Positioning 5G Management Interfaces for Mega-constellations Management (MegaMan)

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Abstract

MegaMan is an ongoing research project (2017–2019) investigating the possibility of reusing 3GPP 5G management interfaces for satellite mega-constellations. During the coming decade, a large number of mega-constellations are expected be launched for providing global internet, IoT, or special services e.g. for military or maritime purposes. With a huge volume of network elements (the satellites) and subscribers, the satellite constellation operators will find themselves in a similar situation as the early GSM

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operators in the 1990s when no standardised management system interfaces were available. Through the MegaMan project we want to lower integration overheads and enable commercial-off-the-shelf management solutions for mega-constellations. This article presents a series of experiments conducted in the first half of the project to apply 5G Management Function services on live satellite and simulated constellations.

Keywords: Satellite mega-constellations, 5G management architecture, 3GPP management interfaces, service-oriented architectures, RESTful interfaces, OpenAPI.

1 Introduction

In the coming decade, constellations of thousands of inter-connected satellites will be launched to serve a range of telecommunications purposes, in particular Internet-of-Things (IoT) services where the excellent coverage properties of low-Earth-orbit (LEO) satellites are more important than high data rates. Compared to traditional, geo-stationary satellites in orbits 36,000 km. above the equator, not really covering the arctic regions, LEO satellites offer much lower latencies and true global coverage. The main differences are shown in Figure 1.

OneWeb, SpaceX/Starlink, Leosat, and Iridium NEXT are the most well-known constellations currently in production or proof-of-concept phase today. These so-called mega-constellations will be offering both traditional voice and data as well as IoT services. In addition, special-purpose constellations will be launched for various science, military, and maritime systems.

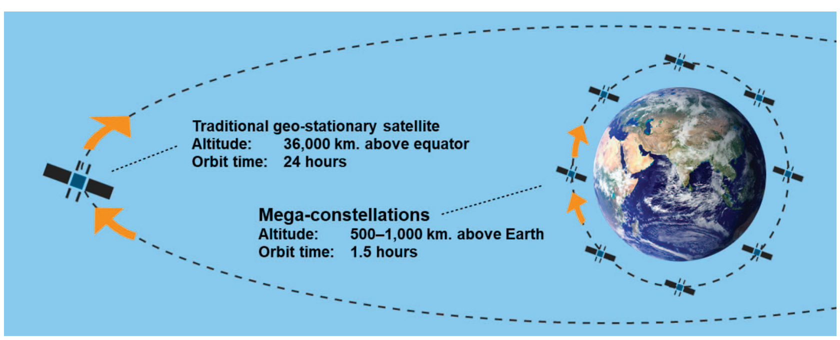


Figure 1 Comparison between geo-stationary satellites and mega-constellations.

With the expected rapid growth in number of subscribers and satellites of these constellations, operators will soon face similar operational challenges as the terrestrial mobile operators in the 1990s when launching GSM. GSM networks offer good-quality voice services and text messaging in combination with cheap and handy devices. This was exactly what the market had been waiting for. Fast growth in both network elements and subscribers led to sudden and high demands for more efficient and effective management systems.

GSM equipment manufacturers had started offering basic, proprietary management solutions, but the operators needed more advanced, scalable, and multi-vendor platforms. Therefore, they had to build own solutions, integrating with whatever interfaces were available. The cost of building an operational network management system was significant.

The MegaMan (mega-constellations management) project aims to pro-actively solve this problem for satellite network operators by building on the learnings from the terrestrial mobile domain. We want to bring best practices, concepts, and standards from terrestrial networks to satellite operations at an early stage to avoid the scalability challenge from early days of GSM. We believe that existing 3GPP specifications for network management can and should be reused for satellite mega-constellations to keep operational costs low. The project is following the ongoing 3GPP management interface standardisation and has done experiments with these on pilot satellite projects as well as in simulations.

MegaMan is a Danish research and innovation project undertaken jointly by a management system provider, *2operate*, a satellite manufacturing pioneer, *GomSpace*, and *Aarhus University*. The project has received support from *Innovation Fund Denmark*.

