU as the regulator role holder in the filling phase.