Routing in Time Varying Networks

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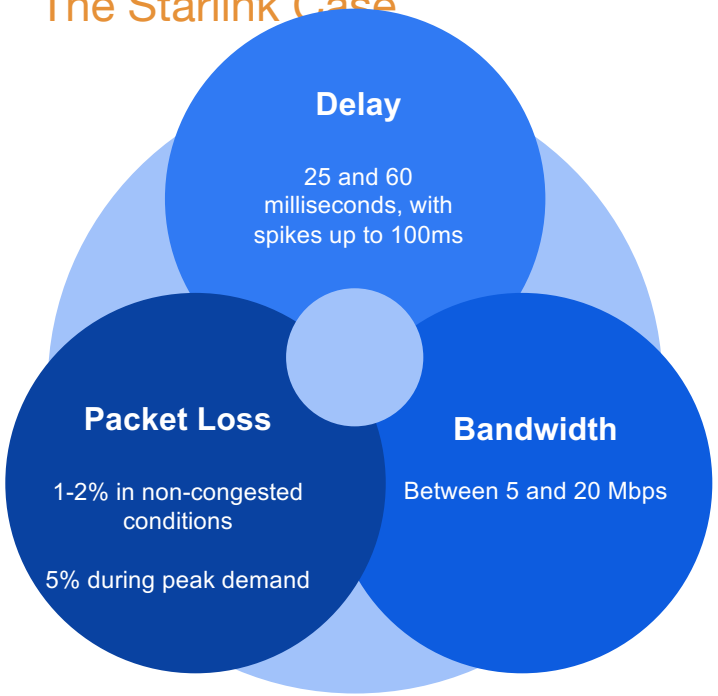
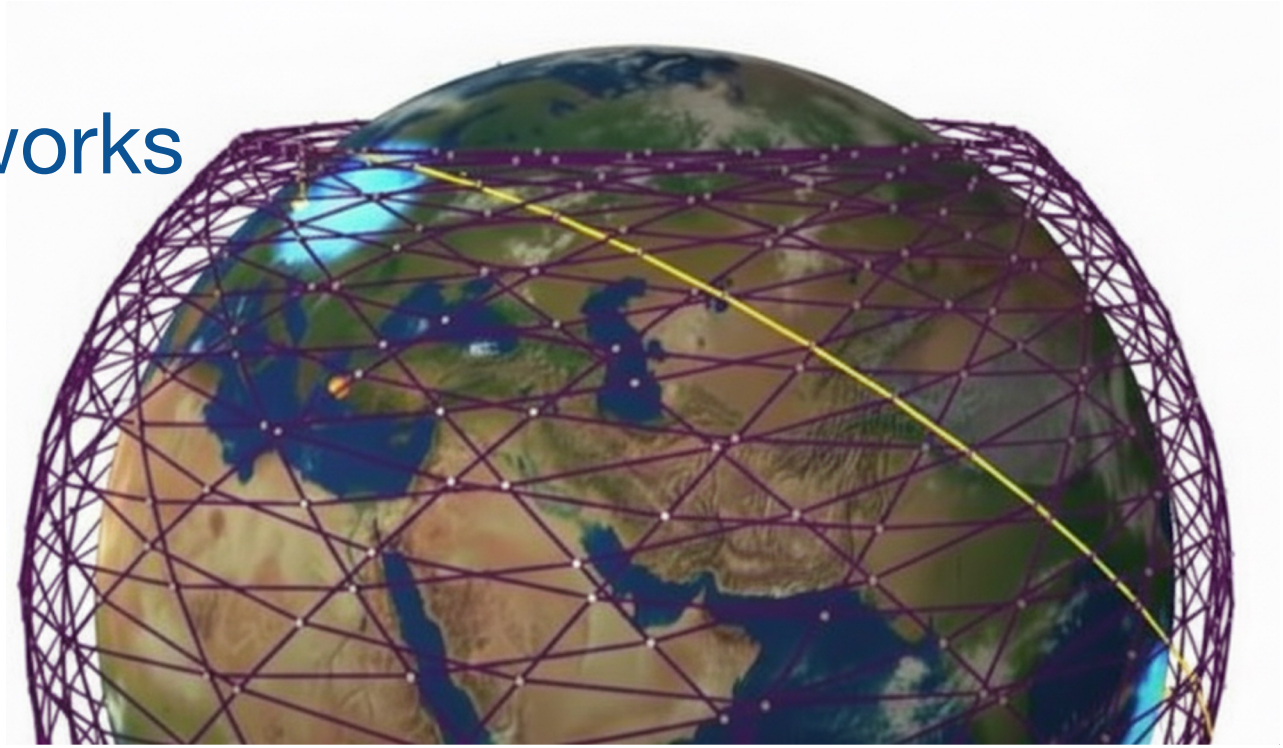
Routing in Time Varying Networks

The Starlink Case





"Postal Service" Routing

High-Level Destination

Packets are assigned a simple, high-level directional tag based on the geographic location of the destination

Autonomous Hop-by-Hop Decisions

Packets sent to the satellite closest to the destination, based on position of satellite, neighboring satellites, and tag carried in the packet

