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The Vulnerability Nexus: Analyzing Risks to Submarine Cable Infrastructure

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Introduction

Currently, there are approximately 600 active submarine cables that provide 99% of international data traffic. TeleGeography reports that the global count of submarine cable systems has surpassed 600, comprising 532 currently operational systems and an additional 77 planned for the future as of September 2024[2]. Among these, the South-East Asia-Middle East-West Europe cable is notable for being the longest undersea cable, stretching an impressive 39,000 kilometers. This single cable is crucial for connecting 33 countries across four continents, linking regions from the UK to Australia[3].

Source: Australian National University

Submarine cables are underwater conduits that enable the transmission of data between continents and countries, playing a vital role in global communication, with new networks in

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[2] Lane Burdette, 'How Many Submarine Cables Are There, Anyway?', 9 September 2024, https://blog.telegeography.com/how-many-submarine-cables-are-there-anyway.

[3] Elina Noor, 'Subsea Communication Cables in Southeast Asia: A Comprehensive Approach Is Needed', *Carnegie Endowment for International Peace* (blog), 18 September 2024, https://carnegieendowment.org/research/2024/12/southeast-asia-undersea-subsea-cables?lang=en.

Asia set to become key nodes in the 21st century[4]. Nearly every facet of our daily lives depends on online connectivity. Specialized cable-laying ships deploy the cables on the seabed, with careful control to prevent damage. In shallow waters, cables may be buried using plowing or jetting techniques for added protection[5]. Despite their significance, the infrastructure of submarine cables faces numerous vulnerabilities that can disrupt this critical connectivity. These vulnerabilities arise from various sources, posing a threat not only to the cables themselves but also to the broader systems that rely on them for functionality. The recent outage of the SEA-ME-WE 5 cable in April 2024, which affected Bangladesh's internet connectivity, also illustrates the vulnerability of global communication networks[6]. This highlights the "vulnerability nexus", which captures the interconnectedness of risks and their potential global cascading effects. As submarine cables link nations and economies, their associated risks are intertwined, creating a complex landscape where disruptions in one area can lead to widespread implications.

Understanding this nexus is crucial for policymakers, businesses, and individuals alike, as it highlights the need for robust strategies to protect this vital infrastructure and maintain the stability of our interconnected world.

A Historical Overview and Its Critical Role in Global Connectivity

The development of submarine cable infrastructure has transformed global communication since the installation of the first Trans-Atlantic telegraph cable in 1854, which connected Newfoundland to Ireland[7]. The first successful transmission in 1858 marked the start of instantaneous communication across vast distances. Advances continued with various telegraph cables in the late 19th and early 20th centuries, and the introduction of coaxial cables in the mid-20th century enhanced capacity and signal quality, leading to the first transoceanic telephone cables in the 1950s. However, it was the advent of fiber optic technology in the late 20th century that revolutionized submarine cables, enabling much higher data transmission rates and transforming the internet's infrastructure.

The global network of submarine cables is an intricate web that spans oceans and connects continents, supporting a myriad of services, including telecommunications, internet access, and financial transactions, making it indispensable to the functioning of the modern economy. By

