Joint Controller Placement and Assignment in SDN-based LEO Satellite Networks

**Abstract**

Low earth orbit (LEO) satellite networks are highly dynamic and resource limited, thus it is much more challenging to construct an efficient SDN control plane inside the LEO satellite constellation. More specifically, this is to dynamically determine which satellite works as the controller and which controller is assigned to which satellite at each time considering the time-varying network topology, resource constraints, system cost, and management effectiveness. It is also one of most critical problem in SDN-based networks for its results fundamentally influence the network performance. A flawed placement or assignment strategy will lead to long and fluctuate response time, eventually resulting in service quality degradation. Here we adopt a convex domain-based three-layer architecture and then formulate and solve the general joint controller placement and assignment problem. The processing capacity requirements are significantly reduced while the convex domain ensures network performance. A validation testbed and experimental results are presented to demonstrate the scalability and performance improvements. In addition, our approach provides a general framework for control plane modeling and construction.

1. The Software Defined Satellite Networks (SDSNs) have become a research hot spot recent years because of its advantages including flexible and fine-grained traffic scheduling, saving energy in the system level and better integration with terrestrial networks. Since data are transmitted according to the flow table produced by controllers, long response time fundamentally limits the SDSN's ability to quickly react to events and may cause transient congestion to last for a long time. Therefore, the controller placement and the assignment significantly influence the performance of SDSNs. Conceptually, the former is to decide the number and locations of controllers and the latter is to decide which nodes are managed by each controller.
2. The dynamics of satellite networks, caused by dynamic topology and time-varying workload, is one of the new core challenges for controller placement and assignment. The length of the inter-plane Inter-Satellite Link (ISL) changes all the time and it will break down when crossing polar regions. Without considering such heterogeneity and using a similar methodology as terrestrial SDN networks will greatly limit the capability and scalability of the network.
3. Another challenge is that the traffic load of a satellite is highly dynamic. The traffic load of a satellite is strictly related to the human activity, thus, it changes dynamically when flying over different areas and time zones. To keep a responsive control plane, the placement and assignment strategies have to be considered jointly and dynamically.
4. Considering the limited satellite resources and long propagation delay of SDSNs, we in this paper adopt the hierarchical SDN architecture because of its great scalability for large-scale networks and its compliance with resource distribution characteristics among terrestrial nodes and satellites. We place domain controllers inside the LEO satellite constellation to achieve short and stable response time while we place root controllers on the ground because of its high resource requirements.
5. To find the optimal controller placement and assignment strategies, we investigate the following two key problems under such architecture. 1) How to model the impact of controller placement and assignment strategy on network performance, what is cost and what is gain? And 2) how to solve the problem in such highly dynamic networks adaptive to satellite mobility and dynamic workload, how to ensure the algorithm's performance with only limited future knowledge?
6. For the first problem, most related work focused on the controller placement and assignment in flat SDN architecture, the overhead models of which are inapplicable to ours. Meanwhile, the influencing factors discussed in existing work, including the transmission overhead, delay, and load balancing, cannot fully reflect the quality of the placement and assignment. Since domain controllers only perform intra-domain routing calculation with partial network information, the way that network is partitioned has a great impact on their capability. How to model such an impact has never been addressed.
7. For the second problem, most previous work targets at topology-stable networks. Controllers are placed at fixed locations cannot cope with the dynamic satellite environment. Although PAPA investigated controller placement in satellite networks. It directly applied a similar method per time slot, leading to frequent switch migration, causing network instability and high migration overhead.
8. Aiming at the first problem, we model different kinds of control overheads and quantify the parameters through proof-of-concept experiments. We next use `modularity', is shown to be one of the most important properties of real-world networked systems, to quantify the quality of domain division. To achieve low control overhead and high modularity, we propose two regularization-based online algorithms. Main contributions are listed as follows.
9. Targeting at the second problem, we