RTG Working Group
Internet-Draft
Intended status: Informational
Expires: September 8, 2022
D. King
University of Lancaster
N. Wang
University of Surrey
March 7, 2022

Routing and Addressing Challenges Introduced by New Satellite Constellations

draft-kw-rtgwg-satellite-rtg-add-challanges-00

Abstract

Future networks, including the Internet, will utilize an increasing amount of space-based transport infrastructure. Control and transport between Earth-based and space-based networks present several problems - high dynamicity, spatial connectivity, continual movement tracking and prediction, ocular obstruction, integration with existing Internet infrastructure, all of which challenge existing architectures, routing mechanisms and addressing schemes.

This document summerises near-to-mid-term space-networking problems; it outlines the key components, challenges, and requirements for integrating future space-based network infrastructure with existing networks and mechanisms. Furthermore, this document highlights the network control and transport interconnection, and identify the resources and functions required for successful interconnection of space-based and Earth-based Internet infrastructure.

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1. Introduction

Exponential increases in Internet speed have facilitated an entirely new set of applications and industry verticals underpinned by evolving fixed network infrastructure. The costs of deploying new fixed fibre networks are a limiting factor. As 5G and Internet infrastructure build-out continues, we must now look up both figuratively and physically, for our next networking opportunity. In the future, space communication [1] will play a significant role in providing ubiquitous Internet communications in terms of both access and backhaul services.

Future space networks will also need to cooperate with the existing

terrestrial network infrastructure (Integrated Space and Terrestrial Networks - ISTNs), exploiting heterogeneous devices, systems and networks. Thus, providing much more effective services than traditional Earth-based infrastructure, and greater reach and coverage than proprietary and isolated space-based networks.

Several challenges are outlined in the bullets below:

- As LEO satellites orbit the Earth at relatively high-speed, the space-based path latency and bandwidth will fluctuate as routes shift across the satellite topology.

- Future LEO satellites will support multiple link types, air interfaces, and frequencies, including high-bandwidth free-space optical links and low-speed radio interfaces.

- Atmospheric conditions and weather severely degrade communication between satellites over space-ground links, significantly reducing throughput or requiring new routing paths to be selected.

- The ISTN links will become bandwidth-constrained, and it be necessary to compute alternative paths around those congested links.

- Dynamic path selection based on current and predicted demands will need to be factored in, thus traditional Dijkstra techniques for path routing will not be sufficient.

Existing Internet architecture and protocol mechanisms will likely apply to converged space-based and Earth-based network infrastructure, however, there will be limitations [2]. This section outlines some of the challenges, requirements, and potential strategies to pursue for future ISTNs.

This document summarises near-to-mid-term space-networking problems and challenges, phrased as research questions. This document does not propose solutions or techniques, or elaborate on specific protocols themselves.

1.1 Terminology

LEO: Low Earth Orbit with the altitude from 180 km to 2000 km.

GEO: Geosynchronous orbit with the altitude 35786 km

IGP: Interior gateway protocol

ISL: Inter Satellite Link

ISLL: Inter Satellite Laser Link

ISTN: Integrated Space Terrestrial Network

MEC: Multi Edge Computing

2. Routing and Forwarding Challenges for ISTNs

Routing and signaling across emerging next generation satellite networks is far from static [3]; satellite-to-satellite connectivity changes frequently, space-based link latencies, and links from space-to-ground will change regularly. Satellites will also have to contend with predictive routing capabilities, as links will only be established when optical alignment is possible. Given that meshes of 100s and 1000s of satellites are also expected, techniques that use per-hop Dijkstra calculation will be extremely inefficient.

Next generation space networks are not static. The satellite that is overhead a particularly ground station changes frequently, the laser links between space-based satellites change often, and link latencies for satellite to ground links will vary based on atmospheric conditions [4].