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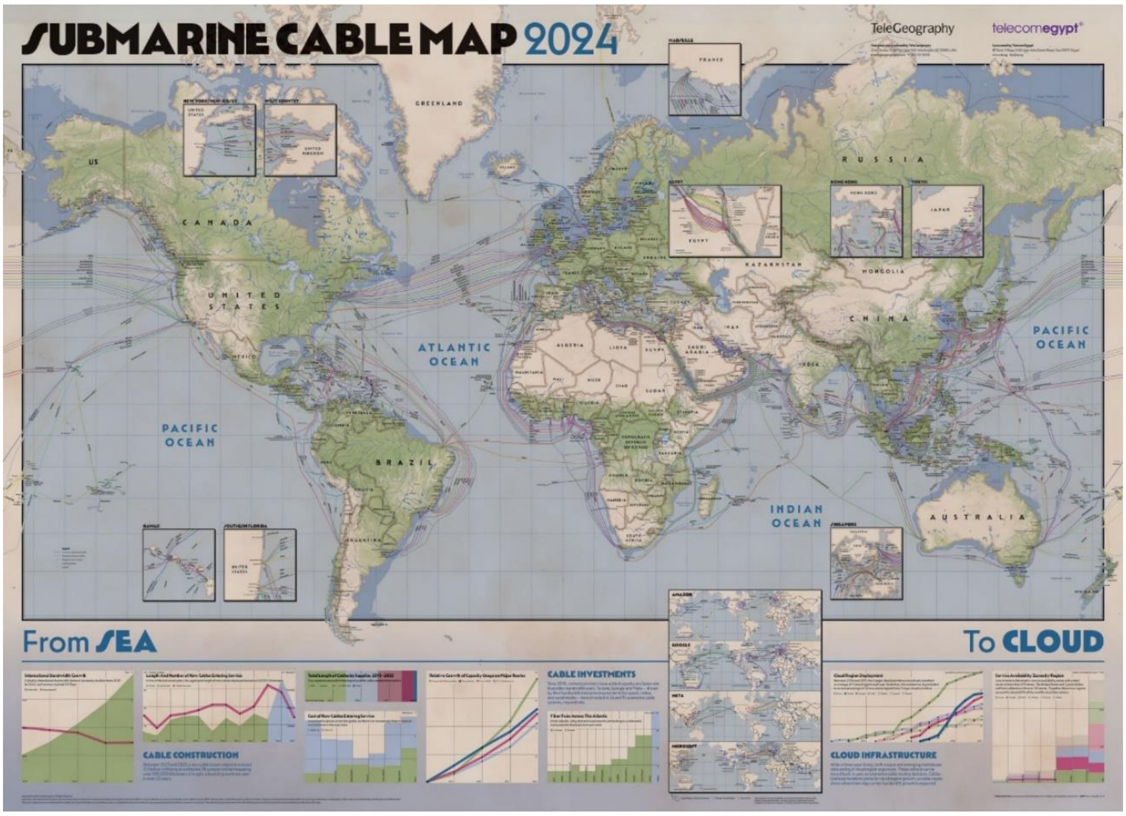
[4] Edward J. Malecki and Hu Wei, 'A Wired World: The Evolving Geography of Submarine Cables and the Shift to Asia', *Annals of the Association of American Geographers* 99, no. 2 (22 April 2009): 360–82, https://doi.org/10.1080/00045600802686216.

[5] Keith Ford-Ramsden and Tara Davenport, 'Chapter 5. The Manufacture and Laying of Submarine Cables', ed. Douglas R. Burnett, Robert Beckman, and Tara M. Davenport (Brill | Nijhoff, 2014), 123–54, https://doi.org/10.1163/9789004260337_007.

