Orbit-Routing Simulator: Advanced Routing in Multi-Orbit Satellite Networks

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***Abstract*—Traditional routing algorithms are not efficient when applied to multi-orbit satellite networks, encompassing LEO, MEO, and GEO satellites, as well as ground stations, since identifying optimal routing strategies jointly with a non-terrestrial network dynamic topology is a challenging topic. In response to that, this paper introduces the *Orbit-Routing Simulator,* a satellite simulation tool designed to tackle the intricacies of advanced routing algorithms. *Orbit-Routing Simulator* provides a robust environment for the design, testing, and evaluation of various routing strategies, tailored to meet the dynamic conditions of complex satellite constellations. It aims to enhance the efficiency and reliability of satellite communications by providing detailed insights into the operational effectiveness of the communication systems. This facilitates improved connectivity and network management by addressing the challenges of high mobility and variable communication channels in satellite networks. The paper concludes with several use cases and scenarios highlighting its practical applications and adaptability to real-world operational adjustments.**

Keywords—multi-orbit satellite networks; dynamic routing, ISL Routing, 5G

I. INTRODUCTION

The advent of low Earth orbit (LEO) and medium Earth orbit (MEO) satellites has revolutionized the communication landscape by offering lower latency and higher data throughput. Integrating LEO, MEO, and geostationary (GEO) satellites into a unified multi-orbit network holds significant potential to address the growing need for high-speed and reliable beyond-5G (B5G) communications [1], [2], [3], [4], [5]. Traditionally, satellite networks have relied on GEO satellites, valued for their ability to cover vast areas with a single satellite [6], [7]. Over time, satellite networks have become a cornerstone of modern communication systems, delivering critical services such as global broadcasting and providing internet access in remote regions [8].

Despite the potential advantages, the dynamic topology of multi-orbit satellite networks poses significant challenges for traditional routing algorithms. These algorithms, designed primarily for static terrestrial networks, struggle to adapt to the frequent changes in satellite positions and the varying link qualities inherent in non-terrestrial environments. As a result, there is a pressing need to test, analyze, and adapt routing strategies to efficiently exploit the unique characteristics of multi-orbit satellite networks.

In fact, traditional routing algorithms, such as Distance Vector and Link State protocols, are not well-suited for the dynamic nature of multi-orbit satellite networks [9]. These algorithms assume relatively stable network topologies and consistent link qualities, conditions that are rarely met in non-terrestrial networks. The frequent handovers between satellites, varying propagation delays, and intermittent connectivity in multi-orbit networks exacerbate the inefficiencies of these traditional approaches. Consequently, identifying optimal routing strategies that can adapt to the dynamic topology of multi-orbit satellite networks is a critical research challenge.

This study aims to address the limitations of traditional routing algorithms by exploring novel routing strategies tailored for multi-orbit satellite networks. The primary objectives are to:

1. Develop a simulation tool for testing routing protocols that can dynamically track the changes in network topology and link quality.
2. Evaluate the proposed routing strategies through simulations and real-world experiments.

To this aim, *Orbit-Routing Simulator* (ORS) was designed to tackle the intricacies of advanced routing algorithms.

ORS features a flexible design specifically crafted to address the diverse challenges of simulating satellite networks. It supports various satellite constellations and communication models across LEO, MEO, and GEO and offers both real-time and accelerated simulation modes to accommodate different research needs.

The tool is equipped with interactive graphical user interfaces that enhance the visualization and management of complex satellite constellations. Coupled with robust data capture capabilities, the ORS is particularly valuable for studying complex behaviors in satellite networks, especially in scenarios involving Inter-Satellite Link (ISL) routing strategies.

Rather than directly managing dynamic routing, the simulator excels in gathering detailed data about satellite network interactions based on specific topologies. This data is crucial for researchers aiming to analyze and identify the most effective routing algorithms.

The development of efficient routing algorithms for multi-orbit satellite networks has far-reaching implications for global communication systems. By enhancing the reliability and performance of satellite networks, this research can contribute to improved Internet connectivity in underserved regions, support disaster recovery efforts, and facilitate the growth of the Internet of Things (IoT) on a global scale. Furthermore, the insights gained from this study can inform the design of future satellite constellations and ground station infrastructures, paving the way for more resilient and scalable communication networks.

