# Bridging Maritime Communication Gaps: The Role of LEO Satellites in Expanding Global Connectivity

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**المستخلص:**
يُعد الاتصال المباشر بين أجهزة المحمول والأقمار الصناعية أحد أهم التحديات التي تواجه قطاع الاتصالات في السنوات القادمة، حيث ظلت الاتصالات عبر الأقمار الصناعية مقتصرة على استخدامات معينة، منها تحقيق الاتصال بين السفن والمحطات الساتلية الأرضية خلال الرحلات الدولية. غير أن السنوات الماضية شهدت طرح فكرة استخدام الأقمار الصناعية لتوفير التغطية في المناطق التي تعاني من ضعف التغطية من قبل شركات المحمول.

في هذا السياق، بدأت بعض الشركات، مثل شبكة "ستارلينك" التابعة لـ"سبيس إكس"، في إطلاق أعداد كبيرة من الأقمار الصناعية التي تعمل في المدارات الأرضية المنخفضة(LEO) ، والتي تهدف إلى تحقيق اتصال مباشر مع أجهزة الهاتف المحمول.

تتناول هذه الورقة البحثية الفرص والتحديات التي تواجه مجموعات الأقمار الصناعية الضخمة وشبكات الأقمار الصناعية في مجال النقل البحري. كما تناقش سبل الاستفادة من القمر الصناعي "طيبة-١" لتوفير اتصال موثوق للسفن داخل المياه الإقليمية المصرية وفي المناطق النائية التي يصعب تحقيق اتصال بينها وبين المحطات الأرضية.

**ABSTRACT**
Direct device -to-device is the latest and potentially the biggest opportunity in the telecom business as the gap between satellite and ground communication is narrowing. Respectively, the telecom companies and mobile network operators are interested in increasing the coverage of their telecom networks which will boost the quality of services and will increase the revenues as well. In this regard, Low-earth-orbit (LEO) satellite mega-constellations, such as SpaceX Starlink, are under fast deployments and promise broadband Internet to remote areas that terrestrial networks cannot reach. This paper will investigate the opportunities and challenges facing the LEO mega-constellation and satellite networks in the maritime industry.

**Keywords:** LEO Satellites, Maritime Communication, Satellite Mega-Constellations, Global Navigation Satellite Systems (GNSS), Starlink, SpaceX, Broadband Internet, Global Connectivity, Maritime Navigation, Tiba-1 Satellite

## 1- INTRODUCTION

Since the very beginning of the implementation of the GNSS technology, GNSSs have shown significant expansion in terms of both adoption and technological advancement. The Global Positioning System (GPS) was created by the US government in the early 1970s and made fully operational in 1995, was the first GNSS. Nearly concurrently constructed and completely operational by 1995 was the Russian system GLONASS. Consequently, some other satellite constellations such as BeiDou and the Galileo system have been providing navigation and communication via GNSS technology for regional and global navigation. Moreover, regional standalone or augmentation systems have been created by Japan and India (NavIC and QZSS, respectively) (Egea-Roca, et al., 2022).

The United States GPS launched for general usage in 2000 after being deemed fully operational in 1995 with 24 satellites offering worldwide coverage. Accuracy was about 10 meters at the time, over 125 navigation satellites were in operation by the year 2020, with three more global satellite navigation systems having been implemented by other countries since then.

The majority of GNSS systems operate with as few as five satellites, however many satellite constellations rely on more than 25 satellites in providing the navigation services to their users. Respectively, it is crucial to have this redundancy for several reasons. Since a huge portion of the sky can now be blocked by local barriers without affecting GNSS performance, the abundance of satellites boosts GNSS availability (Weiqiang, et al., 2021).

The MEO satellites are situated between 8,000 and 20,000 kilometers above the surface of the Earth. This particular positioning has a critical impact on GNSS/GPS antenna operation. Satellites operating at this height are able to cover a larger region with a lower latency than their counterparts in Low Earth Orbit (LEO) and Geostationary Orbit (GEO). For a broad range of GNSS applications, including precision farming and marine navigation, this makes MEO satellites essential.