Ground Station Delivery

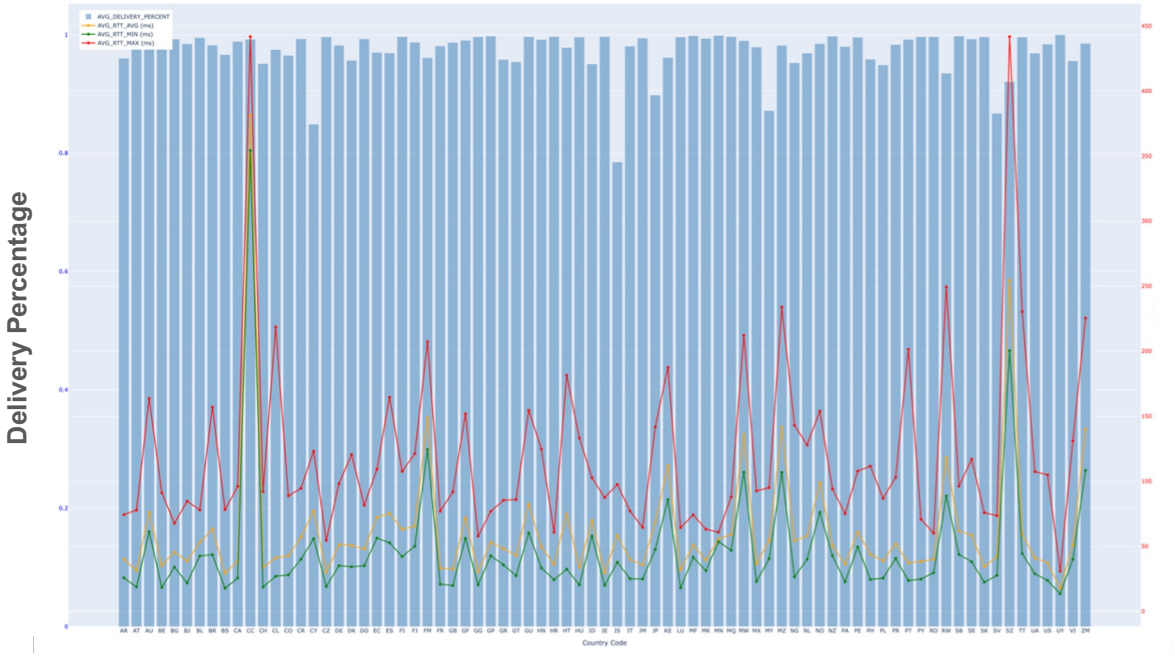
Packet forwarded until they reach a satellite that has a direct line-of-sight to a ground station near the final destination

Routing in Time Varying Networks

The Starlink Case

Cisco SD-WAN Study

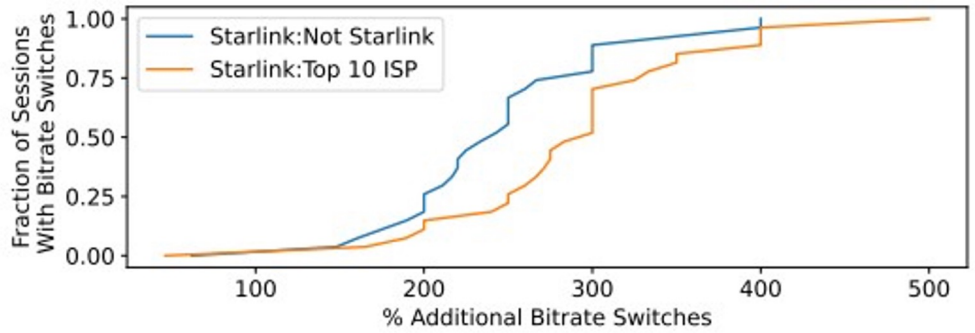
Cisco Catalyst 8300 SD-WAN edge routers: 1 Starlink dish / 1 High-speed ISP



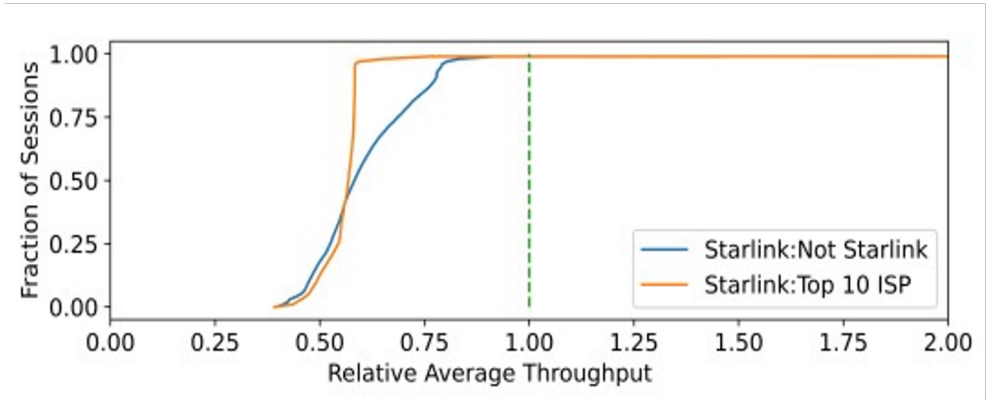
REGION	AVG_DELIVERY_PERCENT	AVG_RTT_AVG	AVG_RTT_MIN	AVG_RTT_MAX
APJC	0.955968248	106.4774047	89.1821277	164.315578
Americas	0.977540009	48.76635648	33.67220151	111.1851741
EMEA	0.974209048	61.38453892	44.1925986	117.9726406
Total	0.969239102	72.20943336	55.68230927	131.1577975

Findings: Average packet loss was 3.07%
Average latency was 72.20 ms

Netflix Video Streaming Study



50% of Starlink sessions have 2 times the number of bitrate switches than non-Starlink



Starlink throughput is nearly always 50% of what a top 10 ISP

Findings: Video streaming with marginal increase in bitrate switches and rebuffers
→ not easily fixed by simply modifying existing congestion control