The remainder of this paper is organized as follows: Section II provides a brief motivation and fundaments of this development. Section III presents the methodology used to develop ORS. Section IV discusses the use cases and provides an analysis of the selected routing scenarios. Finally, Section V concludes the paper and outlines potential directions for future research and development of the tool.

II. MOTIVATIONS

The design of a future non-terrestrial mobile communication infrastructure passes through the analysis of the network topology and the relative routing to address the ubiquitous connectivity and guaranteeing the desired KPIs of Quality of Service. The development of a mission planner is considered one of the mandatory steps in a funded project by space agencies to advance in all the following development steps.

Nowadays, Starlink is the reference non-terrestrial Internet provider with its more than 6K operative satellites that provide almost global connectivity, high data rate, and low end-to-end delay at average costs. At this time, Starlink is not offering 5G services to handheld devices and smartphone but custom Internet access with proprietary equipment, namely the Dishy. However, experimental tests have been conducted [10], [11], [12], [13] to provide broadcast messages to mobile devices during the recent cataclysms in United States. Even if Starlink is mainly operated with a single satellite hop, ISL are enabled and maybe used at very high latitudes.

In order to exploit multi-orbit satellite networks, [14], [15] and on-board routing [16], the design and development of an Orbit-Routing Simulator is hereafter introduced to tackle the intricacies of advanced routing algorithms.

It must be noted that similar tools have been investigated in the literature [17], [18], [19], [20], [21], [22], [23], [24], [25], [26] but none of them was providing the necessary features for routing testing jointly with satellite network topology design. Only Mathworks Matlab currently provides a commercial tool in the communication toolbox to simulate LEO constellations but with two drawbacks: it is not open-source, and the network/routing framework must be developed from scratch.

III. ORS FEATURES

In this section, we will describe the core components of ORS. The tool is developed in Python and utilizes several widely recognized libraries (e.g. [27], [28]). It is designed with a range of key features that enable efficient management and analysis of satellite communications:

- **time management** for controlling the flow of time within simulations to see how satellite networks behave over different periods;
- **topology mapping** for the visualization of how satellites are arranged and connected, crucial for planning and analyzing satellite networks:
    - **graphical tools** for a better understanding and managing satellite positions and connections using dynamic 2D and 3D graphics;
    - **network topology analysis,** which offers crucial insights into graph connectivity and network integrity, enabling efficient identification and management of connectivity issues and disruptions, while supporting scalable network analysis to ensure reliable and effective satellite operations;
- **data storage** that helps keep track of all time-evolving simulation data and the associated metadata, essential for thorough post-processing, analysis, and decision-making;
- **ISL routing and path analysis**, which allow for focusing on how data moves between satellites and determines the best routes, considering the evolving network topology as satellites' positions change over time. This dynamic approach ensures that the end-to-end communication paths are optimized as the spatial relationships between satellites change;
- **challenges and flexibility** that allow the examination of specific issues like routing with fast-moving LEO satellites and adapting the simulator to various scenarios.

Each feature has been selected and implemented to simulate complex satellite interactions and optimize communication strategies in multi-orbit environments: a deeper description is provided in the next subsections.

A. *Time management*

ORS offers precise control over the simulation timeline with near real-time accuracy, which is critical for simulating real-world satellite behavior and communication timings. This feature includes:

- **adjustable time steps** that allow users to set custom time intervals for simulation steps, accommodating various analysis needs;
- **simulation speed control** supporting real-time, accelerated, and step-by-step simulation modes;
- **time synchronization,** which ensures that the simulation stays synchronized with real-world time, which is a critical factor in satellite network operations.

B. *Topology mapping*

This feature provides a comprehensive, real-time visualization and analysis of satellite network configurations. It leverages both dynamic 3D and 2D graphical tools in GML (Graph Modeling Language) format that enable operators to oversee and assess the network's structure and behavior continuously throughout the simulation. The saved GML format is subsequently processed. Specifically, the *Graph() object* (G) is utilized, followed by the application of the *dijkstra_path function* for further analysis. The feature includes:

