Introduction to the Special Section on Advances in Federated and Fractionated Satellite Systems

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THIS Special Section of the *Journal on Spacecraft and Rockets* was created based on the *5th International Workshop on Federated and Fractionated Satellite Systems* (FSS Workshop) that has taken place in at ISAE SUPAERO, Toulouse, France, on 2 and 3 November 2017. The Fifth edition of the Workshop came after four events that had previously taken place at MIT (Boston) in 2012, at the Skolkovo Institute of Science and Technology (Moscow) in 2014, at Cornell University (Ithaca) in 2015, and at La Sapienza University (Rome) in 2016. The workshop aimed at forging links to create a multidisciplinary and international research and industrial community that will follow novel approaches to innovate the way in which spacecraft missions are conceived, designed, implemented, and operated.

During the two day workshop in Toulouse, a keynote address was delivered by Grazia Vittadini, at that time Head of Engineering at Airbus Defence and Space, and a keynote address was delivered by Giancarlo Filippazzo, Copernicus Programme Coordinator of the European Space Agency (ESA). In addition, 10 scientific contributions were made by a variety of contributors from all over the world. For this Special Section, 4 of those contributions have been further developed into full journal papers, that have then been reviewed and handled according to AIAA's *Journal of Spacecraft and Rockets (JSR)* standards.

Federated Satellite Systems (FSS) is a new concept in space systems design aiming at creating a commercial cloud computing environment enabling sharing and trading of in space resources between spacecraft. FSS is an instance of distributed satellite systems; DSS encompass concepts such as fractionated spacecraft, satellite constellations, and other systems architectures looking at distributing decision making, functionality and ownership across multiple flying units. Federated satellites exchange resources such as link capacity, downlink capacity, processing capability and storage capacity. This exchange improves the efficiency utilization of spacecraft resources and makes use of unallocated resource margins of participating missions. The research community started to explore benefits and costs of a federated approach to spacecraft design, and several research avenues have just started opening in this field.

From a commercial perspective, the federated satellite systems concept allows the creation of new markets of in space resources, among other benefits in spacecraft cost, performance, and reliability. The commercial viability of federated satellite system concepts started to emerge in 2017 2018, when we started seeing important investments in space startups developing distributed systems for commercial data relay and cloud data storage, implementing some of the ideas that were originally envisioned in the federated satellite system paradigm. It seems clear that the time is ripe for the exploitation of federative concepts in space. To do so, several technical questions on space systems design and architecture, connectivity, and related research areas need to be solved. This special section addresses some of the abovementioned technical issues, looking at both technology and system layers of federated systems in space.

The first paper, "*Architectural optimization results for a network of Earth observing satellite nodes*" by Carles Araguz et al., describes part of the results of the ONION project, a European research project devoted to study distributed satellite systems and their architecting characteristics. The paper in particular addresses the challenge of designing novel space systems. Very strict requirements, combined with the consolidation of small satellite platforms and novel distributed architecture approaches, are stressing the need to study the design of new, heterogeneous and heavily networked satellite systems that can potentially replace or complement traditional space assets. This paper presents a design oriented framework that allows selecting optimal architectures for a given user needs.

The second paper, "*Cluster keeping Algorithms for the Satellite Swarm Sensor Network Project*" by Eviatar Edlerman and Pini Gurfil, looks into cluster control algorithms for the satellite swarms, illustrated by the Satellite Swarm Sensor Network (S3Net) project. A methodological development of orbit control algorithms is presented, with emphasis on outlining the algorithms structure, information flow, and software implementation. The methodology enables operation of multiple satellites in coordination, to enable fractionation of space sensors and augmentation of data provided therefrom.

In the paper "*Identifying retrofitting opportunities for Federated Satellite Systems*" by Rustam Akhtyamov et al. the authors address the possibilities of including FSS like capabilities in existing satellite structures. Such retrofitting possibilities, for this particular case or in general, are important items for industry today. In this paper, a systematic review of possible retrofitting options such as direct modifications, which include replacement and addition of interfaces, and indirect modifications with adding an intermediary (FSS Negotiator) are addressed.

And finally, in the paper "*Impact of Delayed Acknowledgment on TCP performance over LEO satellite constellations*" by Bastien Tauran et al., the authors aim at quantifying the impact of a default TCP option, Delayed Acknowledgment (DelAck), in the context of LEO satellite constellations. To cope with high channel impairment that may affect such satellite constellations, physical and link layer reliability schemes have been introduced, at the price of an increase of the end to end delay seen by the transport layer (e.g. TCP). Although DelAck is used to decrease the feedback path load and for overall system performance, the use of this option conjointly with satellite link layer recovery schemes might increase the delay and might be counterproductive.

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A. Golkar and R. Vingerhoeds
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