This article is organised as follows: Section 2 provides a brief background and introduction to management interfaces by 3GPP. Section 3 introduces the MegaMan project, which proposes to reuse 3GPP management interfaces for satellite constellations management, and Section 4 presents Delphini-1, a CubeSat project at Aarhus University used as a study case in MegaMan. Section 5 and Section 6 presents two experiments conducted in MegaMan: Section 5 focuses on "classical" use of Performance Assurance interfaces for network element (satellite) monitoring, whereas Section 6 applies Fault Management interfaces for an "alerting service" for deep space events detection. The overall conclusions of presented ideas and experiments are found in Section 7.

2 Management Systems Interfaces in 3GPP

As part of UMTS standardisation around 2000, 3GPP took on the task of specifying management systems interfaces in order to reduce the integration overhead seen in GSM in the 1990s and to open up for a more competitive *Operations & Management* (O&M) market. In the first published version (v.1.0.0) of TS 32.101 [1], it was proposed that: "*For UMTS management, a top-down approach will be followed to streamline the requirements from the perspective of top priority management processes within a UMTS operator*". The main idea of the top-down approach is illustrated in Figure 2.

This so-called *PLMN Management Architecture* was based on ITU-T TMN [2], commonly known as *FCAPS* (Fault, Configuration, Accounting, Performance, and Security management). It was specified down to technology-specific *Solution Sets*, making use of open interface technologies such as CORBA, SNMP, and XML.

The PLMN Management Architecture was applied for 2G and 3G systems, and later reused in LTE. Over time, it was widely accepted by the telecommunications industry, despite some main players insisting on own file formats for a very long time. In 2018, the last of the main network equipment providers adopted the 3GPP XML file format in TS 32.435 [3] as part of its performance management interface.

With a new service-oriented architecture of 5G networks, including network function virtualization (NFV), and with new and more modern options for open interfaces such as REST and JSON, 3GPP has initiated the specification of a new 5G management framework. The overall requirements and architecture were specified in TS 28.500 [4] as part of 3GPP Release 14 (early 2017), and a comprehensive set of specifications for *stage 2* and *stage 3* came in Release 15 (mid 2018).

The MegaMan project focuses on the new 3GPP 5G management architecture as the recommended management interface for new satellite

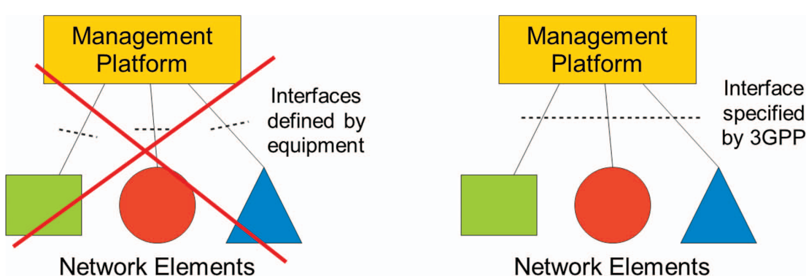


Figure 2 Management systems interfaces bottom-up (left) and top-down (right).

constellations. The project will conduct experiments with these interfaces and try to fill the gaps where the terrestrial concepts do not apply. It is expected by the project partners that the 5G management framework can be applied for satellite constellations with little change. It is further expected that this will facilitate faster and more successful commercialization of services from satellite constellations in the coming years.

3 MegaMan Project Objectives

The MegaMan project aims to build a strong management concept for satellite mega-constellations based on 5G management framework. The project considers both traditional network operations (managing the network entities) and services operations (managing the end "non-network" user services).

The core of the 5G management framework is the *Management Function* (MF) which provides a set of *Management Services* (MnS) for external O&M system(s). The MF may itself consumes services from other network functions. An example of such MF exposing two MnSs for O&M functions and consuming a set of lower-level services is shown in Figure 3.