- **real-time visualization,** which facilitates an immediate and interactive view of the entire satellite constellation, displaying essential details such as the links and distances between individual satellites and ground stations (GSs). This visualization is crucial for operational awareness and decision-making.
- **spatial and connectivity insights**. By offering both 3D and 2D representations, the tool allows operators to toggle between different perspectives depending on their analysis needs. The 3D view provides a spatial understanding of the satellite positions and their orbits, while the 2D view focuses more on connectivity and network topology, simplifying complex relationships into more digestible formats. It also provides an easy-to-use visual understanding of the overall satellite network, such as:
  - visual network topology changes notification;
  - possibility of zooming the 3D graph to visualize the particularities of a small portion of the satellite constellation;
  - taking the snapshot of the 3D visual representation;
- **graph connectivity** which is designed to analyze the connectivity of the satellite network and the results presented on the 2D portion of the visual representation. It can efficiently identify whether the network forms a connected graph or if disruptions, such as satellite malfunctions or environmental interference, have caused any splits or fragmentation. This analysis is crucial for ensuring end-to-end communication and for planning redundancy strategies to maintain network integrity under various conditions, enabling operators to assess and address areas of concern quickly. Redundancies make the network more complex, but the simulator may provide helpful visual information in planning such types of complex aspects;
- **network integrity and reachability assessment**. As the number of satellites increases, the emphasis on graphical visualization may diminish in importance compared to the crucial role of analytical tools, which become increasingly significant as networks scale up. This capability ensures that the network maintains high levels of service reliability and reachability, which are essential for mission-critical satellite operations. The analytical tools provide deep insights into network behavior, helping to manage and optimize connectivity even as the system scales, thus supporting sustained operational effectiveness;
- **path determination** for visualizing and managing the network made of ISLs within the satellite communication simulation. Utilizing graph-based algorithms, the module provides operators with a clear understanding of the dynamic topology and communication paths. This component ensures that network operators can analyze, plan, and manage the satellite constellation with a sufficient degree of accuracy and efficiency.

C. Data storage

This capability ensures efficient data management and supports extensive simulation activities such as:

- **raw data capture and export** for capturing and storing raw simulation data, with options for exporting in standard formats for subsequent analysis;
- **sequential simulation runs**, a capability that supports the execution of multiple simulations one after the other, automating data capture and analysis.

As mentioned above, ORS generates or updates the Graph object (G) based on real-time or step-based satellite position data, ground stations, and user-defined parameters. A simplified version of ORS' *save_graph_and_metadata function* operate as follows:

1. convert the in-memory G object to GML format, and save it to disk with a hash-based filename (e.g., *graph-step{step_index}-{hash}.gml)*
2. create a corresponding JSON metadata file (e.g., *metadata-step{step_index}.json)* containing:
   a. simulation parameters such as satellite coordinates at the current time step, reference to the GML filename (ensuring a direct link between the two files), etc.
   b. user-defined configuration parameters such as GS names, LEO satellites height, inclination, phases, etc.
3. optionally log routing information (e.g., shortest paths, total cost) to a CSV file for further analysis.

Within the context of our ORS, the data storage feature plays an important role, enabling operators to capture extensive simulation data, organize it efficiently, and provide versatile export options, by improving the post-simulation analysis process. The real-time data exchange capabilities extend its functionality further, facilitating a comprehensive environment for both simulation and real-world application testing. For example, graph data may represent a network of nodes and edges, where each node is a satellite or a ground station, and each edge represents a communication link between them. The network is outlined in terms of nodes (identified by IDs and labels) and the edges that connect them (defined by source, target, and weight). A list of successive sets of files may be exported for post-processing.

D. ISL routing and path analysis

Routing in networks that incorporate a mix of LEO, MEO, GEO satellites, and ground stations poses significant challenges: the highly dynamic nature of LEOs' movements, combined with the static position of GEOs, and operational variability of ground stations, requires sophisticated routing strategies to ensure stable and reliable communication paths.

Furthermore, the snapshot analysis for the best *path determination* featured within ORS plays a crucial role in enhancing dynamic pathfinding capabilities by allowing operators to capture real-time snapshots of the network's graph state at specific intervals. This functionality is particularly valuable for post-processing and analyzing how changes in satellite connectivity and network dynamics influence routing decisions over time. By freezing the network's state at various points, users can effectively evaluate and optimize the pathfinding algorithms that are critical for maintaining robust and efficient communication links between satellites in complex and mixed LEO, MEO, and GEO orbits, as well as ground stations while the earth is rotating. The module incorporates:

- **dynamic pathfinding**, which utilizes graph-based algorithms to calculate all possible communication paths and their associated costs, initially based on distance metrics;
- **snapshot analysis**, which allows operators to capture snapshots of raw data on the state of the network at any time, helpful in analyzing changes in connectivity and other dynamics

