Critical Communications in Remote Areas using LEO Satellites

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**Abstract**

This research examines the potential of Low Earth Orbit (LEO) satellites to enhance connectivity and quality of life in remote regions by addressing critical infrastructure gaps in internet access. There is a growing need for reliable internet access in rural areas as fifth-generation (5G) mobile network technology and the Internet of Things (IoT) grow. This is especially pertinent in developed nations such as Canada, Australia, and New Zealand, where practical and geographic limitations constrain traditional broadband solutions. In order to evaluate how important LEO satellite networks are implemented in remote areas, as well as potential environmental pollution, this study synthesises information from more than 15 peer-reviewed sources from a variety of fields using a thematic literature review and secondary data analysis.

The findings reveal that while LEO satellites advance telemedicine and rural connectivity, the increase in satellite launches brings notable environmental concerns, including air and light pollution due to satellite collisions and the reflection of sunlight. Furthermore, the widespread use of blue-light-emitting LEDs exacerbates light pollution, affecting visibility in both urban and rural settings. This research contributes to understanding the trade-offs between connectivity advancements and environmental sustainability.

**Key Terms**: Low Earth Orbit (LEO) satellites, rural connectivity, Internet of Things (IoT), telemedicine, environmental impact, light pollution

**Introduction**

Nowadays, mobile network technology is jumping into an epochal of fifth-generation, relevant Internet of Things (IoT) technology that is also getting to grow up fast. With increased market demand for IoT network communication, people now notice the importance of LEO satellites implementing in remote areas. Such as indispensable internet service providing people a more convenient life in information communication, however, it is not common in most remote areas, not even in a developed country. Broadband Internet is either not available or not fast enough in most rural and remote parts of Canada for cloud-based software, videoconferencing, online classes, and learning tools (Ahmmed et al., 2022). Actually, not only Canada, but also Australia and New Zealand's governments have special problems getting people in remote areas connected to the Internet over very long distances, since fibre and other solutions are not realistic yet. However, a ground station, on the other hand, can only cover a small area, which makes it harder to plan for consistent network management and smooth routeing service (Xia et al., 2019). Due to its limited view of the entire LEO network, a single ground station cannot successfully watch over and direct LEO satellites. Keeping a consistent and complete view of the network is also challenged because LEO satellite networks are dynamic, meaning that the places of the satellites are always changing.

In fact, with the LEO satellite network, the advancement of telemedicine is also making noticeable progress in the past few decades. According to Gustafson et al. (1998), in Manaus, Brazil, telehealth played an important role in follow-up both in sufficient remote consultation and patient care after surgeries, as a complete database of patients’ historical records is a key resource for further reliable medical treatment. In 2024, Comprehensive stroke centers (CSC) even point out that between 2014 and 2019, the rate of patients achieving favorable clinical outcomes increased substantially (Masouris et al., 2024).

In recent decades, the rise in satellite launches has led to notable increases in air and light pollution, especially due to the aftermath of collisions. When satellites break up into small fragments during crashes, these fragments can contribute to pollution, both in the atmosphere and through increased light interference from orbit. As Olivieri et al. (2023) noted, “the probability of massive collisions among spacecraft is directly related to the number of satellites in orbit” (p. 1). Looking forward, it is expected that approximately ten satellites, weighing an average total of seven tons, will be launched daily over the next nine years, further intensifying these risks (Novaspace Forecasting a Daily Average of 7 Tons of Satellites Will Be Launched, 2024). This could be a reason why global air quality is getting worse and worse in both indoor and outdoor spaces. Meanwhile, the other problematic increase in satellite impacts raises concerns about light pollution. This problem has gotten worse with the widespread use of low-cost LEDs, especially those that produce blue light. The atmosphere spreads blue light more easily, making the night sky brighter and making it harder to see the stars (Antonia, 2023). As the number of satellites increases, they reflect sunlight and make the sky brighter at dusk. This makes light pollution an unavoidable environmental problem that affects both cities and rural areas.

In conclusion, the importance of LEO satellite networks, especially in remote areas, has been underlined by the quick development of mobile network technology, which is currently approaching the fifth generation, as well as the rapidly expanding Internet of Things (IoT).

**Literature review**

The purpose of my research is to figure out people’s living experience can be improved with a stable LEO satellite connection and how it brings improvement in local live quality and environmental pollution. It will discuss covering different types of remote areas, such as the sea, rural areas, and mining environments, where establishing reliable LEO satellite architectures is more difficult compared to metropolitan areas. Through a comparative analysis of peer-reviewed research from scholars with varying countries as well as professional backgrounds—including systems, electrical, and computer engineering in Canada, as well as intelligent telecommunication software and multimedia in China. The literature review approach adopted involves a comparative analysis of existing excellent research to measure the viability of various LEO satellite architectures and exact help example in challenging environments with its pollution issues.

