



Literature Review: The Role of Low Earth Orbit (LEO) Satellites in Bridging the Digital Divide in Archipelagic Nations: A Case of Indonesia

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ABSTRACT

Indonesia, as the world's largest archipelagic nation with more than 17,000 islands, faces persistent challenges in achieving equitable internet access, particularly across its 3T regions. Existing national programs, including Palapa Ring and the USO initiative, have not fully addressed these disparities, indicating the need for alternative connectivity strategies. This study provides a critical synthesis of the strategic role of Low Earth Orbit (LEO) satellite systems by integrating technical, regulatory, and socioeconomic perspectives through SWOT and PESTLE analytical frameworks. The novelty of this work lies in its combined evaluation of LEO as both a backhaul and a direct-to-user model within Indonesia's policy landscape, from an analytical angle not previously addressed in the prior literature. The study contributes by: (1) offering a structured assessment of LEO's suitability for Indonesia's archipelagic geography; (2) presenting simple quantitative illustrations that demonstrate LEO's comparative performance advantages and potential user reach; and (3) identifying regulatory priorities and roadmap requirements aligned with the RPJMN agenda. The findings indicate that LEO satellites hold strategic potential to accelerate digital inclusion, provided that spectrum harmonization, financing schemes, and digital literacy programs are strengthened to support sustainable nationwide deployment.

1. Introduction

Equal access to the internet has become a fundamental requirement in Indonesia's accelerating digital transformation agenda. (Vial, 2019). As the world's largest archipelagic nation, with more than 17,000 islands, Indonesia faces inherent challenges in developing equitable connectivity infrastructure, particularly in remote, geographically fragmented regions. Despite nationwide initiatives such as the Palapa Ring and the Universal Service Obligation (USO) program, internet access remains uneven. National penetration rates continue to rise, yet substantial disparities persist between western and eastern Indonesia, where terrain complexity and infrastructural limitations hinder the deployment of terrestrial networks. These persistent gaps disproportionately affect 3T (underdeveloped, frontier, and outermost) regions, limiting access to essential digital services across education, healthcare, commerce, and public administration.

The consequences of unequal connectivity extend beyond communication barriers; they reinforce structural inequalities in socioeconomic development. Communities lacking reliable internet access face restricted opportunities for online learning, digital entrepreneurship, and telemedicine, widening the divide in human capital and welfare outcomes (Ochillo, 2022). While improvements in mobile and fixed broadband performance have been documented in recent national reports, current speeds and latency levels remain insufficient to support more advanced digital applications, particularly in rural settings.

Given these challenges, alternative technological pathways are needed to complement and extend existing terrestrial infrastructure. Low Earth Orbit (LEO) satellite systems have emerged as a promising solution due to their low latency, high throughput, and ability to deliver service across dispersed geographies. Prior studies indicate that LEO networks can provide cost-effective coverage for remote regions and overcome limitations of geostationary (GEO) satellites, making them increasingly relevant in Indonesia’s archipelagic context. (Basak et al., 2023; Mubarak et al., 2020; Osoro & Oughton, 2021).

In light of these considerations, a comprehensive assessment of LEO’s strategic role in strengthening equitable internet access is crucial. This study synthesizes existing research using SWOT and PESTLE analytical frameworks to evaluate the technical, regulatory, economic, and environmental implications of LEO deployment in Indonesia’s 3T regions. The structure of this article is as follows: Section 2 presents a literature review of digital divide dynamics and LEO technology; Section 3 outlines the methodological approach; Section 4 discusses the analytical findings; and Section 5 concludes with implications and recommendations for future research. This structure provides an integrated perspective on how LEO satellite technology may advance Indonesia’s digital inclusion agenda.

2. Literature review

2.1. Digital Divide in Indonesia: Definition and Implications

Digital divide in the context of telecommunications and connectivity refers to the gap between individuals, groups, or regions that have access and the ability to use information and communication technology, such as the internet and telecommunications services, and those who do not. This gap significantly affects economic opportunities, education, and social participation (Riggins & Dewan, 2005). In Indonesia, equitable internet access remains a challenge given the country’s geography of thousands of islands and diverse terrain. Various initiatives have been undertaken by the government, including the Palapa Ring project and the Universal Service Obligation (USO) program, to expand ICT infrastructure in the 3T regions (Handayani & Afrizal, 2018; Saputra et al., 2023). However, according to the APJII report, a significant digital divide persists, as illustrated in Figure 1, where internet penetration remains highly uneven across Indonesian islands.

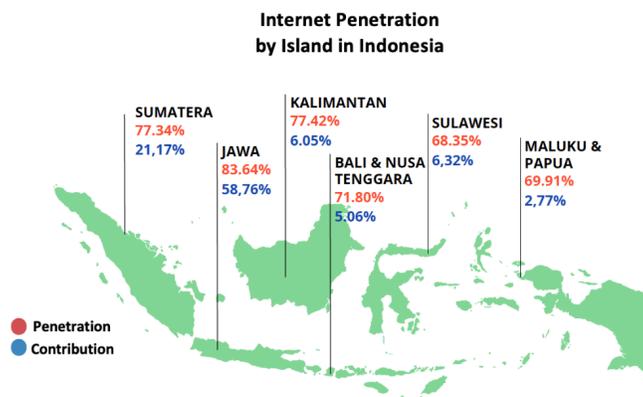


Figure 1. Internet penetration in Indonesia (APJII, 2024)

Figure 1 shows the differences in internet penetration rates across major islands in Indonesia, highlighting the persistent national digital divide. Java records the highest penetration at 83.64% and contributes 58.76% to the national total, followed by Sumatra and Kalimantan with 77.34% and 77.42%, respectively. In contrast, eastern Indonesian regions such as Sulawesi, Bali–Nusa Tenggara, and Maluku–Papua exhibit lower penetration levels ranging from 68–72% and contribute far less to the national total, with Maluku–Papua accounting for only 2.77%. These disparities reflect inequalities shaped by geographic barriers, uneven telecommunications infrastructure, and varying stages of regional development.

Most 3T areas (Frontier, Outermost, and Disadvantaged) are geographically located across the islands of Nusa Tenggara, Maluku, and Papua. Table 1 shows the number of districts, population, and internet penetration rates in these regions, which still lag compared to western Indonesia, such as the islands of Sumatra, Java, and Kalimantan. This digital divide further hampers equitable access to education, healthcare, and the economy for these communities. Therefore, collaborative efforts are needed to expand digital infrastructure and improve the quality of education, healthcare, and digital literacy, thereby creating a more equitable and prosperous society.

Table 1. 3T Distribution and Internet Access by Region

Region	Number of 3T Regency	3T Population (Thousand)	3T Internet Penetration
Papua & Maluku	58	17.157,10	70.85%
Bali & Nusa Tenggara	26	9.804,76	66.93%
Kalimantan	20	5.893,57	79.69%
Sulawesi	19	3.558,58	66.93%
Sumatera	15	3.770,43	78.33%
Jawa	0	0	0

Source: Data being processed based on (Statistik Indonesia 2024, BPS; Kemendagri, 2025)

Table 1 illustrates the distribution of 3T regions in Indonesia, along with their populations and corresponding internet penetration rates, revealing a clear disparity between the eastern and western parts of the country. Papua and Maluku have the largest number of 3T regencies (58), with a population of over 17 million and an internet penetration rate of 70.85%, while Bali and Nusa Tenggara show a similar penetration level of 66.93% despite having fewer 3T regencies. Kalimantan and Sumatra exhibit higher penetration rates of 79.69% and 78.33%, respectively, reflecting better infrastructure development compared to eastern regions. Sulawesi, however, remains relatively underconnected with a penetration rate of 66.93%. Java has no 3T regions recorded in this dataset, indicating its advanced infrastructure and connectivity. Overall, the data emphasize that 3T areas are largely concentrated in eastern Indonesia, where lower penetration levels continue to hinder equitable access to digital services.

