STARMESH™

GLOBAL COMMUNICATIONS

Revolutionizing Low Earth Orbit Satellite Systems

White Paper 2

Transforming Satellite Communications

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STARMESH GLOBAL COMMUNICATIONS
Johns Creek, Georgia | Princeton, New Jersey | McHenry, Illinois

The Development of StarMesh Global™ Satellite Technologies

This document outlines key elements of StarMesh Global's stochastic orbit satellite technology, a breakthrough in Low Earth Orbit (LEO) communications. The technologies discussed are protected by an international portfolio of eleven distinct patent families, which are accessible through our website, www.StarMeshGlobal.com. For further details, refer to White Papers No. 1 and No. 3, available online.

Since 2016, StarMesh Global has pioneered satellite communication systems, beginning with a novel service model that connects two ground stations via a single, innovative satellite. Our patent portfolio now extends across increasingly complex systems, employing advanced satellite and drone technologies to route communications using multi-satellite and ground-to-air algorithms. Leveraging artificial intelligence, these systems deliver global, space-based internet.

The evolution of our patent families (Families A through K) reflects the ongoing advancement of StarMesh's technologies. Systems incorporate novel LEO satellites and, in some cases, drones. These systems enable global communications with unprecedented efficiency, positioning StarMesh as a leader in satellite networking.

FAMILY A: U.S. Patents No. 10,084,536, No. 10,998,962, and No. 11,855,745: "Bent Pipe"

Patent Family A introduces StarMesh Global's innovative reverse-routing technology. U.S. Patent 10,084,536 unveiled a novel approach where onboard satellite computers create transmission routes from a sending ground station to a receiving ground station and then transmit data in reverse from the receiving ground station back to the sender. This system operates without central, system-wide computers to handle routing, relying solely on the onboard capabilities of the satellites and ground station computers. This concept is further detailed in White Paper No. 3.

Key features of the StarMesh reverse-routing system include:

- **Stochastic satellite distribution**: Satellites are randomly placed in orbit without geolocation or attitude control, allowing them to "tumble" while maintaining communication without precise location tracking.
- **Low-cost, lightweight satellites**: Satellites as small as 8–16 inches in diameter, equipped with 4–6-inch directional parabolic antennas, operate at standard satellite frequencies, significantly reducing size and cost.
- **High-gain directional antennas**: These antennas enable bent pipe communication and are designed to transmit and receive signals across a broad spherical area surrounding the satellites and ground stations.
- **Dynamic antenna pairing**: Radio links are dynamically formed when the ground station's directional antenna aligns with a satellite's antenna despite the satellite's tumbling motion and lack of a pre-designated connection.

This system leverages the statistical certainty that at least one satellite will always be visible to ground stations, with a failure rate of only 1 in 4,000,000. This real-time dynamic antenna pairing eliminates the need for heavier propulsion systems, leading to lighter and more affordable satellites.

Patent Family A optimizes system performance based on design factors such as satellite altitude, antenna gain, and the proportion of the satellite surface used for antennas.

With careful engineering, performance improvements can be achieved by increasing the satellite's antenna surface area.

Follow-on Patents No. 10,998,962 and No. 11,855,745, and a pending patent application (Pub. No. US 2024/008992) further extend coverage of these foundational technologies.

FAMILY B: U.S. Patents No. 10,447,381 and No. 11,038,586: "Rotating Satellites"

Patent Family B introduces an enhancement to the "Bent Pipe" technology by incorporating rotating satellites, which increases the statistical likelihood of establishing radio links. For instance, rotating satellites at one revolution per second significantly improves the chances of forming connections, including inter-satellite links. In one variation, satellites rotate around different, randomly oriented axes, offering six to eight additional opportunities per revolution for antenna alignment with ground stations. In another variation, slightly variable spin rates could further increase the probability of establishing connections.