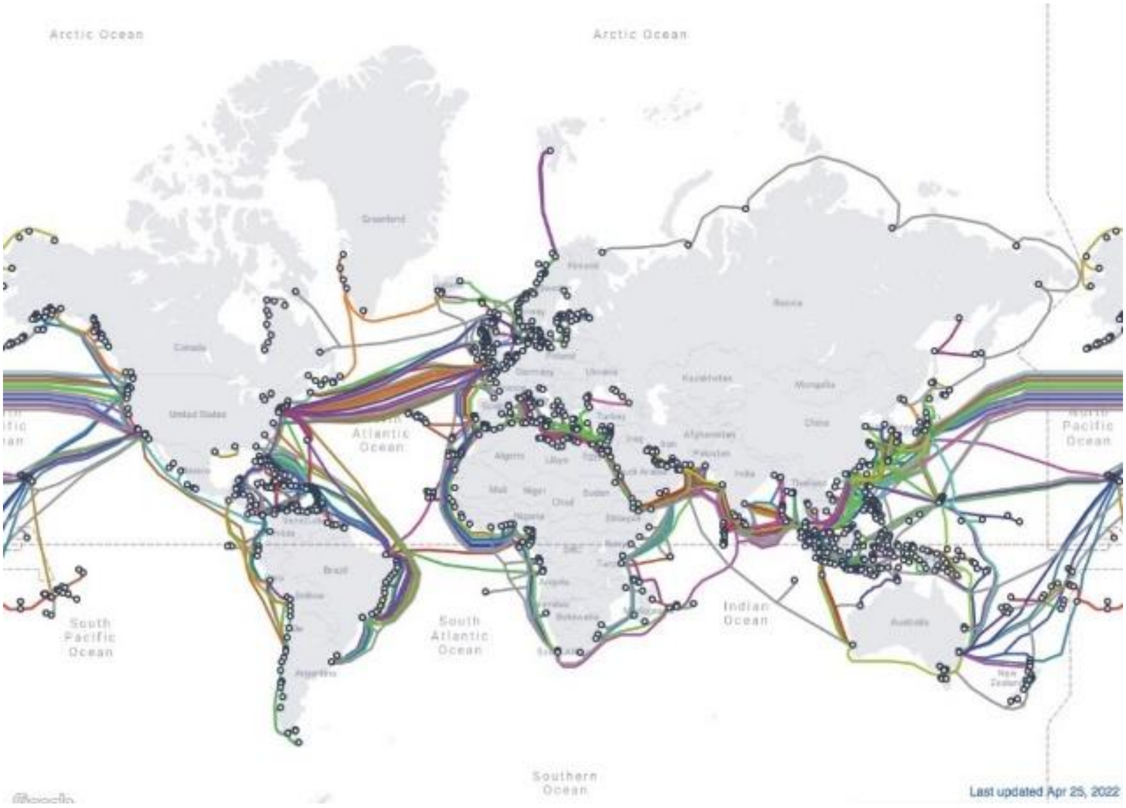
[6] Robbie Mitchell, 'Bangladesh Coping With Submarine Cable Outage Thanks to Indian Terrestrial Cables, Local Content Caches', *Internet Society Pulse* (blog), 25 April 2024, https://pulse.internetsociety.org/blog/bangladesh-coping-with-submarine-cable-outage-thanks-to-indian-terrestrial-cables-local-content-caches.

[7] Bernard Finn and Daqing Yang, eds., 'Communications Under the Seas: The Evolving Cable Network and Its Implications' (The MIT Press, 2009), https://doi.org/10.7551/MITPRESS/9780262012867.001.0001.

enabling the exchange of information at unprecedented speeds, theses cables serve as a highway for data, ensuring that billions of users can connect seamlessly across the globe.



Source: Submarine Cable Map 2024 (TeleGeography)



Source: Submarine Cable Map (TeleGeography, 2022)

The Submarine Cable Map[8] provides a comprehensive view of all active and planned cables worldwide, illustrating their connections across continents and regions. Submarine cable hubs are essential locations where multiple cables converge, with notable hubs including New York and London as key interconnection points for transatlantic cables, Marseille as a strategic Mediterranean hub, and Singapore as a vital center for Southeast Asia[9].

The operational significance of this infrastructure cannot be overstated. As the digital economy expands, the demand for bandwidth continues to rise, pushing the limits of existing cable systems. The current landscape reflects not only the technological advancements in cable design and deployment but also the geopolitical considerations that influence cable routes and ownership[10]. Recent developments, such as increased investments from nations seeking to secure their digital infrastructure, highlight the strategic importance of submarine cables in international relations.

Analyzing the Vulnerability Nexus

The vulnerabilities of submarine cables, which include risks from natural disasters, cyberattacks, and physical damage, must be addressed to ensure the reliability and integrity of global connectivity[11].

Physical Vulnerabilities

The integrity of submarine cable systems is crucial for global communication, yet these systems are susceptible to various physical vulnerabilities:

- **Natural disasters** such as earthquakes and tsunamis can cause substantial damage. For instance, an earthquake can lead to seabed shifts that may sever cables or compromise their structural integrity. For example, the 2006 earthquake off the coast of Taiwan caused multiple breaks in key submarine cables, including the Asia America Gateway (AAG) and the Taiwan Strait Cable System[12]. These disruptions severely affected internet connectivity in various countries, particularly in Asia, where reliance on these cables for data transmission was high. Additionally, underwater landslides can bury cables or exert pressure that leads to cable failure.