E. *Challenges and flexibility*

The fundamental difficulties include:

- **high dynamics of LEO satellites**. The fast-moving nature of LEO satellites necessitates continuous updates to the routing tables to accommodate the frequent changes in topology. This dynamic scenario contrasts sharply with GEO satellites, which remain geostationary relative to a fixed point on the Earth, simplifying their integration into the network;
- **inter-orbital routing complexities**. Integrating LEO and GEO satellites into a single network involves managing the inter-orbital links where communication delays and link stability vary greatly. The difference in orbital velocities and altitudes requires sophisticated algorithms to manage the delays and optimize the routing paths efficiently;
- **visibility and line-of-sight issues**. Given that satellites belonging to one orbital plain, especially in LEO, rapidly enter and exit the line-of-sight with other orbital plain satellites and of ground stations and other MEO and GEO satellites, routing protocols must dynamically adjust to these changing visibility conditions to prevent communication dropouts and manage network latency effectively to guarantee a persistent end-to-end communication.

The ORS is specifically designed to study and optimize routing algorithms in satellite communication networks involving LEO, GEO, and terrestrial nodes. We mainly focus on:

- **algorithm development and testing** processes, leveraging a simulation environment designed to utilize raw data that reflects the time-evolving real-world satellite network behaviors. This data is critical for the development, testing, and validation of new routing algorithms under varied operational conditions;
- **performance analysis** is important in evaluating the effectiveness of new routing algorithms developed for satellite communication networks, as well as conducting comprehensive analyses to compare various routing strategies under a spectrum of operational scenarios that reflect real-world conditions. By examining the outputs of different algorithms, the module aims to identify optimal routing strategies for satellite networks encompassing LEO, GEO, and ground stations;

In this context, ORS's key functionalities and objectives are:

- **comparative analysis**. This function involves running multiple routing algorithms simultaneously under identical conditions to directly compare their performance. Metrics such as latency, throughput, packet loss, and the efficiency of data routing are analyzed to evaluate which algorithms perform best under specific network scenarios;
- **robustness and reliability assessment**. The robustness of a routing algorithm is tested by simulating conditions such as high network traffic, satellite failures, and adverse environmental effects. Reliability is assessed by evaluating the consistency of the algorithm's performance over extended periods and under varying conditions;
- **adaptability to network changes**. One of the critical assessments involves the algorithm's ability to adapt to dynamic changes in the network topology. This includes how quickly and effectively an algorithm can re-route communications in response to satellite movement, newly introduced or retired satellites, and changes in the operational status of network nodes;
- **detailed metrics evaluation**. Performance analysis generates detailed reports that include metrics like route optimization time, error rates, and the algorithm's computational efficiency. These metrics provide deep insights into the practical implications of implementing each routing strategy in operational networks.

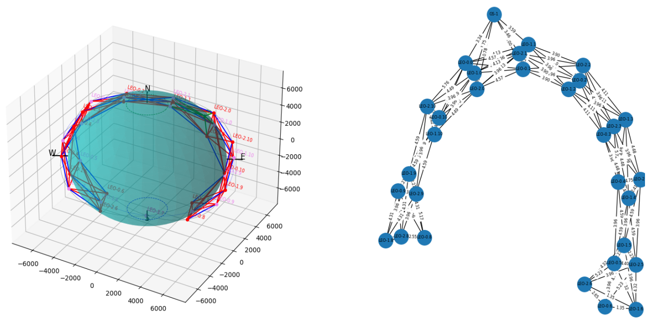

Fig. 1. Total of 11 LEO satellites per each of the three orbital plane and the equivalent 2D network diagram, forming a single connected graph

IV. USE CASES, SCENARIOS, AND TESTS

In this section, two different test scenarios that demonstrate the capabilities of the ORS related to network connectivity and routing aspects are presented. Scenario A is built upon a simple constellation with a few orbital planes and satellites per orbit: it aims to show the path analysis by extracting the optimal one, according to a metric, but also the redundant ones, useful as backup solutions in case of congestion or malfunction of a node of the best path.

Scenario B, instead, shows how ORS scales in complexity by addressing a Mega LEO constellation with a real study case, that is, the Starlink primary “Gen1 Shell” constellation. In the latter scenario, the analysis is shifted to the complexity of the topology of the Inter-Orbit and Intra-Orbit Satellite links, and of the satellite visibility from the ground stations with constraints on the minimum and, eventually, maximum elevation angle.