Taking together Figure 1 and Table 1, the digital divide in Indonesia emerges not only as a matter of overall penetration rates but also as a spatially concentrated challenge, with underserved populations heavily clustered in the eastern archipelago. Existing policy interventions, such as the Palapa Ring and the Universal Service Obligation (USO) program, have primarily focused on expanding terrestrial and fixed backbone infrastructure. This approach is structurally difficult to implement across sparsely populated, multi-island regions. This misalignment between geographic constraints and prevailing infrastructure strategies suggests that conventional terrestrial-centric solutions may be insufficient on their own, underscoring the need to explore alternative architectures, such as Low Earth Orbit (LEO) satellite systems, that are inherently more adaptable to the connectivity requirements of 3T regions.

2.2. Low Earth Orbit (LEO) Technology

2.2.1. Comparison with Other Satellite Types

Based on their orbital altitude, satellite constellations can be divided into three types: geostationary Earth orbit (GEO), medium Earth orbit (MEO), and low Earth orbit (LEO). Each orbit type has unique characteristics that influence how satellites operate, their coverage areas, and their overall functions. Table 2 presents a comparison of characteristics between GEO, MEO, and LEO satellites.

GEO satellites are the traditional backbone for satellite services such as satellite television and fixed communication, as they remain fixed above a single point on Earth. Their main advantage lies in stable coverage and signal reliability without the need for handover, making them ideal for broadcasting and communication in remote areas. However, the extremely high altitude of GEO satellites results in high latency, often exceeding 477 ms, which makes them less suitable for real-time applications. Typically, illustrations of GEO satellites depict a

single satellite “hanging” above the equator, continuously providing coverage to a broad area below. (Vatalaro et al., 1995).

Compared with GEO, medium Earth orbit (MEO) satellites, which operate between approximately 2,000 and 20,000 km, offer improved capacity and reduced latency. However, they still do not fully meet the strict latency requirements for real-time applications. MEO satellites are often used for navigation systems like GPS and Galileo, as they provide wider coverage than LEO while maintaining lower latency than GEO (Garrity & Husar, 2021a)

Table 2. Characteristics of geostationary earth orbit, medium earth orbit, and low earth orbit.

	GEO	MEO	LEO
Altitude Range (km)	~36,800	2,000-20,000	160-2,000
Round-trip Latency (ms)	~477	125-250	30-50
Number of Satellites for Global Coverage	3	5-30	40-80
Cost per Satellite (US\$ million)	100-400	80-100	0.5-45
System Complexity	Low	Medium	High
Orbital Period (hours)	24	2-24	1.5-2
Propagation Loss	High	Medium	Low
Handover Requirement	Almost Zero	Low	High
Effective Lifetime of Satellite	24	2-24	1.5-2

Source: (Garrity & Husar, 2021a)

Table 2 highlights the fundamental differences between GEO, MEO, and LEO satellite systems, particularly in terms of altitude, latency, coverage requirements, and system complexity. GEO satellites, positioned at approximately 36,800 km, provide wide coverage with minimal handovers but suffer from high latency and high deployment costs. MEO satellites offer moderate latency and improved performance for navigation systems, yet still fall short for real-time communication. In contrast, LEO satellites operate at much lower altitudes, resulting in significantly reduced latency (30–50 ms) and lower propagation loss, making them more suitable for broadband internet services. However, their low altitude requires larger constellations and more complex handover management. These characteristics position LEO as the most viable option for bridging connectivity gaps in geographically dispersed regions such as Indonesia.

While comparative studies of GEO, MEO, and LEO orbits consistently emphasize LEO’s advantages in latency and propagation loss, most analyses remain technology-centric and do not explicitly consider archipelagic states such as Indonesia. Prior work generally assumes either continental geographies or homogeneous coverage requirements, which underestimates challenges such as fragmented demand, limited power infrastructure, and regulatory asymmetries across islands. This gap indicates the need for context-specific assessments that link orbital characteristics not only to generic performance metrics but also to concrete deployment scenarios in multi-island, low-density environments.

Seen in this context, the relevance of LEO technology for Indonesia lies not merely in its superior technical specifications but in its potential to overcome the structural limitations of terrestrial systems across thousands of islands. Existing studies have not sufficiently examined how LEO’s architectural features, such as dense constellations, inter-satellite routing, and flexible beam steering, could be adapted to Indonesia’s unique connectivity constraints, nor how these capabilities interact with national regulatory, economic, and infrastructural realities. This study, therefore, extends previous analyses by interpreting LEO’s technical characteristics through a geographically and institutionally specific lens, offering insights that are directly relevant to Indonesia’s efforts to reduce the digital divide.

2.2.2. Overview and Comparison of LEO Constellations: Starlink, Telesat, Kuiper, and OneWeb

Globally, SpaceX (Starlink), OneWeb, Telesat (Lightspeed), and Amazon (Project Kuiper) are front-runners in the deployment of LEO broadband constellations. Table 3 presents a comprehensive comparison of their constellation sizes, technological parameters, and market focus.

Starlink, launched by SpaceX in 2015, is the most advanced satellite deployment with 1,445 satellites in orbit as of April 2021, positioned about 550 km above Earth. The project aims to provide near-global low-cost internet with speeds comparable to fiber-optic technology, with an estimated cost of \$10 billion. SpaceX has also filed for spectrum to launch an additional 30,000 satellites to enhance its service.

Table 3. Differences in Deployments, Constellations, and Satellites.

Characteristics	SpaceX Starlink	OneWeb	Telesat Lightspeed	Amazon Project Kuiper
Number of LEO satellites launched	1445	146	1	0
Constellation size to initiate commercial service	1440	648	298	578
Estimated total bandwidth throughput at the start of commercial operations	23.7 Tbps	1.56 Tbps	15 Tbps	Unknown
Planned expansion (total future constellation size)	12.000 (FCC approved) to 30.000 (submitted to FCC)	2.000	1.600	2.236
Frequency	Ku-band	Ku-band	Ka-band	Ka-band
Orbit	560 km	1200 km	1000 km	590-630 km
Satellite mass	227-260 kg	150 kg	800 kg	unknown
Satellite Life	5-7 years	~5 years	10-15 years	unknown
Latency	<50 ms	<50 ms	<50 ms	unknown
Required reported capital expenditure	\$10 billion	\$2.4 billion	\$5 billion	\$10 billion
Vertical markets publicity targeted	Consumer, broadband, cellular backhaul	Backhaul, government, mobility, broadband	Government mobility, carrier-grade requirements	Broadband, backhaul

Source : (Garrity & Husar, 2021a)

Table 3 provides a comparative overview of four major LEO satellite constellations, highlighting significant differences in deployment scale, technological design, and market orientation. Starlink stands out with the largest number of satellites already in orbit and the most ambitious expansion plan, reflecting its focus on mass-market broadband services. OneWeb, despite its smaller constellation, targets government, mobility, and backhaul sectors with a more specialized user base. Telesat Lightspeed emphasizes carrier-grade performance with heavier satellites and longer operational lifetimes, positioning itself for enterprise and government applications. Meanwhile, Amazon’s Project Kuiper aims to enter the market with a sizable constellation but remains in its initial deployment phase. These variations illustrate the diverse strategic approaches among LEO operators and underscore the importance of selecting a system aligned with Indonesia’s geographic and connectivity needs.

OneWeb’s trajectory highlights the financial vulnerabilities of LEO ventures; despite launching 146 satellites, it faced bankruptcy in 2020 before restructuring under partial UK government ownership. Telesat's Lightspeed constellation, backed by decades of GEO operational experience, plans to deploy 298 satellites with a strong focus on high-reliability enterprise markets. Amazon’s Project Kuiper, supported by significant capital investment exceeding \$10 billion, is positioned as a late entrant but with substantial commercial capacity once operational. These contrasting developments reflect how financial stability, regulatory strategies, and constellation design shape the long-term viability of LEO operators.

