STARMESH GLOBAL™ Multi-Link Routing Protocol

Connecting users in different parts of the world via low flying LEOs and VLEOs requires a fleet of satellites and reliable satellite-to-satellite radio connections. Current approaches use hundreds to thousands of very expensive, more-or-less standard communication satellites, resulting in fleet design, build, launch and maintenance costs totaling hundreds of millions, or even billions, of dollars. Furthermore, satellites operating at these low altitudes orbit at high velocities and atmospheric drag causes significant orbital decay, rapid natural de-orbiting, and a very short lifespan. The result is losses, not profits; it's an unsustainable endeavor.

Today's satellite communications haven't progressed beyond a brute force, centrally controlled route creation process in which every satellite has a fixed orientation and known orbital location so that a particular satellite with data on board can get it to a far-distant destination via more than one satellite. They rely on complex telemetry and thruster technologies to control each satellite's orientation (i.e., roll, pitch and yaw) and position in space so its antennas can find other satellites and ground stations to transmit and receive data. STARMESH GLOBAL™ abandons that approach and introduces a revolutionary freeform routing paradigm enabling the use of small, smart satellites that can be manufactured and deployed at a cost that is orders of magnitude less than satellites currently in use or being planned for LEO and VLEO satellite communications.

STARMESH GLOBAL™ Routing—The Basics

The essence of a STARMESH GLOBAL™ system is its revolutionary satellite radio connection technologies which use the counter-intuitive approach of first creating radio links between satellites "backward," from a ground station where data is going to a ground station where it originates. STARMESH GLOBAL™ route creation involves first creating radio links using signals sent from a "sending ground station" to a satellite and then to a "receiving ground station," either directly or via other satellites or nodes (such as drones and/or balloons). The resulting route then supports data transmission from the receiving ground station that was used to create an optimum data uplink, which becomes an "originating ground station" for data going in the other direction to the sending ground station. Likewise, the sending ground station that was used to create an optimum data downlink is now a "destination ground station" for the data Creating satellite routes between fixed terrestrial ground stations is only one example of STARMESH GLOBAL™ routing protocols. Discussed further below in this White Paper is the power of the same "backward" approach to create routes in a more complex satellite system. In addition to satellites and fixed terrestrial ground stations, STARMESH GLOBAL™ network topologies can include additional nodes such as mobile individual user devices and StarMesh drones and/or balloons positioned in low altitudes to provide enormous signal strength advantages combined with localized line of sight coverage.

Implementation of a practicable system is considerably more sophisticated than the above scenario, but the essentials of route creation still rely in the first instance on what's in the satellites (or perhaps, more accurately, what's not). A STARMESH GLOBAL™ satellite is actually little more than radio chips, antennas, solar panels, batteries, and a microprocessor. Every satellite has multiple directional antennas capable of transmitting radio signals in discrete directions around the satellite. StarMesh ground stations will also have multiple directional antennas pointing in discrete directions around the ground station. Each ground station has an address and each ground station antenna has an identifier. In a satellite each antenna likewise has a unique identifier. A STARMESH GLOBAL™ system typically comprises 200 to 300 satellites (or more depending on the data being transmitted and for what business purposes) deployed in unrestrained orbits and thus spread more or less evenly over the earth's surface.

In an example of a straightforward application involving only terrestrial "ground stations" and satellites, route creation starts when a ground station sends initial information signals from all of its antennas. Given the numbers of satellites deployed and their distribution around the earth, it is virtually certain that any given ground station location will see multiple satellites and any given satellite will in turn see multiple other satellites. Considering that the satellites have antennas pointing in all directions, it is also virtually certain that at least one satellite will receive the initial information signal, even though the sending ground station has no idea where any satellite is and the satellites need no attitude control. The initial information signal includes the address of the ground station (this will be used in the data transmission phase). The satellite notes the antenna on which it received the initial information signal and its signal strength or other parameter that quantifies the quality of a potential radio link between the sending ground station and that satellite.

Next, all of the satellite antennas send a routing signal with two components: the address of the sending ground station and the value of the quality parameter. Again, the number and distribution of the satellites ensure that at least one other satellite will receive a routing signal, as will any ground station in view of the satellite. The satellite or ground station notes the antenna on which it received the routing signal and the ground station address included in it. The satellite or ground station in turn determines the quality parameter of the received routing signal.

While this is going on, the initial information signals sent from all of the sending ground station antennas will likely have been received at other satellites. Those satellites process the initial information signal the same way and send their own routing signals. A single ground station might receive on different antennas from multiple satellites routing signals that include the same sending ground station address. The receiving ground station determines the values of the quality parameters for all of the received routing signals. For example, if the ground station receives routing signals from, say, three different satellites, it knows the quality of the initial information signal received by all of the satellites and the quality of the routing signal received from each satellite. The ground station then applies an algorithm to these quality parameters to determine which satellite represents the optimum route back to the sending ground station. One such algorithm could add the qualities of the received routing signal and its associated initial information signal to identify a potential optimum route with the highest combined quality. Optionally, the algorithm can discard a potential route in which the quality of one of the two signals is below a threshold value. The receiving ground station notes the antenna associated with the received routing signal chosen by the algorithm.

