Sustainable Telecommunications:

A portable, solar-powered balloon for remote connectivity and disaster response

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Executive Summary:

Telecommunications, once considered a convenience, has evolved into a critical infrastructure for modern society. However, traditional communication networks are vulnerable to disruptions caused by natural disasters, infrastructure failures, and geographical constraints. While satellite communication provides an alternative, it comes with significant limitations, including high costs, limited bandwidth, coverage constraints, and reliance on a consistent power supply—challenges that hinder its sustainability, particularly in disaster-stricken areas.

This project explores the design and development of a Low Altitude Platform Station (LAPS) to enhance telecommunication capabilities in remote and disaster-affected regions. The proposed system integrates solar panels as a primary power source, supplemented by batteries for energy storage, ensuring continuous operation regardless of weather conditions. A 3D-printed base secures sensitive components, providing both structural integrity and cost efficiency. Helium-based lift enables the platform to reach an altitude of 500 meters, optimizing line-of-sight connectivity while maintaining FAA compliance for safe and legal deployment in diverse locations[5].

The sustainability and social impact of LAPS extend beyond emergency response. Its portable and cost-effective nature makes it a scalable solution for rural communities with limited connectivity. By rapidly restoring communication after disasters, LAPS reduces the burden on technicians, supports search and rescue operations, and facilitates coordination among first responders. Furthermore, as global demand for connectivity grows—reflected in the increasing investment in Low Earth Orbit (LEO) satellites—LAPS offers a ground-based, energy-efficient alternative that minimizes environmental impact while bridging the digital divide in underserved areas.

Industry Overview

Today's world is more interconnected than ever before, yet instant access to communication is often taken for granted. In remote or disaster-stricken areas, access to a reliable telecommunications system remains challenging. In the USA alone, there are an estimated 142,000 cell towers and 450,000 small cell nodes across the country [1]. However, despite their presence, millions are still facing service issues due to infrastructure costs, geographic barriers, or natural disasters. As a result, gaps in connectivity can hinder critical emergency operations, disrupt coordination in remote expeditions, and leave off-grid teams or rural communities without critical communication when it's needed most.

In today's interconnected world, instant access to communication is often taken for granted. However, millions of people in remote or disaster-stricken areas lack reliable telecommunications access, leading to critical disruptions in emergency response, disaster recovery, and rural connectivity. In the United States alone, there are approximately 142,000 cell towers and 450,000 small cell nodes [1]. Despite this extensive infrastructure, many communities still face connectivity challenges due to geographic barriers, high infrastructure costs, and extreme weather events. As a result, gaps in communication can hinder emergency response operations, complicate coordination in remote expeditions, and leave rural populations without a dependable means of communication when it's needed most.

Current Solutions and Limitations

Existing telecommunication solutions primarily rely on two traditional systems: Low Earth Orbit (LEO) satellites and cell towers. While LEO satellites provide broad coverage, they depend on clear line-of-sight connectivity, making them ineffective in dense forests, canyons, or areas with significant obstructions. High costs, long deployment timelines, and environmental concerns further limit their feasibility. Satellite launches contribute to atmospheric pollution, space debris accumulation, and emissions from rocket launches. Research suggests that metals from re-entering spacecraft could alter the chemical structure of the stratosphere, posing long-term risks [2]. Additionally, deploying a functional satellite network takes years, making it an impractical solution for disaster response.

On the other hand, cell towers require significant infrastructure investment, including underground cabling, maintenance roads, and months of construction before becoming operational. They are also vulnerable to natural disasters such as hurricanes, wildfires, and earthquakes, which can result in prolonged outages when communities need communication the most. In some cases, building new towers in remote areas is not economically viable, leaving entire regions without any access to modern telecommunications.

Other stopgap solutions include portable two-way radios, which offer limited-range communication and require repeater stations for extended coverage. However, these share the same vulnerabilities as cell towers, making them unreliable for large-scale or long-term deployment.

Past Attempts and Unmet Needs

Several innovative solutions have attempted to bridge the telecommunication gap using High Altitude Platform Stations (HAPS). One of the most well-known efforts was Google's Project Loon, a network of stratospheric balloons designed to provide internet access to underserved regions. Each balloon acted as a node, relaying signals between satellites and ground stations. While Project Loon successfully provided emergency network access to Puerto Rico after Hurricane Maria, it was ultimately canceled due to high operational costs and logistical challenges [3].