A. *Initial setup with basic connectivity*

The objective of this scenario is to demonstrate ORS basic functionalities with minimal satellite deployment. TABLE I provides the input parameters used in ORS to test Scenario A.

TABLE I. EXAMPLE OF INITIAL CONSTELLATION CONFIGURATION

Parameter	**Value**
Number of orbits	3
Satellites per orbit	22
Altitude (Km)	550
Inclination	53
Start time	2024-10-06 00:00:00
Ground stations config	ground-stations.yaml
Initial phases	[0.0, 10.0, 20.0]
Max ISLs per satellite	4
Min Elevation GS	20

The ground-stations.yaml file contains the configuration of all the ground stations and in TABLE II it is shown an example of a GS configuration situated in Pisa.

TABLE II. EXAMPLE OF A GROUND STATION CONFIGURATION

Parameter	**Value**
name	GS-Pisa-1
number	20004
longitude	10.4
latitude	43.72
altitude	0

Fig. 2 shows the output of the simulation over a window of 200s considering a time step of 1 second (total of 200 steps). The 3D plot produces the rendering of 3 orbital planes with 22 LEOs for each one and some ground stations (GS) in Pisa, London, Beijing, and Tokyo, respectively.

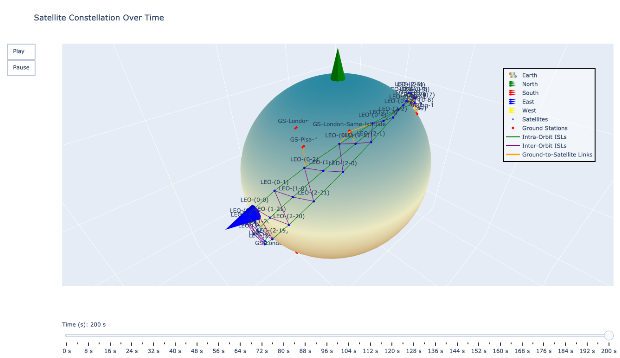

Fig. 2. Total of 3 orbital planes with 22 LEO satellites per planes

In addition, an easy-to-consult time evolution of the best path for each ground station pair is reported in Fig. 3: by pointing the mouse at each point of interest, it is possible to visualize the best path using Dijkstra's algorithm between the pair of ground stations at each time step, including the total cost expressed in km (e.g. GS-Beijing-1 –> LEO-0.7 –> LEO-0.8 –> GS-Tokyo-1, hop count: 3, cost: 4024.37 km).

We have applied two different routing algorithms — namely, Routing Information Protocol (RIP) and Shortest Path First (SPF) using Dijkstra’s algorithm — to ground station pairs and, as an example, TABLE III demonstrates path selection between the GSs GS-Beijing-1 and GS-Tokyo-1 for each time steps (t_i).

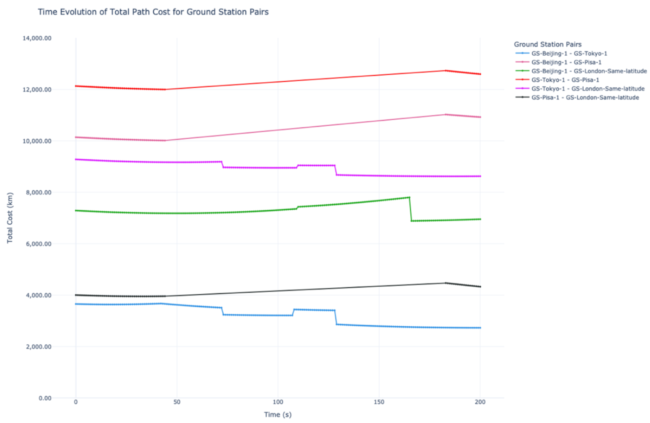

Fig. 3. time evolution of the best path for each ground station pair

We identify the RIP best path based on the least number of hops, providing both the specific route taken (the path) and the total cost in terms of hop count to reach the destination. This approach simplifies routing decisions by focusing on minimizing the number of intermediate nodes, ensuring efficient redundant paths for data transmission across the network.