While rotating satellites present challenges related to signal strength and signal-to-noise ratios—due to reduced time for antenna alignment—these issues are addressed by advanced antenna designs covered in Patent Family C. Furthermore, methods for controlling satellite spin rates are detailed in Patent Family E.

This family includes a pending U.S. patent application (Pub. No. US 2021/0399793), which supports StarMesh's ongoing innovation and the expansion of our intellectual property. Additionally, 12 foreign patents and pending applications in fourteen more countries further reinforce StarMesh's leadership in satellite-based communications.

FAMILY C: U.S. Patents No. 10,085,200, No. 10,791,493, No. 11,356,921, and No, 11,832,160: "Star Antenna"

As data transmission rates increase over radio channels, radio bandwidth expands proportionally, introducing a corresponding rise in background noise received by amplifiers, correlation devices, or other receivers. While increasing transmitter power could address this issue, decreasing antenna beam width offers a more efficient solution.

This patent family proposes several strategies:

- **Larger antennas**: Increasing antenna size reduces beam width, improving signal focus.
- **Multi-feed antennas**: These antennas direct narrow beams more precisely. While traditional systems rely on known satellite locations and orientations to generate beams with side lobes and gaps, StarMesh Global's multi-feed directional antennas produce narrow beams that improve radio link quality. This facilitates real-time dynamic antenna pairing, enhances reception, reduces the need for transmitted power, and minimizes solar panel requirements.
- **Narrow light beams**: Replacing radio signals with narrow light beams offers another method to increase bandwidth.

This patent family, including a pending patent application (Pub. No, US2024/0098616), continues safeguarding StarMesh Global's innovative technologies. It also includes pending applications across 12 countries.

FAMILY D: U.S. Patents No. 10,291,316, No. 10,784,953, No. 11,206,079, and No. 12,074,686: "Routes by Orbital Knowledge"

In traditional satellite communications, systems often rely on satellites knowing their precise orbits. Patent Family D extends this concept by incorporating StarMesh Global's proprietary approach, utilizing satellites in unconstrained orbits. In this system, satellites are aware of both their own and other satellites' orbital paths, enabling sophisticated routing algorithms that create single and multi-satellite radio routes.

These advanced routing methods allow information to be distributed almost simultaneously across a global constellation of satellites. This capability enables the creation of a secure distributed ledger that is entirely space-based—an innovative feature with significant potential for blockchain applications and the implementation of digital currencies.

Additionally, this family encompasses pending applications across ten foreign countries.

FAMILY E: U.S. Patent No. 10,979,136 and No. 12,063,101: "Routing Algorithms for Stochastic-Orbit Satellites"

Patent Family E introduces a suite of inventions to improve satellite routing algorithms in stochastic orbits. This includes a U.S. application (Pub. No. US 2024/0250751) and 20 foreign counterparts, representing a significant milestone in StarMesh Global's expansion of earlier patent families.

This patent emphasizes robust link creation and routing methodologies designed for satellite-based systems. The proprietary algorithms can leverage artificial intelligence to analyze and improve the quality of radio signals exchanged by system nodes as satellite service time increases. The patent provides designers with a comprehensive toolkit to develop advanced satellite communication systems.

Key features of this patent include:

- **Decentralized Route Creation**: The system selects the optimal route from millions of potential paths based on signal quality without relying on a central computer. Each node independently makes routing decisions, significantly reducing preliminary communication between nodes.
- **Dynamic Route Refreshing**: Despite the rapid movement of satellites (18,000 MPH), the system refreshes routes every few seconds to maintain stable connections. This ensures reliable data transmission across multiple stages.
- **Routing Metrics**: Satellites calculate a "figure of merit" based on factors such as signal strength, battery life, and signal-to-noise ratio. These metrics are used to optimize routing decisions.
- **Multi-Link Routing**: When a direct connection isn't available, the system automatically creates multi-link routes between satellites, ensuring almost constant connectivity. This capability is crucial for regions with limited single-satellite access.
- **Innovative Satellite Design**: Non-spherical satellites with side and bottom-pointing antennas increase horizontal coverage, improving statistical connectivity. Electromagnetic rods control the satellite's orientation, stabilizing routes over longer periods.

