Regional clustering for deep space communication

1 Background

Delay-Tolerant Networking (DTN) allows the nodes to operate in a **store-carry-forward** strategy to address the arbitrarily long delays caused by the interplanetary ranges and the arbitrarily long disruptions due to orbital trajectories and planet rotations. Those disruptions are however **highly predictable**, allowing the operators to create a so-called "**contact plan**" listing the future time interval of connectivity, called **contacts**, between any pair of nodes. Contact planning can be, in a first step, very unrealistic, by adding an entry to a contact plan as long as the two nodes are in sight. In a second step, **hardware constraints** shall be taken into account, like the **antenna orientation**, and the inability to communicate with two peers simultaneously, to refine the "greedy" contact plan into a realistic one.

The resulting contact plan is however optimized as if all the nodes were part of a single autonomous system, called a **region**. For a sake of scalability, the Inter-regional support would allow each region to receive a contact plan encompassing only the regional members. Some regional members might be part of 2 regions, so 2 contact plans, and act as **gateways**.

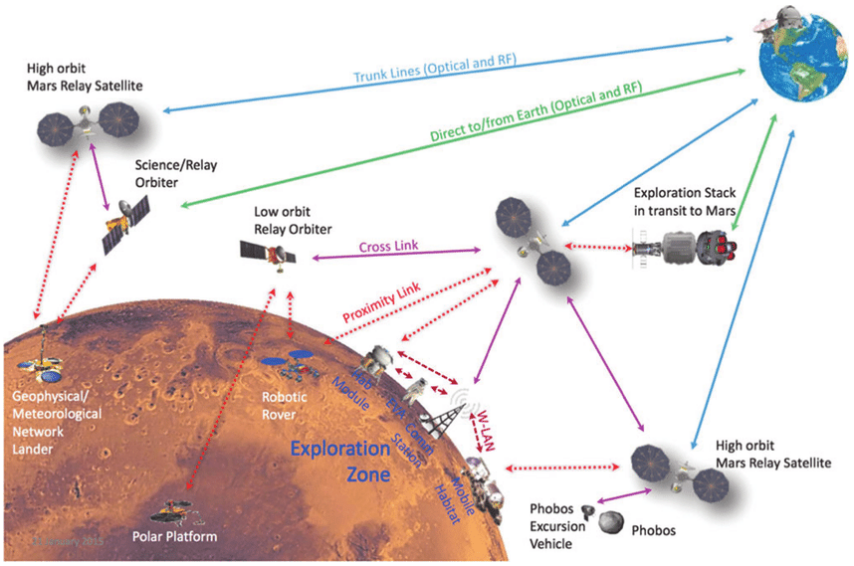

Figure 1: NASA/SCaN's Next Generation Mars telecommunication architecture to enable long-term human exploration. Source: Reinhart et al. (2017).

2 Objective

The goal of this internship is to develop an optimization model allowing to "split" this "greedy" contact plan to create a realistic one that also **assign the nodes to regions** to reach an optimal regional structure. Optimality goals can take various constraints into account on the inter-regional level, e.g. minimizing the interregional delays and hop counts, maximizing the interregional throughput, etc. The connectivity performance between the region members must be maintained (e.g. throughput, delays).

The above scheme naturally leads to **bi-level optimization** problems, where the leader wishes to decide the nodes' topology and partition. At the same time, the followers model the data routing in the resulting network. We shall seek to handle this bi-level exactly or approximately, for instance, relying on the single-level KKT reformulation.

3 Required skills

Mathematical programming, coding. While the developments shall be made in julia, it is similar to python and easy to learn, so previous experience is not necessary.

4 Some references

- **On inter-regional routing:** Madoery, P. G., Fraire, J. A., Raverta, F. D., Finochietto, J. M., & Burleigh, S. C. (2018, December). Managing routing scalability in space DTNs. In 2018 6th IEEE International Conference on Wireless for Space and Extreme Environments (WiSEE) (pp. 177-182). IEEE.
- **On passageway definition:** De Jonckère, O., & Fraire, J. A. (2023, September). Inter-regional routing in interplanetary networks with shortcuts and contact passageways. In 2023 IEEE International Conference on Wireless for Space and Extreme Environments (WiSEE) (pp. 87-92). IEEE.
- **On bi-level optimization:** Beck, Y., & Schmidt, M. (2021). A gentle and incomplete introduction to bilevel optimization.

5 Contact

The internship will take place at the LIRMM in Montpellier and will be co-supervised by Michaël Poss and Olivier De Jonckère. Interested students should send an e-mail including their CV and recent marks to :

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