Existing comparative studies on LEO constellations largely focus on global competition, capital expenditure, and throughput scaling, but give limited attention to how these differing architectures and business models translate into suitability for specific national contexts. For Indonesia, dependence on foreign-owned constellations raises critical concerns regarding gateway placement, data sovereignty, spectrum coordination, and bargaining power in service-level agreements. Yet, the literature seldom evaluates these strategic dimensions from the perspective of an archipelagic developing country. This study, therefore, extends prior analyses by interpreting global constellation characteristics through the lens of Indonesia’s connectivity gaps and regulatory priorities, offering a more context-sensitive framework for assessing LEO adoption.

2.2.3. Deployment Approaches: Backhaul and Direct-to-cell

LEO constellation can be enabled primarily through two methods: backhauling existing terrestrial network and direct user communication (Ahmmed et al., 2022).

2.2.3.1. Backhauling

LEO satellites can serve as a backhaul to connect remote terrestrial base stations (BS) to core networks, especially in geographically challenging areas. This integration supports 4G/5G networks without extensive terrestrial infrastructure, leveraging existing telecom equipment. Figure 2 shows the use case of the LEO satellite providing backhaul by integrating with existing infrastructure in rural and remote regions.

In this backhaul approach, LEO satellites act as relay nodes, connecting ground stations (gateways) in remote areas to the core network via feeder links (uplink/downlink) and intersatellite links (ISLs). LEO satellites move rapidly (around 7.5 km/s), so their visibility time with a single gateway on Earth’s surface is relatively short (about 5-10 minutes per pass). Therefore, the LEO backhaul system must be capable of performing frequent handovers between satellites within the constellation and supporting multi-hop routing among satellites in orbit to ensure uninterrupted data connections (Abdullah et al., 2024; Guidotti et al., 2017)

Technically, ISLs (typically operating at Ka-band frequencies or using laser-based optical links) enable data transfer between satellites before it is downlinked to the target gateway. Each satellite functions as a routing node, with the dynamic routing table updated in real time to select the shortest path and minimize latency (intersatellite routing protocols). The use of ISLs also reduces the need for dense ground gateways and increases the overall system throughput. However, the feeder link handover frequency in LEO is much higher compared to GEO or MEO, so efficient handover control, such as the maximum backhaul capacity handover strategy becomes a main focus to maintain backhaul stability and capacity (Zhou et al., 2023)

Furthermore, the integration of LEO backhaul with 5G terrestrial networks requires precise time synchronization (e.g., through GNSS-based timing reference) to support TDD/FDD duplexing and HARQ (Hybrid Automatic Repeat Request) mechanisms at the PHY/MAC layer. Compensating for Doppler effects (since LEO satellites move relatively fast) is crucial on uplink/downlink links, typically addressed by advanced frequency tracking algorithms that can offset Doppler shifts of up to ± 40 kHz. Thus, the LEO backhaul link can provide capacities of up to hundreds of Mbps per link, enabling edge computing and supporting low-latency services in previously underserved areas. (Vatalaro et al., 1995).

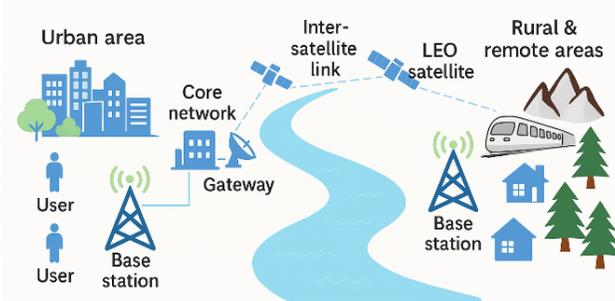


Figure 2. Illustration of LEO satellites providing backhaul by integrating with existing infrastructure (Ahmmed et al., 2022)

Figure 2 illustrates how LEO satellites function as a backhaul solution by relaying data between terrestrial base stations in both urban and remote areas through inter-satellite links and ground gateways. In this configuration, user traffic from rural or hard-to-reach regions is transmitted to a local base station, which then forwards it to a LEO satellite, which routes the data through interconnected satellites before reaching the ground-based core network. This architecture enables continuous connectivity even in areas lacking fiber-optic infrastructure, demonstrating the role of LEO satellites in expanding broadband access and supporting seamless integration with existing terrestrial networks.

2.2.3.2. Direct to User Terminal

LEO satellites can communicate directly with user terminals (UTs), such as satellite dish antennas, providing high-speed broadband internet to end users, as shown in Figure 3. This approach is particularly useful for remote or isolated locations, including small islands or rural regions.

In this scenario, the user terminal (UT), equipped with a phased-array antenna (with beam-steering capability), communicates directly with the nearest LEO satellite. Due to their low orbital altitude (160–2000 km), the round-trip latency is only around 30–50 ms, allowing latency-sensitive applications (VoIP, video calls, gaming) to run normally. Technically, the UT and LEO satellite communicate via a user link in the Ka-band (20/30 GHz) or Ku-band (10–18 GHz), with adaptive modulation and coding schemes (MCS) depending on the channel conditions and link budget. The LEO satellites are equipped with multi-beam antennas that facilitate frequency reuse, where a single satellite can serve hundreds of spot beams to increase capacity per area. This system is supported by power control and beam hopping to adjust dynamic capacity according to the constantly changing user data demand on Earth’s surface (Reid et al., 2018).

At the upper layers (L3/L4), user plane traffic is routed through the inter-satellite mesh (ISLs) to the satellite that has the optimal path to the gateway or terrestrial Point of Presence (PoP). Routing within the ISL utilizes a mesh topology (such as Walker delta or polar constellation) with dynamic routing algorithms (e.g., Dijkstra/OSPF-based adaptations) to maintain end-to-end throughput and QoS. This is combined with forward error correction (FEC) and dynamic rate adaptation to reduce packet loss and jitter on the user broadband connection.

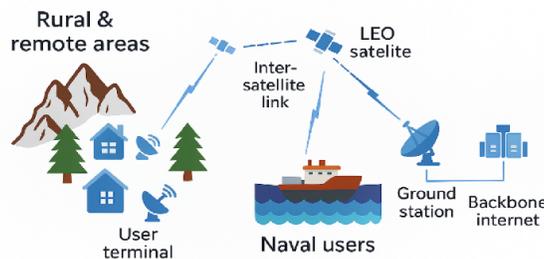


Figure 3. Illustration of LEO satellite beaming internet signals toward user terminals (Ahmmed et al., 2022)

Figure 3 illustrates how LEO satellites deliver broadband connectivity directly to user terminals in rural, remote, and maritime environments. In this configuration, user equipment on land or at sea communicates with the nearest LEO satellite, which relays the signal via intersatellite links before forwarding the data to a ground station connected to the global internet backbone. This architecture enables reliable, low-latency broadband access in areas lacking terrestrial infrastructure, demonstrating the versatility of LEO networks in serving both isolated communities and naval users.

The two deployment approaches, backhaul and direct-to-user, represent distinct design philosophies with different implications for scalability, cost, and governance. Backhaul-oriented deployments favour integration with existing 4G/5G infrastructure and can leverage domestic operators’ networks, but they presuppose a

minimum terrestrial footprint and technical capacity on the ground. Direct-to-user models, by contrast, can bypass local bottlenecks and rapidly connect isolated communities. Yet, they shift more cost and operational responsibility to end-users or local institutions and may exacerbate inequalities if terminal prices remain high. Existing studies typically examine these models in isolation; few analyse how a hybrid approach could be optimized for Indonesia's 3T regions, where both infrastructure gaps and affordability constraints coexist.

