Architecture of a Resilient Network in a Swarm of Nanosatellites

Evelyne Akopyan[1], Riadh Dhaou[2], Emmanuel Lochin[3], Jacques Sombrin[1]

[1]TéSA, F-31500 Toulouse, France
[2]INP Toulouse, F-31400 Toulouse, France
[3] ENAC, Université de Toulouse, F-31400 Toulouse, France

Context of the PhD thesis

Swarms of nanosatellites offer new opportunities to study the outer space, and many scientific projects use these swarms for interferometry measurements, radar testing, etc. [1] The **NOIRE** (*Nanosatellites pour un Observatoire Interférométrique Radio dans l'Espace*) study, supported by CNES [2], assesses the feasibility of a swarm of nanosatellites in lunar orbit as a low frequency radio observatory. However, such swarm comes with very specific network characteristics and constraints:

- Ad hoc network: no infrastructure provided within the swarm
- High mobility of the nanosatellites
- Sparse intermittently connected network: opportunistic routing required
- Limited embedded energy and computing power

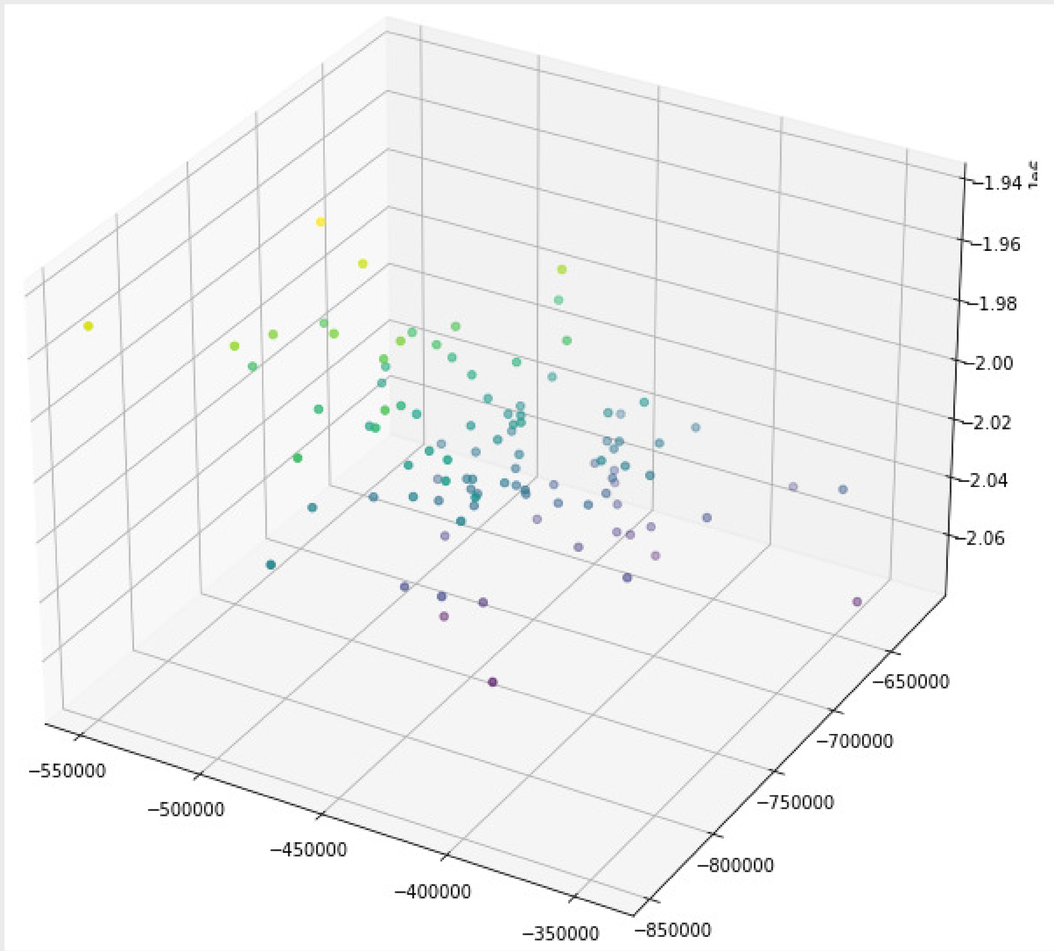

Figure 1: Nanosatellites in space

Objectives

- Define a network architecture capable of **self-configurating** into space (positioning, data sharing within the swarm, etc.) with minimum intervention from the base station
- Implement a routing protocol that complies with the **connectivity-changing nature** of the swarm while minimizing delay and packet loss
- Optimize the **energy management** on board

State of the Art

The first step is to determine the characteristics of the nanosatellite network by computing different **metrics**:

- **Graph theory** approach [3]: degree of the nodes, betweeness, etc. These metrics indicate the most suited type of routing protocols (in our case, Delay Tolerant Network routing)
- Analysis of the **inter-contact time** [3][4] to understand the overall topology of the network and establish an opportunistic routing scheme
- Extended neighbor discovery by defining the **k-vicinity** of each node [5] to optimize data routing

The network characteristics derived from these metrics define the rules for an efficient and optimized routing. In the case of a swarm of nanosatellites, the most interesting routing protocols are based on **hybrid approaches** [6] and **swarm intelligence** [7].