The receiving ground station now knows the directional antenna linked with a satellite that provides an optimum route for data addressed to the sending ground station. That satellite in turn knows its antenna linked to the sending ground station that completes the optimum route for the

STARMESH GLOBAL™ Multi-Link Routing Protocol

data. Thus, when a payload or data needs to be transmitted from the receiving ground station addressed to the sending ground station, the data is automatically transmitted "backward" to the sending ground station over the best available route, which was determined and optimized by the algorithm applied by the receiving ground station. (More details on this routing process are available in STARMESH GLOBAL™ U.S. Patents No. 10,447,381 and No. 10,998,962, among others.)

The situation is considerably more complex when simultaneously creating multi-satellite routes between multiple pairs of ground stations, since all of the satellites in the constellation will be transmitting and receiving routing signals at the same time. However, the principle of "forward" route creation followed by "reverse" data transmission still holds, in that each satellite or receiving (originating) ground station, knows which antenna to use to get the data to the next node, whether it be another satellite or the sending (destination) ground station.

The Power of STARMESH GLOBAL™ Routing

The power of the STARMESH GLOBAL™ freeform routing paradigm extends to systems that include drones and balloons as well as satellites at multiple altitudes and can connect individual users with the same magnitude of cost savings as the StarMesh basic satellite example already discussed. The variations are virtually endless. Low-flying (5–6 miles) drones or balloons linked to terrestrial users can initiate route creation. The same low-flying drones and balloons can create their own local network for terrestrial nodes (ground stations or individual users) within their range. A STARMESH GLOBAL™ system can create direct drone/balloon-to-GEO links for long-distance communications. Details of these and other technologies and applications are described in STARMESH GLOBAL™ U.S. Patent No. 10,979,136, Figure 22 (reproduced here), and Publ. No. US 2022/0173796, Figure 12.

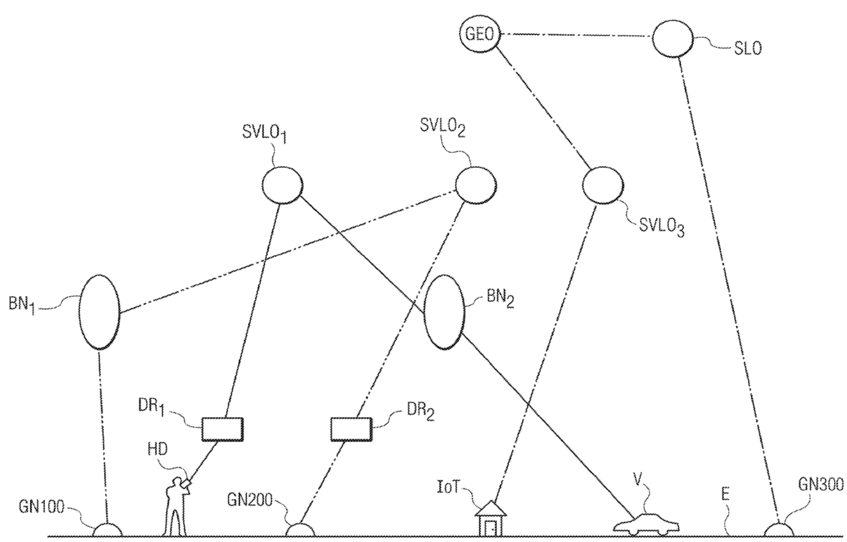

FIG. 22

The revolutionary STARMESH GLOBAL™ multi-link routing protocols are equally applicable to and can be implemented in traditional satellite communication systems with satellites having strict attitude control and occupying fixed orbits. Applying the concepts described in the STARMESH

GLOBAL™ patents listed in the StarMesh Global™ Worldwide Patent Portfolio will facilitate the rapid route creation required for important applications such as broadband communications, and can be used with systems with satellites and drones and/or balloons deployed at different altitudes. It can improve long-distance communications by incorporating high-flying, fixed-orbit geostationary satellites (GEOs) to minimize the number of nodes required to link far-distant users.

Tremendous Cost Savings of a STARMESH GLOBAL™ Satellite

The cost savings of a STARMESH GLOBAL™ patented system is made possible because its LEO/VLEO satellites do not require heavy and expensive rocket-fueled or electric thrusters and complex ground and onboard telemetry systems and positioning sensors to maintain them at known altitudes and in particular locations and attitudes to establish reliable satellite-to-satellite radio links, no matter how far apart the terminal points of the route. In addition to reducing cost by eliminating onboard satellite hardware, it also drastically cuts satellite size and weight resulting in reduced launch cost. These patented StarMesh design modifications contribute to cost reduction in still another way because a STARMESH GLOBAL™ satellite doesn't need robust engineering design to ensure that the satellites survive launch forces and the hostile environment of space. The orbit altitude for release and deployment of a fleet of STARMESH GLOBAL™ satellites do not need the expensive precision and accuracy of traditional deployment sequences for each satellite, as STARMESH GLOBAL™ satellites can use random and arbitrary orbits alleviating wasted cost on precise orbital insertion distributions.

All of the above innovations significantly reduce the cost to design, build, launch, deploy and maintain a STARMESH GLOBAL™ satellite communication system. And while STARMESH GLOBAL™ LEO/VLEO satellites are subject to de-orbiting because they don't maintain their original insertion altitude, their affordability far outweighs the comparative cost of satellites with components made superfluous by STARMESH GLOBAL™ satellites since they can be replaced as needed at minimal cost. This makes STARMESH GLOBAL™ even more advantageous because its cost savings enable it to use satellites that fly below installations such as the International Space Station at 250 miles, thus not contributing to the space junk problem plaguing the Industry.

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