MegaMan is considering the application of 5G MF on different aspects of the mega-constellations system. This is illustrated in Figure 4 where 5G MFs are shown as the management interface for both network elements (the satellites), user services, devices (specific to the service), and the *Network Management System* (NMS).

The main architectural elements of a satellite mega-constellation communicate in accordance with a few assumptions and principles:

- Satellites are able to communicate with other satellites via *inter-satellite links* (ISL). It is typically possible to maintain strong links to two other satellites in the same plane (in-plane), since these will stay in the same relative position, traveling in same speed and direction. Cross-plane connections are usually much more unpredictable.
- Satellites will connect with ground stations over *ground-satellite links* (GSL) to transfer user/service data to/from services platforms as well as to transfer *Operations & Management* (O&M) data with the NMS.
- Satellites may (depending on the purpose of the constellation) connect with devices on the ground over GSL.

In order to distinguish GSL towards ground stations and towards user devices, we may sometimes for clarity denote these *GSL ground station* and *GSL user*, respectively.

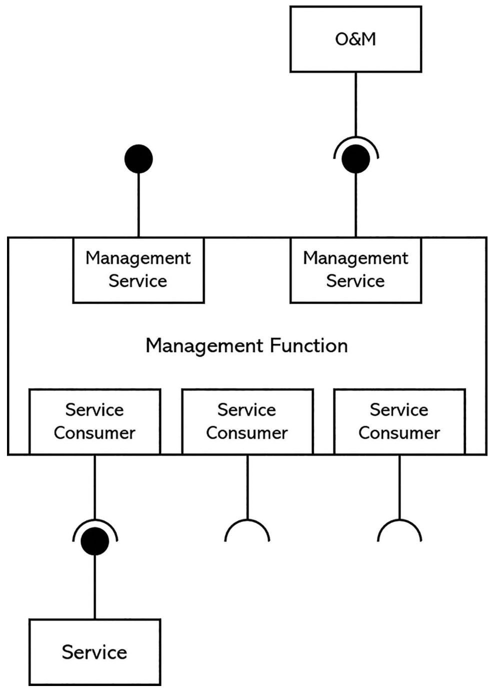


Figure 3 The 3GPP 5G Management Function (MF), source TS 28.533 [5].

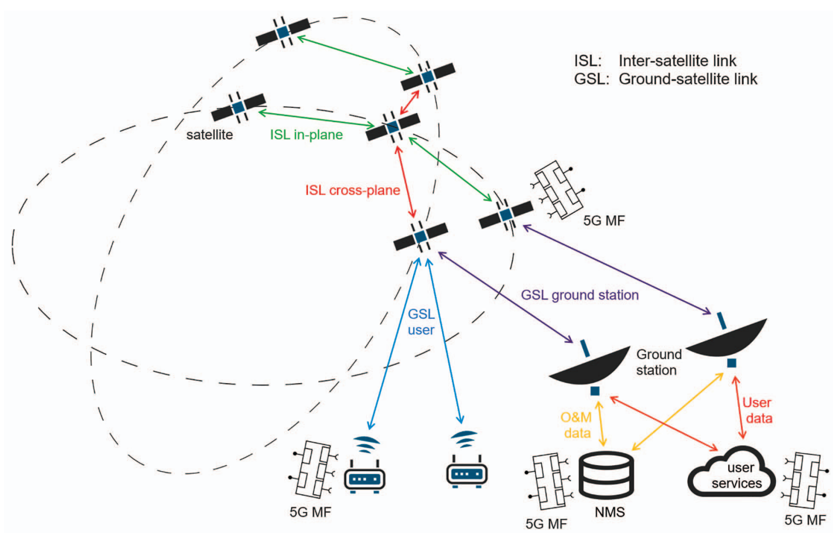


Figure 4 MegaMan investigates applying 5G MFs for network, devices, and services.

4 The Delphini-1 Project

The Delphini-1 project is a joint effort between three departments of the Faculty of Science and Technology at Aarhus University. The Delphini-1 project aims to assemble, test and operate a scientific satellite. The satellite is a 10 × 10 × 10 cm CubeSat equipped with a camera and communications gear. The satellite is supplied by the nanosatellite pioneer GomSpace, as an assembly kit.