More recently, communication failures during major disasters have underscored the urgent need for a cost-effective, rapidly deployable, and self-sustaining telecommunications system. For example, Hurricane Helene in 2024 left over 600 people unaccounted for as collapsed networks prevented any form of communication [4]. Similarly, wildfires in California destroyed telecommunication infrastructure, initially leaving thousands of residents without emergency alerts or real-time updates.

The Need for an Innovative Solution

To address these challenges, a new approach to telecommunications is necessary—one that is portable, cost-effective, rapidly deployable, and independent of traditional infrastructure. Low Altitude Platform Stations (LAPS) offer a sustainable and scalable solution to ensure continuous connectivity in remote areas, disaster-stricken zones, and underserved communities. By leveraging solar power, helium lift, and modular 3D-printed components, LAPS can provide reliable, self-sustaining communication without the environmental and financial burdens of traditional satellite and tower-based systems. This innovation has the potential to transform emergency response, disaster relief, and rural connectivity, ensuring that no community is left without access to life-saving communication when it matters most.

Design, Functionality, and Durability:

The design will focus on creating a low-altitude platform station (LAPS) that must meet several functionality requirements:

- Provide temporary network coverage.
- Deployed easily and within an hour.
- Operate continuously without maintenance.
- Be self-sustaining and airborne for an extended period, while remaining stable in various types of weather conditions.
- Accommodate an interchangeable payload (such as a mesh network module, radio repeater, camera, etc.).
- Comply with FAA regulations, including signal lights, tethering requirements, and a rapid deflation device [5].

Additionally, it must meet several key performance needs:

- Having a coverage area of about $5km^2$.
- Compact when stowed away and easily airdropped by emergency relief planes.
- Maintain an altitude of about 100-500 feet.

- Have an operational duration of a day to a week.
- Power itself and other devices via solar panels.
- Have a payload capacity of close or up to 1 kg.
- Survive the effects of UV and temperatures ranging from -10°C to 50°C.

Ultimately this system will be composed of two main parts: a spherical balloon and a payload box. The balloon is about 2.5 meters in diameter and made of latex, which will allow it to be lightweight and elastic. It will be inflated with a small helium canister and connected to a polystyrene box via a hook. The box is 22x22x18 cm in dimension, and that will house and protect the onboard electronics. Figure 3 provides an external view of the overall balloon, showing its structure and scale. All of this will be connected via a tethered cable that will be marked with reflective strips every 15 meters and securely fastened with metal ground anchors. Per regulations, the balloon is also equipped with an LED strobe for visibility at night and a mechanical striker system that will puncture the balloon in the event of a tether failure. The exterior of the payload will be wrapped in foil to protect against electromagnetic interference and four mini solar panels will cover each side to provide power to all the various components. Figure 1 provides a mockup of what this payload system would look like. These components will include two rechargeable batteries, a control module for power management, a LoRa mesh node module with an external antenna, and the aforementioned LED strobe light. All of this will be housed within a 3D-printed plastic tray. An example of a possible setup is indicated in Figure 3, while Figure 2 shows how it would look inside the payload container. Besides the battery, control module, and light, the tray and components within the payload can be easily modified based on the customer's needs. The current mesh node will work as a demonstration to show the feasibility of using this platform but could be swapped out for a cellular network module or even an environmental sensor for weather data collection. When not in use, the product can be easily stowed compactly. The balloon will be tucked away and the whole system can be wrapped in a protective cover to prevent damage. The helium canister will need to be either stored separately or attached to the payload temporarily with Velcro sleeves.

One consideration that should be taken into account is that the system relies on helium, which is a finite resource and may affect deployment frequency. As an alternative, hydrogen can be used, but that also has its safety concerns. The risk of a tether failure is also a possibility, as stress or abrasion could weaken it over time, therefore it should be made out of a high-strength material and undergo regular inspections. Lastly, external factors like rough weather and physical strikes pose a risk for this system. High winds or lightning strikes can disrupt operations entirely, while birds, drones, or planes can compromise the balloon or tether. Both situations can also create potential hazards for others, so it's important to mitigate these risks.