All ships, regardless of size, must have a receiver for a GNSS or a terrestrial radio navigation system in accordance with SOLAS Regulation V/19.2.1.6. To ensure adherence to the SOLAS guidelines, these days, GNSS receivers are incredibly dependable and user-friendly. A variety of applications on ships and are a significant source of both in terms of time and placement. Activities that take place in maritime surroundings (IMO, 2023).

In this regard, The IMO resolution A.1046 (27) on the global radio navigation system includes the main technical requirements for all radio navigation systems on board of IMO vessels. Respectively, the satellite positioning systems already recognized by IMO as meeting the required standards in order to be used as a component of the WWRNS include GPS (since 1995), GLONASS (since 1996) and Beidou (since 2014).

Consequently, The Automatic Identification System is an advanced system that allows vessels on the sea and rivers to be identified by their routes. It does this by transmitting important data regarding the identity of the ship, its cargo, key characteristics, and its navigation status at all times of day or night. When paired with an inland ECDIS, the AIS system—which was initially implemented in river and maritime navigation—allows for the practical replacement of a large portion of the position and distance data for nearby vessels, greatly increasing navigation safety.

In this Respect, according to the IMO regulation, all passenger ships, regardless of size, cargo ships, with a gross tonnage of 500 or more that are not involved in international trips, and ships with a gross tonnage of 300 or more that are engaged in international voyages must have AIS installed.

The use of satellites to track fishing activity has been implemented in many countries across the globe. In this regard, The European Union (EU) has deployed a satellite-based vessel monitoring system (VMS) which entails to track the fishing vessels activities on a regular basis (Maina, et al., (2018). Alternatively, In the United States 4,000 vessels are monitored by the VMS, which represents the world's largest national VMS fleet. The VMS data is shared with designated authorities which includes the U.S. Coast Guard, academics, and the coastal states (Fisheries, 2024).

A satellite in low-Earth orbit (LEO) typically orbits hundreds of kilometers above the planet in a much lower orbit. Approximately 100 kilometers above the International Space Station, the original Starlink constellation orbits at a distance of about 550 km.

According to Business Research Insights, the LEO satellite market is anticipated to expand from over US $4 billion in 2022 to about $7 billion in 2031 (*Broadband Connectivity*, 2023). The most famous LEO broadband communications satellites are likely SpaceX's Starlink spacecraft, however, Amazon has started launching its own Project Kuiper spacecraft and plans to start operations in 2024. Not only are other businesses joining the market to supply broadband connection, but they are also producing the smaller rockets. Airbus, Ariane Group, China Aerospace Science and Technology Corp., and Tata Advanced Systems are a few of them (Androjna, et al., 2020).

Starlink Internet broadband is a highly advanced system that uses space to carry information quicker than fiber optic cables, allowing for faster access to more people and places. Starlink is a constellation of many satellites in low Earth orbit (LEO), unlike conventional satellite Internet systems that rely on single geostationary satellites orbiting around 35,000 km. Starlink satellites are in low orbit, resulting in significantly lower round-trip data time (delay) compared to geostationary satellites.

The Starlink satellite project aims to provide high-speed internet connection to rural places in developing countries, potentially boosting economic development and social welfare. Concerns have been expressed regarding the potential detrimental impact on local Internet service providers and the possibility of establishing a digital divide between those who can afford and those who cannot.

Establishing a rural network presents further challenges due to increased capital and operating costs in addition to the lower average revenue per unit ARPUs ,the Security challenges , distant location, and inconsistent power are among the challenges facing the telecom operators to expand their coverage to the rural areas .In the past few years , some of the obstacles have been partially overcome by using off-grid electricity and establishing microwave towers every 20 to 30 kilometers (instead of fiber optics). However, there is still a security breach, and theft is still a serious risk, particularly in underdeveloped nations.

On the satellite Internet providers that provide worldwide connectivity have become more prevalent in the US market. Organizations such as O3B, SpaceX, and One Web aim to create satellite constellations that provide a global internet connection.

According to (Mukto, M. M., et al, 2022) 45% of the internet users will prefer to use satellite internet services over the internet service provided using Ethernet cables due to the environmental impact of the copper discharge in the environment.

