Increasing the efficiency of next-generation space operations by exploiting predictability

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Abstract—**Spacecraft networks are characterized by the predictability of node movement and communication opportunities. In this paper, we extend our previously proposed Predictable Link-State Routing (PLSR) protocol to solve routing and Quality-of-Service problems in these networks and thereby increase the efficiency of next-generation space mission operations. We validate our claims through realistic network simulations in the context of a communication infrastructure for a next-generation Mars mission.**

Motivation and Previous Work: Spacecraft networks and inter-spacecraft communication are topics of growing importance within space agencies and industry. Emerging application areas such as Earth orbit constellations and Moon/Mars mission support require an efficient-, and interconnected communication environment in space. As a result, multi-purpose space network concepts are under development by space agencies. From a network protocol R&D perspective, such networks constitute a subclass of mobile, heterogeneous networks that is characterized by the predictability of node movement and communication opportunities.

In our previous work, we have proposed and formalized a topology model and routing protocol for predictable mobile networks. The topology model decomposes a dynamic predictable mobile topology into a series of static topology snapshots that abstract the topology and its evolution over time. Our routing protocol, called the Predictable Link-State Routing (PLSR) protocol [1], utilizes the snapshots to build routing tables. These tables are constructed with minimal communication, necessary only in the event of rare unpredictable changes. We validated PLSR's performance in a generic, random mobility setting against state-of-the-art mobile routing protocols. Following this, we also validated the protocol in a LEO/GEO spacecraft hybrid network scenario and a simple Mars rover communication scenario.

Contribution: Our contribution is to provide and evaluate additional possibilities to use the PLSR protocol to provide Quality-of-Service. One of the challenges in spacecraft networks is the possible presence of temporal network separation which requires the deployment of a Delay Tolerant Network (DTN) [2]. We extend PLSR to support the DTN routing protocol with snapshot information that would allow routing in the presence of predictable changes also for data store-wait-and-forward operations. By achieving this, we can guarantee error-free routing and also consider the DTN node buffer load as an additional routing metric for PLSR. This mechanism can support load-balancing between the available DTN buffers in various nodes that occupy alternate routing paths. We further show that physical layer mechanisms (such as mechanical antenna pointing or alignment of optical connections) can also benefit from PLSR. Finally, we propose to use PLSR to support energy-budget management for energy-constrained entities such as Mars rovers. Currently, the daily energy-budget of a rover is planned beforehand by the mission operations team based on the limited environmental information that is available at this time. The rover therefore cannot react dynamically to fluctuations in the power supply caused by sandstorms and other phenomena. Adding energy-related information to snapshots makes it feasible for the rover to react and account for such unpredictable changes in the energy budget state. Therefore, with PLSR, a rover can use its available energy reserves more efficient than with manual commanding.

Evaluation Methodology and Results: We evaluate the above extensions through simulation in a next-generation Mars mission scenario. In this scenario, we consider a total of 25 heterogeneous nodes, including spacecrafts and robotic ground assets. The dynamic topology model is constructed using the state-of-the-art commercial Satellite Tool Kit (STK). Subsequently, we use our own topology generator to generate the topology snapshots from the flight dynamics data that is generated by our STK scenario. We use the widely recognized ns-2 network simulator to compare PLSR, and our extensions in particular, to traditional link-state routing and manual commanding. We measure routing overhead production and traffic throughput. Our results indicate that, when compared to the simpler scenarios of our previous work, the usage of PLSR allows more efficient and correct routing of the growing payload telemetry that is generated by the large and also growing number of robotic explorers at Mars. Further, our measurements confirm that the proposed extensions of PLSR do only cause little additional overhead but significantly improve the routing and communication performance of the network.

References

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