[8] 'Submarine Cable Map 2024', accessed 30 December 2024, https://submarine-cable-map-2024.telegeography.com/

[9] Nicole Starosielski, 'The Undersea Network' (Duke University Press, 2015), dup;9780822376224/1, https://doi.org/10.1215/9780822376224.

[10] Hilary McGeachy, 'The Changing Strategic Significance of Submarine Cables: Old Technology, New Concerns', *Australian Journal of International Affairs* 76, no. 2 (4 March 2022): 161–77, https://doi.org/10.1080/10357718.2022.2051427.

[11] Yuka Koshino, 'The Changing Submarine Cables Landscape | European Union Institute for Security Studies', 30 October 2024, https://www.iss.europa.eu/publications/briefs/changing-submarine-cables-landscape.

[12] Y. Kitamura et al., 'Experience with Restoration of Asia Pacific Network Failures from Taiwan Earthquake', *IEICE Transactions on Communications* E90-B, no. 11 (1 November 2007): 3095–3103, https://doi.org/10.1093/IETCOM/E90-B.11.3095.

- **Human activities** such as fishing practices, particularly those involving trawling, can inadvertently snag and damage cables[13]. Similarly, anchoring by ships can pose a threat, as anchors may drag across the seabed, impacting buried cables. An historical disruption occurred in 2008 when a series of undersea cable breaks in the Mediterranean Sea severely impacted internet connectivity across the Middle East, North Africa, and parts of Europe[14]. The incidents were attributed to various causes, including ship anchors. Also, construction activities, including dredging and the establishment of offshore installations, further exacerbate these risks by altering the seabed and potentially exposing or damaging existing cable systems.

- **Maintenance** of aging submarine cable infrastructure is fraught with challenges. As cables age, their susceptibility to damage increases, necessitating regular inspections and maintenance to ensure operational integrity. However, the logistics of repairing undersea cables are complex, involving specialized vessels and equipment capable of operating in deep-sea environments.

Geopolitical Risks

Geopolitical tensions significantly impact the stability and security of submarine cable systems, often leading to targeted disruptions that can have far-reaching consequences. For instance, the ongoing conflict involving the Houthis in Yemen has raised concerns over the safety of undersea cables in the Red Sea[15]. More recently, in November 2024, two incidents causing disruptions in the Baltic Sea were reported. The first involved the severing of submarine cables in Swedish waters, with investigations centering on the Chinese cargo ship *Yi Peng 3*, which was in proximity to the site of the incident at the time[16]. The Swedish authorities were subsequently denied permission to conduct a comprehensive investigation aboard the vessel. The second incident pertained to the *Eagle S*, a ship believed to be associated with a Russian “shadow fleet”, which is linked to the rupture of an electrical cable connecting Finland and

[13] Charlotte Jarvis, Maria Pena Ermida, and Ole Varmer, ‘Threats to Underwater Cultural Heritage from Existing and Future Human Activities’, *Blue Papers* 2, no. 1 (31 March 2023): 76–83, https://doi.org/10.58981/bluepapers.2023.1.08.

[14] Tomasz Bilski, ‘Disaster’s Impact on Internet Performance – Case Study’, ed. Andrzej Kwiecień, Piotr Gaj, and Piotr Stera, vol. 39, Communications in Computer and Information Science (Berlin, Heidelberg: Springer Berlin Heidelberg, 2009), 210–17, https://doi.org/10.1007/978-3-642-02671-3_25.

[15] United Nations Office on Drugs and Crime, ‘Assessment of the Response to Illicit Weapons Trafficking in the Gulf of Aden and the Red Sea’ (United Nations, 2024), https://doi.org/10.18356/9789213589304.