- **Multi-Altitude Support**: The system supports satellites at various altitudes, including GEO and MEO satellites, optimizing long-distance routes and minimizing the number of required links. This flexibility extends to drones and balloons, which can serve as nodes within the network.

Patent Family E represents a leap forward in StarMesh Global's ability to provide scalable, efficient satellite communications, ensuring global connectivity even in dynamic and decentralized networks.

FAMILY F: Pub. No. 11,870,543: "Data Transmission Diversity"

Patent Family F (including pending application No. 18/401,534) highlights the utilization of established diversity techniques to ensure data integrity within StarMesh Global's satellite communication systems. Although our systems represent a significant advancement in satellite technology, data transmissions still occur between satellites thousands of miles apart, traveling at 18,000 MPH. As described in Family E, maintaining the integrity of these transmissions is crucial as signal quality fluctuates with the relative movement of satellites along each route.

In one embodiment, particularly applicable to multi-satellite routes, satellites transmit data to the next satellite using at least two different technologies, a concept known as "format diversity." The '543 patent highlights four conventional technologies that can be used in various combinations to achieve this:

- **Frequency modulation (FM)**: Often used in cellular telephony.
- **Code division multiple access (CDMA)**: Allows multiple signals to share the same frequency band, pioneered by Qualcomm Inc.
- **Frequency division multiple access (FDMA)**: Sends the same signal on two different frequencies.
- **Time division multiple access (TDMA)**: Transmits the same signal simultaneously.

Data is transmitted in packets that include conventional error-coding information. Each receiving satellite applies the appropriate error correction algorithm and then forwards the corrected data in at least two available formats. During route creation, each satellite consults a look-up table to determine the format for sending corrected data based on how it was received. This ensures that data is continuously corrected and transmitted effectively through each route stage (Figure 4 of the '543 publication).

Another approach in this patent family uses "space diversity," where data packets are transmitted via two distinct routes. StarMesh Global's routing protocols can identify multiple potential routes for data transmission, ultimately allowing the system to transmit data back to the sending ground station via two different antennas along separate routes. The receiving ground station then applies the correct error correction algorithm to reassemble the original data packet (see Figure 5 of the '543 publication). In some variations, signal and format diversity are applied simultaneously to enhance data integrity further.

FAMILY G: Pub. No. US 2022/0029699: "Aerodynamic LEO and VLEO Satellites"

Using low-altitude satellites as nodes in communication systems offers several advantages. As the distance between antennas decreases, signal strength improves, enabling low-flying satellites to connect directly with personal devices such as smartphones and tablets. This eliminates the need for users to rely on ground stations to access the internet. Lower orbits also require less power for satellite-to-ground links, reducing the need for heavy batteries and solar panels, making these satellites lighter and more cost-effective.

Lower-altitude satellites offer additional benefits by reducing the risk of collision with higher-orbiting satellites, including the International Space Station (ISS), which orbits 250 miles above Earth. Satellites in higher orbits often require propulsion systems to maintain their altitude and safety mechanisms to destroy them if they fail, which risks creating hazardous space debris. Conversely, low-altitude satellites experience faster orbital decay due to atmospheric drag, and traditional large solar panels on existing satellites can exacerbate this problem. If one of these satellites fails, it can be costly to replace, and large fragments might survive reentry and reach the ground.

The ‘699 publication presents a streamlined StarMesh Global satellite design to reduce atmospheric drag, particularly in low orbits that do not endanger the ISS. While an ellipsoid shape is used as an example, other streamlined designs are possible. The satellite’s casing encloses fewer internal components, characteristic of StarMesh Global designs, allowing solar panels and antennas to be flush with the surface, minimizing drag.