According to ITU Global Connectivity Report 2022, 67 percent of the global population, or 5.4 billion people, is currently online. This highlights global internet adoption, with billions of people benefiting from digital access. However, the ITU report demonstrated that the digital gap remains a key concern. In low-income nations, where internet connectivity has grown the most rapidly, less than one-third of the population has access to the internet. Despite a 17 percent growth in internet users in these regions over the last year, the majority of individuals in these countries remain isolated from the internet (Weiqiang, et al., 2021).

Broadband service providers who primarily rely on terrestrial networks have found it unprofitable to provide broadband connectivity in these rural areas via the fiber network infrastructure. In this regard, satellite service providers are offering broadband connectivity with high speeds and competitive prices in comparison to terrestrial service providers. Satellite communications services can contribute to the decrease of the existing connection gap between the developed and undeveloped countries or between the urban and rural areas within the same country (Graydon, & Parks, (2020).

On the other hand, Among the 17 Sustainable Development Goals (SDGs) is the SDG 9 which aims to increase the investments in ICT access and quality education to promote lasting peace, which aims to increase the number of people connecting to the internet, reducing the digital divide between the developing and developed countries or between the urban and rural areas within the same country (Martin, 2023).

## 2- LITERATURE REVIEW

According to (Androjna, et al, 2020) one of the main challenges facing the implementation of the GNSS technologies in the maritime domain is the automatic update of the location every 15 minutes regardless of the type of vessel and the type of operation or maneuvering involved in. From another perspective, the implementation of new technologies promoted by the IMO as the new trends in maritime transportation such as e-navigation, e-maritime services, and MASS, all require an efficient utilization of the GNSS.

Weiqiang, et al. (2021) investigated the potential challenges facing the implementation of the GNSS technology in the navigation systems of the autonomous vehicle.

Ilcev, (2022) explores alternative satellite systems that could enhance the GMDSS network, including Low Earth Orbit (LEO) and Medium Earth Orbit (MEO) satellites. These alternatives promise better global coverage, lower latency, and potentially reduced costs.

Innac, et al, (2022) evaluated the European Geostationary Navigation Overlay Service EGNOS utilization in the maritime navigation, the research examined the satellite visibility during in different navigation situations, in this respect, the number of GPS satellites during navigation varied from a minimum of six satellites to a maximum of ten, with an average of eight visible GPS satellites also guaranteeing a solution availability and continuity equal to 100%.

Li, Wang, Xu, & Xu, (2024) examined how cloud and edge computing operate together in satellite networks by using game theory. The interactions between various network nodes, including as satellites, edge devices, and cloud servers, are modeled using game theory with the goal of establishing a compromise between maximizing detection accuracy and decreasing resource usage.

Pekkanen, Aoki, & Mittleman, (2022). Highlights the significance of big data in handling and interpreting the enormous volumes of data that tiny satellites are collecting. Finding patterns, anomalies, and trends that can point to questionable or unlawful activity in maritime environments is made possible by big data analytics.

Oligeri, et al., (2020) examined an adversary model that detects spoofing on the IRIDIUM signals through the utilization of a GNSS spoofing software tool, an antenna, and an SDR.

Respectively, Androjna, & Perkovič, (2021) investigated the strengths and weaknesses of the AIS system using SWOT analysis, one of the threats was the vulnerability of the AIS service threatening attack as spoofing of ships that may mislead national authorities regarding maritime surveillance, while among the opportunities of the AIS application was its contribution in reduce the rate of collisions among the navigating vessels.

Alternatively, The US Radio Technical Commission for Maritime Services (RTCM) examined in conference document NCSR 11/6/5 the viability of combining class D DSC and class B AIS radios to a single VHF antenna, during its examination, RTCM took into account the effect that a transmitting VHF radiotelephone has on the AIS receiver. This included the case of combination units that use two VHF antennae instead of one, as well as the case of separate AIS and VHF radios installed on different vessels.

Maina, et al (2018) utilized the Vessel Monitoring System VMS data over a 6-year period (2010–2015) to investigate the spatiotemporal patterns of fishing effort of Greek trawlers operating in the Aegean Sea.

Fournier, et al., (2018) explored the S-AIS applications from 2004 to 2016: The article reviewed the different ways that S-AIS technology was used during this time, such as:

Monitoring vessel movements to avert collisions and mishaps is known as maritime safety.