2.3. Global Use Cases of LEO Satellites

Research by (Ahmmed et al., 2022) highlights the role of LEO satellites as both backhaul and direct user access solutions to bridge the digital divide in remote areas of Canada, such as the Northwest Territories and Yukon. The study found that integrating LEO into 4G/5G networks enables providers like Telesat to collaborate with terrestrial operators (e.g., TIM Brasil) to deliver high-capacity broadband connectivity in areas lacking fiber-optic infrastructure. They noted that this implementation improved users' average speeds and reduced latency to below 100 ms.

Meanwhile, Malaysia and the Philippines have also expanded broadband access to their smallest islands using Starlink. Starlink entered the Philippine market in February 2023, focusing primarily on rural areas that are difficult for traditional ISPs to reach. For example, Lacaron Integrated School (Antique) increased its download speed from around 6-7 Mbps to 217-325 Mbps after installing Starlink, with latency as low as 30-68 ms (Isagani, 2023). In Malaysia, Starlink officially launched in July 2023 after receiving approval from MCMC as a fully foreign entity. The government even ordered 40 installation kits for schools, such as UiTM, as part of a national education program (Vatalaro et al., 1995) Offered speeds range from 100-248 Mbps download, with latency between 25-60 ms, comparable to 4G/5G terrestrial connections. The standard consumer package includes an automatic antenna and a dual-band WiFi 5 router, while the "High Performance" package (RM 11,613) offers higher performance and better weather resistance.

Additionally, tests conducted on the Makah Indian Reservation (a remote area in Washington, USA) using Starlink's 58 cm dish antenna to connect users to LEO satellites showed that Starlink's internet speeds can reach 148 Mbps (download) and 13.6 Mbps (upload). Although this is slower than the U.S. national average, it is still far superior to local services, which only provide 1 Mbps (download) and 0.5 Mbps (upload). In Canada, tests conducted in the first quarter of 2021 recorded download speeds of 53.61–80.57 Mbps. It is expected that these speeds could potentially double once Starlink's laser inter-satellite link system is active, reducing the need for direct communication with ground stations (Ahmmed et al., 2022)

These international use cases collectively demonstrate that LEO-based broadband can substantially outperform legacy terrestrial or GEO-based services in remote settings, often transforming previously unusable connections into functionally adequate links for education and public services. However, most documented deployments occur in high-income or upper-middle-income regulatory environments with relatively mature digital ecosystems. As such, their experiences cannot be transplanted directly to Indonesia, where institutional capacity, subsidy mechanisms, and regulatory frameworks differ markedly. This underscores the need for a tailored assessment that draws on global practice while critically examining its applicability to Indonesia's socio-economic and geographic conditions.

2.4. LEO Satellites in Indonesia

Starlink, operated by SpaceX, began operations in Indonesia in May 2024, launching services in Denpasar, Bali, focusing on providing access to remote health clinics and schools. On May 15, 2024, PT Telkom Satellite Indonesia signed a cooperation agreement to utilize Starlink as a backhaul channel for local ISPs in 3T (frontier, outermost, and disadvantaged) regions that are difficult to reach with fiber-optic networks or other terrestrial infrastructure. This collaboration forms the basis of a hybrid space-terrestrial architecture, allowing

local ISPs to expand service coverage more quickly and cost-effectively than building new physical infrastructure in geographically challenging areas.

Nonetheless, current discussions on LEO in Indonesia are dominated by policy announcements, news reports, and vendor-driven narratives, with limited independent academic analysis of their long-term strategic implications. Existing work rarely integrates technical performance, regulatory constraints, and socio-economic impacts into a unified evaluative framework. In this context, the present study contributes by systematically positioning LEO within Indonesia's digital inclusion agenda using SWOT and PESTLE analyses, thereby bridging the gap between global technical literature and the country-specific policy debates surrounding satellite-based connectivity.

3. Methodology

3.1. Data Collection

This study uses secondary data collected through published articles, government reports, white papers, and policy documents. The data collection process was carried out through a structured literature review, identifying relevant studies and data sources via a systematic keyword search across academic literature and official publications. No primary data collection or processing, or quantitative data, were carried out, so the analysis is based solely on existing, publicly available literature.

Unlike previous studies that rely heavily on technical simulations or operator-reported performance metrics, this research deliberately adopts a qualitative synthesis approach to address the wider institutional, infrastructural, and regulatory complexities surrounding satellite deployment in Indonesia. This design choice is essential because the central question of LEO suitability in 3T regions cannot be answered through performance metrics alone; it requires integrating policy constraints, geographic fragmentation, and market dynamics, which are best captured through secondary-document synthesis rather than experimental data collection.

3.2. Analytical Frameworks

This study uses a qualitative analysis approach based on study literature. Data collected from various sources are systematically reviewed, then coded and categorized to identify key findings and insights. The synthesis process is carried out by triangulating key findings from various sources to provide a comprehensive understanding of the opportunities and challenges associated with implementing LEO technology in Indonesia's 3T regions.

The selection of SWOT and PESTLE frameworks is grounded in the need to bridge technical assessments with socio-political realities. LEO deployment in Indonesia involves not only engineering considerations but also spectrum governance, state-private coordination, community adoption barriers, and environmental risk factors. Alternative frameworks, such as purely technical link-budget modeling or economic cost-benefit analysis, were deemed insufficient on their own because they do not capture these multidimensional interactions. Thus, SWOT and PESTLE were chosen to systematically translate heterogeneous insights from the literature into a structured evaluative framework.

3.2.1. SWOT Analysis

The SWOT method (Strengths, Weaknesses, Opportunities, Threats) is a strategic analysis tool used to identify internal factors (strengths and weaknesses) as well as external factors (opportunities and threats) that affect an organization or project. SWOT is widely used in business planning, strategy development, and project evaluation across various fields, including the telecommunications industry, due to its simplicity and flexibility. This analysis helps organizations understand their current position and formulate appropriate strategies by leveraging strengths, addressing weaknesses, seizing opportunities, and anticipating threats (Pickton & Wright, 1998). The SWOT analytical framework is used to identify internal and external factors influencing the implementation of LEO satellite technology in Indonesia, based on the findings from secondary data.

In this study, SWOT was operationalized by coding recurring themes from secondary data into four analytical clusters. Technical performance indicators such as latency, throughput, and handover mechanisms were classified as strengths or weaknesses depending on their relative advantage over terrestrial or GEO-based

systems. Meanwhile, policy opportunities and market risks, including regulatory uncertainty, dependency on foreign operators, and infrastructure alignment, were categorized as opportunities or threats. This operationalization enables the SWOT framework to provide a strategic, not merely descriptive, lens for evaluating LEO adoption in Indonesia.

3.2.2. *PESTLE Analysis*

PESTLE analysis is a strategic management tool used to evaluate the external macro factors that affect an organization's operations, including Political, Economic, Social, Technological, Legal, and Environmental factors. By analyzing these six aspects, an organization can understand the dynamics of the external environment that may impact performance and strategic decision-making, such as when entering a new market or facing major industry changes (Vilas Belsare, 2025). This analytical model is also often used in conjunction with other analyses, such as SWOT, to provide a more comprehensive overview of the business situation (Westover, 2024). The PESTLE analysis complements the SWOT analysis by assessing macro external factors: political, economic, social, technological, legal, and environmental, that may impact the adoption of LEO satellite technology.

Operationalization of the PESTLE framework followed a macro-contextual mapping approach, in which political, economic, social, technological, legal, and environmental themes were extracted from policy documents, regulatory reports, and cross-country case studies. Each external factor was assessed for its potential enabling or constraining effect on LEO deployment. For instance, spectrum licensing processes were analyzed under the “Legal” dimension, while infrastructure subsidies and market readiness were placed under “Economic” and “Social” dimensions. This approach ensures that the PESTLE analysis does not function merely as a checklist but as an integrative diagnostic tool aligned with Indonesia’s national digital transformation agenda.

3.3. *Limitation of the Method*

This study has several limitations as below:

- a. The analysis is solely based on secondary data available in public literature, without any primary data collection or field studies.
- b. There is a potential bias in data interpretation due to subjectivity inherent in qualitative synthesis
- c. The possibility of gaps or outdated information in the available literature may affect the completeness of the analysis.