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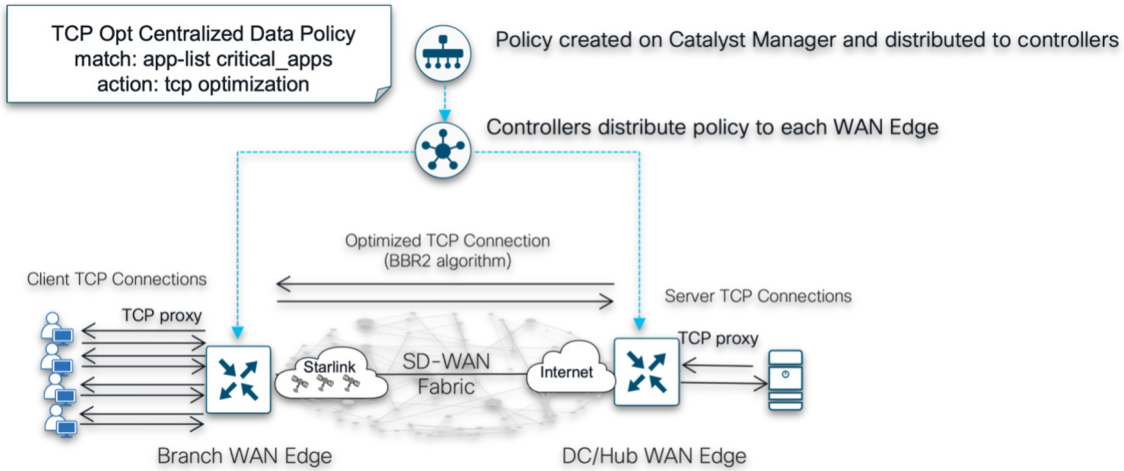
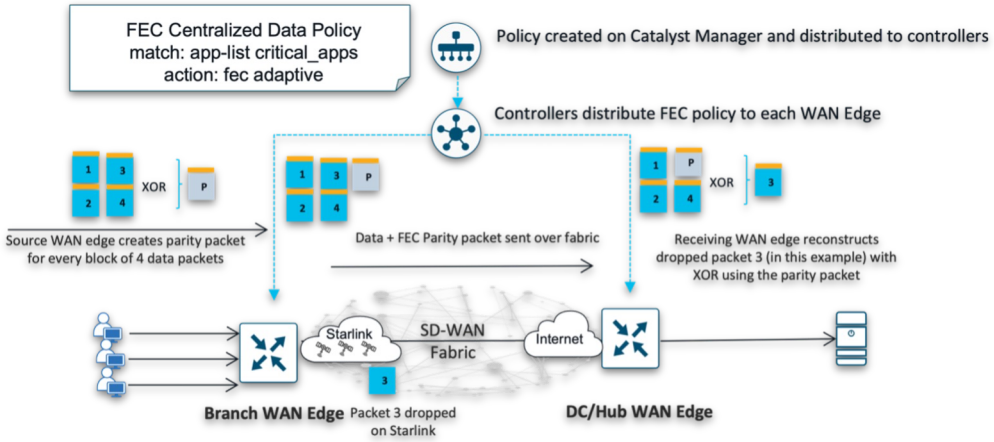
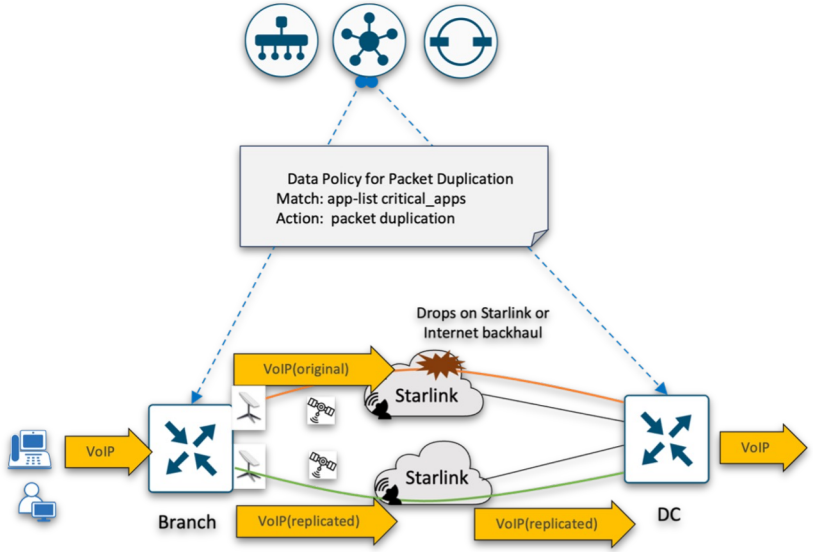
The Starlink Case

Optimization

- Alternative Congestion Control algorithms, e.g. BBR
- Alternative Forward Error Correction methods
- Multipath transport sessions
- Data redundancy elimination
- Alternative adaptive bitrate streaming algorithms
- Delay Tolerant Transport
- Alternative routing protocols