For this literature review, we will procedure a thematic approach to present, analyse, evaluate, and synthesize the existing research on the use of LEO satellites for critical communications in remote areas. This approach will focus on key themes: challenge with its practical solution, telemedicine, and environmental pollution. The review will integrate insights from various sources and compare their contributions to the development of stable LEO satellite networks in such environments. The two amazing research written by Xia et al. (2019) and Ahmmed et al. (2022), propose solutions like the hierarchical terrestrial controllers architecture (HTCA) and increasing ground station density to enhance network management and reduce latency. These approaches are capable but also face practical hurdles, such as the high cost of deploying additional ground stations and the complexity of managing dynamic satellite handovers in vast and remote areas.

By comparing existing peer-reviewed studies and examining practical case studies, this research will provide a comprehensive analysis of potential network architectures and implementation strategies that can improve the existing limitations. Finally, it will firstly contribute to the ensuring reliable communication networks for people who lives in remote areas or isolated regions globally; Secondly, protect environment while developing relevant technology, achieving purpose of sustainable environment.

In additionally, these findings could have positive impact on global society and local industries such as agriculture, mining, and disaster recovery, improving the standard of living in many developing countries. However, despite the valuable contributions of these studies, there are notable gaps in the literature. Few works address the specific needs of extremely remote environments, such as deep-sea regions or isolated mining areas, where ground station deployment is highly impractical.

**Methodology**

The Internet is now going deeper and deeper within people’s lives under faster-developing GNSS technology. Areas that are indebted to GNSS are not only cosmopolitan with high population density but also remote areas that have very limited infrastructure, with essential services frequently lacking, and rural areas that are characterised by lower population density and often associated with agriculture or natural resource-based economies, according to the RRMA (Rural, Remote and Metropolitan Areas) definition in Australia and New Zealand (McGrail and Humphreys., 2009). GNSS, in combination with other technologies, such as Low-Power Internet of Things (LPIoT) and Unmanned Aerial Vehicles (UAVs), provides essential services in remote areas, covering sectors like agriculture, environmental monitoring, and emergency services (Andreadis et al., 2023). Also, telemedicine has helped people in remote and rural areas many years since 1998, improving their life quality and happiness.

Moreover, some environmental pollution issues are rise to surface of water with relevant technological advancement. According to Ahmmed et al. [2022], Canada's increasing satellite count—particularly in LEO constellations—has sparked worries about light pollution and space debris, which can have an impact on astronomical observations as well as space operations. These technologies offer problems that require careful management to maintain sustainability and minimise possible environmental impact, even as they aid in closing the digital gap and enhance environmental monitoring. The advent of telemedical services has transformed underprivileged communities' access to healthcare, particularly in vital areas like stroke care. For example, by offering round-the-clock access to specialised treatment, telemedical stroke care networks, like the NEVAS network in Bavaria, Germany, have greatly improved patient outcomes. Through these networks, regional hospitals can seek the advice of specialists when making decisions on urgent medical care, such as intravenous thrombolysis (IVT) and other life-saving measures. Telemedicine networks have improved recovery results, decreased death rates, and sped up response times for stroke patients in remote locations, according to data from long-term research (Manouris et al., 2024).

Thus, although it has been discussed in some papers before, pay more attention to the topic of preventing environmental damage while developing technology is urgent to being a part of earth; time is of the essence. The case study-based research work is going to figure out how Leo satellites can help people stay outside of the cosmopolitan regions with at least average life quality, as well as what the consequences are regarding developing this technology through comparing over 15 peer-reviewed published research papers done by researchers from various profession backgrounds. In order to achieve this goal, secondary data will be adopted in this research and will be further discussed and summarised in the next session. Secondary data refers to data that has already been collected, analysed, and published by other researchers, institutions, or organizations. This data will be gathered from peer-reviewed journal articles, government reports, white papers, and relevant studies that focus on the role of GNSS, LEO satellites, IoT, environmental impact, and telemedicine in rural and remote areas.

Even though data is carefully gathered and summed up, it is important to remember that technology and information are changing at a speed that has never been seen before. Because of this, as a result, some statements and findings derived from secondary data may not fully align with the most current developments in society. This problem comes with using external data for research: there is a time lag between collecting the data, publishing it, and using it in the research. This means that the part of stated information might not be up to date with how technology or society works now.