Nevertheless, the use of well-established analytical frameworks (SWOT and PESTLE) ensures a systematic and structured approach to drawing conclusions from the available data. Furthermore, the absence of primary data means that this study cannot directly validate technical performance claims or measure user experience in Indonesia’s 3T regions. However, because the objective of this research is to assess strategic feasibility rather than operational performance, the use of secondary data remains appropriate. The methodological design therefore prioritizes breadth of contextual insight over precision of measurement, providing a foundation for future empirical work.

4. **Result and Discussion**

4.1. *SWOT Analysis of implementation LEO in Indonesia*

4.1.1. *SWOT Analysis: LEO Satellites as Backhaul for Terrestrial Networks in Indonesia*

Given Indonesia's geographic context as an archipelago comprising more than 17,000 islands, the equitable distribution of telecommunications infrastructure presents a significant challenge. One rapidly developing solution is the use of Low Earth Orbit (LEO) satellite constellations as a backhaul network to support connectivity in remote areas. In this approach, LEO satellites act as intermediaries, linking local base transceiver stations (BTS) or other terrestrial network nodes to the national or global core network. Unlike the direct-to-user access model, the backhaul approach enables the provision of cellular services (e.g., 4G/5G) while still relying

on standard user devices. Table 4 shows the SWOT analysis of the implementation of LEO satellites as backhaul for existing infrastructure in Indonesia.

The backhaul approach using LEO satellites offers a range of advantages well-suited to Indonesia's geographical challenges. LEO satellites exhibit low latency, typically between 30–50 ms, which is significantly lower than GEO satellites that exceed 600 ms. This is critical for time-sensitive applications such as VoIP, real-time video, and data synchronization for edge computing (Zhou et al., 2023). In addition, LEO enables wide and adaptive coverage for areas that are difficult to reach with fiber optic infrastructure due to geographic or cost constraints (Garrity & Husar, 2021a). Another notable advantage is the capability of LEO satellites to support the 5G Integrated Access and Backhaul (IAB) standard, allowing a single satellite node to deliver both access and backhaul services simultaneously, thus enhancing spectrum efficiency (Abdullah et al., 2024).

LEO also offers the ability to integrate with Inter-Satellite Link (ISL) systems, enabling data transmission between satellites without needing to return to Earth. This increases overall efficiency and reduces the reliance on expensive and sparsely available ground gateways (Zhou et al., 2023). Moreover, this approach minimizes dependency on the construction of costly undersea cables, which are prone to natural or technical disruptions (Okati & Riihonen, 2022). Additionally, LEO-based network architecture is modular and easily scalable in line with traffic growth, eliminating the need for large capital investments typically required for fiber optic networks.

Although promising, there are several technical and operational limitations in utilizing LEO technology as a backhaul solution. The high orbital velocity of LEO satellites (approximately 7.5 km/second) results in limited visibility time with ground stations, which is typically only 5 to 10 minutes. This necessitates advanced feeder link handover strategies to maintain a stable connection. Additionally, integration with 5G systems requires highly precise time synchronization using GNSS or alternative timing systems to ensure support for features such as HARQ, TDD/FDD duplexing, and QoS-aware routing (Vatalaro et al., 1995).

Table 4. SWOT Analysis for LEO satellites deployment as backhaul links in 3T regions of Indonesia

Strengths	Weaknesses
<ul style="list-style-type: none"> • Delivers low latency and high throughput • Provides wide and adaptive coverage for remote areas • Supports integration with 5G Integrated Access and Backhaul (IAB) • Enables integration with multi-hop Inter-Satellite Links (ISL) • Reduces dependency on fiber optic infrastructure • Features modular and scalable architecture 	<ul style="list-style-type: none"> • Complex integration with terrestrial spectrum and 5G handover mechanisms • High initial cost for satellite gateway deployment • Dependency on terrestrial infrastructure, which may be absent in ultra-remote islands • Regulatory uncertainty due to the absence of national standards
Opportunities	Threats
<ul style="list-style-type: none"> • Supports national digitalization programs in frontier, outermost, and least-developed (3T) regions • Serves as a foundation for developing edge computing and IoT ecosystems • Enables partnerships with local operators and regional governments • Utilizes LEO for disaster mitigation and emergency communication • Strengthens cloud-native strategies and network function virtualization 	<ul style="list-style-type: none"> • Dependence on foreign satellite providers • Increased risk of orbital debris and satellite collisions • Vulnerability to atmospheric and weather disturbances • Cybersecurity threats and potential vulnerabilities • Commercial investment risks without supporting subsidy policies

Table 4 provides a detailed SWOT analysis of LEO satellite deployment as backhaul infrastructure in Indonesia's 3T regions, highlighting both the strategic advantages and the operational challenges associated with this approach. Interoperability issues also arise due to technological differences between LEO satellite vendors and terrestrial network operators (such as ISPs and MNOs), particularly in the complex management of Ka and

Ku band spectrum. Other technical complexities include the need for advanced network design, such as dynamic routing across inter-satellite links (ISLs), cache-aware network slicing, and latency jitter mitigation caused by satellite handovers. Furthermore, although generally more cost-effective than fiber optics, the deployment of LEO gateways still requires significant capital investment, as well as locations that are free from physical obstructions and must be connected to terrestrial infrastructure for local service distribution (Okati & Riihonen, 2022).

LEO satellite backhaul has the potential to accelerate digital inclusion across Indonesia, particularly in 3T regions (underdeveloped, frontier, and outermost areas) that are prioritized in national development agendas. This aligns with the Palapa Ring program and the broader national digitalization agenda. A stable LEO infrastructure also supports the growth of edge computing and the Internet of Things (IoT), opening opportunities in sectors such as precision agriculture, environmental monitoring systems, and early warning mechanisms for natural disasters. The availability of such connectivity enables real-time integration with various local systems.

In addition, mobile network operators can form strategic partnerships with satellite providers and local governments to develop micro-cellular networks powered by satellite backhaul, while also engaging local SMEs to manage community-based networks. LEO satellites can also serve as a redundancy layer for emergency communication systems, such as healthcare logistics and disaster response, when fiber optic or microwave infrastructure is disrupted. From a technological standpoint, LEO-based networks support cloud-native principles and network function virtualization (VNF), as well as the implementation of SD-WAN, due to their inherently IP-based and packet-switched architecture (Abdullah et al., 2024).

However, several strategic threats must be considered, including Indonesia's heavy reliance on foreign operators such as Starlink, OneWeb, or Kuiper, which raises concerns over data sovereignty and national control of critical communication infrastructure (Ahmmed et al., 2022). Additionally, the increasing number of satellite deployments heightens the risk of orbital congestion and satellite collisions, which can disrupt communication systems and generate long-lasting space debris (Reddy et al., 2023). From a regulatory perspective, Indonesia still lacks a comprehensive legal framework governing spectrum integration between satellite and terrestrial networks, hindering spectrum harmonization and consistent quality of service.

Atmospheric conditions, especially during heavy rainfall, remain a significant source of interference for LEO signal quality, particularly in the Ka-band frequency. Moreover, the open nature of LEO networks, which can be accessed from multiple nodes, makes them vulnerable to cybersecurity threats such as DDoS attacks and traffic sniffing if not protected with robust end-to-end encryption (E2E) and strict access controls. Additionally, the commercial investment risk increases in the absence of fiscal incentives or subsidy policies that guarantee a return on investment, particularly for gateway infrastructure in 3T regions that are economically less attractive (Ahmmed et al., 2022).