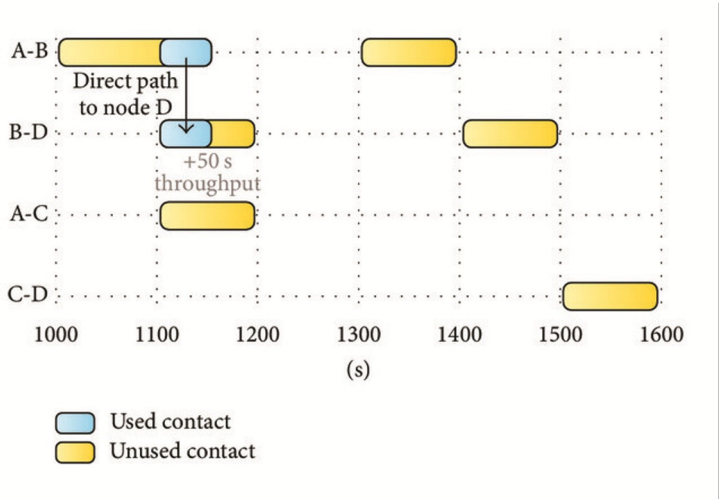




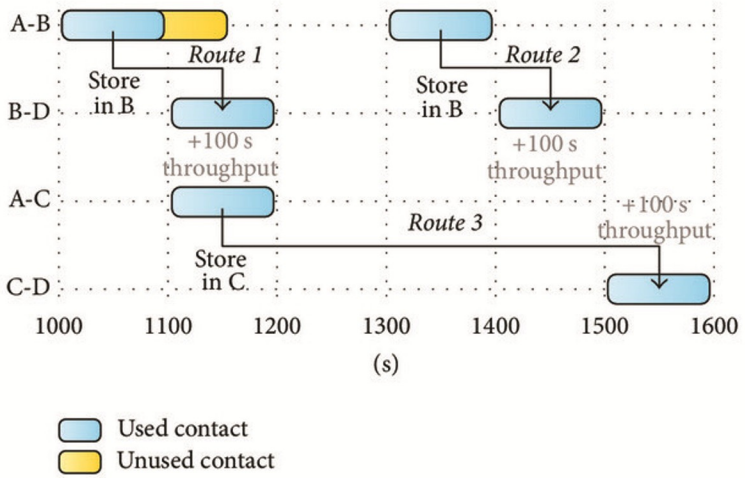
Figures courtesy of Cisco

Routing in Time Varying Networks

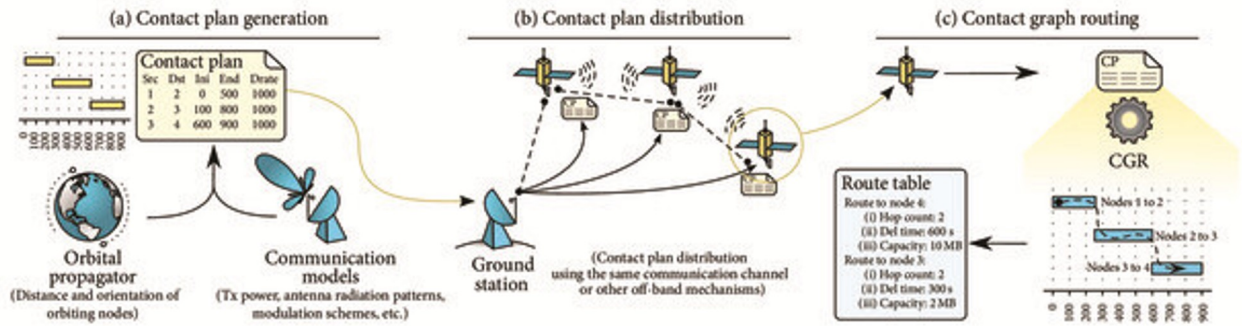
From Greedy Geographic Routing to Link-State Routing



Effective throughput with TCP



Effective throughput with DTN store-and-forward



Potential Solution - Contact Graph Routing (NASA 2011)

- Take advantage of the fact that communication operations are planned in detail
- Predicted information is used to construct contact graphs
- Graph uploaded to all satellites
- Link-state information and dijkstra algorithm is used to compute paths between any pair of satellites

J. A. Fraire et al, "Assessing Contact Graph Routing Performance and Reliability in Distributed Satellite

Routing in Time Varying Networks

From Greedy Geographic Routing to Link-State Routing

Main Issues about using link-state information on LEO constellations

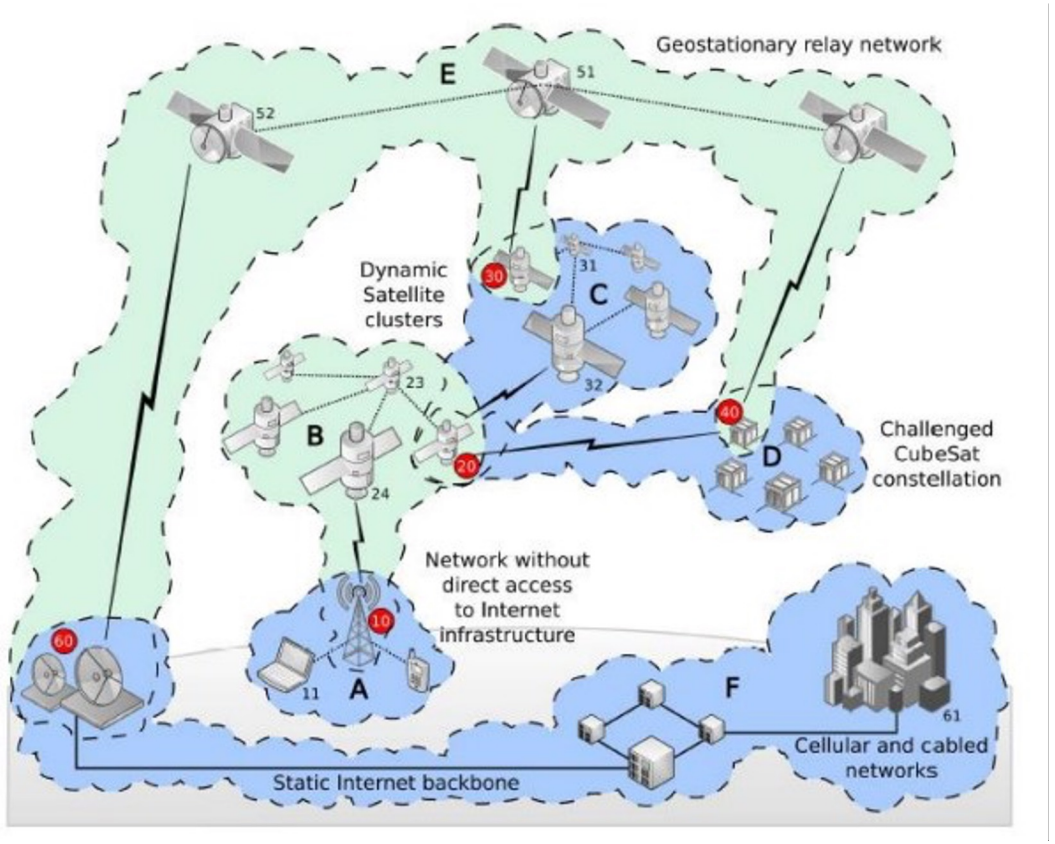
- Need knowledge of all current and future connections.
- low in large networks

Alternative Solution

- Divide the network into subnetworks (clusters)
- Reduce computation overhead

Challenges

- What is the best intra-cluster and inter-cluster routing approach?
- What is the best clustering algorithms?