First analysis results

Hypothesis: two nodes are connected if they are within each other's **connection range**. We set 3 different connection ranges representing each of these 3 **states**:

- Sparse intermittent connection (20 km)
- Stable connection (40 km)
- Strong connection (60 km)

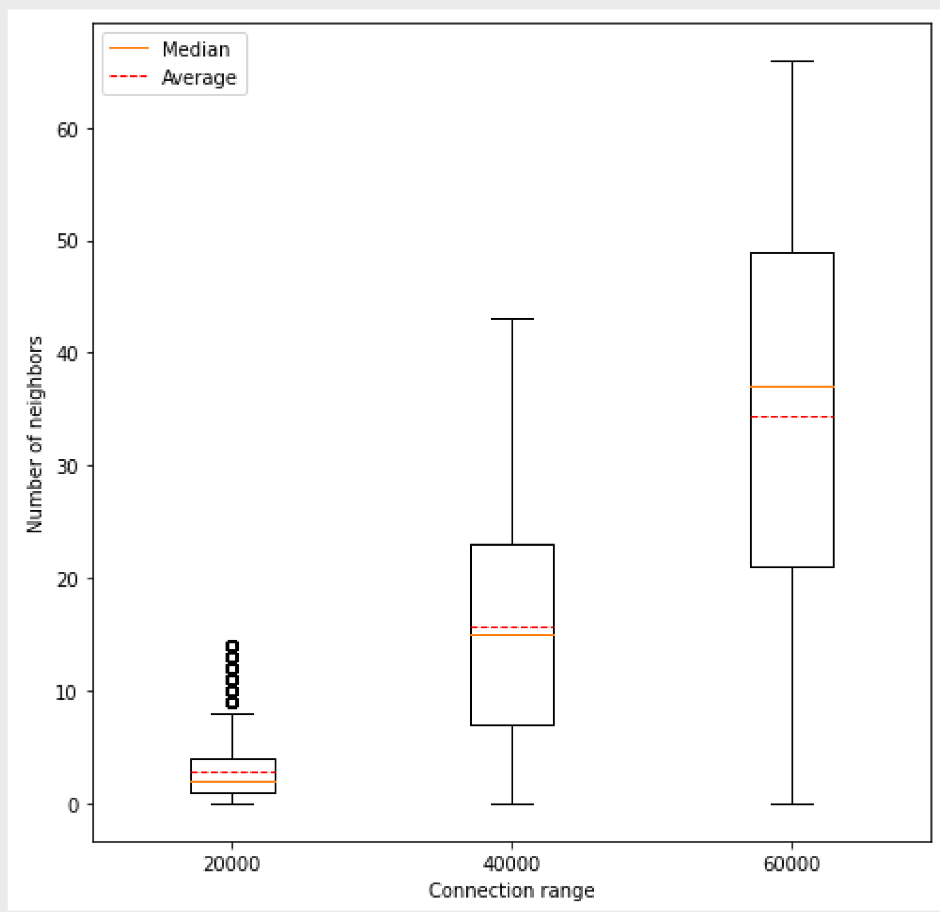

Figure 2: Distribution of the degree of the nodes for each state

References

[1] Budianu, A., Meijerink, A., Bentum, M. J. (2015). Swarm-to-Earth communication in OLFAR. Acta astronautica, 107, 14-19.

[2] Cecconi, B., Dekkali, M., Briand, C., Segret, B., Girard, J. N., Laurens, A., ... Bentum, M. (2018, March). NOIRE study report: towards a low frequency radio interferometer in space. In 2018 IEEE Aerospace Conference (pp. 1-19). IEEE.

[3] Diana, R. (2012). Le routage dans les réseaux DTN: du cas pratique des réseaux satellitaires quasi-déterministes à la modélisation théorique (Doctoral dissertation, Toulouse, ISAE).

[4] Conan, V., Leguay, J., Friedman, T. (2007). Characterizing pairwise inter-contact patterns in delay tolerant networks. Autonomics, 7, 19.

[5] Phe-Neau, T., De Amorim, M. D., Conan, V. (2013, April). The strength of vicinity annexation in opportunistic networking. In 2013 Proceedings IEEE INFOCOM (pp. 3369-3374). IEEE.

[6] Whitbeck, J., Conan, V. (2010). HYMAD: Hybrid DTN-MANET routing for dense and highly dynamic wireless networks. Computer communications, 33(13), 1483-1492.

[7] Di Caro, G., Ducatelle, F., Gambardella, L. M. (2005, June). Swarm intelligence for routing in mobile ad hoc networks. In Proceedings 2005 IEEE Swarm Intelligence Symposium, 2005. SIS 2005. (pp. 76-83). IEEE.