4.1.2. *SWOT Analysis: LEO Satellites as Direct-to-User Terminals for Internet Access in Indonesia*

The direct-to-user access model offered by Low Earth Orbit (LEO) satellite constellations presents new opportunities for expanding digital connectivity, especially in regions completely untouched by terrestrial infrastructure such as base transceiver stations (BTS) or fiber optic cables. In this scheme, end users connect to the internet directly via self-contained satellite terminals, eliminating dependence on ground-based network nodes. This model has been popularized by operators like Starlink, OneWeb, and Amazon Kuiper, and has begun to see early implementation in several 3T (underdeveloped, frontier, and outermost) regions of Indonesia. The SWOT Analysis for LEO satellites as direct-to-user broadband access in 3T regions of Indonesia is presented in Table 5.

The direct-to-user approach utilizing LEO satellites offers significant advantages for expanding internet access in Indonesia's 3T regions. One of its main benefits is the elimination of the need for terrestrial

infrastructure such as BTS towers or fiber optic cables, making it ideal for small islands, mountainous regions, and maritime areas. Additionally, services like Starlink have proven capable of delivering speeds between 50–200 Mbps with latencies below 50 ms, making them competitive with fiber (Fraire et al., 2019a). The quick deployment of terminals, their mobile and scalable nature, and their ability to serve as backup connections during disasters make this a practical and strategic solution for expanding connectivity. This model is also well-suited for implementing community networks and wide-coverage public Wi-Fi.

However, this approach also faces several technical and structural challenges. One major barrier is the high cost of terminal devices, which still range between USD 400–600 (Ahmmed et al., 2022). Additionally, the limited capacity of spot beams means service quality may degrade significantly when too many users are concentrated in one area. The shortage of skilled human resources in 3T areas also presents challenges for installation and maintenance. Environmental factors such as heavy rain or visual obstructions, as well as potential interference with astronomical and climate research, add to the list of issues that need to be addressed. Furthermore, high-traffic use cases, such as schools or healthcare facilities, require additional network distribution to maintain optimal service quality.

Table 5. SWOT Analysis for LEO satellites as direct-to-user broadband access in 3T regions of Indonesia

Strengths	Weaknesses
<ul style="list-style-type: none"> • Not dependent on terrestrial infrastructure, making it easier to allocate • Competitive speed and latency compared to fiber optic networks • Easier and faster deployment and activation • High mobility and scalability • Can serve as a backup connectivity option during disasters • Suitable for community models and public Wi-Fi 	<ul style="list-style-type: none"> • High cost of user equipment • Limited capacity per spot beam • Lack of qualified human resources • Susceptible to environmental and weather disruptions • Not suitable for large-scale traffic demands • Interference issues with astronomy and climate research • Regulatory uncertainty due to the absence of national standards
Opportunities	Threats
<ul style="list-style-type: none"> • Digital leapfrogging for remote communities • Supports national digitalization programs in frontier, outermost, and least-developed (3T) regions • Facilitates integration of Smart Village and Green Energy Systems • Enables partnerships with local operators and regional governments • Utilizes LEO for disaster mitigation and emergency communication • Strengthens cloud-native strategies and network function virtualization 	<ul style="list-style-type: none"> • National data security concerns • Physical security risks of terminal equipment • Dependence on foreign satellite providers • Increased risk of orbital debris and satellite collisions • Vulnerability to atmospheric and weather disturbances • Commercial investment risks without supporting subsidy policies

Table 5 provides a comprehensive SWOT analysis of LEO satellite deployment for direct-to-user broadband services in Indonesia’s 3T regions, emphasizing the strategic opportunities as well as the limitations that must be addressed for effective implementation. On the opportunity side, this technology enables digital leapfrogging, allowing regions with no previous connectivity to directly access modern broadband services. This has a direct impact on accelerating the digital economy and social development. With internet access in place, digital education and healthcare programs can be implemented immediately without waiting for terrestrial infrastructure development. There is also growing potential for synergy with digital literacy efforts, MSME empowerment, and the integration of Smart Village initiatives and green energy systems. Furthermore, LEO terminals can be used in the maritime transport sector to support real-time location reporting and weather

monitoring, and to provide access to digital financial services, including e-ID registration and digital-based social assistance distribution.

Despite its vast potential, this approach also poses several strategic threats. Dependence on foreign providers such as Starlink or OneWeb raises concerns about national sovereignty and data security, particularly in the absence of adequate encryption regulations or data storage controls. Unregulated commercialization could worsen the digital divide, as only citizens who can afford the expensive equipment would be able to enjoy the connection. Moreover, the increasing number of terminals without proper spectrum management could lead to interference. Long-term reliance on foreign providers also creates a “lock-in” effect, making it difficult for users in the event of price hikes or service disruptions. Equally important, the expensive devices installed in open areas are vulnerable to theft, sabotage, or damage from vandalism.

4.2. PESTLE Analysis of the Implementation of LEO in Indonesia

The PESTLE analysis is a strategic framework used to evaluate external macro-environmental factors that influence the successful implementation of technology, specifically low Earth orbit (LEO) satellite constellations aimed at enhancing digital connectivity in Indonesia’s 3T regions (frontier, outermost, and disadvantaged areas). Table 6 presents the analysis across the political, economic, social, technological, legal, and environmental dimensions, illustrating the complexity of the ecosystem that must be considered in the planning and execution of LEO adoption.

Politically, the development of LEO-based connectivity aligns closely with the Indonesian government's vision of expanding digital access across the entire archipelago. Initiatives such as the Universal Service Obligation (USO) and the Palapa Ring program have established policy frameworks that support the integration of this technology into national schemes. According to a study by (Muhamad Samingan et al., 2024) strong political support is crucial in driving the adoption of satellite technology in regions with limited infrastructure.

Challenges arise from the regulatory complexity surrounding the allocation and licensing of frequency spectrum for foreign operators. LEO satellites operate with orbital patterns and channel densities that differ significantly from conventional GEO satellites, necessitating relevant policy revisions (Abdullah et al., 2024). Furthermore, reliance on global operators such as SpaceX or OneWeb raises serious concerns about digital sovereignty and control over strategic data, particularly in maritime zones and remote outer islands.

The need for harmonization between national policies and international standards is increasingly critical, particularly in the context of managing orbital slots and spectrum rights regulated by the International Telecommunication Union (ITU). Public-private partnerships (PPP) can also serve as an effective collaborative mechanism to build national capacity while reducing external dependency.

From an economic perspective, LEO technology presents significant opportunities to unlock new economic potential in rural and maritime regions. Internet access can activate sectors such as digital fisheries, rural e-commerce, and online education that were previously inaccessible. However, the high initial costs remain a major barrier. The procurement of satellites, user terminals, and the operation of gateways require substantial investment, which not all market players are prepared to face.

Research by (Mubarak et al., 2020) indicates that financing schemes combining public funds and private investment can foster a more inclusive business model. A hybrid model that integrates terrestrial and satellite networks is also believed to reduce operational costs in the long run. However, without subsidies or micro-financing schemes for end users, the adoption of LEO technology in low-income communities may stagnate.

In addition, LEO technology opens up new market opportunities for local service providers to offer community-based digital products. With appropriate regulatory support, 3T regions could become fertile ground for digital startups and platform-based cooperatives that have previously been constrained by inadequate infrastructure.

The social implementation of LEO technology can serve as a major catalyst for advancing digital inclusion. Internet access in previously isolated regions enables communities to access health, education, and economic services online. According to research by (Fraire et al., 2019b) communities affected by natural disasters can also benefit from satellite-based communication systems due to their resilience against physical damage to terrestrial infrastructure.

However, access alone does not automatically ensure optimal utilization. Low levels of digital literacy and the lack of local technical personnel can hinder the installation and maintenance of the system. Therefore, community training and capacity building must be an integral part of the adoption strategy for this technology. (Onitsuka et al., 2018).

Another challenge is the potential for excessive commercialization, which could exacerbate social exclusion. If operators prioritize high-population areas due to greater profitability, smaller communities in 3T regions may remain marginalized. Service distribution policies must consider the principle of spatial equity to ensure that the benefits of technology are fairly distributed.