Yael Kirkpatrick et al, "Cooperative Clustering Techniques Applied to Contact Graph Routing", Space-Terrestrial

Routing in Time Varying Networks

Intra-cluster and inter-cluster routing approaches

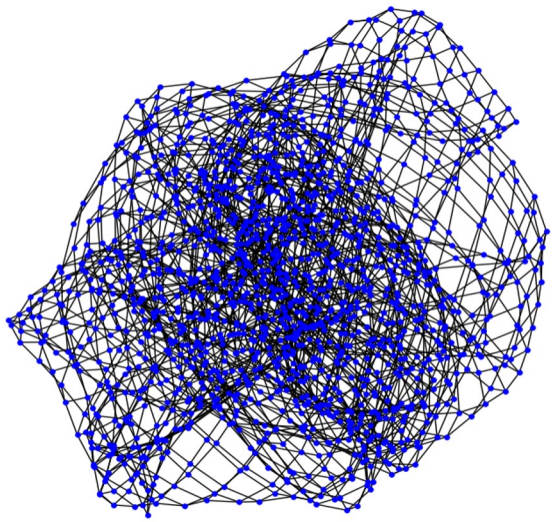
Analysis of link-state and distance-vector routing in clustered and non-clustered LEO constellations

- Evaluate the time required to compute one route (fix S-D)

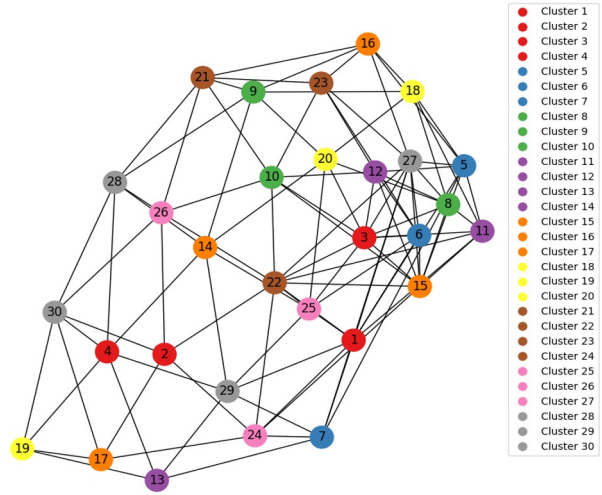
Routing algorithms

- Dijkstra algorithm
  - Widely applicable
  - Efficiency in finding shortest paths
  - Base for protocols such as OSPF

- Bellman-Ford algorithm
  - Ability to handle dynamic topologies
  - Robust in environments characterized by frequent changes and varying link states



Non-clustered network



Clustered network

LEO constellation with up to 1600 satellites
Routing, SDN Style

Juliano Silva, Paulo Mendes, Edison Freitas, "Resilient Software Defined Satellite Networks: Combining

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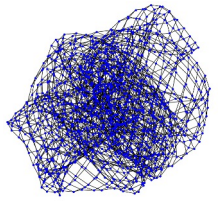
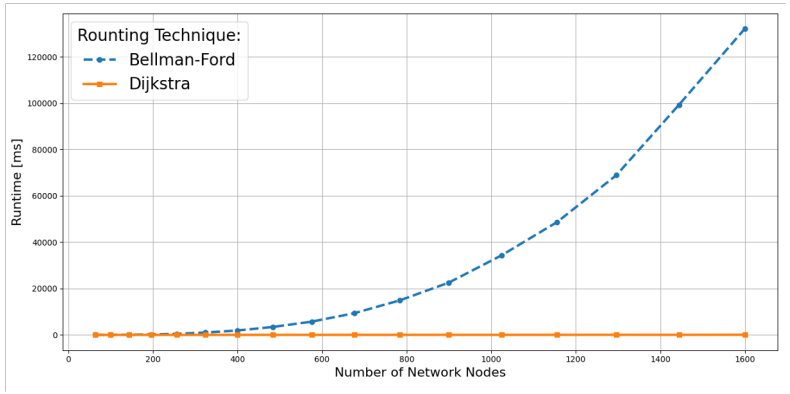
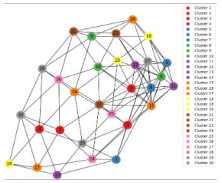
Intra-cluster and inter-cluster routing approaches



Network without Clusters

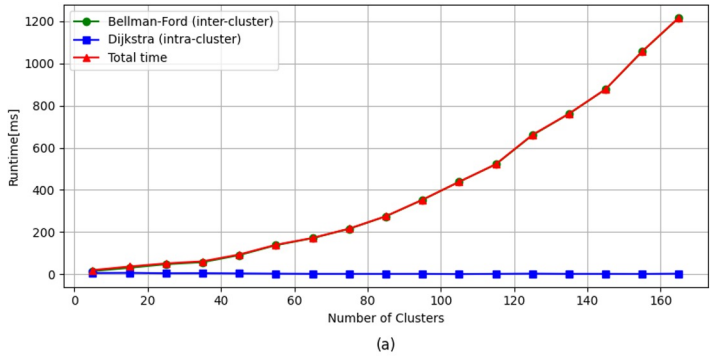


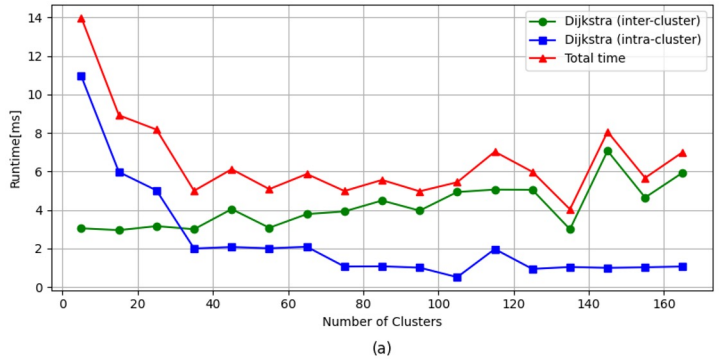
- 1600 satellites
  - Dijkstra algorithm: ~ 61 ms
  - Bellman-Ford: ~132.14786 s