[16] Miranda Bryant and Miranda Bryant Nordic correspondent, ‘Sweden Says China Denied Request for Prosecutors to Board Ship Linked to Severed Cables’, *The Guardian*, 23 December 2024, sec. World news, https://www.theguardian.com/world/2024/dec/23/china-refused-investigation-into-ship-linked-to-severed-baltic-cables-says-sweden.

Estonia[17]. Such events illustrate how disruptions in one area can ripple through international relations, affecting trade, diplomacy, and economic activities across multiple countries.

Source: Submarine Cable Map (TeleGeography, 2024)

In addition to direct conflicts, international laws and regulations pose significant challenges that can create vulnerabilities in global communication networks. The regulatory landscape governing submarine cables is complex, with multiple jurisdictions often involved in the ownership and operation of these systems[18]. This fragmentation can lead to inconsistencies in security protocols and maintenance practices, increasing the risk of vulnerabilities that adversaries could exploit. Furthermore, regulatory gaps can lead to inadequate enforcement of maritime practices, such as those concerning fishing and shipping operations, which can inadvertently compromise the integrity of undersea cables.

[17] Cachella Smith, 'Finland Investigates Russian Ship after Electricity Disconnection', accessed 30 December 2024, https://www.bbc.com/news/articles/cr56l7prj2mo

[18] Abra Ganz et al., 'Submarine Cables and the Risks to Digital Sovereignty', *SSRN Electronic Journal*, 2024, https://doi.org/10.2139/ssrn.4693206.

Technological Risks

The increasing reliance on submarine cable networks for global communication has made them prime targets for cyberattacks[19]. Cyberattacks can manifest in several forms, including hacking, data breaches, and sabotage. Such incidents not only threaten the operational integrity of cable operators but also have the potential to disrupt services across interconnected systems, leading to widespread ramifications. For instance, a successful cyber intrusion could result in unauthorized access to sensitive data transmitted through these cables, thereby jeopardizing both corporate and personal information. Furthermore, the possibility of sabotage can lead to prolonged outages and significant economic losses. The ripple effects of such disruptions can extend beyond immediate financial impacts, influencing public trust in digital communications and potentially destabilizing financial markets.

In conjunction with cybersecurity threats, the issue of aging infrastructure poses a critical challenge to the resilience of submarine cable networks. Many existing systems rely on outdated technology, which increases their vulnerability to both physical and cyber threats[20]. The deterioration of physical components can lead to malfunctions or failures, while outdated software and security protocols may be ill-equipped to defend against modern cyber threats.

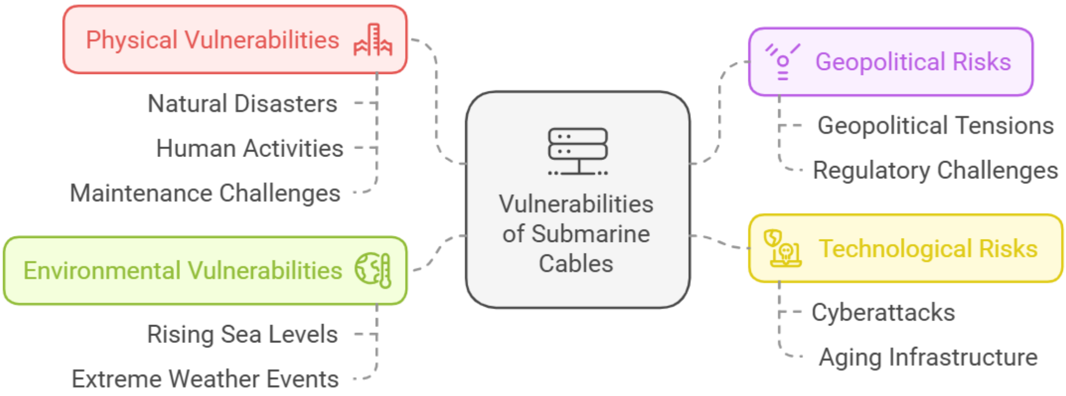
Environmental Vulnerabilities

Climate change represents a significant threat to the integrity and functionality of submarine cable infrastructure. One of the most pressing concerns is the effect of rising sea levels, which can lead to increased flooding and erosion in coastal areas where cable landing stations are located[21]. As sea levels continue to rise, the physical security of these installations may be compromised, heightening the risk of damage from storm surges and extreme weather events. Such damage can result in substantial disruptions to global communication networks, as cables can become severed or degraded, leading to outages that affect numerous sectors reliant on uninterrupted connectivity.