LEO technology is evolving rapidly and offers technical characteristics well-suited to geographically diverse countries like Indonesia. LEO satellites provide low latency (approximately 30–50 ms), high throughput, and dynamic beamforming capabilities, allowing for capacity adjustment based on regional needs (Lagunas et al., 2024). However, this system also presents its own complexities, particularly in managing handovers between satellites and the limited capacity per beam in densely populated areas, which can negatively affect service quality (Zhou et al., 2023).

Integration with 5G networks and edge computing architecture offers further optimization opportunities. However, strong spectrum coordination is required to prevent frequency interference, especially between environmental monitoring and astronomy systems operating in similar frequency bands.

Legally, implementing LEO technology requires regulatory reform encompassing spectrum allocation, operational rights, and data protection. Current laws and their derivative regulations generally refer to the geostationary satellite paradigm, which is inadequate for accommodating the unique characteristics of LEO systems (Pickton & Wright, 1998). Additionally, legal responsibility for incidents such as satellite collisions or service outages must be explicitly defined. This is increasingly crucial, given that most LEO operators are foreign entities, which makes it essential to clarify jurisdiction and consumer protection within bilateral and multilateral frameworks. Security and privacy standards must also be strengthened to align with the Personal Data Protection Law.

The environmental impact of LEO satellites is becoming increasingly prominent in the discourse on sustainable space development. While this technology offers a smaller carbon footprint than constructing fiber networks in remote areas, its effects on the outer space environment remain significant. The high density of LEO constellations increases the risk of space debris and the potential for a domino effect, such as the Kessler Syndrome (Reddy et al., 2023).

Reflected light from satellites also interferes with astronomical observations, particularly in regions like Papua, which possess naturally dark skies. On the other hand, LEO technology can serve as a crucial tool for monitoring climate change, tracking forest fires, and mapping natural resources in real time. Therefore, orbital sustainability must be ensured through environmentally friendly satellite design and well-defined deorbit procedures.

Table 6. PESTLE analysis for LEO satellites deployment in 3T regions of Indonesia

Factor	Key Points
Political	<ul style="list-style-type: none"> • Strong alignment with Indonesia’s national broadband and digital inclusion initiatives • Regulatory complexity in licensing and spectrum allocation, especially foreign LEO operators • National sovereignty concerns due to reliance on foreign-owned LEO constellation • Need for harmonizing national and international policies on orbital resource management

Factor	Key Points
	<ul style="list-style-type: none"> • Opportunity for public-private partnerships to strengthen national satellite capacity and policy development
Economic	<ul style="list-style-type: none"> • Potential to unlock rural economic growth through digital inclusion • High upfront investment costs for satellite deployment and user terminals • Creation of new markets for digital services in rural and maritime communities • Opportunity for lower long-term operational costs with hybrid terrestrial satellite models • Risk of digital divide persistence if financial support for user adoption is inadequate
Social	<ul style="list-style-type: none"> • Potential to close digital divide and improve social equity across Indonesia’s archipelago • Challenges in digital literacy and local capacity to manage and maintain satellite terminals • Opportunities to support disaster response and community resilience • Influence on cultural preservation and local economies by enabling remote communities to engage in digital economy • Risks of unequal access and exclusion if rollout prioritizes commercial interests over social goals
Technological	<ul style="list-style-type: none"> • Rapid advancement of LEO constellation enabling low-latency broadband • Technical challenges with handover management and capacity in dense areas • Integration with 5G and future 6G terrestrial networks for hybrid connectivity • Vulnerability to radio frequency interference with scientific and environmental monitoring • Ongoing research and development in satellite routing and caching technologies to improve performance
Legal	<ul style="list-style-type: none"> • National regulation of spectrum and orbital slots critical to operational success • Intellectual property and licensing challenges for international LEO services • Legal liability and risk management in the event of satellite collisions for failures • Evolving standards for data security and privacy in satellite-based broadband • Indonesia’s alignment with international ITU and UN treaties on orbital and frequency rights
Factor	Key Points
Environmental	<ul style="list-style-type: none"> • Risk of orbital congestion and long-term sustainability of LEO constellations • Light pollution and environmental impacts on astronomy and biodiversity • Opportunity to support climate monitoring and environmental data collection • Reduced carbon footprint for remote broadband compared to fiber deployment in rugged terrain • Importance of sustainable satellite design and deorbiting strategies for environmental stewardship

Table 6 provides a PESTLE analysis outlining the broader external factors that shape the implementation of LEO satellite systems in Indonesia’s 3T regions. Politically, LEO deployment aligns with national digital inclusion agendas but faces regulatory complexity and sovereignty concerns related to foreign operators. Economically, LEO networks offer opportunities for rural economic growth yet require substantial upfront investment and carry risks of unequal adoption without adequate subsidies. From a social perspective, LEO technology can expand access to essential services and strengthen community resilience, though challenges remain in digital literacy and ensuring equitable distribution. Technologically, rapid advancements in LEO constellations provide low-latency connectivity, but handover management, spectrum coordination, and interference risks must be addressed. Legally, deployment hinges on clear regulations governing spectrum rights, data protection, and liability. Environmentally, LEO systems present both benefits, such as reduced terrestrial infrastructure footprint and enhanced climate monitoring, and risks, including orbital debris and light pollution, underscoring the need for sustainable satellite design and deorbiting policies.

In the Indonesian context, the legal framework for non-GEO satellite systems, including LEO constellations, remains fragmented and has not yet been consolidated into a dedicated national satellite regulation. As a result, Indonesia relies on general telecommunications and orbital spectrum regulations, which were originally designed for GEO systems. Strengthening this regulatory foundation is essential, particularly through alignment with the national development agenda outlined in the RPJMN 2025–2029, which emphasizes digital

inclusion, satellite infrastructure modernization, and sovereignty over strategic communication assets. A national LEO roadmap, supported by a specialized regulatory instrument or satellite act, would provide clearer guidelines on licensing, spectrum harmonization (Ka/Ku band), data governance, local gateway requirements, and mandatory collaboration with domestic operators. Such a framework would not only reduce regulatory uncertainty but also ensure that LEO deployment contributes directly to Indonesia’s long-term digital transformation goals.

4.3 Simple Quantitative Illustration Supporting LEO Deployment

4.3.1 Latency Comparison Between GEO, MEO, and LEO Satellites

To enable a quantitative comparison of orbital performance, representative latency values were derived from benchmark ranges reported in the literature. Since GEO, MEO, and LEO satellites provide latency in the form of ranges, the midpoint of each range was used as an approximate measurement to allow numerical analysis and visualization. This approach provides a simplified yet meaningful comparison of real-world performance, demonstrating how LEO systems deliver latency levels that are an order of magnitude lower than GEO and significantly lower than MEO. The representative values used for this illustration are summarized in Table 4.3-1 and serve as the basis for subsequent graphical analysis.

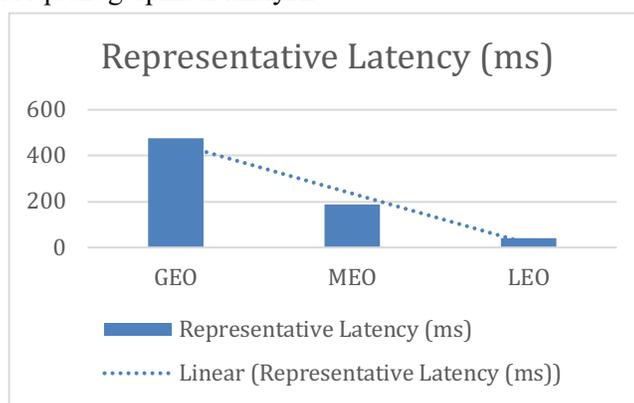


Figure 4. Representative Latency Values for GEO, MEO, and LEO

Figure 4. illustrates the representative latency values for GEO, MEO, and LEO satellite systems, showing a steep decline in latency as orbital altitude decreases. GEO systems exhibit the highest latency at around 477 ms, while MEO systems offer moderate improvements with a representative latency of approximately 188 ms. LEO satellites demonstrate the most significant improvement, achieving a latency of nearly 40 ms, making them nearly 12 times faster than GEO satellites. This simple quantitative illustration confirms that LEO technology is the most suitable option for real-time applications required in Indonesia’s remote 3T regions.