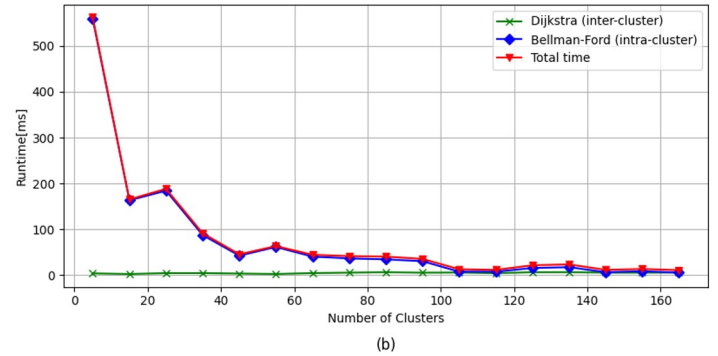


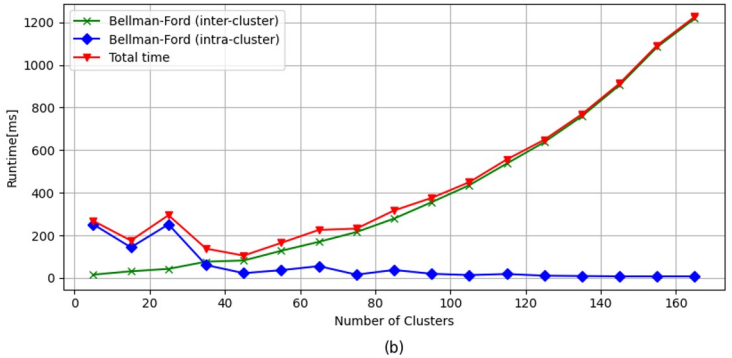
Clustered Network

Algorithm: Spectral clustering







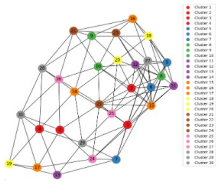


- Dijkstra consistently: total execution time of less than 15 ms, regardless of the number of clusters
- Bellman-Ford present a total execution time that can surpass 1,200 ms (with 165 clusters)

Juliano Silva, Paulo Mendes, Edison Freitas, "Resilient Software Defined Satellite Networks: Combining Clustering Techniques with Efficient Routing Protocols"