To ensure that the system remains functional throughout its lifetime, some testing must still be done before deployment. The tether would undergo a stress test to see how it would fair in the environment. The balloon itself could be tethered at a low altitude and without a payload to see how well it retains helium over a long time, how it fairs in different types of weather, and its temperature resistance. The deflation device needs to be evaluated to ensure that it activates immediately upon release of the tethers. Lastly, the solar panels will need to be tested to see how efficient they are in low-light conditions, and the batteries will need to be put through multiple charge and discharge cycles to observe how well they perform long-term and in different temperature conditions as well.

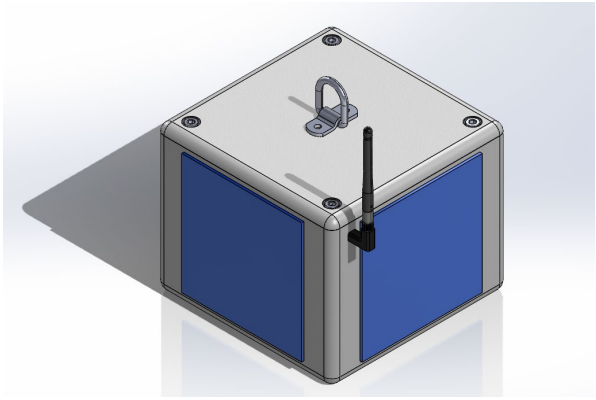

Figure 1. Exterior view of payload

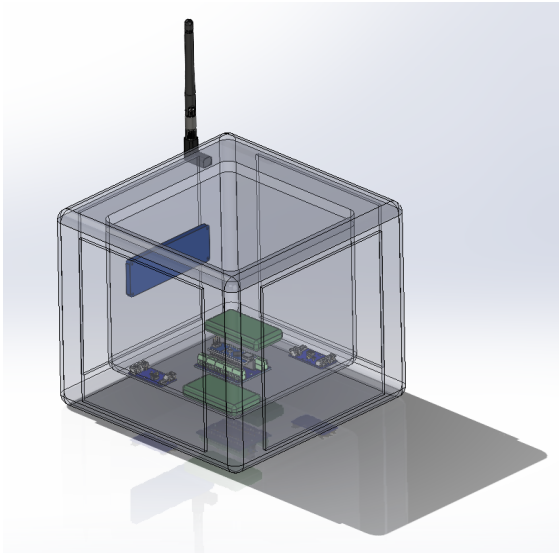

Figure 2. Interior view of payload

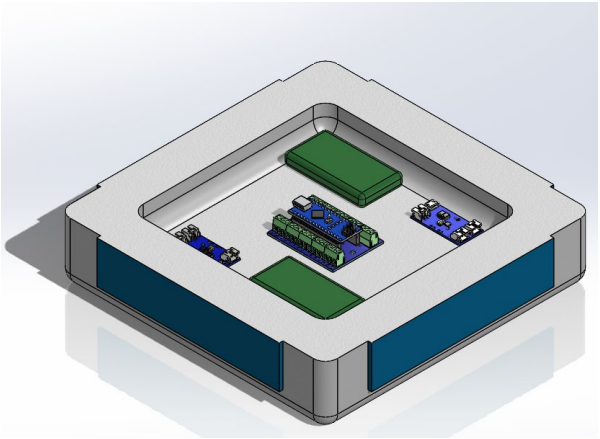

Figure 3. Payload's electronic components

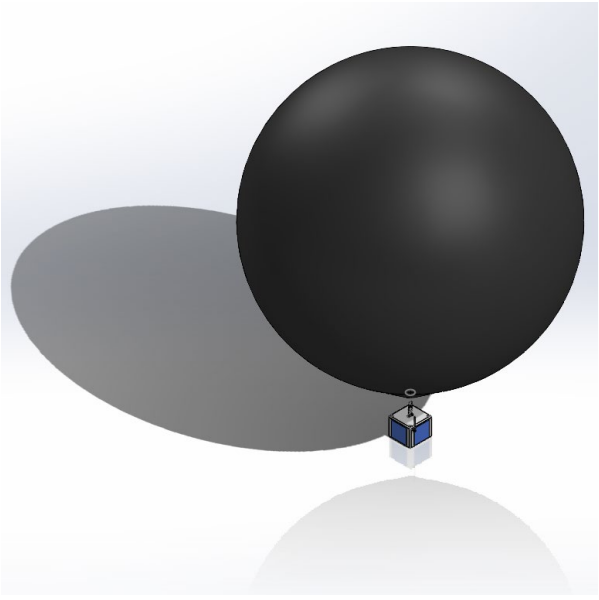

Figure 4. Balloon to payload scale

Design Integration of DDM Materials and Processes:

While the two primary components of the LAPS system—the balloon and payload box—are manufactured using traditional methods, several critical parts will be fabricated using Additive Manufacturing (AM) to enhance customization, weight reduction, and rapid prototyping. These include the electronics tray, attachment hook, and tether mounts, all of which play essential roles in the system's functionality and adaptability. Utilizing Material Extrusion (MEX), specifically Fused Filament Fabrication (FFF), allows for complex geometries without the need for costly tooling, making it an ideal solution for low-volume production and iterative design improvements. The use of AM enables lightweight yet structurally sound components that can be easily modified to accommodate different payloads, a key requirement for modularity in telecommunications applications.

Justification of AM Materials

The selected materials for AM components must be durable, weather-resistant, and capable of withstanding mechanical stress. ABS (Acrylonitrile Butadiene Styrene) and ASA (Acrylonitrile Styrene Acrylate) are excellent choices due to their UV resistance, impact strength, and weather durability, making them suitable for outdoor exposure. ASA, in particular, offers superior UV stability compared to ABS, ensuring that prolonged sun exposure does not lead to rapid material degradation. Another material under consideration is PA6-CF (Nylon 6 with Carbon Fiber Reinforcement), which provides a superior strength-to-weight ratio, making it particularly effective for components subjected to mechanical loads, such as the tether mounts and attachment hook. The carbon fiber reinforcement enhances stiffness while minimizing creep deformation, a critical factor for maintaining the system's structural integrity in varying environmental conditions.

Compared to traditional manufacturing methods, these materials offer significant advantages in weight reduction and production flexibility. Conventional machining processes, such as CNC milling, would result in stronger components but at the cost of increased weight, complexity, and material waste. Injection molding, while effective for mass production, lacks the ability to support rapid design modifications and small-batch manufacturing. By utilizing AM materials, the design maintains an optimal balance between strength, cost efficiency, and adaptability, making it a viable solution for both prototyping and functional deployment.

Justification of AM Processes

The primary AM process chosen for this project is Material Extrusion (MEX - FFF) due to its affordability, accessibility, and ease of producing customizable parts. This process enables low-cost, rapid prototyping and production, which is especially beneficial for a project requiring frequent design iterations. The use of multi-material printing is also possible, allowing for hybrid components that combine rigid and flexible materials to optimize both durability and adaptability.

In addition to plastic-based AM, metal AM techniques such as Selective Laser Melting (SLM) or Electron Beam Powder Bed Fusion (EBPBF) could be used for tether mounts and attachment hooks to further enhance their load-bearing capabilities. If transitioning to EBPBF, modifications

such as optimized support structures and post-processing heat treatment would be necessary to ensure material integrity and stress relief. By leveraging AM, the design achieves a balance of customization, material efficiency, and structural resilience, ensuring it meets the demands of real-world deployment.

Adaptability for Other AM Processes

While MEX-FFF is the primary AM process, the design can be adapted for alternative AM methods based on specific requirements. Vat Photopolymerization (SLA/DLP) could be employed for high-precision enclosures and small electronic housings, offering a smooth surface finish and excellent detail resolution. Binder Jetting (BJ) or Multi Jet Fusion (MJF) could be used for batch production of plastic parts, allowing for increased durability and scalability while reducing material waste. For components requiring enhanced mechanical strength, Direct Metal Laser Sintering (DMLS) or EBPBF could replace plastic tether mounts with titanium or aluminum alloys, providing increased structural integrity while maintaining a low weight. The ability to adapt the design for different AM processes ensures that the LAPS system remains versatile, scalable, and suitable for varied deployment conditions.

Pre/Post-AM Processing Considerations

To enhance durability and ensure long-term performance, several pre- and post-processing steps will be implemented. For MEX-FFF components, annealing will be applied to improve layer adhesion and reduce brittleness, particularly for tether mounts and attachment hooks that are subject to continuous mechanical stress. Vapor smoothing will be used for ABS/ASA components to enhance surface finish and water resistance, preventing premature degradation from environmental exposure.