[19] Tawfiq M. Aljohani, 'Cyberattacks on Energy Infrastructures as Modern War Weapons—Part I: Analysis and Motives', *IEEE Technology and Society Magazine* 43, no. 2 (June 2024): 59–69, https://doi.org/10.1109/mts.2024.3395688.

[20] Ganz et al., 'Submarine Cables and the Risks to Digital Sovereignty'.

[21] M.A. Clare et al., 'Climate Change Hotspots and Implications for the Global Subsea Telecommunications Network', *Earth-Science Reviews* 237 (February 2023): 104296, https://doi.org/10.1016/j.earscirev.2022.104296.



Source: Daversin Alice (2024)

Recommendations for Mitigation

The increasing vulnerabilities faced by submarine cable infrastructure necessitate a comprehensive approach to risk mitigation. This includes strategic investments, robust policy frameworks, and enhanced monitoring systems. Below, we outline key recommendations aimed at bolstering the resilience of submarine cable networks.

- **Enhancing the resilience of submarine cables requires increased investment in modern technology and redundancy systems**. As data transmission demands rise, cable operators must upgrade infrastructure to better withstand natural and human threats. This includes using advanced materials to combat environmental stressors and developing redundant pathways to maintain connectivity during disruptions. Such investments will bolster network reliability and support long-term economic stability by reducing the impact of outages on businesses and consumers.

- **Comprehensive policy frameworks are essential for protecting submarine cable infrastructure[22].** International cooperation is vital, as cables often span multiple jurisdictions. Governments should promote collaborative agreements that safeguard these critical assets, establishing protocols for maritime activities that may threaten cable integrity. Regulatory frameworks must also include best practices for installation and maintenance, ensuring environmental assessments identify potential risks. A cooperative approach among nations will enhance security for submarine cable operations and bolster global communication reliability.

[22] Jason Halog, Paul Margat, and Michael Stadermann, 'Submarine Infrastructures and the International Legal Framework', *Transactions on Maritime Science* 13, no. 1 (15 March 2024), https://doi.org/10.7225/toms.v13.n01.w16.

- **Implementing real-time monitoring systems is crucial for early detection of potential threats[23].** Advances in technology enable the deployment of sensors that continuously track the condition of submarine cables and their environment. These systems can provide early warnings for threats such as seismic activity, underwater landslides, or human-induced risks like trawling. By adopting proactive measures, operators can respond swiftly to incidents, preventing significant disruptions. Integrating monitoring systems with response protocols will also facilitate coordinated efforts among stakeholders to effectively mitigate disruption impacts.

Conclusion

The vulnerabilities facing submarine cable infrastructure create a complex nexus of risks that significantly threaten global stability and connectivity. This intricate web includes natural disasters, geopolitical tensions, human activities, and technological threats, all of which collectively jeopardize this critical backbone of the digital economy. To effectively tackle these interconnected challenges, it is imperative for stakeholders—including governments, private sector entities, and international organizations—to prioritize the resilience of submarine cable systems.

Moving forward, ongoing research and adaptation are essential to navigate emerging threats within this vulnerability nexus. By fostering collaboration and investing in protective measures, we can safeguard the integrity of submarine cables and ensure robust global communications for the future.

[23] Steinar Bjørnstad et al., 'First Impact Movement Characterization of Shallow Buried Live Subsea-Cable', *Optical Fiber Communication Conference (OFC) 2024*, 2024, M4E.4, https://doi.org/10.1364/ofc.2024.m4e.4.