The satellites are oriented with their central axis facing the direction of travel, achieved through electromagnetic rods interacting with Earth's magnetic field (see Family E). This system also maintains the solar panels on the top surface and antennas on the bottom and sides. Despite the enhanced design, these satellites maintain the hallmark simplicity of StarMesh Global technology, with no active location or altitude control, keeping construction and deployment costs low.

Key features of this streamlined design include:

- **Improved signal strength**: This allows IoT applications to function through obstacles like roofs and car tops. Signal strength can be further boosted by closed-loop power control responding to weaker ground station signals.
- **Low-orbit satellite integration**: StarMesh Global’s routing logic can integrate these streamlined satellites into a broader system that includes a higher-orbit backbone of GEO and MEO satellites.
- **Cost-effectiveness**: As with all StarMesh Global satellites, these streamlined versions can be built and launched at a fraction of the cost of traditional satellites. Atmospheric drag-related losses at lower altitudes are mitigated by the ability to replace satellites at less than $50K each.
- **Safe reentry**: Being small and lightweight with fewer components, these satellites will burn up entirely upon reentry, preventing dangerous debris from reaching the ground.

This family also includes pending applications in six foreign countries.

FAMILY H: Pub. No. US 2022/00173795: “Connecting Moving Users Via Satellites”

This patent family outlines how StarMesh Global’s space-based communication technology can serve users on the move, whether in automobiles, airplanes, ships, or other conveyances. Previous systems typically assume that ground stations are fixed, with virtually unlimited power and space for antennas that project narrow, high-power radio beams. In contrast, most moving vehicles lack the power resources and antenna space that stationary ground stations can provide.

Optimized antenna design and placement and robust StarMesh Global routing protocols make communication with moving users possible. Wide-beam antennas are mounted strategically on the vehicle, maximizing coverage of the surrounding space. Although fewer routes (or antennas) may be available for data transmission compared to stationary systems, StarMesh Global's probabilistic routing process ensures that at least one, if not more, routes will almost always be accessible.

If no route is immediately available, a new route will likely form seconds later during the next route creation phase, maintaining seamless connectivity.

While moving users may experience more variable link quality due to their mobility and that of the satellites, the diversity techniques described in Family F can be applied to preserve data integrity during transmission, even in these dynamic environments.

FAMILY I: US Patents No. 11,968,023 and No. 12,081,310: "Worldwide Communications Using Drones and Satellites"

These patents and pending application Pub. No US 2024/0031008 expand upon StarMesh Global's technology by exploring new applications. It begins with a review of key features, advantages, and uses, offering a concise overview of StarMesh Global's capabilities.

Part I: Duplex Operation Support
This patent family details how StarMesh Global systems support duplex operation, where terminal locations (such as ground stations or smartphones) can transmit and receive content simultaneously. This feature is critical for applications like cellular telephony. The Family B patents outline a method for creating duplex bent pipe routes, where satellites are designated as Type TR (transmit and receive on different frequency bands) and ground nodes as Type RT (receive and transmit on corresponding bands). This allows simultaneous transmission and reception.

However, multi-satellite routes present challenges, as satellites cannot always communicate directly. To address this, StarMesh Global proposes placing dual-type ground stations (TR and RT) in high-density areas, such as large cities, to increase the number of potential routes. Figures 6, 7, and 8 in the '023 patent illustrate this approach.

Part II: High-User Capacity Systems
This section of the patent family discloses two specific systems: one capable of supporting 100 users and another designed for 300 users. These systems utilize a two-phase process for route creation and data transmission, ensuring efficient operation for many users.

- **100-User System**: Routes are refreshed every four seconds using a cyclical two-phase approach. A three-second data transmission phase follows a one-second route creation phase. Satellites process routing signals in successive 100 msec time slots, allowing them to interconnect 100 ground stations within one second.

Data transmission occurs over three seconds, with routes refreshed in the next cycle. Full details of this process are available in Figure 9 of the '023 patent.