For metal-printed components manufactured via SLM or EBPBF, heat treatment and stress relief will be critical post-processing steps to eliminate internal stresses and enhance mechanical properties. Additionally, support removal and surface finishing will be necessary to ensure aerodynamics and prevent stress concentrations that could lead to structural failure. These pre- and post-processing techniques are essential for optimizing the performance, longevity, and reliability of AM components within the system.

Serviceability, End-of-Life, and Environmental Impact

The LAPS system is designed with modularity and serviceability in mind, allowing for easy part replacement without requiring a complete system overhaul. If upgrades or modifications are needed, the electronics tray can be reprinted or redesigned to accommodate new payloads, ensuring the system remains adaptable to future telecommunications needs. Additionally, the use of recyclable plastic materials minimizes environmental impact, as ABS, ASA, and PA6-CF can be repurposed rather than discarded.

For components manufactured using metal AM, recycling options are available where obsolete or damaged parts can be reprocessed into powder feedstock for future production. Compared to traditional manufacturing methods that often generate excess material waste, AM enables efficient material usage and lower carbon footprints. Furthermore, since helium usage is a known environmental concern, the system is designed to explore hydrogen as a potential alternative,

despite its additional safety considerations. By incorporating AM processes, sustainable materials, and modular design principles, the LAPS system ensures a minimal environmental impact while maintaining high performance and cost efficiency.

Digital and Physical Infrastructure:

The Low Altitude Platform Station (LAPS) can be introduced as an open-source project, fostering a collaborative innovation ecosystem where subject matter experts, hobbyists, and manufacturers can contribute to iterative design improvements. By leveraging open-source platforms such as Thingiverse, GrabCAD, and GitHub, the LAPS design can be disseminated globally, allowing for a distributed manufacturing model. This approach enables regional vendors, small-scale manufacturers, and service bureaus to fabricate components based on local demand, reducing reliance on a centralized production facility and enhancing agility in manufacturing and deployment.

A distributed manufacturing approach also aligns with lean manufacturing principles, such as Just-in-Time (JIT) production, by minimizing inventory costs and lead times. Since manufacturers will only produce components as needed, the risk of overproduction and material waste is reduced, making the supply chain more sustainable and cost-effective. Additionally, the modular nature of LAPS components ensures that individual parts can be replaced or upgraded independently, further reinforcing continuous supply chain availability. This allows multiple manufacturers to specialize in specific components, ensuring a steady supply of replacement parts without overburdening any single supplier.

To ensure seamless integration into real-world telecommunications infrastructure, collaboration with local telecommunication providers and emergency response agencies is essential. These partnerships will help optimize network coverage, disaster response effectiveness, and service reliability. By working closely with first responders, NGOs, and government agencies, LAPS can be rapidly deployed in disaster zones, providing immediate communication support where traditional infrastructure has failed. Furthermore, these partnerships will help establish an agile feedback loop, allowing real-time user input to inform continuous design refinements.

The resilience of the LAPS supply chain is strengthened by reducing dependence on single-source suppliers and geographic constraints. Since multiple independent manufacturers and makers can fabricate components locally, regional disruptions—such as geopolitical tensions, natural disasters, or logistical bottlenecks—will not halt production. This decentralized approach enhances rapid deployment capabilities, ensuring that LAPS units can be assembled and delivered to disaster-stricken areas or remote locations without major supply chain delays.

By integrating open-source collaboration, lean manufacturing techniques, modular design principles, and strategic industry partnerships, the LAPS system will maintain a continuous cycle of innovation, production flexibility, and operational resilience. This agile and decentralized manufacturing approach ensures that the product remains scalable, adaptable, and widely accessible, delivering critical telecommunications services where they are needed most.

Cost Benefit Analysis:

Compared to existing telecommunications solutions, the Low Altitude Platform Station (LAPS) offers a cost-effective, rapidly deployable alternative to Low Earth Orbit (LEO) satellites, traditional cell towers, and High-Altitude Platform Stations (HAPS). Current solutions require extensive infrastructure investments and can take months to years to fully implement. LEO satellites cost hundreds of millions of dollars to develop and launch, while cell towers require significant construction, permitting, and maintenance costs, often reaching hundreds of thousands of dollars per tower. HAPS systems, while promising, have proven to be too complex, expensive, and difficult to scale, as seen in the failure of Google's Project Loon. In contrast, LAPS provides a functional, adaptable alternative at a fraction of the cost—with an estimated production price of around $500 initially, expected to decrease to approximately $150 with optimized manufacturing and scaled production.