Delphini-1 was launched on SpaceX CRS-16 on December 5, 2018, as secondary payload of a re-supply mission for the International Space Station (ISS). On January 31, 2019, the satellite was released to its own orbit, following a launch from the ISS. The satellite is estimated to have a lifetime of less than one year before it burns up in the atmosphere.

Delphini-1 was used in the MegaMan project as a demonstration on how to integrate with its back-end data repository over 5G Release 15 *Performance Assurance* and *Fault Supervision* interfaces. This integration is presented in more detail in Section 5.

Figure 5 shows an artistic photo of Delphini-1 in space. Figure 6 shows the launch of SpaceX CRX-16 (Dragon resupply mission for ISS) from Cape Canaveral on December 5, 2018, with Delphini-1 inside.

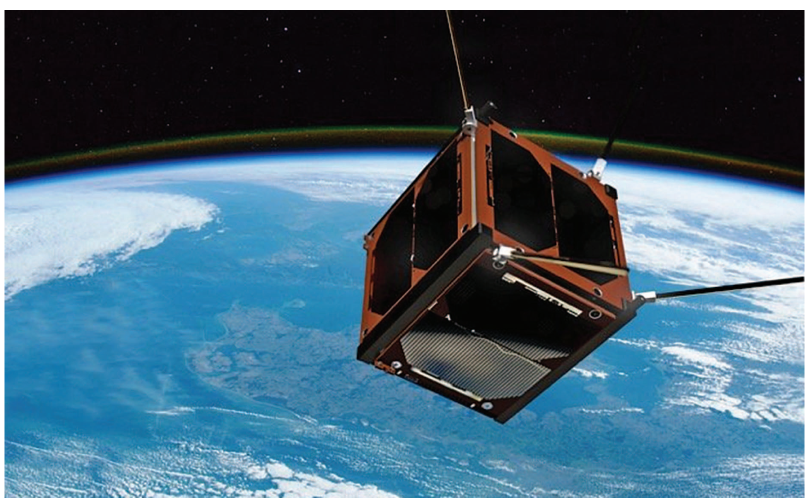


Figure 5 The Delphini-1 CubeSat from Aarhus University.

Source: GomSpace.

Figure 6 SpaceX CRS-16 launch on December 5, 2018.

Photo: Victoria Antoci.

5 Satellite Management over 5G Management Interface

It was decided to focus the MegaMan project on the set of generic management services specified in TS 28.532 [6]:

- Provisioning (ProvisioningMnS): Management services for the preparation, commissioning, operation and decommissioning of network entities.
- Fault Supervision (FaultMnS): Management services for notifying external systems about events and alarms from network entities.
- Performance Assurance (PerformanceMnS): Management service for collecting and reporting performance data from network entities.

These management services are specified down to detailed RESTful interfaces in OpenAPI [7] (except PerformanceMnS where the OpenAPI specification is missing in Release 15).

Figure 7 illustrates how a 5G MF layer was developed on top of the back-end data storage (a MongoDB database from GomSpace, here "GOM"). In this case only the PerformanceMnS was developed. The MF itself exposes its functionality as a RESTful interface, and the external system similarly exposes a RESTful interface for receiving notifications (notificationSink).

The resulting solution user interface based on the 2solve O&M platform from 2operate can seen in Figure 8. The integration was successful, and performance data from the satellite is presented for a number of *Key Performance*

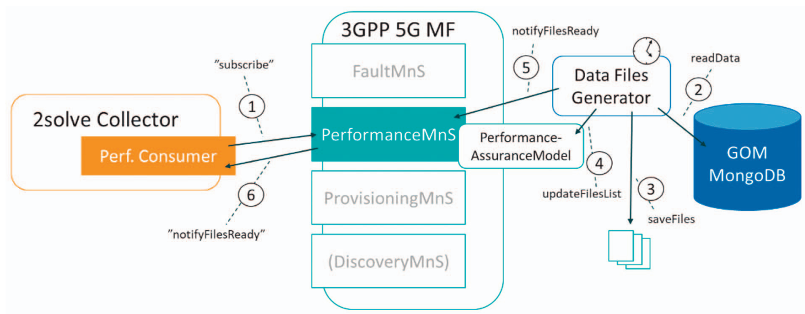


Figure 7 The 5G MF layer was developed on top of the satellite back-end (right).