- **300-User System**: This system adapts the time-slot protocol used in the 100-user system by dividing 100 msec time slots into 25 msec subsegments. The 300 satellites process initial signals from 300 ground stations in groups of 100, with routing messages transmitted in subsequent segments. This method allows for efficient interconnection of 300 ground stations within the same one-second period. Further technical details can be found in columns 23-28 of the '023 patent.

Part III: Hybrid Systems with Aerial Nodes

StarMesh Global envisions the future of space-based communications to involve non-orbiting aerial nodes, such as balloons. This hybrid system adapts StarMesh Global's routing protocols to support local and global communications for many users.

StarMesh Global's system uses aerial nodes organized into four distinct layers at varying altitudes, labeled as levels A, B, C, and D. This multi-layered architecture allows low-altitude, non-orbiting aerial nodes (such as drones and balloons) at level A to service local terrestrial clusters, while higher-altitude satellite nodes at levels B, C, and D handle longer-distance communications.

Figure 12

The four layers are defined as follows:

- **Layer/Cohort A**: Drones below 400 feet or a combination of drones, balloons, and airships at 10–20 miles altitudes. This layer supports local communication.
- **Layer/Cohort B**: Satellites at 200–400 miles altitudes, with a preference for satellites below 250 miles. These satellites are designed to reduce aerodynamic drag, as discussed in Family G.
- **Layer/Cohort C**: Satellites positioned at 800–1000 miles. Depending on the application, this layer may require orbital maintenance or, in some embodiments, can be omitted.

- **Layer/Cohort D**: Satellites orbiting above 2,000 miles, where geostationary satellites may be used to fulfill this layer's function.

An important feature of this system is its hybrid routing protocol, which determines the highest layer necessary for a route based on a zip code-like paradigm. Though beyond the scope of this document, the routing process leverages the "Spanning Tree" method introduced in Family E. The '023 patent uniquely applies this approach, allowing satellites to form three-dimensional spanning trees that connect ground stations across multiple layers through optimal radio links.

In the embodiment illustrated in Figure 12 of the '023 patent, local area communications are handled solely within Layer A (drones and balloons), servicing urban centers and dense areas. More complex routing, which requires transitioning to higher layers for longer distances, is outlined in columns 33-29 of the ‘023 patent.

This hybrid protocol combines the signal strength advantages of low-altitude aerial links (as discussed in Family G) with the capacity for global communication through orbiting satellites. Even in remote locations without drone or balloon coverage—such as ships at sea—route creation can still begin at Layer B (low-altitude satellites), ensuring robust worldwide connectivity.

FAMILY J: Pub. No. W02023/229923: “Lighter-Than-Air and Lift-Assisted Non-Orbiting Nodes for Aerial Mesh Communication Systems”

Patent Family J introduces designs of lighter-than-air and lift-assisted non-orbiting nodes, such as drones and balloons, to enhance StarMesh Global’s aerial mesh communication systems. These non-orbiting nodes are pivotal in extending StarMesh’s capabilities by providing flexible, low-altitude connectivity that complements the satellite-based network.

The inclusion of drones and balloons as nodes offers several advantages. Positioned at lower altitudes (e.g., Layer/Cohort A in Patent Family I, Part III), these aerial nodes provide proximity to ground users, enabling direct communication links with minimal latency. This proximity increases signal strength and reduces the power required for communication, making these nodes ideal for serving densely populated areas, remote regions, or locations with limited infrastructure, such as disaster zones or areas with sparse satellite coverage.

Lighter-than-air and lift-assisted nodes are particularly effective in scenarios where orbiting satellites might be less efficient or impractical, such as in urban environments with high buildings, mountainous terrain, or temporary events requiring rapid communication infrastructure deployment. The aerial nodes in the ‘923 application are designed to integrate seamlessly with StarMesh Global's broader satellite system, facilitating the smooth data handoff between terrestrial nodes and higher-altitude satellites.