4.3.2 Population Gap and Potential LEO Users in 3T Regions

To further illustrate the potential impact of LEO satellite deployment in underserved areas, a simple quantitative analysis was conducted to estimate the population segments in Indonesia’s 3T regions that remain unconnected or only partially connected to the internet. Using penetration data from Table 1, the coverage gap for each major region was calculated by subtracting existing internet penetration rates from full coverage. This allows an approximation of the number of individuals who could benefit from LEO-based connectivity solutions. The resulting estimates provide a clearer understanding of the scale of unmet demand and highlight the critical role that LEO infrastructure could play in accelerating digital inclusion across remote and isolated communities. Figure 5 illustrates the estimated number of potential LEO users across Indonesia’s 3T regions, based on existing population and internet penetration gaps. Papua and Maluku represent the largest unmet demand, with nearly 5 million potential users who could benefit from LEO connectivity, followed by Bali and Nusa Tenggara at approximately 3.2 million users. Kalimantan and Sulawesi show more moderate demand, each with around 1.2 million and 1.18 million potential users. Sumatra exhibits the smallest gap at 0.82 million. The declining trend

across regions highlights the significant concentration of underserved populations in eastern Indonesia, reinforcing the strategic importance of prioritizing LEO deployment in these areas to accelerate digital inclusion.

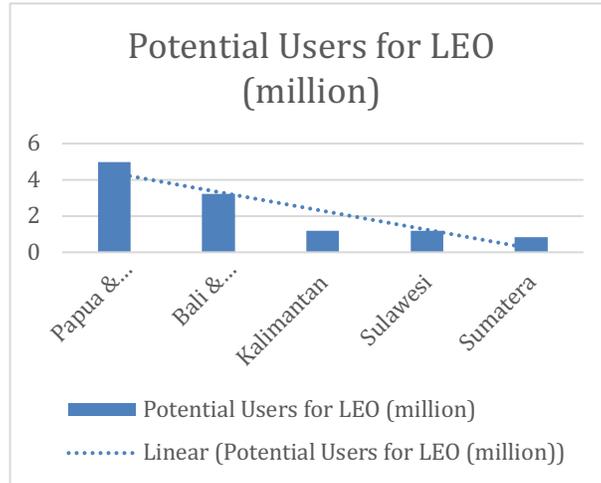


Figure 5. Potential LEO Users

4.3.3 Estimated User Capacity Based on LEO Constellation Throughput

To complement the population-based analysis, a simple quantitative estimation was performed to assess the potential user capacity that major LEO constellations can support based on their advertised total system throughput. By converting each operator's aggregate bandwidth into an estimated number of users using a standard minimum requirement of 25 Mbps per household for rural broadband, this calculation provides an indicative measure of how effectively each LEO system could address connectivity gaps in Indonesia's 3T regions. Although the values are theoretical and depend on real-world factors such as beam allocation and network congestion, the estimation offers a useful baseline for understanding the scalability of different LEO architectures and their suitability for national and regional deployment strategies.

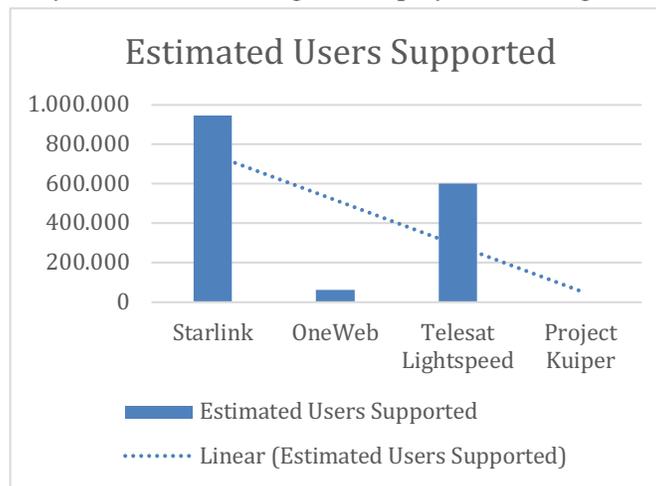


Figure 6. Estimated Users Supported

Figure 6 illustrates the estimated number of users that major LEO constellations can support based on their total system throughput, assuming a minimum bandwidth requirement of 25 Mbps per household. Starlink demonstrates the highest user capacity, potentially serving nearly one million users due to its large aggregate throughput. Telesat Lightspeed follows with an estimated capacity of around 600,000 users, reflecting its strong focus on high-performance enterprise-grade connectivity. In contrast, OneWeb shows a significantly lower

capacity of approximately 62,000 users, while Project Kuiper remains unassessed due to unavailable throughput data. The declining trend across operators highlights substantial variation in system scalability, underscoring the importance of selecting LEO architectures that can meet Indonesia's large-scale rural broadband needs.

Taken together, the qualitative insights from the SWOT PESTLE evaluation and the quantitative illustrations presented in this section show that the feasibility of LEO deployment in Indonesia's 3T regions cannot be assessed solely from technical performance or market potential. Instead, the results reveal a multidimensional interplay between latency gains, coverage capacity, regulatory constraints, and socioeconomic readiness. This integrated interpretation clarifies which factors are most decisive for Indonesia, namely spectrum governance, affordability mechanisms, and infrastructure interoperability, and strengthens the distinction between background information and analytical findings, addressing key concerns raised in prior assessments.

5. Conclusion and Suggestion

Indonesia's archipelagic geography continues to pose substantial barriers to achieving equitable internet access, particularly in 3T regions where terrestrial infrastructure development remains slow and uneven. Persistent disparities in penetration rates demonstrate that existing national programs such as the Palapa Ring and USO have not fully addressed structural limitations across dispersed islands, indicating the need for more adaptive connectivity solutions.

This study shows that Low Earth Orbit (LEO) satellite systems offer strategic advantages, such as low latency, higher throughput, a flexible architecture, and broad area coverage, that closely align with Indonesia's geographic realities. Through SWOT and PESTLE analyses, LEO technology is shown to be most effective when deployed through hybrid models: as backhaul to strengthen 4G/5G expansion and as direct-to-user access for isolated communities. However, its success depends on resolving interoperability challenges, ensuring affordability, and establishing clear regulatory pathways, particularly concerning spectrum allocation, gateway placement, and data sovereignty.

Overall, LEO satellites emerge not merely as a technological alternative but as a strategic enabler for digital inclusion and economic transformation in rural and maritime regions. Accelerated regulatory harmonization, targeted subsidy mechanisms, and strengthened local capacity are essential to ensure sustainable deployment.

Future research should include field-based performance validation in 3T areas, comprehensive techno-economic evaluations, and comparative regulatory studies to support the formulation of Indonesia's Non-GEO Satellite Act. Further technical investigations on inter-satellite routing, handover optimization, and orbital sustainability will also be critical for guiding long-term implementation.

Executive Summary

This article examines the role of Low Earth Orbit (LEO) satellite systems in reducing Indonesia's digital divide, particularly in remote 3T regions. Through a synthesis of recent literature and SWOT-PESTLE analyses, the study highlights LEO's advantages, including low latency, high throughput, and compatibility with 4G/5G infrastructure. Simple quantitative illustrations show LEO's potential to significantly outperform GEO systems, connect millions of underserved users, and support large-scale broadband capacity. The findings emphasize that effective LEO deployment requires harmonized national regulations, integration with the RPJMN agenda, sustainable financing, and digital literacy initiatives to ensure inclusive and lasting impact

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