Figure 8 Delphini-1 integration over 5G Performance Assurance MnS is complete, here integrated with the 2solve O&M platform.

Indicators (KPIs). The bursty nature of the data is due to periodic access to the satellite over the GSL.

Another successful experiment of the PerformanceMnS interface was done for offline data from a demo constellation of two satellites, also provided by GomSpace.

The experiments conducted in the project on PerformanceMnS and to some extent on FaultMnS proved that these generic interfaces were directly applicable for the management of a few satellites such as Delphini-1.

Although these experiments were based on only few satellites, we saw that scalability properties of the 5G MF concept are excellent, and we concluded that the developed platform would work well also for larger constellations of satellites.

6 Scientific Service: Detection of Short Gamma Ray Bursts

Within the scope of the MegaMan project was a separate activity to apply satellite constellations for the localisation of *Short Gamma Ray Bursts* (SGRBs) as electromagnetic counterparts to gravitational wave signals.

Figure 9 illustrates the principle: We want to localise SGRB signals based on the triangulation method using a mega-constellation of CubeSats. Prompt localisation of SGRBs will allow the fully automated *Stellar Observations Network Group* (SONG) telescopes to perform follow-up observations of the SGRB source. Following the receipt of the SGRB signals at each CubeSat, the time stamp information together with the latitudes and longitudes of each CubeSat will be downlinked to a ground station, where the localisation computations will take place. Coupling the SONG with a mega-constellation of CubeSats will enable the SONG to join the efforts to perform multi-messenger astronomy to help decipher underlying physics.

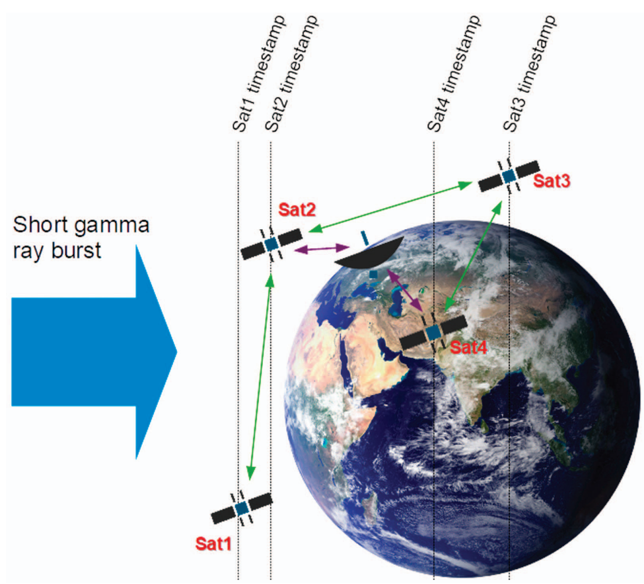
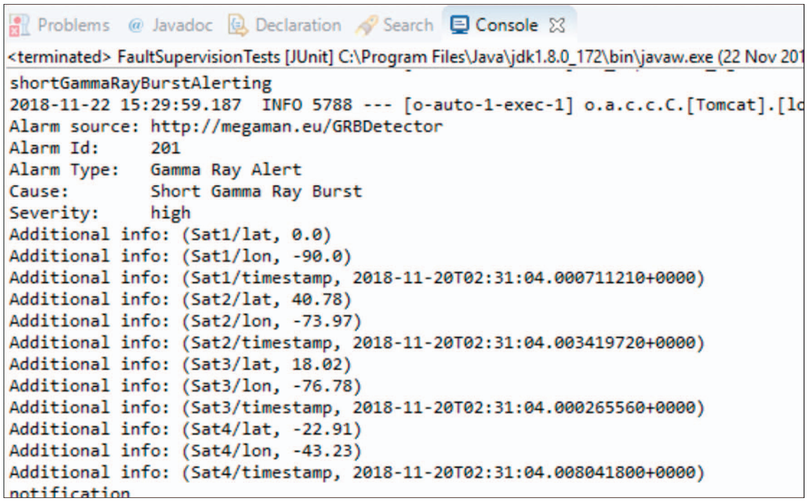


Figure 9 The use of satellites in constellation to determine the origin of SGRB.