As these drones and balloons move within their designated airspace, they create highly adaptable and reconfigurable networks capable of responding to changing environmental conditions, user demand, or emergency situations. The ability to establish and maintain connections across vast areas enhances coverage and resilience for communication systems, especially in challenging geographical regions.

Patent Family J enables StarMesh Global to offer even greater flexibility in deploying and maintaining networks. By incorporating these non-orbiting nodes into the aerial mesh communication system, StarMesh can provide scalable, efficient, and low-cost communication solutions that fill coverage gaps and ensure continuous global connectivity. This technology is particularly beneficial for supporting Internet of Things (IoT) applications, remote sensing, disaster relief, and other use cases where ground infrastructure or conventional satellite coverage may be insufficient or impractical.

FAMILY K: PCT Application No. PCT/US2024/31191: "Systems and Methods for Secure Satellite Communications"

Patent Family K introduces advanced encryption techniques that leverage StarMesh Global's unique routing protocols to enhance the security of satellite communications. Unlike traditional encryption methods that rely on fixed encryption keys, this system creates dynamic encryption codes that evolve as data passes through each node in the network, ensuring that the encryption key is never fully known by any individual node.

In the context of StarMesh Global's decentralized, probabilistic routing processes, the encryption in Patent Family K is built on the system's ability to select routes on the fly, node by node, autonomously. As data packets travel through the network, each node contributes a piece of the encryption code. This dynamic construction ensures that no single node, whether satellite or ground station, possesses the complete encryption key. Distributing the encryption process across multiple nodes minimizes vulnerabilities and mitigates the risk of interception or decryption by malicious actors.

The encryption methods in Patent Family K integrate seamlessly with StarMesh's hybrid routing architecture. Whether data is routed through low-altitude aerial nodes (Layer A) for local communications or higher-altitude satellites (Layers B, C, and D) for long-range transmissions, encryption codes are continuously updated and re-encrypted as the data progresses through each layer. This multi-layered encryption system significantly enhances security, especially in the dynamic and decentralized environments where StarMesh Global operates.

Additionally, the autonomous, decentralized nature of StarMesh's routing algorithms ensures that even if one node is compromised, the encryption for the entire transmission remains intact. The route itself is never predictable, further adding to the difficulty of intercepting or deciphering the data. The system's reliance on node-specific encryption also ensures that any data intercepted mid-route remains encrypted, and only the final recipient can decrypt the entire transmission once it has passed through all necessary nodes.

Patent Family K is crucial in ensuring secure communications across StarMesh Global's global satellite network. Whether used for commercial applications, defense communications, or secure financial transactions, the combination of dynamic encryption and autonomous routing solidifies StarMesh as a leader in secure satellite communications, offering unparalleled privacy and security in space-based networks. The '191 application will be published later this year. Copies can be obtained now from StarMesh Global.

In Summary
StarMesh Global's revolutionary satellite technologies are driving the future of global communications. By leveraging a unique stochastic orbit architecture, multi-satellite and drone networks, and cutting-edge artificial intelligence, StarMesh delivers efficient, reliable, and scalable satellite-based internet connectivity.

Spanning eleven distinct patent families, our innovations—ranging from reverse-routing and rotating satellite systems to hybrid routing protocols and data transmission diversity—solve key challenges in satellite communications. The multi-layered satellite and aerial node infrastructure enables seamless communication across varying altitudes and distances, offering unprecedented global coverage.

As we continue to advance our technologies, StarMesh Global remains committed to reshaping the landscape of satellite networking with cost-effective, reliable, and future-proof solutions for an interconnected world.

About StarMesh Global

StarMesh Global has evolved from a conceptual think tank into a technology development and engineering leader, pioneering groundbreaking satellite designs and communications systems. Leveraging low-earth orbit satellite networks, StarMesh provides global connectivity at a fraction of the cost of traditional industry solutions.

With its extensive international patent portfolio, StarMesh drives innovation and disruption across the aerospace, defense, and communication sectors while enabling various commercial applications.

To learn more, visit www.starmeshglobal.com.

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