Several control plane challenges have been identified for space-based networks [5], these include:

o New link acquisition, predicted link availability, and link metric dynamicity: as the acquisition and tracking of satellites and links change, there is a need to adjust basic link and TE metrics (delay, jitter, bandwidth) and update the existing routing traffic engineering database.

o Space-based path computation: selection of the best path across ISLs and direct uplinks and downlinks, consideration of cloud cover, air turbulence and external object occlusion.

o Temporal routing: consideration of the time-varying topology of the space network will necessitate frequent routing updates.

o Predictive routing: time-scheduled routing paths based on expected satellite orbits and air-interface alignment.

o Rerouting of paths: which may be required in the event of

projected space-based debris orbits that prevent line-of-sight between adjacent nodes, interface and node failures, and adverse weather which may affect space-to-ground communication points.

- Resilience: overall, the network must be resilient to failures, and capable of routing with low latencies, even when traffic levels are significant enough to oversubscribe the preferred paths.

3. Network Control and Addressing for ISTNs

Integrating the space-based infrastructure with an existing network might be achieved using traditional Internet routing techniques and identifying the extra-terrestrial portion of the network as a specific domain (such as an IGP area or an AS) [6]. The space-domain might run a traditional routing control plane, likely logically within an Earth-based representation which programs the path via an SDN-programming technique [7]. However, this approach would not be capable of computing paths based on the unique space connectivity dynamics. Furthermore, if the space-domain was connected to traditional Earth-based Internet domains (including ASes via BGP), it might create unwanted route flapping, causing routing instability.

Due to the unique characteristics of the space-based nodes (which may have multiple interfaces and lines of sight to next-hop satellite nodes or ground stations, may fluctuate), other network control methods may be needed.

4. System Resilience for ISTNs

Legacy satellites might typically operate independently from their orbiting counterparts. However, next generation space-based infrastructure will be utilizing multiple links between satellite nodes and ground-stations, which leaves potential network paths susceptible to the consequences of node and link failures or anomalies. Loss of node payload, communication link, or other sub-system components might render the entire satellite node inoperable.

4.1 Routing Resilience for ISTNs

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infrastructure will be utilizing multiple links between satellite nodes and ground-stations, which leaves potential network paths susceptible to the consequences of node and link failures or anomalies. Loss of node payload, communication link, or other sub-system components might render the entire satellite node inoperable.

In a satellite network, there several types of failures a routing system might be concerned with; these include:

- Failures of components in the forwarding plane, e.g., ISL communication failure.

- Control plane malfunction, if the central controller is destroyed or disconnected, or the distributed control plane suffers a catastrophic failure or attack.

- Misconfiguration of satellite node or ISL forwarding, or degradation of satellite orbit and loss of communication sight to neighbouring node.

In general, satellite node failures or components of the forwarding plane are problematic but as the latest generation of space infrastructure is highly meshed, routing around node failures is feasible. Once a failure occurs, the centralized controller, or distributed control plane, would have to respond and update the forwarding state in devices to route traffic around the failed nodes or links. As failure may be seen as an extreme case of an unexpected change in traffic level, a traffic reoptimization mechanism would likely be required.

5. Multi-layer Networking in ISTNs

The Low Earth Orbit (LEO) satellite uses a lower physical orbit, which provides latency benefits, but this orbit will incur more dynamic connectivity and oscillating link characteristics [9]. The Medium Earth Orbit (MEO) and Geostationary Orbit (GEO) satellites provide more physical stability, and reduced dynamicity of the links as the satellites remain static. The current GEO satellite system mostly provides relay function; however, in the next generation, satellite systems could interact providing multi-layer routing and forwarding functions [8] between satellite layers, akin to multi-layer networking in terrestrial networks.

6. ISTN Traffic Engineering

Traffic Engineering (TE) has been well investigated for more than two decades in the context of the traditional terrestrial Internet. However, TE has not been systematically understood in the integrated space and terrestrial network environment, especially given the district characteristics of the two types of networks and also the mega-constellation behaviors of LEO satellites. It is generally understood that the inter-satellite link capacity is not compared to the optical fiber links in the terrestrial Internet. As such, the traffic injected into the space network has to be selective.