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<terminated> FaultSupervisionTests [JUnit] C:\Program Files\Java\jdk1.8.0_172\bin\javaw.exe (22 Nov 201
shortGammaRayBurstAlerting
2018-11-22 15:29:59.187  INFO 5788 --- [o-auto-1-exec-1] o.a.c.c.C.[Tomcat].[lo
Alarm source: http://megaman.eu/GRBDetector
Alarm Id:     201
Alarm Type:   Gamma Ray Alert
Cause:        Short Gamma Ray Burst
Severity:     high
Additional info: (Sat1/lat, 0.0)
Additional info: (Sat1/lon, -90.0)
Additional info: (Sat1/timestamp, 2018-11-20T02:31:04.000711210+0000)
Additional info: (Sat2/lat, 40.78)
Additional info: (Sat2/lon, -73.97)
Additional info: (Sat2/timestamp, 2018-11-20T02:31:04.003419720+0000)
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Additional info: (Sat3/lon, -76.78)
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Additional info: (Sat4/lat, -22.91)
Additional info: (Sat4/lon, -43.23)
Additional info: (Sat4/timestamp, 2018-11-20T02:31:04.008041800+0000)
notification
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Figure 10 The output of a 5G FaultMnS on Short Gamma Ray Bursts (simulation).

In the project, we considered this to be an example of a "user service" (see Figure 4), and we did an experiment to test the applicability of the 5G FaultMnS implemented as a RESTful service for such alerting service. Satellite locations (latitude, longitude) as well as the timestamps were put in the "Additional info" fields of the alarm. Output from this experiment is shown in Figure 10.

The experiment showed that it was possible to make use of the 5G FaultMnS for "non-network" purposes, although the benefits were not so clear (does this add any value compared to a special-purpose RESTful service for doing the same thing?).

Using triangulation calculations on the output in Figure 10 (see e.g. [8]), it is straight-forward to conclude that telescopes all over the world should immediately point themselves in direction (10.000N, 80.000W). Because of Earth's rotation, this direction should be adjusted by ¼ degree in Western direction per minute of delay after 02:31:04 UTC.

7 Conclusions

The MegaMan project has identified an emerging need for efficient and scalable O&M systems for the operations of satellite mega-constellations. We are concerned that operators will suffer huge integration costs and inefficient O&M platforms if no pro-active action is taken now to standardize the O&M interfaces of satellite networks.

Within the scope of the MegaMan project, we have made prototype implementations of 5G Management Functions on top of live experimental satellite systems (Delphini-1). We have also simulated the use of the FaultMnS for a scientific service of automatically alerting telescope operators about Short Gamma Ray Bursts from deep space events.

The overall conclusion is that the new 5G management architecture which is specified as part of 3GPP Release 15 is directly applicable for satellite network management systems. The benefits are clear:

- Top-down specification (standardization) of O&M interfaces ensures easy (low-cost) integration with network equipment.
- Standardized interfaces make life easier for equipment providers, since they do not need to invent yet another interface.
- Standardized interfaces enable a competitive market of innovative and effective O&M systems.

The MegaMan project will be completed by November 2019.

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Biographies

Lars Moltsen is the CEO and founder of Moltsen Advisory. He is an experienced telecom/space/software engineer and entrepreneur. Lars holds an MSc degree in computer science and mathematics from Aalborg University (1996) and has contributed to a range of international research projects while working at Nokia, Texas Instruments, and three start-ups of his own, including most recently 2operate. Lars has authored around 20 conference and journal articles. He is the author of one patent (US7339950) in the field of mobile network (UMTS) access control algorithms. Lars acted as the project manager of the MegaMan project until January 2019.