Security: keeping an eye on ship movements to spot and stop illicit activity like smuggling and piracy.

Monitoring the environment: Assisting in the tracking and remediation of environmental risks such as oil spills.

Search and rescue: Helping to find and organize rescue efforts for vessels that are in trouble.

Fisheries Management: observing fishing operations to make sure rules are being followed.

Alternatively, et al., (2023) highlights the main obstacles to maritime broadband communications, including the threatening maritime environment, latency, and coverage gaps. It addresses possible solutions, such as mesh networks, adaptive communication methods, and the placement of Low Earth Orbit (LEO) satellites.

## 3- SWOT Analysis of GNSS Technologies and Satellite Systems in the Maritime Sector

A SWOT analysis is an approach in strategic planning that helps determine and assess project's, companies, or initiative's Strengths, Weaknesses, Opportunities, and Threats. Internal factors like assets, abilities, or procedures that either facilitate success or provide difficulties are referred to as strengths and weaknesses. External elements that may have an impact on an organization's success are known as opportunities and threats. These factors could include competition, market trends, or economic situations. A SWOT analysis evaluates these four areas to assist entities in creating plans to take advantage of opportunities, address weaknesses, exploit strengths, and minimize threats, respectively, in this respect, we are going to demonstrate a SWOT analysis of GNSS and satellite systems the maritime sector the data review in the literature.

INTERNAL FACTORS

| STRENGTHS + | WEAKNESSES – |
|---|---|
| • **Global Coverage and High Accuracy:**<br>• GNSS and satellite systems provide comprehensive global coverage, ensuring vessels can navigate accurately across vast and remote oceanic areas.<br>• EGNOS and other GNSS enhancements improve GPS reliability, ensuring continuous and precise positioning data.<br>• **Enhanced Safety and Security:**<br>• Satellite systems like S-AIS contribute to maritime safety by enabling vessel tracking, reducing collision risks, and facilitating search and rescue operations.<br>• The integration of LEO and MEO satellites in GMDSS can enhance global maritime distress and safety communications.<br>• **Support for Advanced Maritime Operations:**<br>• GNSS technologies are vital for emerging trends such as e-navigation, MASS, and e-maritime services, providing the necessary infrastructure for efficient and safe operations.<br>• Big data analytics in satellite systems help in monitoring and interpreting maritime activities, enhancing security and environmental protection. | • **Vulnerability to Interference and Spoofing:**<br>• GNSS signals can be vulnerable to spoofing and jamming, which can lead to misleading navigation data and pose security risks.<br>• AIS systems, despite their benefits, can be susceptible to cyber-attacks, potentially compromising maritime surveillance.<br>• **Technical Challenges and Limitations:**<br>• Automatic updates every 15 minutes regardless of vessel type or operation can lead to inefficiencies, particularly in dynamic maritime environments.<br>• Latency issues in maritime broadband communications, especially in challenging environments, can hinder real-time data transmission and coordination.<br>• **Dependency on Infrastructure:**<br>• The effectiveness of GNSS and satellite systems is heavily dependent on the infrastructure's reliability, including ground stations and satellite networks. Any disruption can impact maritime operations significantly. |

Figure 1 – demonstrates the strengths and weaknesses of the deployment of GNSS and satellite systems the maritime sector.