Policies can be enforced either based on the traffic type and their QoS requirements or based on other contexts such as the distance between source and destination pairs. For instance, in it has been argued that routing through a chain of LEO satellites will outperform the usage of terrestrial Internet in terms of end-to-end delay if the distance of the source and destination is beyond 3000 kilometres. It is also worth noting, the capability of TE in the space network also largely depends on the specific routing mechanisms that are deployed, which has been the case in terrestrial network environments, e.g., IP/MPLS/SDN. As mentioned above, the capability of TE in integrated space and terrestrial network infrastructures will also depend on the routing mechanisms deployed in the two network environments, either with separated protocols (the case today) or with a unified protocol suite.

6.1 ISTN Resource Slicing

In the context of 5G, network slicing has been deemed as a promising feature for operators to provision network resources and functions to tailor for heterogeneous requirements of emerging applications and services. While the business model for network slicing on the traditional network operator side has been relatively clear, a more complex scenario of involving satellite operators has not yet been previously elaborated. As a starting point, a terrestrial network operator can rent virtual network resources provided by a satellite operator to build a dedicated backhaul link for connecting its point of presences (PoPs). In this case the terrestrial network operator can create end-to-end slices for supporting different application types, and the backhaul component of a selected subset of slices (e.g., eMBB (Enhanced Mobile Broadband) for video content delivery) can leverage on the satellite capability.

On the other hand, a satellite operator could also slice its own satellite link resources and lease to multiple terrestrial network operators for backhauling or extended access services, by applying intelligent beamforming techniques to cater for different geographical areas. As shown in Figure 1 (for simplicity only one

satellite is shown, but it can be a chain of LEO satellites), sliced satellite link capabilities can be leased to terrestrial network operators (e.g., mobile operators) in order for them to build their own service-tailored slices provided that the sliced satellite capability is able to fulfil the targeted service requirements. For instance, once a terrestrial network operator has deployed a MEC-based content prefetching/caching network function within its network slice for transmitting 4K/8K video content, then it can use leased satellite capability for backhauling 4K/8K video in that slice. From the business point of view, we can envisage a cash flow from end customers (subscribers of terrestrial network slices) to the terrestrial network operators and further to the satellite operator.

7. Semantic Routing

The current architecture for IP networking is built using a best-effort philosophy. Several techniques exist that offer better-than-best-effort delivery, but require additional hardware and software overhead. The start-point and end-point of a path are identified using IP addresses, and traffic is steered along the path that does not necessarily follow the "shortest path first" route through the network. Furthermore, the path might not run all the way from a packet's source to its destination. The assumption is that a packet reaching the end of a path is forwarded to its destination using best-effort techniques.

Semantic Routing is the process of routing packets that contain IP addresses with additional semantics, possibly using that information to perform policy-based routing or other enhanced routing functions. Thus, facilitating enhanced routing decisions based on these additional semantics and provide differentiated paths for different packet flows, distinct from simple shortest path first routing.

In a satellite network, a path might be comprised of mainly FSO links to meet latency and bandwidth requirements, or use specific ground-stations, gateways, or follow a designated orbital direction.

The process of known as Semantic Routing is discussed further in the document [9].

7.1 Applicability of Semantic Routing

Strategies for implementing and operating IP routing effectively within LEO satellite constellation networks and ISTNs, given known

constraints on the constellation, may include semantec routing [9] and addressing [10] techniques.

Typically, in an IP-based network packets are forwarded using the least-cost path to the destination IP address. Service Providers may also use techniques to modify the default forwarding behavior based on other information present in the packet and configured or programmed into the routers.

As outlined in this I-D numerous challenges exist for network control of space-based infrastructure, and addressing ISTN issues. Semantic routing facilitates path decisions based solely on the address and without the need to find and process information carried in other fields within the packets, reducing node computational power and complexity.

We will continue to discuss the applicability of semantic techniques in further detail, in future versions of this document.

8. Security Considerations

To be discussed.

9. IANA Considerations

This document makes no requests for IANA action.

10. Acknowledgements

To be discussed.

11. Contributors

To be discussed.

12. Informative References

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Authors' Addresses

Daniel King
Lancaster University
UK

Email: d.king@lancaster.ac.uk

Ning Wang
University of Surrey
UK

Email: n.wang@surrey.ac.uk