**Using ground relays for low-latency wide-area routing in mega constellations(No System and Networking Stack Realism)**

* Use ground-based relays as a substitute for ISLs to provide low-latency wide area networking
* Laser ISL link supports lower data rates than Startlink’s RF link (ISL as bottleneck)
* Low orbit combined with high slant angle regains some of the low latency properties that previously required laser ISLs
* Simulate SpaceX Starlink network
* Using Dijkstra’s algorithm to determine the lowest latency path using any of the relays
* Compared different satellite-plane topology(with ground station relay) to Internet RTT is 76ms

**Potential Downside Relay Density vs Route Stability**

* Addition relays inflate the number of links in the network graph. A link that exists from a ground station to any satellite that is within range can slow down the routing computation.
* More relays, the lowest latency route changes more frequently
* Computing routes is expensive, computing them this frequently could be a problem

**Solution**

* User terminals might be used as relays.
* A network with ISLs would perform better still, with a mean of around 43ms compared to 48ms using ground relays
* There would be a clear win for ISLs, but until that technology is ready, ground relays should be a viable solution

**Cons**

* As the topology changes constantly, most time is spent rebuilding the routing graph
* Rebuilding the routing graph and then running Dijkstra’s algorithm takes 1.55s, the mean time in this configuration between shortest path route changes is 2.5s

**Hybrid Networks**

* A direct ISL between a pair of satellites will always give lower latency than using a relay.
* It is better to conisde both ISL and grounds relays when computing low latency routes

**Delay is not an option.**

* How to use laser links to provide a network connection
* A dense LEO constellation has two main advantages over terrestrial networks. First it can connect almost anywhere, Second, the speed of light in a vacuum is 47% higher than in optical fiber.
* However, over longer distances the extra latency getting between Earth and the nearest satellite may be more than offset by routing around the world between the satellites
* Two neighbors always remain in the same locations, the next one ahead on the same orbital plane, and the one behind on that orbital plane. Only the satellites in the neighboring orbitals planes remain consistently in the range
* The network is not static; the satellite most directly overhead changes frequently, the laser links between NE and SE bound satellites change frequently
* Routing vertically upwards to a satellite then horizontally then vertically downwards takes a longer path than necessary

**Multipath**

* A LEO constellation can provide many paths between the same city pair

**Load-Dependent Routing**

* Regular Internet traffic will not get such priority treatment, so a LEO constellation operator needs to perform active traffic traffic engineering to avoid creating hotspots in the network.

**Hybrid Solution**

* High priority low-latency traffic always gets priority, admission controls limit its volume, preventing it from causing congestion and it gets explicit routing ensuring minimum latency, for the remaining traffic, satellites monitor link load; this is broadcast to all groundstations globally.
* Dense LEO constellations have very many paths available, and many of them are of similar latency.

**Internet backbones in spaces**

* Latency optimization needs to be dynamic, as the length of the satellite path segments changes as satellites move, and the GSTs chosen as source and destination may become disconnected because of weather phenomena.
* This requires a routing architecture that provides path control. And is thus able to dynamically select the end-to-end path, making informed choices about the state of the links on route.
* By contrast, the current Internet architecture gives no control on the path, aside from the choice of the next step

Path -aware-network

* PAN distribute information about the state of the network to end hosts, and enable them to make routing decision based on this information.
* In contrast to the CDN-like Deployment, in which traffic is re-routed from inactive GSTs to active ones, which incurs in additional latency.
* The main difficulty for routing was the frequency with which GSLs become available and unavailable