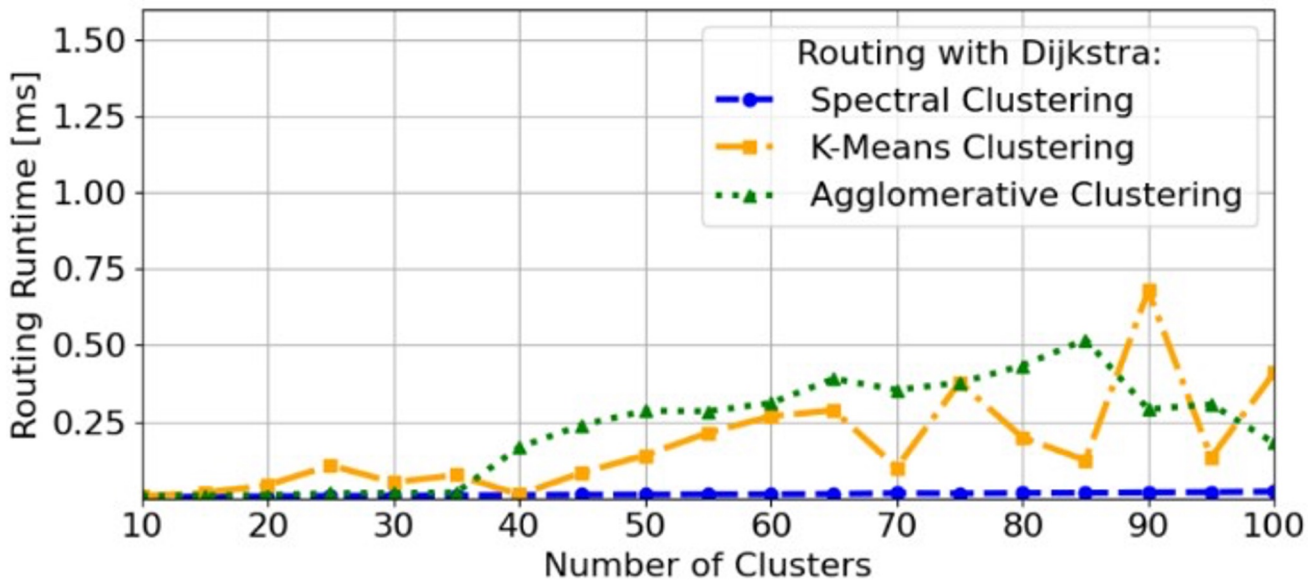
Routing in Time Varying Networks

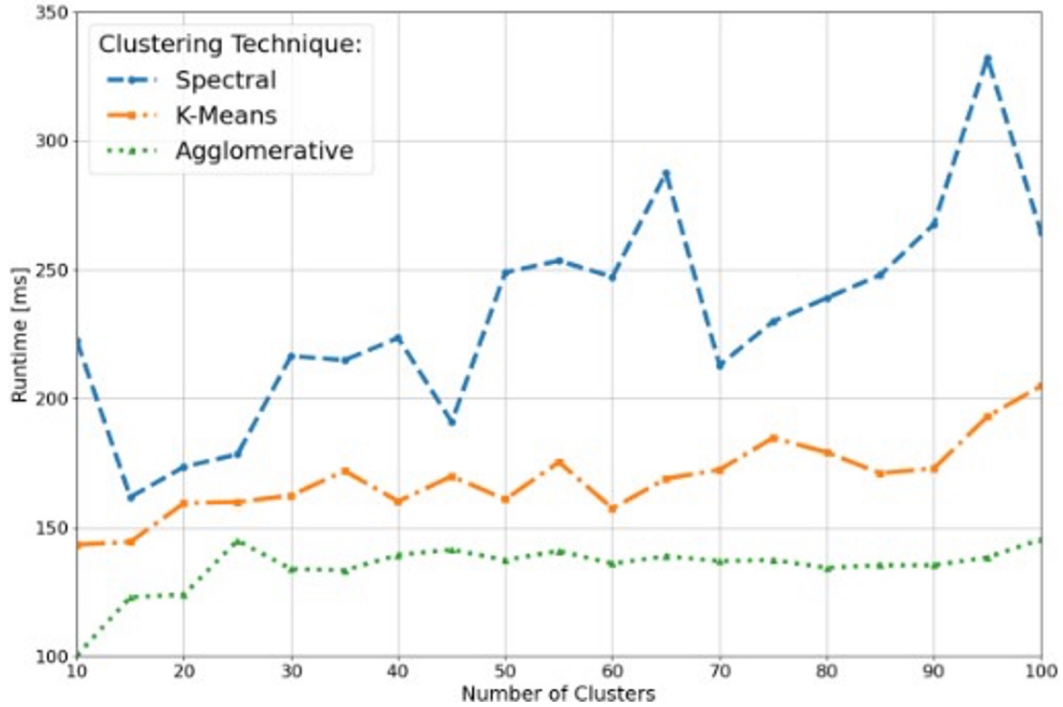
Impact of Clustering Algorithms



Clustered Network

Algorithms: Spectral clustering, K-Means, Agglomerative





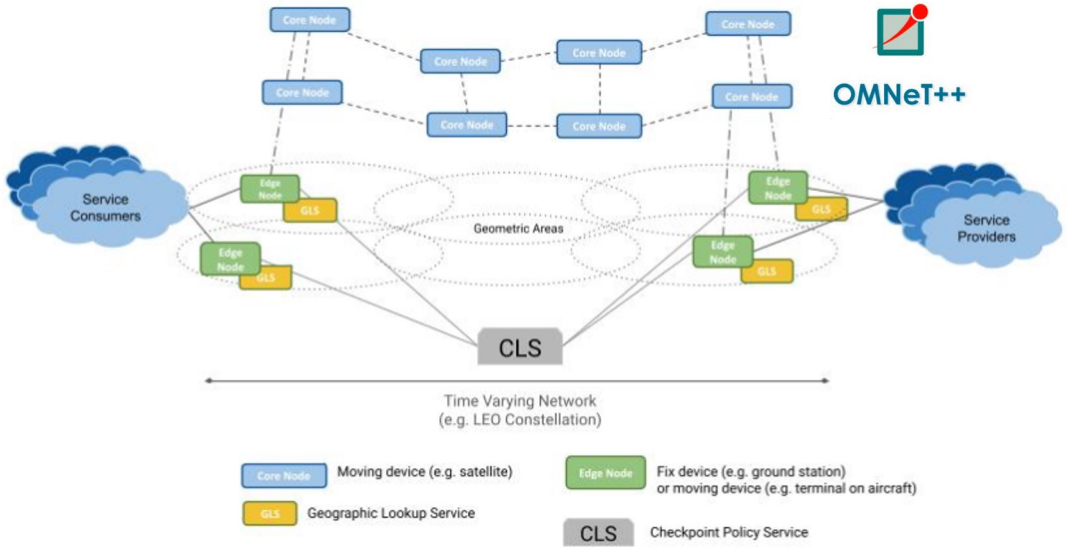
Juliano Silva, Paulo Mendes, Edison Freitas, "Evaluating Clustering on Routing Efficiency in HAPS Networks Supporting LEO Constellations", under submission

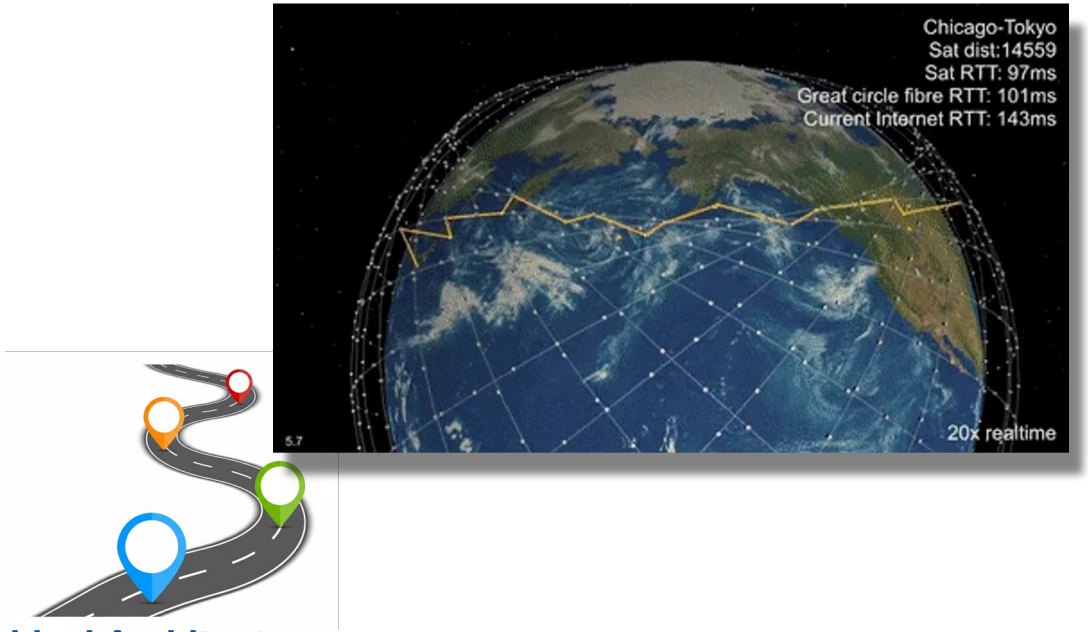
Routing in Time Varying Networks

Somewhere in the Middle - Handling Geographic Segments

Geographic Checkpoint Routing

- Semantics: geolocation, service name, congestion thresholds
- Segments based on geographic checkpoints:
  - Able to pass through or avoid specific areas
  - Able to avoid congested network areas
- Easy integration of satellite and terrestrial networks
- Increase robustness by limiting impact of topological changes





Hierarchical Architecture

- **Edge Nodes**: Handle communication at the domain boundary, interfacing with External Nodes. (E.g., Ground Stations and terminals)
- **Core Nodes**: Manage data forwarding and network connectivity within the domain. (E.g. Satellites)
- **Geographic Lookup Service** (GLS): Provides Ingress Nodes with geographical locations of Egress Nodes for a given service address.
- **Checkpoint Policy Service** (CPS): Provides Edge Nodes an interface to compute Checkpoint Policies for outbound packets