TABLE III. EXAMPLE OF PATH SELECTION BETWEEN GS-BEIJING-1 AND GS-TOKYO-1 USING RIP AND SPF ALGORITHMS

t_i	**Path**	**Routing alg.**	**Hop count**	**Cost (km)**
0	GS-Beijing-1 –> LEO-0.7 –> LEO-0.8 –> GS-Tokyo-1	RIP	3	4024.37

	GS-Beijing-1 –> LEO-1.6 –> LEO-1.7 –> GS-Tokyo-1	RIP	3	3652.85
	GS-Beijing-1 –> LEO-1.6 –> LEO-1.7 –> GS-Tokyo-1	SPF	3	3652.85
1	GS-Beijing-1 –> LEO-0.7 –> LEO-0.8 –> GS-Tokyo-1	RIP	3	4014.74
	GS-Beijing-1 –> LEO-1.6 –> LEO-1.7 –> GS-Tokyo-1	RIP	3	3650.75
	GS-Beijing-1 –> LEO-1.6 –> LEO-1.7 –> GS-Tokyo-1	SPF	3	3650.75
…	…	…	…	…

To provide a clear understanding of the evolution of the best path costs over time between each pair of ground stations, we have compiled a concise report. As shown in TABLE IV, for each GS pair, we present the time range of the simulation and the corresponding range of total costs for the best paths observed.

TABLE IV. SCENARIO A'S TIME AND COST RANGES FOR BEST PATHS AMONG GS PAIRS

Best path cost report		
GS Pair	***Time Range***	***Cost Range***
GS-Beijing-1 GS-Pisa-1	0 to 200.0s	10013.598 km to 11025.391 km
GS-Beijing-1 GS-London-Same-latitude	0 to 200.0s	6884.147 km to 7800.708 km
GS-Tokyo-1 GS-Pisa-1	0 to 200.0s	11999.738 km to 12733.322 km
GS-Tokyo-1 GS-London-Same-latitude	0s to 200.0s	8619.316 km to 9279.778 km
GS-Pisa-1 GS-London-Same-latitude	0s to 200.0s	3949.923 km to 4468.272 km

Finally, for each experiment, we provide a concise report on the number of satellites visible to each ground station at every time step. While this visibility data is collected for all time steps, in TABLE V it is presented an example for time step 0.

TABLE V. SATELLITE VISIBILITY PER GROUND STATION AT TIME STEP 0 – BASIC SCENARIO (SCENARIO A)

At time 0 s, Ground Station GS-Beijing-1 has 2 visible satellite(s).
At time 0 s, Ground Station GS-Melbourne-1 has 0 visible satellite(s).
At time 0 s, Ground Station GS-Tokyo-1 has 3 visible satellite(s).
At time 0 s, Ground Station GS-Pisa-1 has 1 visible satellite(s).
At time 0 s, Ground Station GS-London-4 has 0 visible satellite(s).
At time 0 s, Ground Station GS-London-south-hemisphere has 0 visible satellite(s).
At time 0 s, Ground Station GS-London-Same-latitude has 2 visible satellite(s).
…

B. *Complex network visualization*

As shown in Fig. 4, in this scenario, we have reproduced the Starlink's primary "Gen1 Shell", which consists of 72 orbital planes with 22 satellites per plane (totaling 1,584 satellites) and is recognized as the first major deployment that provides substantial global coverage at mid and lower latitudes. The output of the simulation visualizes the 3D topology at time step "92 second" over a time window of 200 seconds.

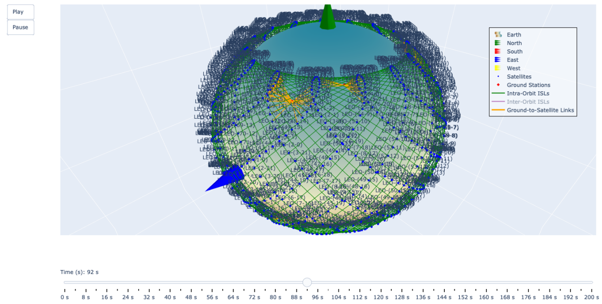

Fig. 4. Total of 72 orbital planes with 22 LEO satellites per plane

Analogously to Scenario A, for each pair of ground stations, in TABLE VI a short report is provided on the cost ranges of the best path evolution with time; for brevity, only a short snippet of the report is given.