This method focuses on using previous information to gain insight into how LEO satellites, IoT, and telemedicine can improve the quality of life in rural and remote places while also taking their effect on the environment into account. Peer-reviewed journal papers and government studies about technology advances and their effects will be used to gather data for the study. The study compares more than 15 studies from different fields to find out how LEO satellites can improve services and connections in places that are not cities. To mitigate these issues, the research aims to provide a broader understanding of long-term trends and underlying patterns. While this approach allows for a deeper exploration of the relationship between technology and environmental sustainability, it also underscores the need for continuous research and updates to ensure ongoing relevance in a fast-changing technology.

**Results and Discussion**

*Telemedicine in Rural and Remote Areas*

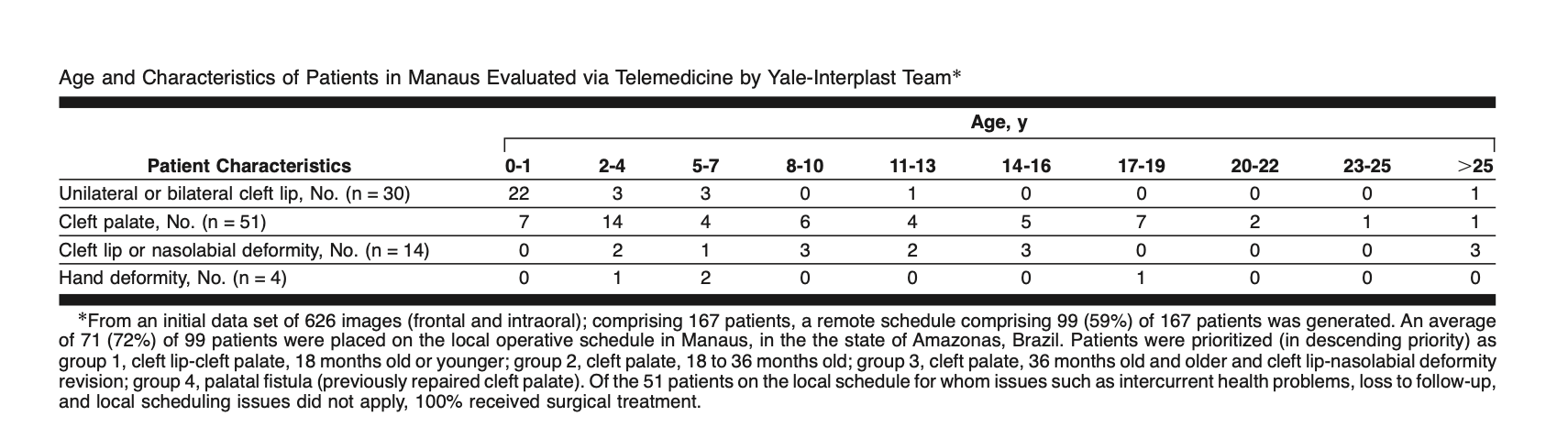


Table 1 - Telemedicine in 1998

The table shows the range of ages and other features of patients in Manaus, Brazil, who were seen by the Yale university via telemedicine. Patients were put into four groups based on their conditions: cleft lip (one or both sides), cleft palate, cleft lip or nasolabial deformity, and hand deformity. Out of the 30 people who had either one or both cleft lips, 22 were babies between 0 and 1 year old and only a few bigger kids and one adult were there. The 51 patients with cleft lip, on the other hand, were spread out across a bigger range of ages. The most common age group was 2–4 years old, with 14 patients, followed by 17–19 years old with 7 patients. The 14 patients who had cleft lip or nasolabial deformities were mostly between the ages of 2 and 4 and 11 to 16 years old. Lastly, the four people who had defects in their hands were all different ages. This information came from a first set of 626 pictures of 167 patients. Using telemedicine, 99 patients were put on a plan for surgery that could be done from afar, with problems like cleft lips or palate fistulas getting surgery first because they were more serious or needed to be fixed right away. This method made it possible to treat all of the patients on time, which made the local surgery team as efficient as possible.

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Table 2 - Telemedicine in 2024

The table shows basic information about stroke patients who were treated in rural hospitals through the NEVAS telemedicine network in 2014–2015, 2016–2017, and 2018–2019. There has been a steady rise in the number of TIA and stroke cases, with 1,885 people in 2018–2019 compared to 1,544 in 2014–2015. In the past few years, the median age of patients went from 77 to 78 years old. The percentage of female patients stayed the same but went from 50.7% to 47.3%. The NIHSS score at the start of the stroke showed that it got better over time, with the median score going from 3 to 2, which means that the strokes were less serious when they were admitted. Key stroke risk factors went down, including high blood pressure (from 75.2% to 66.4%) and diabetes (from 24.7% to 20.4%), with both drops being statistically significant. Atrioventricular fibrillation also went down from 27.5% to 23.7%. For stroke detection, all patients always got a CT scan and a CT angiography. The median number of hospital days dropped from 6 days (IQR 4–10) to 6 days (IQR 4–9), which means that people were there for less time. This may be because they were getting better care and treatment. The amount of time between the start of symptoms and admission to the hospital stayed the same at about 4 hours. The number of patients who received intravenous thrombolysis (IVT) went up from 8.9% to 9.8%, but this increase was not statistically significant. Overall, the table shows that stroke care has gotten better, with shorter hospital stays, faster healing times, and better control of risk factors.