Valentin Hartig, Marcin Bosk, Paulo Mendes, Nitinder Mohan, "Segment Routing based on Geographic

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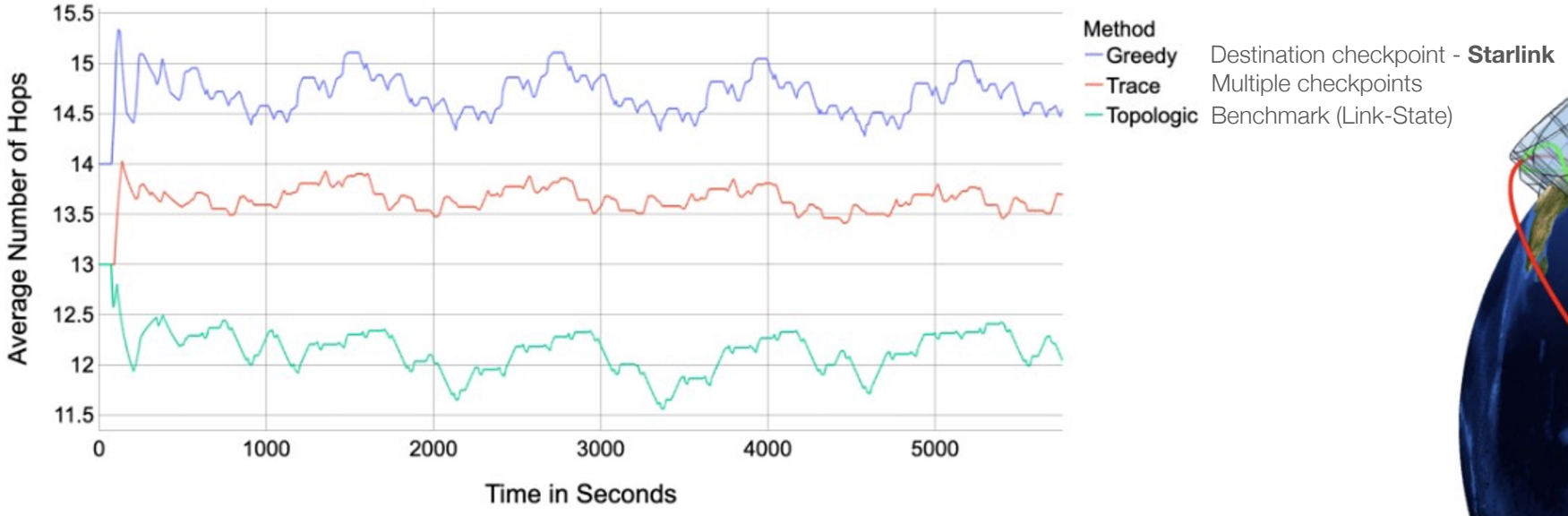
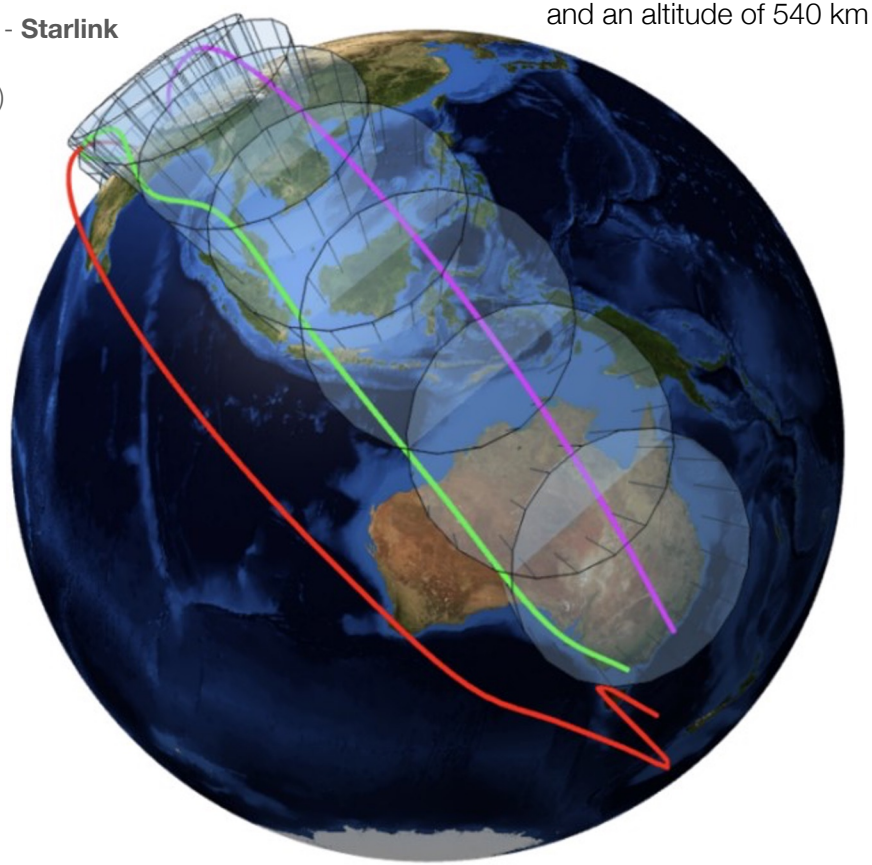
Geographic Checkpoint Routing



Destination checkpoint - **Starlink**
Multiple checkpoints
Benchmark (Link-State)

Routing Policy	Propagation Delay (ms)	Processing Delay (ms)	RTT (ms)
Topologic	61.616	12.85	148.932
Greedy	78.195	14.23	184.85
Trace	62.77	12.60	150.74

Second orbital shell of Starlink, consisting of 72 orbital planes, each with 22 satellites, at an inclination of 53.2° and an altitude of 540 km



Route calculated by Topologic (purple), Greedy (red) and Trace (green) from Germany to Australia

Thank You

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> "The future of networking lies in the seamless integration of terrestrial and satellite systems, enabled by intelligent routing protocols that adapt to the dynamic nature of space-based communications."