TABLE VI. SCENARIO B'S TIME AND COST RANGES FOR BEST PATHS AMONG GS PAIRS

Best path cost report		
GS Pair	***Time Range***	***Cost Range***
GS-Beijing-1 GS-Melbourne-1	0 to 200.0s	11565.325 km to 12381.720 km
GS-Beijing-1 GS-Tokyo-1	0 to 200.0s	2457.823 km to 4024.370 km
…	…	…
GS-Beijing-1 GS-Pisa-1	0s to 200.0s	9421.777 km to 11454.797 km
GS-Beijing-1 GS-London-4	0s to 200.0s	10117.928 km to 11873.211 km

The report in TABLE VII demonstrates that with a complete constellation, the number of satellites visible to each ground station at every time step increases significantly.

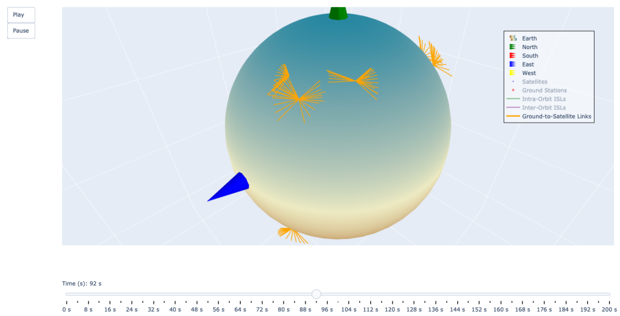

Fig. 5. elevation of the ground/satellite hop in visibility

TABLE VII. SATELLITE VISIBILITY PER GROUND STATION AT TIME STEP 0 – FULL CONSTELLATION SCENARIO (SCENARIO B)

At time 0 s, Ground Station GS-Beijing-1 has 16 visible satellites.
At time 0 s, Ground Station GS-Melbourne-1 has 16 visible satellites.
At time 0 s, Ground Station GS-Melbourne-1 has 16 visible satellites.

At time 0 s, Ground Station GS-Tokyo-1 has 16 visible satellites.
At time 0 s, Ground Station GS-Pisa-1 has 26 visible satellites.
At time 0 s, Ground Station GS-London-4 has 27 visible satellites.
At time 0 s, Ground Station GS-London-south-hemisphere has 15 visible satellites.
At time 0 s, Ground Station GS-London-Same-latitude has 20 visible satellites.
At time 1 s, Ground Station GS-Beijing-1 has 16 visible satellites.
At time 1 s, Ground Station GS-Melbourne-1 has 16 visible satellites.
At time 1 s, Ground Station GS-Tokyo-1 has 16 visible satellites.
At time 1 s, Ground Station GS-Pisa-1 has 26 visible satellites.
At time 1 s, Ground Station GS-London-4 has 27 visible satellites.
At time 1 s, Ground Station GS-London-south-hemisphere has 15 visible satellites.
At time 1 s, Ground Station GS-London-Same-latitude has 20 visible satellites.
At time 2 s, Ground Station GS-Beijing-1 has 16 visible satellites.
At time 2 s, Ground Station GS-Melbourne-1 has 16 visible satellites.
At time 2 s, Ground Station GS-Tokyo-1 has 16 visible satellites.
At time 2 s, Ground Station GS-Pisa-1 has 25 visible satellites.
At time 2 s, Ground Station GS-London-4 has 27 visible satellites.
At time 2 s, Ground Station GS-London-south-hemisphere has 15 visible satellites.
At time 2 s, Ground Station GS-London-Same-latitude has 20 visible satellites.

Finally, Fig. 5 shows all the possible links of each GS with satellites in visibility with the relative elevation angle, as well as the distance: at each time step, it is possible to evaluate the relative parameters and the latency to access each satellite.

V. Conclusions

The ORS provides a powerful platform for simulating complex satellite networks. With its high precision, flexibility, and comprehensive feature set, the tool enables detailed analysis and effective management of satellite communications, allowing for the simulation of realistic scenarios. In this paper, we have presented a set of features to test some routing algorithms. To prove the scalability of the system, we have performed two incremental tests: a simple scenario (Scenario A), which validates a few orbital planes with few satellites, and a very complex scenario (Scenario B) performed by Starlink constellation, which is a reference, nowadays, concerning Mega-LEO constellation for broadband Internet connectivity. ORS was developed to address one of the milestones of the design of a future 6G LEO constellation for ubiquitous and global mobile connectivity and to experiment the routing policies for the next generation mobile Internet.

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