*LEO Satellites Caused Environmental Pollutions*

In additionally, In the last few decades, the natural night sky has been affected by more things than ever before.

| **Parameter** | **500 km Altitude** | **1,200 km Altitude** |
| --- | --- | --- |
| **Observer Location** | Cerro Pachón, Chile (Rubin Observatory, LSST) | Cerro Pachón, Chile (Rubin Observatory, LSST) |
| **Constellation** | 1,296 satellites at 50° inclination, 36 planes, 36 satellites per plane | Same as 500 km altitude |
| **Simulations Performed** | Summer and Winter | Summer and Winter |
| **Maximum Night Sky Illumination (Winter)** | Up to 4 hours of illuminated satellites | Up to 8 hours of illuminated satellites |
| **Number of Satellites Illuminated at Twilight** | ~40 satellites | ~100 satellites |
| **Sky Percentage Containing Illuminated Satellites (Winter, End of Twilight)** | 63% | 80% |
| **Sky Percentage Receiving Reflections (1 Hour Into Night)** | 28% | 58% |
| **Time Until Satellites No Longer Illuminated (Winter)** | 2 hours after twilight | 4 hours after twilight |
| **Summer Night Illumination** | Illumination never completely ends | Illumination never completely ends |
| **Number of Illuminated Satellites in Summer Night** | Drops significantly but persists | Drops significantly but persists |

Table 4 – Light Pollution

Aerospace made a model of how satellites reflecting sunlight would change astronomy data. The model focused on made-up groups at 500 km and 1,200 km altitudes. The study took place on Cerro Pachón in Chile, which is home to the Rubin Observatory and the Large Synoptic Survey Telescope (LSST). It used a group of 1,296 satellites spread out over 36 orbital planes, with 36 satellites in each plane. There were two models, one for summer and one for winter, to show how the seasons change and how long an astronomical night is. At night in the winter, up to 4 hours (at 500 km altitude) or 8 hours (1,200 km altitude) of satellite light could shine on the telescope. At the end of cosmic twilight, between 40 and 100 satellites (500 km) are lit up, covering 63% (500 km) to 80% (1,200 km) of the sky. Sunlight can still reach 28% (500 km) to 58% (1,200 km) of the sky an hour after activities ends at night. After 2 hours (500 km), the spot goes out of the sun's light, and after 4 hours (1,200 km), it goes into Earth's shade. The number of lighted satellites drops by a large amount during the shorter summer nights, but the light never goes out totally.

By 2040, based on Perez published paper in 2023, 19% of the world's power is used for outdoor lights in cities, however, it is expected to rise to 27% by 2040. This further causes greenhouse gas emissions that add to climate change. He also motioned that Lighting alone is responsible for 1,471 million tonnes of CO2 emissions every year, which is about 18% of all emissions in China and 27% of all emissions in the US. Using too much lighting, or over illumination, has become series issues. This wastes energy, costs money, and releases more greenhouse gases into the air. Furthermore, the world's population is expected to exceed 9.6 billion by 2050, with 68% of those people living in cities. Light pollution is likely to get worse very quickly as the people and economy continue to grow. Between 2017 and 2022, sales of LEDs grew by 18% per year. From 2022 to 2027, they are expected to grow by another 15%, hitting $141 million USD per year. However, many LEDs add to light pollution because they give off too much blue light, which is easier for the air to spread.

**Conclusion**

To sum up, despite previous papers showing that LEO satellites can provide people who live in remote areas, especially in medicine, even longer than 20- years ago, more and more environmental problems have also been demonstrated in past decades. As need of IoT integration technology is very popular in the market, the number of satellite constellations also grows up in order to respond the need. Sunlight reflection issues by satellites during twilight hours are very challenged topic in this century, it first makes astronauts more difficulted to observe the night sky at telescopes around the world, furthermore, impact people’s daily life. The fast growth of city lighting, especially LEDs that cause a lot of blue light, makes light pollution problems cannot be ignored. This is because blue light is easily spread through the air, making the sky brighter in both cities and rural areas. As a result, it is suggested that this society can make more effort to protect the environment from satellite-related issues, rather than solely focusing on developing more advanced satellite technologies. Finally, by balancing technological advancements with environmental sustainability, we can ensure that these innovations surely improve quality of life within a sustainable and healthy living environment.

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