Maximizing throughput in interplanetary networks

Abstract

Interplanetary Network (IPN) or Deep Space Network (DSN) provides communication between stations on Earth and other remote Spacecrafts, Satellites, Orbiters, Lander and Rovers. Interplanetary communication is different from our terrestrial communication because it poses some specific characteristics like long propagation delay, intermittent connectivity, asymmetric bandwidth, etc. In future, many more spacecraft, landers, rovers and relay orbiters will be launched in deep space and therefore, deep space network has to undergo many changes as traffic load and type of communication. Deep space data transmission, therefore, will not be a pre-scheduled time/bandwidth specific communication as it exists now. Multiple deep space nodes may transmit huge amount of data to the Earth station (destination) using limited bandwidth and multiple hops. Therefore, we must critically examine whether the limited and precious bandwidth of the network is being put to the best possible use.

In our first work, we have formulated the problem of maximizing the throughput through deep space network and then with a naive approach, we have shown that computing the optimal flow through deep space network is super-exponential in nature. Therefore, we have fallen back to the existing heuristic. It is found in the literature that Contact Graph Routing (CGR) has been specifically designed for routing the data through the deep space network. We have enhanced the performance of existing CGR by incorporating some new techniques and have proposed two variants of exiting heuristic, i.e., CGR-BF and CGR-SPI.

In order to get an estimate about the quality of the solution we get from CGR and its variants, in our second work, we have compared the results of CGR with those from a hypothetical algorithm. After realizing a significant gap between the performances, we have developed an interplanetary testbed to evaluate and identify the issues that constraints the performance of CGR in a future deep space environment where multiple sources generate data simultaneously. It is observed that the performance of CGR degrades due to inefficient distribution of network bandwidth among the sources that lead to issues like long queues of data in intermediate nodes, inappropriate route selections etc.

Upon realizing the problems mentioned above in our third work, we have developed a new formulation of the problem of maximizing the flow considering the predictability (of topology and contacts) of the future deep space network. In this work, we derive a number of pruning techniques to reduce the search space of the complex augmented deep space networks. We show that applying pruning techniques reduce the deep space networks into trivial cases where optimal flow (and corresponding routing) is easily derived. However, it is also found that it is not always possible to completely reduce a network to a trivial one.

In our next work, we have derived optimal algorithms for small pruned networks (OASN) and a new heuristic to find a good solution for the large pruned network (HALN). We have simulated the corresponding routing of our proposed algorithms by varying the network topologies and the traffic generation rates of the sources. We have given a comparative simulation study and analysis between the performance of our proposed techniques and the standard CGR.

Finally, in the last work, we have done node/region-wise analysis of performance and based on this analysis, we have developed heuristics based on priority and fairness between the nodes.