Beyond cost savings, LAPS adds significant social, environmental, and operational value. Unlike LEO satellites, which contribute to space debris, emissions from rocket launches, and atmospheric pollution, LAPS has minimal environmental impact and does not require extensive infrastructure development. The system also addresses regulatory challenges more efficiently, as it is designed to comply with FAA regulations for low-altitude tethered balloons, reducing legal and logistical hurdles. The health and safety benefits are substantial, particularly for disaster response teams, where quickly restoring communications can save lives and enhance coordination in emergency situations. Additionally, remote communities that lack permanent telecom infrastructure can use LAPS as an affordable connectivity solution, ensuring greater social inclusivity and digital equity.

Testing and prototyping will initially increase costs, as multiple design iterations are required to validate performance under real-world conditions. Key tests, such as helium retention trials, tether stress testing, and solar power efficiency validation, will incur additional costs but are critical to ensuring product reliability and longevity. However, once the design is finalized, mass production and streamlined supply chain processes will significantly reduce per-unit costs, making LAPS a highly scalable, affordable, and sustainable solution for emergency responders, commercial telecom providers, hobbyists, and research organizations alike.

By offering a significantly lower cost, faster deployment time, and reduced environmental impact compared to existing telecommunications solutions, LAPS presents a transformational opportunity for enhancing global connectivity while maintaining sustainability and operational efficiency.

Conclusion

The Low Altitude Platform Station (LAPS) presents a novel, cost-effective, and rapidly deployable telecommunications solution for remote and disaster-stricken areas. Designed to bridge the gap in connectivity where traditional infrastructure is unavailable or impractical, LAPS offers a modular, lightweight, and sustainable alternative to conventional LEO satellites, cell towers, and High-Altitude Platform Stations (HAPS). The system's key aspects include a helium-inflated balloon for lift, a 3D-printed payload housing, solar-powered energy autonomy, and an adaptable communications module. By integrating additive manufacturing (AM) with traditional fabrication methods, LAPS leverages the advantages of digital manufacturing, distributed production, and rapid iteration to create a scalable, low-cost, and customizable solution.

AM processes, specifically Material Extrusion (MEX-FFF), play a crucial role in enhancing design flexibility and manufacturing agility. Components such as the electronics tray, attachment hook, and tether mounts are 3D-printed using weather-resistant ABS/ASA and high-strength PA6-CF (carbon fiber-reinforced nylon). This approach enables lightweight, durable, and modular parts,

which can be easily replaced, upgraded, or adapted for different payload configurations. The integration of AM and digital design platforms (Thingiverse, GrabCAD, GitHub) also supports a distributed manufacturing model, allowing for localized production, reducing supply chain dependencies, and ensuring rapid deployment in critical situations.

Beyond the technical aspects, LAPS introduces a highly innovative use of digital and physical infrastructure. By utilizing open-source platforms, decentralized fabrication, and lean manufacturing principles, the system maximizes supply chain resilience, production efficiency, and adaptability. Strategic partnerships with telecommunication providers, emergency response agencies, and local manufacturers further enhance the deployment and scalability of LAPS, ensuring that it remains functional and accessible in a variety of real-world applications.

The novelty of LAPS lies in its unique combination of affordability, rapid deployment, and adaptability. Unlike LEO satellites or cell towers, which require substantial financial and infrastructure investments, LAPS can be deployed within an hour, at a fraction of the cost, and in geographically challenging areas where other solutions fail. The system's modular architecture, reliance on renewable energy, and compliance with FAA regulations make it a sustainable and regulatory-friendly solution for emergency responders, researchers, and underserved communities.

The impact of LAPS extends beyond immediate telecommunications needs—it represents a new paradigm in agile, sustainable, and distributed telecommunications manufacturing. Its low environmental footprint, minimal infrastructure dependency, and scalability make it a transformative solution for global connectivity challenges. By combining AM innovations, digital manufacturing, and strategic deployment models, LAPS provides an unprecedented level of flexibility and accessibility in modern communication infrastructure, ensuring that no community is left without critical connectivity in times of need.

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