EXTERNAL FACTORS

| OPPORTUNITIES + | THREATS – |
|---|---|
| • **Technological Advancements:**<br>• The development of new satellite technologies, such as LEO and MEO constellations, offers opportunities for improved coverage, lower latency, and reduced costs in maritime communications.<br>• Integration of cloud and edge computing with satellite networks can enhance data processing capabilities, allowing for more efficient and accurate maritime operations.<br>• **Expansion of Services:**<br>• Tiba-1 and similar satellites can extend broadband connectivity to remote maritime regions, reducing the digital divide and supporting economic growth in coastal communities.<br>• The adoption of e-navigation and MASS creates opportunities for the maritime sector to optimize operations, reduce costs, and improve safety through automation and better data utilization.<br>• **Environmental Monitoring and Compliance:**<br>• Satellite systems enable better environmental monitoring, such as tracking sea conditions and pollution levels, helping the maritime industry meet regulatory requirements and protect marine environments.<br>• VMS data and S-AIS applications can aid in sustainable fisheries management by ensuring compliance with fishing regulations and preventing illegal activities. | • **Regulatory and Legal Challenges:**<br>• The adoption of new GNSS technologies and satellite systems may face regulatory hurdles, particularly regarding international standards and the integration of new systems with existing maritime infrastructure.<br>• Legal issues related to the cybersecurity of GNSS and AIS systems could pose challenges, especially concerning liability in the event of system failures or breaches.<br>• **Environmental and Operational Risks:**<br>• Harsh maritime environments can impact the performance and reliability of satellite communications, posing risks to navigation and safety.<br>• The maritime industry may face operational disruptions due to space weather events, such as solar storms, which can affect GNSS signals and satellite communications.<br>• **Competition and Market Dynamics:**<br>• The rapid development of new satellite systems and technologies may lead to increased competition, which could affect the pricing and availability of satellite-based services.<br>• Emerging alternatives to traditional GNSS, such as terrestrial-based positioning systems, could potentially reduce the reliance on satellites, impacting the satellite services market. |

Figure 2 – demonstrates the opportunities and threats of the deployment of GNSS and satellite systems the maritime sector.

**4- CASE STUDY TIBA-1 AND NILE SAT 301**

The Egyptian satellite Co. Nilesat was established in 1996, for the purpose of operating DTH broadcasting satellites and up-linking facilities. Nilesat is broadcasting digital TV channels and digital radio channels, in addition to data transmission and turbo internet services.

Nilesat offers various communication services in the Middle East and North Africa (MENA) region, including satellite broadband over Egypt and direct-to-home (DTH) broadcasting. Millions of homes, companies, and governmental institutions get a vast array of television and radio stations, as well as data and internet connectivity, from its fleet of geostationary satellites.

Currently operating Nilesat 201, Nilesat 301, and previously Nilesat 101, Nilesat 102, and other satellites in the 7° West orbital slot are all part of Nilesat's fleet, over 100 million households are covered by these satellites throughout a large territory that includes portions of Africa and the MENA regions.

On November 26, 2019, the Egyptian telecom satellite Tiba-1 was launched. The 300-hour voyage culminated in the satellite's launch into orbit. In September 2021, the satellite's extensive testing was finished.

The satellite's goal is to give the public and private sectors access to space communications. The 5600 kg satellite, orbiting at 35.5° E, is traveling at 11,000 km/h while 36,000 km above Earth. Egypt and the economic waterways are covered by the satellite. It also spreads to a few adjacent nations and the nations of the Nile Basin.

Tiba 1 offers satellite communications services both inside and outside the nation's borders, encompassing one-third of the planet.

Covering one third of the globe, Tiba 1 provides satellite communications services inside and outside the Egyptian borders.

The Tiba 1 satellite was created in Egypt without the assistance of any foreign experts, and it is equipped with high-quality, high-resolution cameras for the satellite imaging service. It was produced by the French firms "Airbus" and "Thales Alenia Space," with Egyptian professionals involved in every phase of the production process, from design to operation

Tiba 1 provides complete coverage to some nations in the Nile Basin and North Africa, as well as communications services to the commercial and governmental sectors.
Tiba1 satellite contributes to development by bridging the digital divide between urban and rural areas and supporting development projects in remote and isolated locations by delivering internet and broadband communications infrastructure.

Based on the transponder bandwidth, frequency band (such as C-band, Ku-band, or Ka-band), and the particular service being offered, TIBA-1 are made to accommodate a range of data speeds. For instance, whereas C-band and Ku-band satellites may support lesser data rates, Ka-band satellites frequently enable higher rates, occasionally approaching gigabits per second (Gbps).