Rune Hylsberg Jacobsen is an Associate Professor at the Department of Engineering and head of the Networks an Analytics research group. He received an MSc degree (1995) in physics and chemistry and a PhD degree (1997) in optoelectronics from Aarhus University, Denmark. He is currently active in research and teaching in communication networks and is head of the research group Networks an Analytics. His professional career includes more than 13 years of industrial R&D from the telecommunication and IT industry where he has managed research & development products and teams.

Furthermore, he acts as an independent expert evaluator for the European Commission. His main research interests include networking, wireless communication, cybersecurity, data analytics, cooperating networks, and smart grids.

Fadil Inceoglu (FI) received his MSc degree in Nuclear Sciences in 2010 from Nuclear Science Institute of Ege University, Turkey, and his PhD degree in Physics in 2015 from Aarhus University, Denmark. FI worked a Postdoctoral Researcher in the Electrical and Computer Engineering Section at the Department of Engineering of Aarhus University, Denmark between 2017–2019. His research mainly focuses on heliophysics, solar-terrestrial physics, and solar physics. He was a member of the Aarhus University Satellite Program, AUSAT (Delphini-1), for designing nanosatellite missions in the field of space weather and astrophysics. His main research interests include solar physics, heliophysics, CubeSats and machine learning.

Victoria Antoci is an Assistant Professor at Aarhus University, at the Stellar Astrophysics Centre hosted by the Department of Physics and Astronomy. Her research background is stellar astrophysics (Asteroseismology). Victoria completed her PhD in Astronomy at Vienna University (Austria) in 2012. She is the Project Scientist and the Aarhus University Project Manager of the Delphini-1 mission. In addition to Delphini-1, Victoria has been actively working on data from several space missions related to her research (MOST, Kepler/K2, TESS).

Néstor J. Hernández Marcano received the MSc in Electronics Engineering from Universidad Simón Bolívar, Venezuela in 2013 and the PhD degree in Wireless Communications from Aalborg University, Denmark in 2016. He is a Postdoctoral Researcher in the Electrical and Computer Engineering Section at the Department of Engineering of Aarhus University, Denmark since 2017. His research focuses on communication technologies for nanosatellite applications, Unmanned Aerial Vehicles (UAVs), the Internet of Things (IoT), network security, and cellular networks having also industrial experience in this latter. He is a member of the Aarhus University Satellite Program, AUSAT, for designing nanosatellite missions in the field of communication system and payloads. His main research interests include communication networks, CubeSats, network coding, radio frequency systems, signal processing for communications, security, and machine learning.

Lars K. Alminde has a PhD from Aalborg University in control engineering and has worked through his academic and professional career to develop nanosatellite technology and applications hereof. He is co-founder of GomSpace and is today serving as its Chief Product and Innovations Officer and is also leading GomSpace's initiative to bring the cost disruption of nanosatellites to the ground segment through its GomSpace Luxembourg subsidiary.

Per Henrik Michaelsen is a Software Engineer at GomSpace A/S, Denmark, in the Satellite Communications group that he joined in 2017 working on satellite systems networking related solutions. Current work includes the first implementation of an OpenAPI (RESTful) interface for providing access to satellite telemetry (TMTC) and alarm information in accordance with the 3GPP specifications, and a longer-term focus on a networking design based on Delay and Disruptive Tolerant Networking (DTN). Per Henrik holds a M.Sc. degree in Control Engineering from Aalborg University, Denmark.

Christian Ingerslev Sørensen is the CEO of 2operate. Christian holds a Master's degree in Control Systems Engineering together with a Master of Business Administration which gives him the technical insight and market-oriented mindset. For more than 10 years he has been working in leading positions in the Danish ICT sector, including Telenor Denmark and Bredband Nord, covering roles within management, strategy, and business development.

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