In this respect Tiba 1 has the capacity to provide one of the following Services; (The Egyptian Satellite Company, 2024)

- Service packages for internet access for home subscribers (The Egyptian Satellite Company
- VOIP
- Land mobile
- Maritime
- Aeronautical
- Backhauling
- Trunking
- Oil & Gas
- enterprices
- ministries and government agencies Services
- content distribution
- Platforms (VIP – Shahid)
- Internet of things IOT

**5- COMPARISON BETWEEN THE CAPABILITIES OF STUDY TIBA-1 AND NILE SAT 301**

| | **Tiba-1** | **Nilesat** |
|---|---|---|
| Purpose | Telecommunication, Data Communication | direct-to-home (DTH) broadcasting satellite system |
| Frequency Bands | Ka-band | Utilizes Ku-band for broadcasting and Ka-band for data services. |
| Coverage | Focused on Egypt, with additional coverage extending over North Africa and the Middle East. | Covers the Middle East, North Africa, and parts of Sub-Saharan Africa, focusing on broadcasting services. |
| Data Handling Capacity | Tiba-1 is equipped with advanced communication payloads that can handle high-capacity data transmission | While Nilesat does offer broadband services, its primary focus on broadcasting means its capacity for data transmission is more limited compared to satellites like Tiba-1, |

**6- TIBA-1 UTILIZATION IN THE MARITIME SECTOR:**

The capabilities of Tiba-1 can be applied to a range of maritime applications, with a focus on improving connectivity and communication for vessels that are within its coverage area. The maritime sector can make use of Tiba-1 in the following ways:

**6-1 Improved Vessel Communication**

Broadband Internet Access: Ships operating at sea, particularly those in areas unreachable by conventional terrestrial networks, can benefit from Tiba-1's high-speed internet connectivity. For data transfer, online service access, and real-time communication.

By supporting VoIP and satellite communication, the satellite makes it possible for maritime crews to stay in touch even when they are in far-off places.

**6-2 Navigation and Safety:**

Tiba-1 can help GNSS-based applications by providing a stable communication channel for the transfer of GNSS correction data, improving the accuracy and dependability of positioning data for marine navigation even though it is not a GNSS satellite.

Data from the Automatic Identification System (AIS), which is necessary for tracking vessel movements and enhancing marine safety, can be transferred more easily with the help of Tiba-1.

Through Tiba-1, ships may transmit and receive AIS data, making themselves visible to other ships and maritime authorities.

**6-3 Maritime Monitoring and Surveillance:**

The Vessel Monitoring System (VMS), which keeps tracks on the location and activities of other ships and fishing vessels, is compatible with Tiba-1. In order to maintain maritime security, avoid illicit fishing, and comply with regulations, this is very crucial.

Enabling the transfer of data from sensors and devices on board ships, the satellite can help with environmental monitoring. This data may contain details about the state of the sea, the weather, and pollution levels in the environment.

**6-4 Emergency Response and Disaster Management:**

Tiba-1 can offer an essential means of communication for distress signals, rescue operation coordination, and real-time updates to and from ships in the case of an emergency at sea, such as a natural disaster.

**6-5 Supporting Maritime Economic Activities:**

Commercial Operations: Tiba-1's high-speed connectivity can improve commercial shipping operations such as fleet coordination, logistics management, and cargo tracking.

Fishery sector: By guaranteeing regulatory compliance, boosting vessel safety, and optimizing fishing operations' efficiency, Tiba-1's services can help the fishing industry**.**

**6-6 Reducing the Digital Divide in Maritime Communities:**

Connectivity for Coastal Communities: Tiba-1 is able to provide internet and communication services to ports and coastal communities, which are essential for integrating with international trade networks and fostering economic growth.

## 7- CONCLUSION

By bridging the gaps in global connection, the combination of LEO satellites and other satellite technologies like Tiba-1 is transforming maritime communication. LEO mega-constellations like Starlink and regional satellites like Tiba-1 are emerging as crucial options, providing dependable and fast internet connection to vessels and coastal towns, as traditional terrestrial networks struggle to reach remote places. These developments are critical to guaranteeing safety through systems like AIS and VMS, as well as improving real-time communication and navigation for maritime operations.

Furthermore, by offering necessary broadband services, these satellite technologies are significantly contributing to closing the digital divide, especially in rural and developing nations. This connectedness facilitates improved emergency response and catastrophe recovery, enhances safety and monitoring, and promotes economic development.

By utilizing LEO satellite constellations as Tiba-1 that promote connectivity to the rural and urban areas, which represent an opportunity for maritime communication in the local and regional sea areas. Through the deployment of this satellite constellation, the maritime sector is set to experience greater efficiency, safety, and economic growth as the industry continues to progress.

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